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Tree-ring indicators of rainfall and streamflow for the Ili-Balkhash Basin, Central Asia since CE 1560

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ABSTRACT

We reconstructed previous July–current April total precipitation in the upper Ili-Balkhash Basin of Central Asia, using a transfer equation based on the correlation between regional tree-ring width series and local precipitation data. Dry periods were identified from 1586–1612, 1637–1669, 1695–1721, 1759–1782, 1804–1864, 1907–1930 and 1974–1993, while wet periods occurred from 1560–1585, 1613–1636, 1670–1694, 1722–1758, 1783–1803, 1865–1906, 1931–1973 and 1994–2006. Spatial correlation analysis indicates that our precipitation reconstruction is broadly representative of precipitation in the entire Ili-Balkhash Basin. The precipitation timeseries is also strongly related to streamflow measurements, revealing that variations in precipitation in the upper Ili-Balkhash Basin have a dramatic influence on streamflow into Lake Balkhash. The precipitation reconstruction also compares well with various streamflow reconstructions from the Tien Shan, and exhibits an increasing streamflow trend in the 1980s through 2000s. Spectral analysis showed significant 60-, 33-, 11-, 2.8- and 2.1-year cycles over the past 447 years. Our 447-year precipitation reconstruction provides the basis for comparing past and present hydroclimate changes, which will be important for detection and attribution of hydroclimate variation in the Ili-Balkhash Basin.

1. Introduction

Demands on water resources in Central Asia are growing rapidly, due to the development of agricultural and industrial production, as well as urbanization and population growth. However, Central Asia experiences some of the most serious water shortages in the world, and nations in the region are facing serious problems of water supply and distribution (Kezer and Matsuyama, 2006; Seidakhmetov et al., 2014; Sorg et al., 2014). During the past 30 years, high temperature has accelerated the melting of glacier and results in the consistent increase in Asia's runoff (Niederer et al., 2008; Bai et al., 2011; Sorg et al., 2014; Gan et al., 2015; Duethmann et al., 2015; Liu et al., 2017a, b). Central Asia's runoff will decrease under continuous warming and current precipitation conditions in the future (Chen et al., 2017). However, the fresh water supply potential of Central Asia's rivers, essential for residents living along rivers, is not well understood in long-term perspective largely due to the scarcity of instrumental streamflow data. In many areas of Central Asia, climate and streamflow records are too sparse to determine large-scale hydrologic and climatic patterns, and most instrumental datasets did not begin until the 20th century. The poor temporal and spatial coverage does not allow for a comprehensive picture of modern climate and hydrology, and provides little information about variability in the pre-instrumental period.

As one of the biggest rivers in Central Asia, the Ili River and the system of reservoirs in its watershed provide over 60% of the water supply to the cities of the Ili-Balkhash Basin, while about 70–80% of runoff flows into Lake Balkhash, which is fed by the Ili River (Deng et al., 2011; Imentai et al., 2015). Climate and streamflow changes in the Ili-Balkhash Basin can potentially have major influences on the water level of Lake Balkhash. Human activity and drought during the 1970–1980s dramatically lowered the water level, and caused serious concerns about the future of the regional water supply in the face of continuous population growth, economic development, and changing climate (Kezer and Matsuyama et al., 2006; Deng et al., 2011). Rising salinity levels, resulting from persistently low streamflow, have raised further concerns about the environment of the Ili-Balkhash Basin; it is feared that Lake Balkhash will meet a similar fate as the Aral Sea (Kezer and Matsuyama, 2006; Allouche, 2007; Propastin, 2013; Izhitskiy et al., 2016; Deng and Chen, 2017). Although some efforts are underway to reduce potential environmental risks, our understanding of extreme drought events and long-term trends in the water supply is still limited by the short record of instrumental hydroclimatic data.

Proxy records, such as tree rings, can provide reliable information over longer timescales, and are needed to assess the recurrence probability of flood and drought conditions, and better manage water

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resources. Numerous reconstructions of streamflow, precipitation, and drought have been developed across Central Asia based on tree-ring data (e.g. Li et al., 1994; Esper et al., 2001; Davi et al., 2006; Yuan et al., 2007; Fang et al., 2010; Chen et al., 2013, 2015, 2016a, 2016b; Zhang et al., 2013; Cook et al., 2013; Seim et al., 2016; Zhang et al., 2016; Opała et al., 2017). These records have become an important basis for water management plans in Central Asian countries.

The thickness of tree rings in Schrenk's spruce (*Picea schrenkiana*) trees is highly sensitive to variations in precipitation, and has been used to reconstruct climate variability at moisture-sensitive sites in the upper Ili-Balkhash Basin (Yuan et al., 2000; Chen et al., 2010). However, these reconstructions cover a relatively short time interval, and do not include streamflow in the Ili-Balkhash Basin. In this study, we develop a new precipitation reconstruction based on tree-ring width series from the upper Ili-Balkhash Basin, to interpret hydrometeorological variability of the Ili-Balkhash Basin and compare it to other existing streamflow reconstructions from the Tien Shan.

