Tree-ring based drought reconstruction for the central Tien Shan area in northwest China

Jinbao Li,[1,2] Xiaohua Gou,[1] Edward R. Cook,[3] and Fahu Chen[1]

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[1] A robust ring-width chronology developed from two sites of *Picea schrenkiana* in the central Tien Shan area of northwest China was employed to study regional drought variability. Our analyses demonstrate both temperature and precipitation have significant effects on tree growth, thus both should be considered for climate reconstruction. Regional drought history (1675–2002 A.D.) was therefore reconstructed by calibrating with the Palmer Drought Severity Index (PDSI). Our reconstruction not only captured well those extreme drought events recorded in local historical archives, but also revealed the long-term pattern of drought variability, especially the trend of increasing moisture during the 20th century. Multi-taper method spectral analysis indicates the existence of some low- and high-frequency cycles (146–171, 11.5, 10.6, 9.7, 6.1, 3.9, 3.4, 3.2, 2.4 and 2.1 yr). Overall, our study indicates the feasibility of combining tree-rings and the PDSI to reconstruct large-scale drought patterns over this area. **Citation:** Li, J., X. Gou, E. R. Cook, and F. Chen (2006), Tree-ring based drought reconstruction for the central Tien Shan area in northwest China, *Geophys. Res. Lett.*, *33*, L07715, doi:10.1029/2006GL025803.

1. Introduction

[2] The occurrence of drought remains a serious concern around the world, especially in arid and semi-arid regions [*Cook et al.*, 1999; *Qian and Zhu*, 2001]. Recently this concern was heightened as the increasing intensity of global warming may contribute to potential development of more frequent and persistent droughts [*Cook et al.*, 2004; *Dai et al.*, 2004]. It is thus of critical importance to understand the drought patterns as well as their potential forcing mechanisms, which are essential to establish the fundamentals for drought forecasting.

[3] Quantitative information about long-term drought variability is particularly valuable in drought study. Direct measurements of meteorological parameters, however, are often limited in both time and space. It is therefore necessary to recover long-term drought history from proxy records. Among them tree-ring analysis is highly valued due to its precise dating, extensive spatial availability, and high climatological sensitivity [*Fritts*, 1976]. The fidelity of tree-ring records to drought reconstructions has been well demonstrated by numerous studies [see, e.g., *Stahle et al.*, 1985; *Cook et al.*, 1999].

[4] Common to all types of drought is the fact that they all result from the accumulated effect of precipitation deficit over some time period [*Wilhite and Glantz*, 1985]. Thus the meteorological drought attracts more attention in current research. And to this end, the Palmer Drought Severity Index [*Palmer*, 1965] is perhaps the most well-known and widely used drought index across the United States [*Heim*, 2002]. The PDSI can detect the existence of dry and wet spells and further allow them to be quantified for direct comparisons across regions and time [*Alley*, 1984]. It has therefore been widely used for a variety of applications over the United States [*Alley*, 1984; *Heim*, 2002]. Recent studies have also employed the PDSI to study droughts beyond the United States [*Ntale and Gan*, 2003; *Dai et al.*, 2004], indicating its potential for global applications.

[5] Combining tree-rings and the PDSI together for the purpose of drought reconstruction has been achieved in many areas [*Briffa et al.*, 1994; *Cook et al.*, 1999, 2004]. Unfortunately, this method has not been widely used for the drought reconstructions over Asia. Here we describe a case study to showing its feasibility for the drought reconstruction in northwest China, and seeking to understand long-term drought variability in the study area.

2. Data and Methods

[6] Standard dendrochronological techniques were employed in this research. Tree-ring samples were taken from two sites in central Tien Shan Mountain (Figure 1). One site (MIQA) is located at (43°46′N, 87°55′E), at an elevation of 1970 m, and another site (MIQB) at (43°48′N, 88°01′E), at an elevation of 2080 m. Both sites are near to the lower forest limits, where tree growth is supposed to be mainly controlled by the moisture availability [*Fritts*, 1976]. Increment cores were taken from the same tree species (*Picea schrenkiana*) at both sites. In total 52 (60) cores from 27 (31) trees were retrieved at the site of MIQA (MIQB), respectively.

