

## Tree-Ring Record of Precipitation Variation in the Sayram Lake Basin, Xinjiang, over the Past 373 Years (Postprint)

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### Abstract

Using a tree-ring standardized width chronology collected from the Sayram Lake basin in the western Tianshan Mountains, we reconstructed precipitation variations from previous August to current July over the past 373 years in the Sayram Lake basin. The explained variance of the reconstruction reaches 39.8%, and multiple verifications indicate that the reconstruction results are stable and reliable. Analysis of historical precipitation variation characteristics shows that precipitation in the Sayram Lake basin over the past 373 years underwent six dry and seven wet stage variations. Among these, the longest persistent dry period was 1762–1791, while the driest period was 1841–1865; the longest persistent wet period was 1794–1840, while the wettest period was 1734–1761. Historical precipitation in the Sayram basin featured three extreme wet years (1749, 1876, and 1924) and four extreme dry years (1714, 1775, 1847, and 1917), with the 1910s being the driest decade. Precipitation variation exhibits quasi-periodic variations of 11–12a, 3.0a, 2.5a, 2.1a, and 2.0a. The stage variations, periodic variations, and extreme precipitation years over the past 373 years in the Sayram Lake basin all show good consistency with precipitation variations in the mid-western section of the northern Tianshan slope and the Central Asian Tianshan mountainous region, and the precipitation reconstruction sequence of this study can well represent historical precipitation variations in the mid-western section of the northern Tianshan slope and most regions of Central Asia.

### Full Text

### Preamble

**Tree-Ring-Based Precipitation Variability over the Past 373 Years in the Sayram Lake Basin, Tianshan Mountains**

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## Abstract

Using a tree-ring standardized width chronology developed from samples collected in the Sayram Lake Basin of the western Tianshan Mountains, we reconstructed precipitation variability in this region over the past 373 years. The reconstruction explains 39.8% of the precipitation variance during the 1960–2009 calibration period, and multiple validation tests confirm the stability and reliability of the results. Analysis of historical precipitation characteristics reveals that the Sayram Lake Basin has experienced six drier and seven wetter periods. The longest sustained drought phase occurred during 1910–1919, while the most severe drought year was 1917. The basin also recorded four extreme wet years (1749, 1876, 1924, and 1933) and four extreme dry years (1714, 1775, 1847, and 1917). The precipitation series exhibits significant quasi-periodic cycles of 11–12 years, 3.0 years, 2.5 years, 2.1 years, and 2.0 years. Both the periodic variations and extreme precipitation years show strong consistency with precipitation patterns in the central-western northern Tianshan slopes and the broader Central Asian Tianshan region. This reconstruction effectively represents historical precipitation changes across the central-western northern Tianshan slopes and most of Central Asia.

**Keywords:** Sayram Lake Basin; Tree rings; Precipitation; Climate change; Tianshan Mountains

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## Introduction

The Fifth Assessment Report of the IPCC confirms global warming as an unequivocal reality, yet substantial uncertainty remains regarding regional climate change patterns. Global warming has induced divergent changes in precipitation and hydrological cycles across different regions. Huang et al. [3] suggest that climate warming accelerates the expansion of dryland areas. Current research on extreme climate events such as droughts and floods remains in its infancy, with both methodological approaches and research content requiring strengthening. In-depth analysis of drought evolution trends under climate change is crucial

for rational drought early warning, assessment of basin-scale drought disaster effects, optimal water resource allocation, and sustainable basin development.

The Tianshan Mountains constitute a critical water source region in Central Asia, spanning China, Kyrgyzstan, and Kazakhstan. Dominated by westerly winds, this mountain system plays a significant role in global climate change research. Understanding the mechanisms of climate change in this region is vital for sustainable water resource utilization [5]. Shi et al. [6] demonstrated that northwestern China has experienced fluctuating warming and drying since the end of the Little Ice Age, with a notable shift from warm-dry to warm-wet conditions in the western Tianshan region beginning around 1987. Revealing past climate change facts in the Sayram Lake Basin benefits climate diagnostics for western China, particularly Xinjiang, and supports decision-making for disaster prevention, water resource management, and the development of the Silk Road Economic Belt and the northern Tianshan slope economic zone.

