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Tree-ring based drought reconstruction in the central Hengduan Mountains region (China) since A.D. 1655

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Introduction

The Tibetan plateau has a mean elevation of more than 4,000 m asl. and covers an area of more than 2 million km^2. Thus, it acts as a heating surface during spring and summer and plays a key role in driving the Asian summer monsoon circulation (Murakami 1987, Webster *et al.* 1998). However, climate stations were not installed on the Tibetan plateau before 1950. This limits the analysis of long-term climate trends from meteorological records and requires the study of climate history from high-resolution proxy data like tree rings. In recent years, considerable progress was achieved to construct century to millennial-long tree-ring chronologies from north-eastern Tibet (e. g. Zhang *et al.* 2003, Shao *et al.* 2004) and from the southern parts of the Tibetan Plateau (Wu *et al.* 1991, Bräuning 2004, Bräuning and Grießinger 2006). However, only few dendroclimatological studies were conducted in the north-south oriented Hengduan Mountains. Here we present four new tree-ring width chronologies from the central Hengduan Mountains at the southern rim of the Tibetan plateau. We analyze the relationships between tree growth and climatic variables to examine the regional climate variability during the past 350 years.

Material and Methods

Chronology development

The four chronologies presented in this study come from three coniferous tree species, i.e. *Picea likiangensis* Pritz, *Tsuga dumosa* (D. Don) Eichler, and *Abies ernestii* Rehd. Increment cores from 93 trees (136 cores) were extracted with an increment borer at four sites on the west facing slopes of the Baima Snow Mountains, NW Yunnan (Fig. 1).

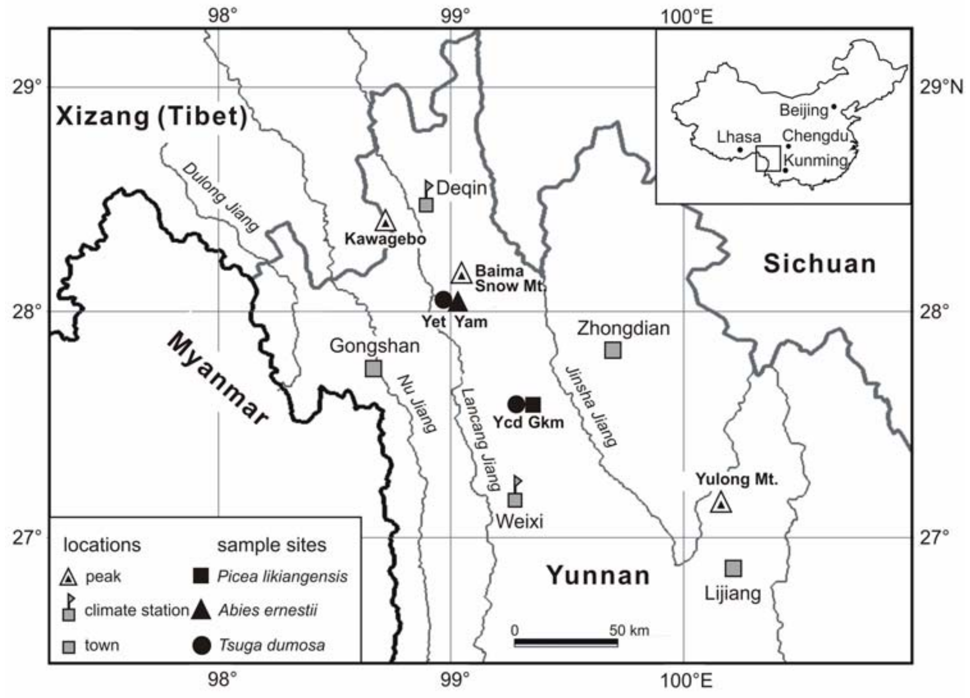

Figure 1: Map of the sampling sites in the Baima snow mountains, northwestern Yunnan.