[7] After air drying and sanding, all the samples were cross-dated with skeleton plot and subsequently measured to ±0.001 mm precision. The quality of visual cross-dating was further checked by COFECHA program [*Holmes*, 1983]. These methods will ensure exact dating for each annual ring-width.

[8] The linear correlation between the raw measurements of the two sites is 0.69 ($p < 0.001$), and the first principal component explains 85.35% of their total variance. Further considering the close locations of the two sites and their

[1]Center for Arid Environment and Paleoclimate Research (CAEP), MOE Key Laboratory of West China's Environmental System, Chinese Academy of Engineering Physics (CAEP), Lanzhou University, Lanzhou, China.

[2]Now at Tree-Ring Laboratory, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA.

[3]Tree-Ring Laboratory, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York, USA.

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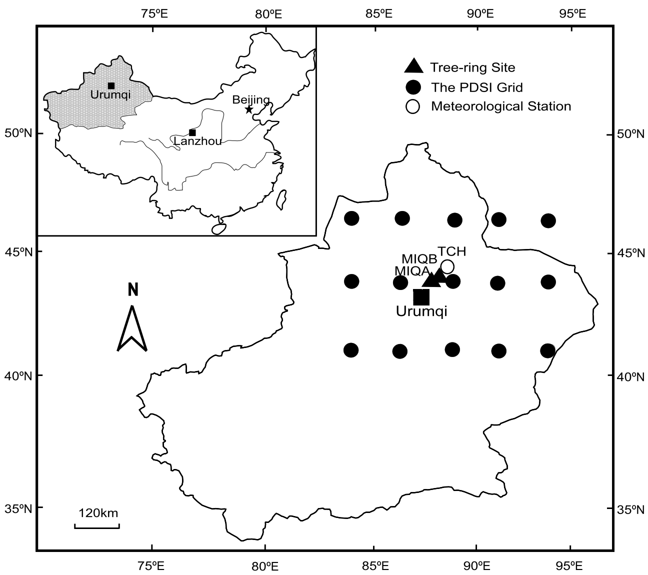

Figure 1. Map showing the two tree-ring sampling sites, the meteorological station and the PDSI grids developed by *Dai et al.* [2004].

high environmental homogeneity, we put all the measurements together to develop one ring-width chronology to indicate a regional climate signal. The chronology was developed by ARSTAN program [*Cook*, 1985] with conservative methods by fitting a negative exponential curve or a straight line of any slope. A cubic spline with a 50% frequency-response cutoff equal to 67% of the series length was also used in a few cases (8 out of the 96 cores) when anomalous growth trends occurred. As generally the sample size declines in the early portion of a tree-ring chronology, we used the subsample signal strength (SSS) [*Wigley et al.*, 1984] with a threshold value of 0.85 to evaluate the most reliable time span of the chronology. To reduce the potential influence due to the changing sample size, the chronology was further put through a process of variance stabilization prior to regression analysis [*Meko et al.*, 1993]. Based on these techniques we consider our ring-width chronology to be valid for dendroclimatic study. The final chronology extends from 1675 to 2002, is composed of data from 96 cores of 51 trees, and has a mean segment length of 263 years.

[9] The climate data used in this study include local monthly temperature and precipitation records as well as the monthly PDSI data developed by *Dai et al.* [2004] (Figure 1). The instrumental data, spanning 1959–1998, were obtained from the nearest meteorological station TCH (43°53′N, 88°07′E; 1935 m). The PDSI grid point used in this study is located at (43.75°N, 88.75°E), which is the nearest one to the sampling sites and has a time span of 1941–2003.