Sayram Lake is located in the central western Tianshan Mountains, at the southwestern edge of the Junggar Basin, in the upstream region of westerly weather systems. Long-term understanding of moisture changes and their patterns at decadal to centennial scales requires proxy data, as meteorological stations are sparse in the Sayram Lake Basin. Among various proxy data sources, tree rings offer high resolution, wide sample distribution, and accurate dating, making them valuable for paleoclimate reconstruction and paleoenvironmental evolution studies [7–12]. Previous research in the Tianshan Mountains has shown that tree radial growth responds more strongly to precipitation than to temperature, and multiple precipitation series have been reconstructed using tree-ring width data [13–25]. However, no historical climate series has been established for the Sayram Lake Basin until now. This study uses Schrenk spruce (*Picea schrenkiana* Fisch. et Mey) tree-ring samples from the Sayram Lake Basin in western Tianshan to reconstruct moisture changes over the past 373 years, analyze historical wet-dry variation characteristics, and explore potential influencing factors, thereby contributing to a broader climate reconstruction network and improved understanding of climate change mechanisms in the Central Asian arid region.

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## 1. Study Area and Tree-Ring Data

Sayram Lake is situated in the arid region of northwestern China ( $44^{\circ}27' - 44^{\circ}45' \text{ N}$ ,  $80^{\circ}55' - 81^{\circ}21' \text{ E}$ ), with a lake surface elevation of 2,072 m and a catchment area of 1,408 km<sup>2</sup>. The basin is influenced by the westerlies, with prevailing west or west-southwest winds year-round. Moisture transported by westerly circulation constitutes the primary precipitation source [26]. Schrenk spruce (*Picea schrenkiana* Fisch. et Mey) is widely distributed around the lake, forming pristine dark coniferous forests on shady slopes and valley bottoms of the surrounding subalpine zone (2,150–2,600 m) [27].

Tree-ring samples were collected in 2010 from the Haixigou site (HXG, 81°11 E, 44°43 N, 2,240–2,280 m elevation) on the northern slope of the Sayram Lake Basin. The sampling site is located in the middle-lower forest line on a north-facing shady slope.

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## 2. Meteorological Data

Meteorological data were obtained from the nearest Wenquan County meteorological station (81°01 E, 44°58 N, 1,353.9 m elevation) for the period 1959–2010. The region has a temperate continental climate characterized by concurrent rainfall and heat, long sunshine hours, and large diurnal temperature ranges. The mean annual temperature is 3.9°C, and the mean annual precipitation is 228 mm.

To assess the spatial representativeness of our reconstruction, we compared it with the high-resolution global monthly gridded dataset from the Climatic Research Unit (CRU) at the University of East Anglia (<http://cdc.cma.gov.cn/>). We selected the CRU TS 3.23 precipitation data spanning 1901–2009, which overlaps with our reconstruction period.

Location of tree-ring sampling site

[FIGURE:2] Mean monthly temperature and precipitation at Wenquan meteorological station (1959–2010)

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## 3. Methods

Tree-ring samples were air-dried in the Key Laboratory of Tree-Ring Physical and Chemical Research of the China Meteorological Administration. After surface polishing, ring widths were measured using a Velmex measuring system (Velmex Inc., Bloomfield, NY, USA) with a precision of 0.001 mm. Cross-dating quality control was performed using the COFECHA program from the International Tree-Ring Data Bank [29]. One core with a missing ring was excluded from the analysis.

Detrending was conducted using the ARSTAN program [10]. The spline function method, which does not assume a specific growth trend form and is suitable for humid regions [30], was employed. Although our study area is in an arid to semi-arid region, the Schrenk spruce grows in relatively favorable habitats with dense stands. To preserve more low-frequency climate signals and reduce effects from varying age-related growth rates, we applied a spline function with a 50% frequency response cutoff at 67% of the series length. The final standardized tree-ring width chronology was developed using ratios and arithmetic averaging.

To ensure reliable climate reconstruction, we selected a chronology length with adequate sample size [30]. The resulting reliable chronology spans 374 years



Figure 1: Figure 1

(1637–2010) with high signal-to-noise ratio (SNR = 32.28) and strong inter-series correlation ( $r = 0.397$ ).

Correlation and response analyses were used to interpret climate-growth relationships [31]. Stepwise regression was employed to develop transfer functions for precipitation reconstruction. Given the short meteorological record, we used the leave-one-out method for cross-validation, examining error reduction (RE), first-difference correlation, sign test, and product mean statistics to verify reconstruction stability.

Multi-taper spectral analysis [29–31] was applied to extract quasi-periodic signals. All reconstructed series were subjected to 10-year low-pass filtering to extract low-frequency variations for comparison with other Tianshan precipitation reconstructions.

[FIGURE:3] Tree-ring width standardized chronology and sample depth

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#### 4. Historical Precipitation Reconstruction and Validation for Sayram Lake Basin

The Haixigou (HXG) tree-ring width standardized chronology has a mean sensitivity of 0.152, an inter-series correlation of 0.397, a signal-to-noise ratio of 32.28, and a missing ring percentage of 0.316%. The expressed population signal (EPS) value of 0.97 indicates that the chronology contains substantial climate information.