The forests at the sampling sites are hardly disturbed by human activity. At each site, a minimum of sixteen trees were cored at breast height. Ring widths were registered with a LINTAB measuring system with a resolution of 0.01 mm, and all cores were cross-dated by visual growth pattern matching, skeleton plotting and statistical tests (sign-test and t-test) in the software package TSAP (Stokes and Smiley 1968, Rinn 1996). The variance of each series was stabilized using a data-adaptive power transformation, then standardization was carried out in two steps in ARSTAN (Cook 1985). After fitting a negative exponential or a linear regression curve of negative slope, the tree-ring sequences were detrended with a cubic smoothing spline with a 50% frequency-response cutoff equal to 67% of the series length. The final tree-ring index chronologies were obtained by calculating differences between the transformed ring width measurements and the fitted splines. All detrended series were averaged to chronologies by computing the biweight robust mean in order to reduce the influence of outliers (Cook and Kairiukstis 1990). To reduce the potential influence of decreasing sample depth with increasing age, the variance of the chronology was stabilized (Osborn *et al.* 1997).

Climate data

The region’s climate is temperate and is characterized by a rainfall maximum during the summer months. Summer rains originate from monsoonal air masses flowing over the Bay of Bengal, whereas winters are generally dry (Xu *et al.* 2003). There are two meteorological observation stations relatively close to the sampling sites (Figure 1), located in Deqin (28.48°N, 98.92°E, 3320 m a.s.l., record length 1957-2000) and Weixi (27.17°N, 99.28°E, 2325 m a.s.l., record length 1961-2000). A dataset for the Palmer drought severity index (PDSI) on a 2.5°×2.5° grid was developed by Dai *et al.* (2004). The two grid points (26.25°N, 98.75°E and 28.75°N, 98.75°E) next to our sampling sites were used for detecting the growth response to moisture conditions. A regional series of climate data was created from the two meteorological stations for their common period of 1961-2000, and from the two PDSI grid points for 1951-2000 (Jones and Hulme 1996).

Growth-climate response

The climate-growth relationships were examined by computing correlation functions between climate data and tree-ring index chronologies and the score of PC#1, respectively. Pearson correlation coefficients were calculated between the ring width chronologies and the monthly regional series of temperature and precipitation for a 15 month period ranging from July of the summer prior to growth until September of the growth year (Deqin *v.s* Yam and Yet; Weixi *v.s* Gkm and Ycd). PC#1 was compared with the regional climate series of relative humidity and PDSI for a 15-month period from July of the summer prior growth to September of the growth year.

Results

The Rbar and EPS statistics of the site chronologies signal strength range from 0.28 to 0.37 and from 0.77 to 0.87, respectively. Three site chronologies meet the 0.85 EPS criterion after AD 1655, except for site Yet whose EPS is above 0.75 at 1655 and reaches the 0.85 limit only after 1730. Nevertheless, we regarded the period 1655-2005 (351 years) as common period of acceptable chronology quality for further analyses. Despite of the different species analyzed, the four chronologies correlate with each other significantly over the common period 1655-2005, with correlation coefficients ranging from 0.40 to 0.55 ($p<0.01$). Ring-width patterns are very similar among the four chronologies, especially concerning high and middle frequency growth variations. The principle component analysis of the four chronologies shows that only the eigenvalue of PC#1 was greater than one and that PC#1 accounts for 60.5% of the total variance. The four chronologies show common positive loadings on PC#1: 0.78 for Gkm, 0.79 for Ycd, 0.75 for Yam and 0.79 for Yet, respectively. Therefore, PC#1 reflects the common growth response to regional climatic variations, and the score of PC#1 can be used to evaluate the regional climate-growth relationships and to indicate regional climate variability. Correlation analyses indicate that tree growth is mainly affected by early spring precipitation, especially during January, March and May (Fig. 2). The correlation coefficients between seasonal precipitation (March to May) and the residual ring-width index chronologies are significant ($p<0.05$) except for site Yet ($r=0.56$ for Gkm, 0.57 for Ycd, 0.33 for Yam, 0.25 for Yet).