2. Materials and methods

2.1. Study area

The Ili-Balkhash Basin is located in China and Kazakhstan (Fig. 1). The mountains in the upper Ili-Balkhash Basin are up to 4500 m high. The general inclination of the mountains which are exposed to westerly disturbances causes large amounts of precipitation and snowfall. The glaciers of Tien Shan in the Ili region of China is considered as the source of several permanent rivers flowing into neighboring arid regions and thus of enormous importance for the industrial and agricultural water supply. The region has a semiarid continental climate, with temperature and precipitation largely dependent on elevation. Data from Zhaosu climate station (43°09′N, 81°08′E, 1854.6 m) indicate a mean annual precipitation of 506.5 mm, and an annual mean temperature is 3.2 °C (mean temperatures of July and January are 14.9 °C and −11.2 °C, respectively; Fig. 2). Mean relative humidity is 50–60%, while the annual frost-free period averages 98 days. Vegetation patterns in the Ili-Balkhash Basin are generally influenced by slope aspect and elevation, but are also dependent on cold-air drainage and other factors. Vegetation zones, in ascending order of elevation, are the semiarid grass zone, deciduous broad-leave forest zone, coniferous forest zone, and shrub zone. Soils in forested areas are mainly mountain dark-brown forest soils.

Schrenk's spruce (*Picea schrenkiana*) is one of the dominant species in the forests of the Tien Shan. It is typically found between 1800 and 3000 m elevation in the mountains of Central Asia, in areas with thick winter snowpack and wet summers. All tree-ring data used in this study come from three tree-ring sites (Codes KRK, XBD and QLK) located in the upper Ili-Balkhash Basin. We selected trees growing in open stands growing on shallow soils at high elevation (2500–2800 m) for sampling, to minimize the influence of inter-tree competition on growth dynamics. The slopes range from 5 to 50°, and are generally 20–40°, and the exposure range from 0.2 to 0.4. Information about the three sites is listed in Table 1.

2.2. Chronologic framework

Two cores were taken from each tree, drilled from opposite sides using increment borers. In total, the three sites provided 160 cores, extracted from 76 individual trees. All cores were mounted on holders and air dried, then polished using sand paper. A Velmex measuring system was used to determine the widths of annual tree rings, with an accuracy 0.001 mm. COFECHA software (Holmes, 1983) was used to check the results of cross-dating. To remove non-climatic trends, original tree-ring width data was detrended with a negative exponential curve (Fritts, 1976). The detrended ring width data were combined into site chronologies, using the ARSTAN program (Cook, 1985; Cook and Kairiukstis, 1990). Table 2 shows that strong correlations were found between the three site chronologies. These are hypothesized to reflect a common monthly response to the hydrologic and climatic factors; consequently, ring width series from all three sites were combined to construct a new regional standard chronology.

2.3. Hydrologic and climatic data and statistical methods

Climate records from the Zhaosu station in the upper Ili-Balkhash Basin, including mean monthly temperatures and total precipitation,

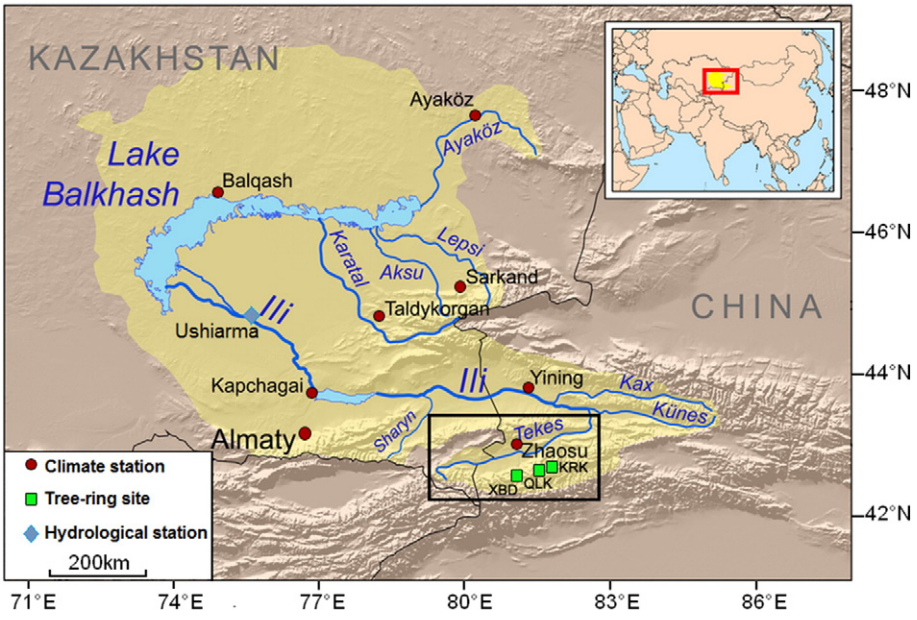

Fig. 1. Map showing the Ili River-Balkhash Basin (shaded area), the location of the Ushjarma hydrological station, and the locations of the three tree-ring sites. Inset shows location of study area in Central Asia. The black box represents the upper Ili River-Balkhash Basin. The geographic base map (Author: Kmusser) was obtained from the Wikipedia, through their web site: https://commons.wikimedia.org/wiki/File:Lakebalkhashbasinmap.png.