3. Results

[10] Climate-growth responses were analyzed for the common period when both meteorological records and tree-ring data are available (i.e., 1959–1998). The analyses were undertaken for the period of a biological year (i.e., last October to current September). As shown in Figure 2a, the significant correlations between temperature and tree-ring data were found in April (r = −0.36), May (r = −0.44), June (r = −0.40) and July (r = −0.35), based on the 95% confidence level. Meanwhile, the significant correlations between precipitation and tree-ring data were found in January (r = 0.32), April (r = 0.47), May (r = 0.42) and July (r = 0.31). As discussed below, neither temperature nor precipitation alone is an appropriate single climate parameter to be reconstructed, and the reconstruction should take both into consideration.

[11] The correlations between tree-rings and the monthly PDSI data were further analyzed for their common period of 1941–2002. As the PDSI is a direct measure of soil moisture availability, we analyzed their correlations for the period of current growth season (i.e., March–October). As shown in Figure 2b, all the correlations are at or over the 95% confidence level, with peak correlation found in May (r = 0.60). As seasonally averaged PDSI is more representative of moisture condition than just one single month, we further explored the appropriate season for reconstruction. The highest correlation between tree-rings and the seasonalized PDSI was found in April–June (r = 0.57); therefore April–June was used as the reconstruction season.

[12] A linear regression model [*Cook and Kairiukstis*, 1990] was employed in our study to perform the reconstruction, and the statistical fidelity of this model was examined by the split sample calibration-verification tests [*Meko and Graybill*, 1995]. As shown in Table 1, the values of two most rigorous tests for model validation, the reduction of error (RE) and the coefficient of efficiency (CE), are both positive. The results of sign test for 1972–2002 are all at the 0.01 confidence level, while for 1941–1971 the results are slightly weak, which is possibly due to the large amplitude of moisture variation during 1941–

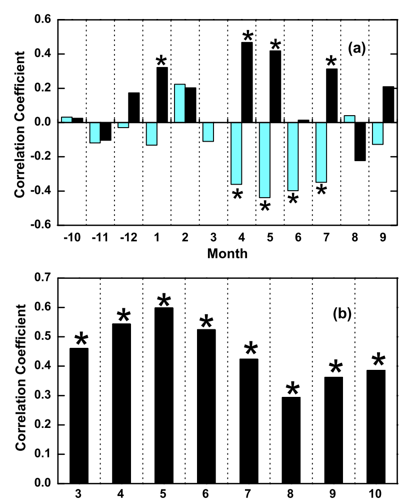

Figure 2. Correlations of tree-ring data (a) with monthly precipitation (solid bars) and temperature records (light bars) for the period of a biological year (1959–1998), and (b) with the monthly PDSI data for current growth season (1941–2002). The asterisks indicate the correlations over 95% confidence levels.

Table 1. Statistics of Calibration and Verification Test Results for the Common Period of 1941–2002

	Calibration (1941–1971)	Verification (1972–2002)	Calibration (1972–2002)	Verification (1941–1971)	Full calibration (1941–2002)
r	0.531	0.619	0.619	0.531	0.574
r^2	0.282	0.383	0.383	0.282	0.330
RE	—	0.472	—	0.329	—
CE	—	0.342	—	0.260	—
Sign test	18+/13−	23+/8−[a]	24+/7−[a]	18+/13−	—

[a]Significant at $p < 0.01$.

1960 (Figure 3). At any rate, the overall test results sufficiently proved the validity of our regression model. The reconstruction accounts for 33.0% of the actual PDSI variance during 1941–2002, which is not very strong but significant (Figure 3). Based on this model, the drought history for central Tien Shan area was reconstructed, which spans 1675–2002 A.D. (Figure 4).

[13] Multi-taper method (MTM) spectral analysis [*Mann and Lees*, 1996] was employed to examine the characteristics of drought variability in frequency domain. The analysis over the full range of our reconstruction revealed some low- and high-frequency cycles (Figure 5). Low-frequency peaks were found at 146–171 yrs (99% level), 11.5-yr (90%), 10.6-yr (near 90%) and 9.7-yr (90%). Other significant peaks were found at 6.1-yr (90%), 3.9-yr (99%), 3.4- and 3.2-yr (95%), 2.4-yr (95%) and 2.1-yr (99%).