Previous studies in the Sayram Lake Basin [27] showed that tree-ring width correlates best with precipitation from previous August to current July (L8–7), suggesting that moisture during the pre-growing season and growing season is the primary limiting factor for radial growth—a finding consistent with many Tianshan studies [13–16].

Stepwise regression between the HXG chronology and monthly precipitation data from Wenquan station yielded the following transfer function:

$$L8-7 = 8.9 + 226.0 \times HXG$$

The reconstruction explains 39.8% of precipitation variance ( $R^2 = 0.398$ , adjusted  $R^2 = 0.385$ ,  $F = 31.68$ ,  $p < 0.0001$ ). The equation was used to reconstruct August–July precipitation for the Sayram Lake Basin from 1637–2009.

[FIGURE:4] Reconstructed precipitation series for Sayram Lake Basin

Validation statistics (Table 1) show strong agreement between reconstructed and observed values. The first-difference correlation is 0.632, sign test ratio is 14/50, first-difference sign test ratio is 12/49, and product mean is 5.139. The error reduction (RE) value of 0.399 exceeds the 0.0001 significance level, indicating that the reconstruction reliably captures both high-frequency variations and low-frequency trends.

[FIGURE:5] Comparison of reconstructed and observed precipitation series

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## 5. Precipitation Variability in Sayram Lake Basin Over the Past 373 Years

The 10-year low-pass filtered reconstruction reveals six dry periods and seven wet periods from 1644–2008. The longest drought lasted 30 years, while the most severe drought phase occurred during 1910–1919, with precipitation 11.6% below the mean. The longest wet period spanned 1749–1876, and the wettest phase was 1924–1933, with precipitation 9.7% above average.

To identify extreme events, we defined years with precipitation exceeding  $\pm 1$  standard deviation as extreme wet/dry years. This yielded four extreme wet years (1749, 1876, 1924, 1933) and four extreme dry years (1714, 1775, 1847, 1917). The 1910s was the driest decade, consistent with documented severe droughts across the Tianshan region [15–16, 20, 25, 32–33].

Multi-taper spectral analysis reveals significant quasi-periodic cycles of 11–12 years, 3.0 years, 2.5 years, 2.1 years, and 2.0 years (Figure 6). The 11–12 year cycle aligns with the Schwabe solar cycle, while the 2–3 year cycles correspond to the quasi-biennial oscillation (QBO) and may relate to ocean-atmosphere coupling. Studies show significant correlations between Northwest China precipitation and Arctic Oscillation (AO) at quasi-11-year scales [35–36].

Correlation analysis with the North Atlantic Oscillation Index (NAOI) shows a significant relationship ( $r = 0.210$ ,  $p < 0.05$ ) during 1960–2009, suggesting that precipitation variability may be influenced by large-scale climate systems including solar activity, NAO, and AO [15].

Comparison with other precipitation reconstructions from the northern Tianshan slopes demonstrates strong consistency in wet-dry patterns (Figure 7). Spatial correlation analysis with CRU precipitation data (Figure 8) indicates that our reconstruction effectively represents August–July precipitation variability across the central-western northern Tianshan slopes and most of Central Asia.

[FIGURE:6] Multi-taper power spectra of reconstructed precipitation

[FIGURE:7] Wet-dry changes over the past 300 years in central-western northern Tianshan slopes

[FIGURE:8] Spatial correlation between Sayram Lake reconstruction and CRU precipitation (August–July)

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## 6. Conclusions

Using a tree-ring standardized width chronology from the Sayram Lake Basin in the western Tianshan Mountains, we successfully reconstructed precipitation variability over the past 373 years. The reconstruction explains 39.8% of precipitation variance and passes rigorous validation tests, confirming its stability and reliability.

The Sayram Lake Basin experienced six dry and seven wet periods from 1644–2008. The longest drought lasted 30 years, while the most severe drought phase was 1910–1919. The basin recorded four extreme wet years (1749, 1876, 1924, 1933) and four extreme dry years (1714, 1775, 1847, 1917), with 1917 being the driest single year.

Precipitation exhibits significant quasi-periodic cycles of 11–12 years, 3.0 years, 2.5 years, 2.1 years, and 2.0 years, likely influenced by solar activity and large-scale climate oscillations (NAO/AO). The reconstruction shows strong consistency with precipitation variations in the central-western northern Tianshan slopes and Central Asian Tianshan region, effectively representing historical precipitation changes across these areas.

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