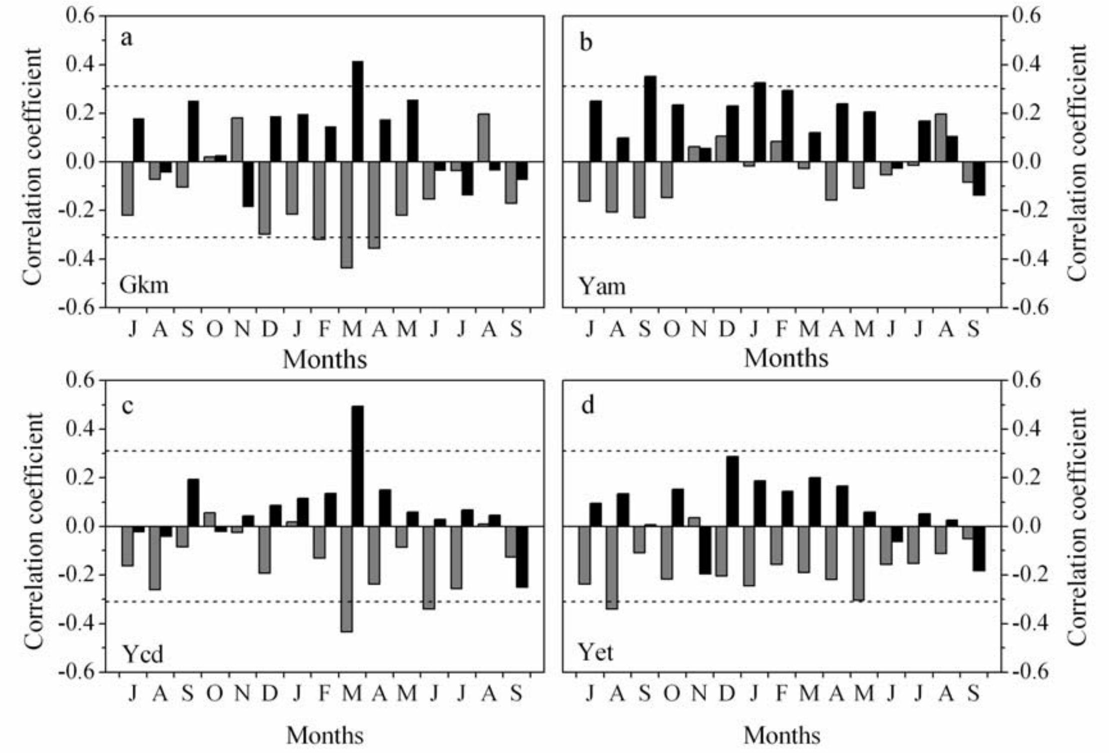

Figure 2 Correlation coefficients between radial growth and monthly mean temperature (gray) and total monthly precipitation (dark) at nearby meteorological stations. Correlations are computed from previous year July to current year September over 1957-2000 for Deqin and 1961-2000 for Weixi. Horizontal dashed lines denote the 95% levels of significance.

When standard chronologies instead of residual chronologies are compared with climate parameters, we find the same general patterns but lower correlations (not shown). PC#1 of the four residual chronologies correlates positively with the PDSI (Fig. 3a) and with relative humidity (Fig. 3b) in the spring of the growth year. The highest correlation between PC#1 and PDSI occurs for the season March to May ($r=0.65$, $p<0.01$) which was therefore reconstructed by using PC#1 of the four residual chronologies as predictor variable.

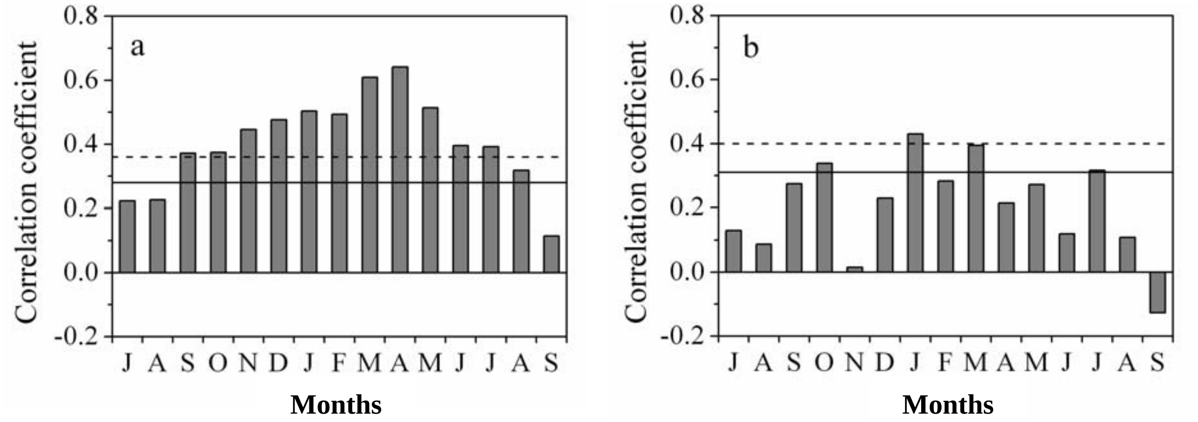

Figure 3 Correlation of thePC#1 with (a) PDSI data (1951-2000) and (b) the regional monthly relative humidity (1961-2000) from previous year July to current year September. Horizontal bold and dashed lines denote the 95% and 99% significance levels, respectively.

A linear regression model was developed to reconstruct the drought history for the central Hengduan Mountain region. During the common period of tree rings and PDSI data (1951-2000), the reconstruction accounted for 42% of the actual PDSI variance (Tab. 1).

Table 1: Statistics of calibration-verification test results for the common period 1951-2000.

Split-sample calibration-verification								
Calibration				*Verification*				
Period	*R*	*R^2*	*F*	*Period*	*Sign test*	*Pmt*	*RE*	*CE*
1951-1980	*0.65*	*0.42*	*20.4***	*1981-2000*	*14/6***	*2.50***	*0.318*	*0.298*
1981-2000	*0.68*	*0.47*	*15.9***	*1951-1980*	*22/8**	*2.51***	*0.374*	*0.359*
1951-2000	*0.65*	*0.42*	*34.5***					
Leave-one-out verification								
1951-2000	*0.61*				*38/12***	*2.75***	*0.372*	

The spring PDSI estimates derived from this model show high agreement with the yearly departures from the long-term mean in the observed data (Fig. 4a). Split-sample calibration-verification and leave-one-out cross verification methods (Michaelsen 1987) were employed to evaluate the statistical fidelity of this model. The reduction error (RE) and the coefficient of efficiency (CE) are positive, which indicate significant skill in the tree-ring estimates (Fritts 1976). The results of the sign test and product mean test demonstrate the validity of our regression model (Tab. 1).

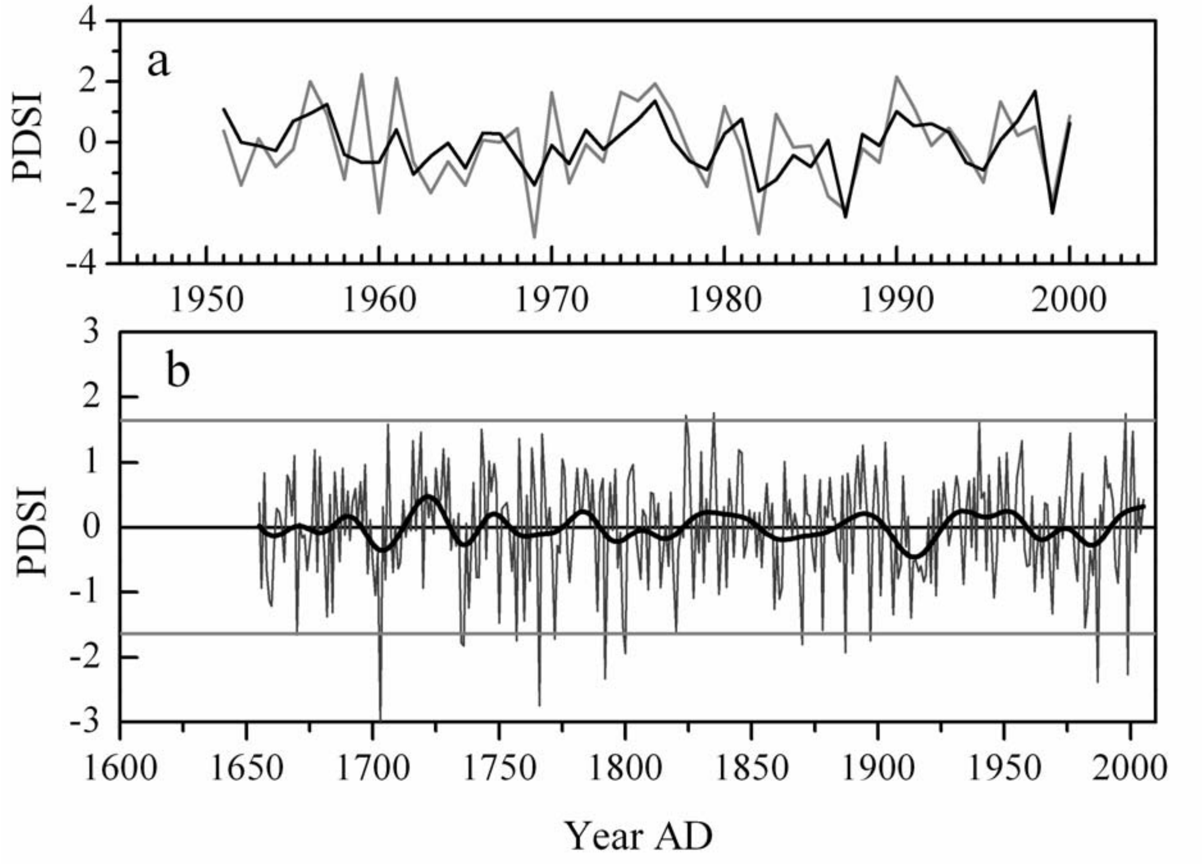

Figure 4: a) Actual (gray) and reconstructed (dark) March to May PDSI during their common period 1951-2000. b) The reconstruction of March-May PDSI in the central Hengduan Mountain region over the past 350 years. The thin line represents the annual value and the thick line was smoothed with an 11-year FFT-filter (Fast Fourier Transform) to emphasize long-term fluctuations. The gray line indicates the ±2 SD values.

The spring (March-May) PDSI reconstruction (Fig. 4b) shows that wet periods prevailed in the 1690s, 1715-1730, 1750s, 1780s, 1825-1850,1900s, 1930-1960, and 1990-present. Extremely wet years (≥2SD) occurred in AD 1703, 1824, 1835, 1940, and 1998. In contrast, the intervals AD 1700-1715, 1733-1745, 1790-1820, 1860-1890, 1910-1925, and 1960-1990 were relatively dry. Extremely dry years (≤2SD) were more frequent than extremely wet years and are concentrated during AD 1730-1800 and 1870-1900, and after 1980, respectively. From the higher mean correlation between the four individual chronologies, it can be concluded that these were time periods of strong climatic forcing of regional tree growth patterns. Particularly dry years occurred in AD 1670, 1706, 1735-1736, 1757, 1766, 1772, 1792, 1800, 1820, 1870, 1887, 1897, 1987, and 1999.

Discussion

We found significant positive correlations between tree growth and precipitation in January, March and May (Fig. 2). The correlation between PC#1 and relative humidity and the PDSI also indicates that the spring moisture availability is a major limiting factor for tree-ring growth (Fig. 3). In southern Tibet, dry and warm conditions before the onset of the summer monsoon cause drought stress to the trees and are thus limiting growth (Bräuning and Grießinger 2006). Thus, tree growth benefits from former winters' and current spring precipitation, which increase the soil moisture content during the early part of the growing season. This growth response is not surprising for trees growing on steep slopes in a subtropical climate. Our study sites are located at middle elevations, far away from the upper tree line which lays around 4200 meters a.s.l. in the Baima Mountain region.

Although our PDSI reconstruction is based on the residual tree-ring chronologies, considerable decadal scale moisture variability is retained in our reconstruction. The dry springs in the 1700s, 1730s and 1790s-1820s (Figure 4b) were also detected as dry periods in the same area by Wu *et al.* (1988). The dry periods in the 1800s are synchronous with dry conditions in Mongolia and in the western Himalaya (Pederson *et al.* 2001, Singh *et al.* 2006). Other intervals in the 18th century were relative wet, especially the period 1715-1730. The period 1825-1850 was a relatively prolonged wet period, which has also been reported as a prolonged phase with wet springs (AD.1820s to 1840s) in the western Himalayan region of India (Singh *et al.* 2006).

The most severe drought period in the past 350 years occurred during 1910-1925. This severe drought has also been recorded in tree-rings from North China (Liang *et al.* 2006) and southern Tibet (Bräuning and Grießinger 2006). Liang *et al.* (2006) combined tree-ring records and historical records (meteorological, hydrological and documentary evidence) and reported that the 1920s drought was severe and sustained across northwest China. Spring climate was relatively wet from 1930 to 1960, which was also reported by Wu *et al.* (1988). The period 1960-1990 was relatively dry, especially in 1983-1988. The last ca. 15 years were comparatively wet, but were still within the range of fluctuations over the last 350 years.

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