4. Discussion and Conclusions

[14] As shown in Figure 2a, significant positive correlations exist between tree growth and the precipitations in January, April, May and July. Tree growth benefits from former winter's precipitation, as the latter works to enrich soil moisture storage, which is crucial for the coming year tree growth. The precipitation in the current growth season works to directly increase the soil moisture availability, and thus compensates for the soil water loss due to evapotranspiration. High temperature during current growth season tends to enhance evapotranspiration and thus decrease the soil moisture availability. This is why negative correlations between tree growth and the temperatures of April, May, June and July were found. Clearly both temperature and precipitation have strong effects on tree growth, thus neither of them alone is an appropriate climate parameter to be reconstructed.

[15] Our reconstruction using the PDSI quantitatively extends the drought history of central Tien Shan area back to 1675 A.D., providing a longer background to evaluate local drought variability (Figure 4). The mean PDSI value of our reconstruction is −1.19, which is significantly lower than the defined normal moisture status (PDSI = 0.0 ± 0.5) [*Palmer*, 1965]. As the classification scale of moisture conditions according to the PDSI was arbitrarily defined by *Palmer* [1965] based on his research in the central and western Great Plains, it may be not appropriate for the moisture conditions in northwest China. We therefore used the PDSI values of (−1.0 ± 0.5) to represent the normal moisture condition and the values of (≤−4.0 or ≥2.0) to represent the extremely dry or wet conditions in the study area.

[16] The moisture condition of late 17th century (i.e., 1675–1699) is at near normal state, except for an extremely dry event in 1690. After that, three distinct stages can be identified in our reconstruction: a comparatively wet 18th century, a dry 19th century and a consistent moisture increase during the 20th century.

[17] The 18th century is comparatively wet, especially from 1740s to 1780s. 1784 is the most extremely wet year in our reconstruction. Lichens on the moraine sediments indicated a strong glacier advance of the No. 1 Glacier in central Tien Shan around 1777 ± 20 [*Chen*, 1988], which corresponds to this wet period. This wet period was also evidenced by the drought reconstructions in northeastern and west central Mongolia [*Pederson et al.*, 2001; *Davi et*

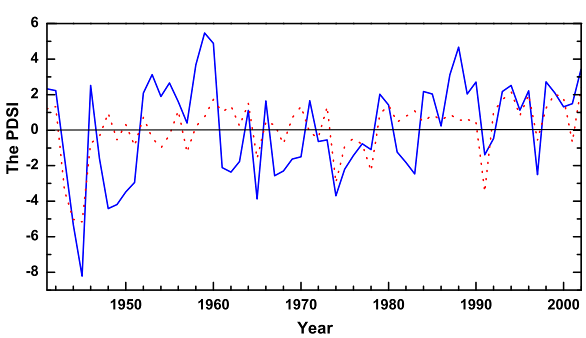

Figure 3. Actual (solid) and estimated (dotted) April–June PDSI for 1941–2002. The estimation explains 33.0% of the actual PDSI variance in this common period.

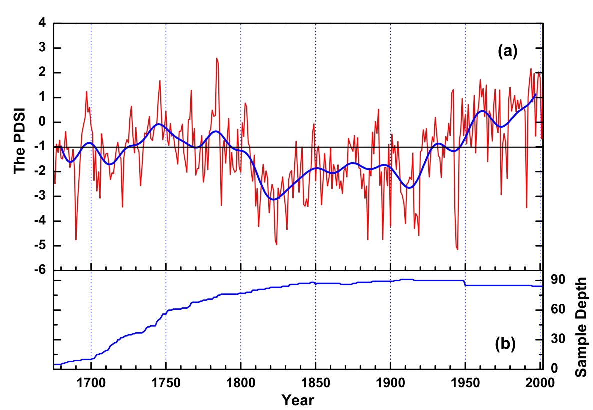

Figure 4. (a) Reconstruction of April–June PDSI (solid line) for 1675–2002 A.D. and its 11-year running average (bold line); and (b) the corresponding sample depth.

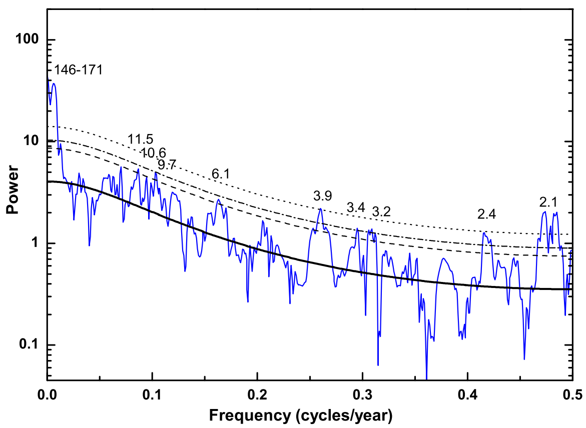

Figure 5. MTM spectral density of the drought reconstruction. The bold line indicates the null hypothesis; the dash, dash-dot and dotted lines indicate the 90%, 95% and 99% significance level, respectively.

al., 2006]. Meanwhile, no extremely dry years were found for this century.

[18] The 19th century is comparatively dry, especially around 1820s. This dry epoch was also clear in west central Mongolia, but much weaker in northeastern Mongolia [*Pederson et al.*, 2001; *Davi et al.*, 2006]. Many of the extreme drought events during this century were recorded in local historical archives, such as those in 1823, 1843, 1885, and 1895 [*Li et al.*, 1989].

[19] The most noteworthy feature in the 20th century is a clear trend of increasing moisture intensity. The early 20th century is dry. Starting from 1920s the moisture intensity has increased step by step, even though it was interrupted by several short dry intervals. The moisture increase in this area was also evidenced by the actual precipitation and PDSI data [*Wang and Zhou*, 2005; *Zou et al.*, 2005]. Interestingly, this moisture increase is in phase with the changes of Northern Hemisphere temperature [*Jones and Moberg*, 2003], thus may indicate some causal relationship between them.

[20] Despite of the dominance of moisture increase, several extreme droughts occurred in the 20th century. Among them the drought in 1943–45 was the most severe one since 1675. This severe dry period was widely recorded in local historical archives [*Li et al.*, 1989; *Ye and Yuan*, 1999], and was also found to occur in Mongolia [*Pederson et al.*, 2001]. Other extreme dry events in this century, including those occurred in 1900, 1910 and 1916–19, were all recorded by local historical archives [*Li et al.*, 1989; *Ye and Yuan*, 1999].

[21] The MTM results indicate the existence of some important cycles for regional drought variability (Figure 5). The century-scale cycle (146–171 yrs) is most significant in our reconstruction. However, this result should be interpreted with caution, as our reconstruction only covers two cycles of this periodicity. The peaks at ~11-yr resemble other findings in surrounding areas and may suggest the influence of solar effects [*Pederson et al.*, 2001; *Liu et al.*, 2003]. Peaks at 6.1-yr and ~2–3-yr fall within the range of variability of El Niño-Southern Oscillation (ENSO) [*Allan et al.*, 1996]; the peaks at ~2-yr are also within the band of tropical biennial oscillation (TBO) variability [*Meehl*, 1987]. These high-frequency cycles may suggest strong teleconnections of local drought variability with tropical ocean-atmosphere systems.

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F. Chen and X. Gou, Center for Arid Environment and Paleoclimate Research (CAEP), MOE Key Laboratory of West China's Environmental System, Chinese Academy of Engineering Physics (CAEP), Lanzhou University, Lanzhou 730000, China. (xhgou@lzu.edu.cn)

E. R. Cook and J. Li, Tree-Ring Laboratory, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA.