Available online at www.sciencedirect.com

ScienceDirect

Dendrochronologia 26 (2008) 97–107

DENDROCHRONOLOGIA

www.elsevier.de/dendro

ORIGINAL ARTICLE

Annual temperature reconstruction in the central Hengduan Mountains, China, as deduced from tree rings

Ze-Xin Fan[a,b], Achim Bräuning[b,*], Kun-Fang Cao[a]

[a]The Chinese Academy of Sciences, Xishuangbanna Tropical Botanical Garden, 88 XueFu Road, Kunming 650223, China
[b]Institute of Geography, University of Erlangen-Nuremberg, Kochstrasse 4/4, D-91054 Erlangen, Germany

Received 30 August 2007; accepted 3 January 2008

Abstract

We developed five tree ring-width chronologies from one fir (*Abies georgei*) and four spruce (*Picea brachytyla*) stands near the upper treeline in the central Hengduan Mountain, northwestern Yunnan, China. Similar growth patterns and significant correlations are embodied among the five chronologies. A principal component analysis for the four spruce chronologies indicated that the first component accounts for 54.8% of the total variance over the period 1750–2003. Climate–growth response analysis revealed that radial growth is mainly controlled by temperature variations, especially in the winter season. The first principal component of the spruce chronology network accounts for 43% of the annual mean temperature (from previous October until September) variance during the common period 1959–2003. By using a linear regression approach, we reconstructed annual mean temperature for the past 250 years. The reconstruction shows that the central Hengduan Mountain experienced some cool episodes during the 1810s, 1860s, and during 1960–1980. Warm intervals occurred during the 1780s, 1850s, 1940–1960 and in the past two decades. These general patterns are in general accordance with other records from nearby regions.

Keywords: Dendroclimatology; Hengduan Mountain; Ring-width; Temperature

Introduction

Based on tree-ring width and maximum latewood density chronologies, long-time climate variations have been successfully reconstructed on regional (Jacoby et al., 1996; Luckman and Wilson, 2005) and hemispheric spatial scales (Mann et al., 1998; Esper et al., 2002; Briffa et al., 2004). The mountain regions of western China and the Tibetan Plateau are an area which is especially sensitive to climatic change (Liu and Chen, 2000). However, temperature reconstructions derived from ice cores (Yao et al., 2006) and multiple archives (Yang et al., 2003) indicate that decadal-scale temperature fluctuations occurred asynchronously in different parts of the vast Tibetan Plateau during the last millennium. To relate these complex spatio-temporal differences of paleoclimate to related atmospheric circulation patterns that are the driving factors of climate variability, a dense network of past climate information has to be established. However, meteorological records in Tibet are short and sparse in spatial

---

[*]Corresponding author. Tel.: +49 9131 8529372; fax: +49 9131 8522013.
E-mail address: abraeuning@geographie.uni-erlangen.de (A. Bräuning).

1125-7865/$ - see front matter © 2008 Elsevier GmbH. All rights reserved.
doi:10.1016/j.dendro.2008.01.003

distribution, therefore high-resolution proxy data like tree rings are needed to shed more light on the climate history of the Tibetan Plateau.

Trees growing in the cold–moist environment near the upper treeline in eastern Tibet are sensitive to temperature variations (Bräuning, 2001). In the last decades, the knowledge of past climate changes in China derived from dendroclimatic studies has drastically increased. Century- to millennial-scale temperature fluctuations were reconstructed for northeastern Tibet (e.g., Kang et al., 1997; Jin et al., 2005; Gou et al., 2006) and for the southern parts of the Tibetan Plateau (Wu et al., 1989; Bräuning, 1994). Late summer temperature over the past 400 years was reconstructed from a network of 22 maximum latewood density (MLD) chronologies of high elevation conifer sites in southeastern Tibet (Bräuning and Mantwill, 2004). Gou et al. (2007) reconstructed winter minimum temperature in the northeastern part of the Tibetan Plateau and showed that the minimum temperature of the winter half-year has increased by 2.5 °C during the last 50 years.

However, only a few dendroclimatological studies have been conducted in the north–south oriented mountain ranges called Hengduan Mountains (Wu et al., 1988; Bräuning, 2001), which form the southern rim of the Tibetan Plateau and are strongly exposed to the South Asian summer monsoon. Wu et al. (1988) reconstructed fluctuations of air temperature during the last 400 years in the Hengduan Mountains. The winter season minimum temperature series has also been reconstructed from West Sichuan (Shao and Fan, 1999). Here we present a new tree ring-width chronology network from upper treeline sites from the central Hengduan Mountains, and derived temperature variability over the last 250 years.

Materials and methods

Study area

The study sites are located in the central Hengduan Mountains, northwestern Yunnan Province, China (Fig. 1). Four of Asia's major rivers, namely Jinsha Jiang (upper Yangtse), Lancang Jiang (upper Mekong), Nu Jiang (upper Salween) and Dulong Jiang (a tributary of Irrawaddy) converge within a 90 km corridor in this portion of the Hengduan Mountain range. The resulting landscape patterns include extreme topographic gradients between deeply incised parallel gorges of approximately 1500 m elevation and glaciated peaks (>6700 m a.s.l.) within a distance of 20 km or even less. These gorges form passageways for the monsoonal air masses to penetrate into the dry interior of Tibet (Chang, 1981). The pronounced altitudinal climatic gradients lead to a differentiation of mountain forests into several altitudinal belts.

Sampling and chronology development

Ring-width chronologies were developed from five stands near the upper treeline in the Central Hengduan Mountains (Fig. 1; Table 1). In total, 161 increment

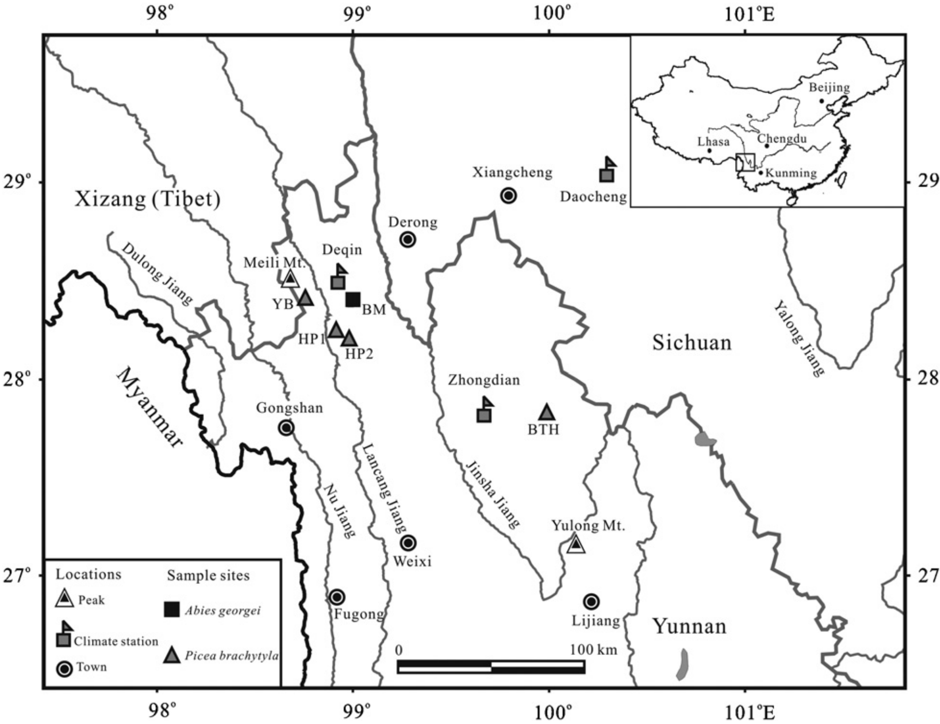

Fig. 1. Locations of the sample sites and meteorological stations.

Table 1. Site characteristics and chronology statistics

Site	Lat/Lon	Elev (m)	Trees (cores)	Period	AGR[a] (mm)	MS[b]	AC1[b]	Rbar[c]	EPS[c]
BM	28.38/98.99	4100	24 (49)	1651–1999	0.57	0.13	0.77	0.27	0.87
HP1	28.25/98.91	3600	18 (32)	1688–2005	1.35	0.16	0.73	0.32	0.85
HP2	28.24/99.01	3500	32 (46)	1738–2005	1.43	0.18	0.70	0.46	0.96
BTH	27.82/99.99	3540	18 (19)	1634–2003	0.85	0.16	0.63	0.29	0.83
YB	28.40/98.76	3280	15 (15)	1696–2003	1.25	0.15	0.71	0.21	0.74

BM: Baima pass (*Abies georgei*); HP1, HP2: Hong Po at the Baima snow mountain (*Picea brachytyla*); BTH: Bitahai Nature Reserve (*Picea brachytyla*); YB: Yu Beng at the Meili snow mountain (*Picea brachytyla*); Lat: laditude; Lon: longitude; Elev: elevation; AGR: average growth rate; MS: mean sensitivity; AC1: first-order auto-correlation; Rbar: mean inter-series correlation; EPS: expressed population signal.

[a] Calulated for raw ring-width values.

[b] Calculated for ARSTAN standard chronologies.

[c] Calculated for ARSTAN residual chronologies for 30-year intervals with 15-year overlaps.

cores from 107 trees were sampled from *Abies georgei* Orr and *Picea brachytyla* (Franch.) Pritz. At each study site, at least 15 trees were sampled at breast height with an increment borer. After air drying, the surface of a core was prepared with razor blades and the surface contrast was enhanced with chalk. Ring widths were registered with a LINTAB II 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, 2003).

The final chronologies were developed with the ARSTAN program (Cook, 1985). The raw ring-width series were standardized to remove biological growth trends as well as other low-frequency variations due to stand dynamics. Prior to standardization, the variance of each series was stabilized using a data-adaptive power transformation based on the local mean and standard deviation (Cook and Peters, 1997). A fixed 120-year spline (with a 50% frequency-response cut-off at wavelengths of 60 years) was fitted to each raw series, and this trend was then removed by subtraction. This detrending method allows maximizing the common signals among individual tree-ring series; however, it also removes information on century-scale climate variability. Therefore, our discussion on past climate variability will focus on multidecadal climate excursions, and does not include long-term trends. 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 on the variance in the older parts of the final chronology, the variance of the chronologies was stabilized according to the method described by Osborn et al. (1997). We produced two versions of each chronology. The first version is a standard chronology where low-order persistence has been retained, the second version is the prewhitened or residual chronology where significant low-order persistence has been removed (Cook, 1985).

Signal strength of the site chronologies was assessed by the mean inter-series correlation (Rbar) and the expressed population signal (EPS; Wigley et al., 1984). EPS is a function of Rbar and the sample size and estimates the variance fraction of an infinite, hypothetical population expressed by the chronology. A level of 0.85 in EPS is considered to indicate a satisfactory quality of a chronology. This prevents a loss of explained climate variance due to the reduction of sample depth in the early part of the chronology (Wigley et al., 1984). Both Rbar and EPS were calculated for 30-year moving windows with 15-year overlaps along the chronology.

Climate data

Monthly temperature (maximum, mean and minimum) and precipitation data were obtained for three stations nearby our sample sites from the National Meteorological Information Centre (NMIC) of China (Fig. 1). Data homogeneity was tested by applying the double-mass analysis techniques, a graphical technique (Kohler, 1949). The monthly records from Deqin (28.48°N, 98.92°E, 3320 m a.s.l.) station contain heterogeneities, which are caused by the relocation of the station in January 1981 and April 1994. Therefore, Deqin station data were excluded from further analysis, despite its close location to some of the study sites. A regional meteorological data series for the study region was developed from monthly records of the two high elevation stations Zhongdian (27.83°N, 98.67°E, 3276 m a.s.l.) and Daocheng (29.05°N, 100.3°E, 3729 m a.s.l.), by applying the techniques outlined in Jones and Hulme (1996). Monthly values for each station were standardized as *z*-scores relative to the 1958–2004 common periods and averaged to calculate monthly *z*-scores for the regional average series. The monthly *z*-scores were then converted to ‘absolute’ temperature values using the average of means (grand mean) and standard deviations

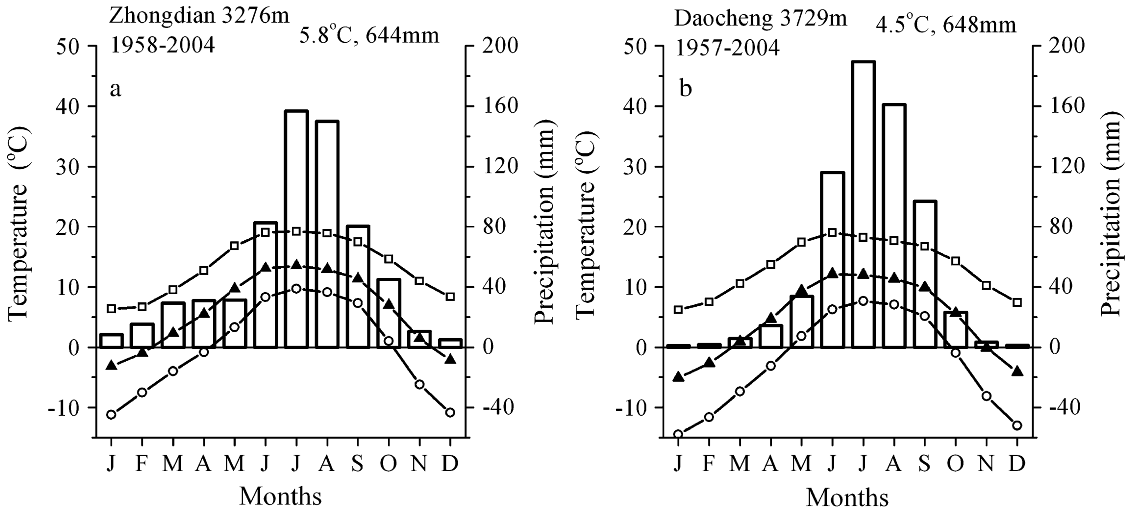

Fig. 2. Monthly total precipitations (bars), mean maximum temperature (line with squares), and mean temperature (line with triangles) and mean minimum temperature (line with circles) for the two meteorological stations in the central Hengduan Mountains.

(grand standard deviation) of each of the original monthly series. Daily temperature range (DTR) was calculated by subtracting regional monthly maximum temperature by the minimum temperature (Fig. 2).

The climate–growth relationships were analyzed by using the software DENDROCLIM 2002 (Biondi and Waikul, 2004). We calculated simple linear correlation functions between the individual site chronologies and the monthly regional series of temperature and precipitation for an 18-month period ranging from May of the year prior to growth to October of the growth year. To consider possible multicollinearity between the climate data series, we also calculated so called response functions (Fritts, 1976), in which uncorrelated principal components of the climate data are regressed against the tree-ring chronologies.

Results

Analyses of meteorological data

The analyses of regional climate data revealed a significant warming trend of annual mean temperature ($0.029\,^{\circ}\mathrm{C\,yr^{-1}}$) since 1958. However, this warming trend was mainly contributed by an increase of minimum temperature ($0.09\,^{\circ}\mathrm{C\,yr^{-1}}$) instead of maximum temperatures. The regional DTR has been decreasing since the early 1980s (data not shown). These findings coincide with other instrumental climate records at regional scales (Wilson and Luckman, 2002) and high elevation sites (Diaz and Bradley, 1997). Increased cloud cover may lead to a decrease in DTR because daytime $T_{\max}$ is reduced due to greater reflection of incoming radiation from the upper surface of clouds and night time $T_{\min}$ increases because of enhanced downward radiation from clouds (Easterling et al., 1997).

Chronology comparison

Common signals between the individual chronologies were assessed by applying correlation analysis and principal component analysis. Fig. 3 shows that the five chronologies share a lot of common decadal variation, which is also reflected by the significant correlations between the chronologies (Table 2). The average correlation between all chronologies is 0.36 for the well-replicated period 1850–1999. Correlations between individual spruce chronologies are normally higher (mean $r = 0.47$) and amount to 0.81 between the neighboring sites HP1 and HP2 (Table 2). The fir chronology BM shows only weak correlations to the four spruce chronologies (mean $r = 0.21$). This can probably be attributed to the different autocorrelation structure of the fir chronology (Table 1) and to a different climate response, especially concerning the relatively strong influence of previous year's climate on growth (Fig. 4).

The moving Rbar and EPS statistics of the site chronologies signal strength range from 0.21 to 0.46 and 0.74 to 0.96, respectively. All chronologies meet the 0.85 EPS criterion after AD 1750, except for site YB whose EPS is above 0.80 at 1750 and reaches the 0.85 limit only after 1780. Due to the different behavior of the fir chronology, subsequent principal component analysis

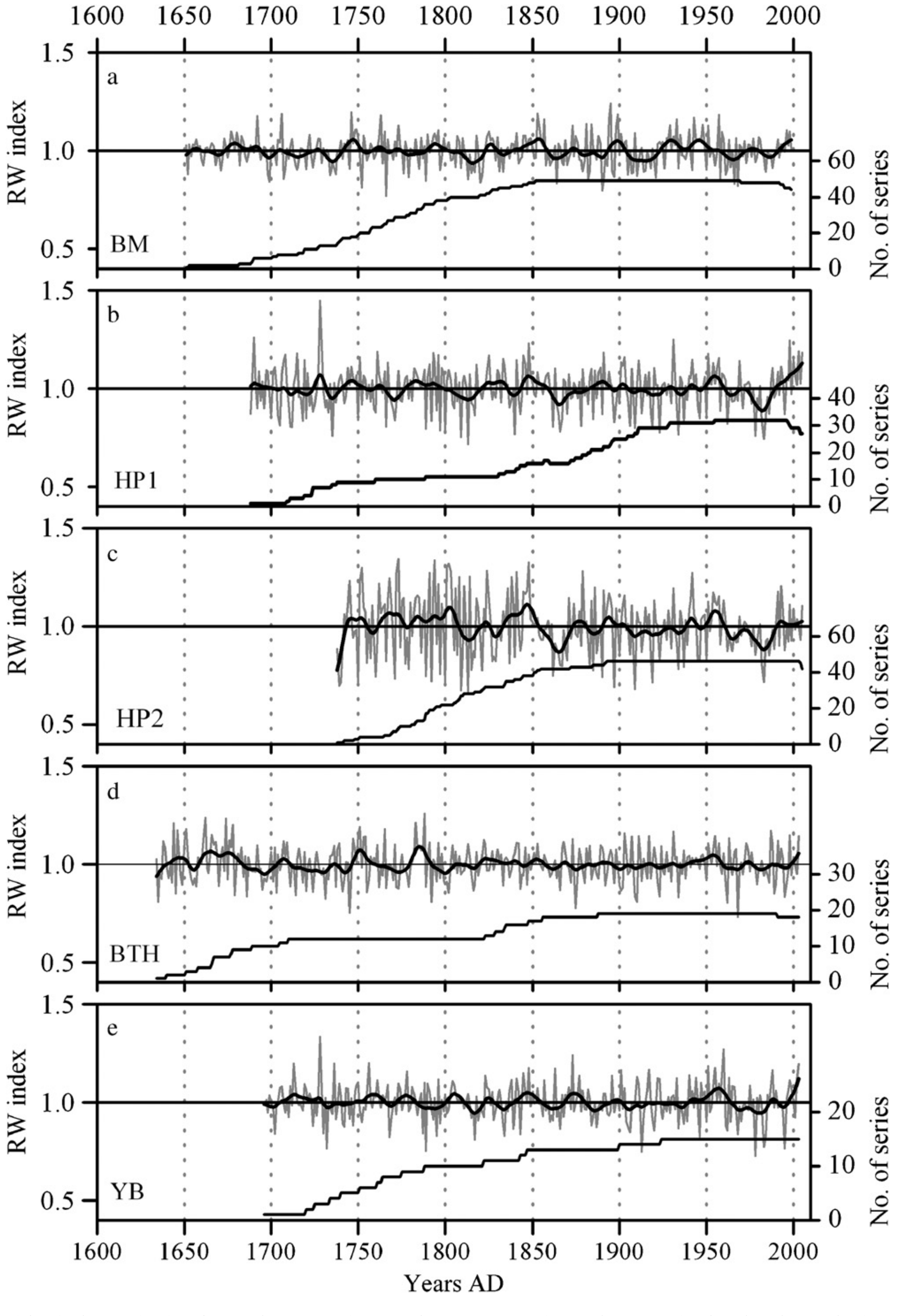

Fig. 3. The five residual chronologies from the central Hengduan Mountains. The sample depths through time are shown in the lower sections of each graph. Thin lines represent annual values; bold lines are 15-year cubic smoothing splines.

was only performed for the set of spruce residual chronologies. Only the eigenvalue of the first principle component (PC#1) was greater than one and PC#1 accounts for 54.8% of the total variance for the period 1750–2003 (Table 3). The factor loadings for PC#1 of all chronologies are positive and very similar in magnitude (0.89 for HP1, 0.80 for HP2, 0.61 for BTH, 0.61 for YB, respectively).

Climate-growth analysis

Correlation analysis with regional climate data indicates that the radial growth rates are mainly influenced by temperature conditions (Fig. 4). For the fir (site BM), temperature conditions in the winter season prior to growth (November and December, $r = 0.53$, $p < 0.01$) have a predominant influence on

Table 2. Pearson correlations among the residual chronologies for the period 1850–2003

	HP2	BTH	YB	BM
HP1	0.81	0.44	0.48	0.23
HP2	1	0.35	0.37	0.20
BTH		1	0.35	0.18
YB			1	0.22

All correlation are significant at the $p < 0.05$ level.

radial growth. For the four spruce chronologies, warm temperatures have a positive impact on tree growth throughout the year, especially in the winter season (Fig. 4). Correlations between ring width and precipitation are generally low and rarely exceed the 95% significance level. Previous year's rainfall during summer and autumn generally has a positive influence on tree growth in the following year (Figs. 4 and 5d). Rainfall during the growing period (July and August) also stimulates

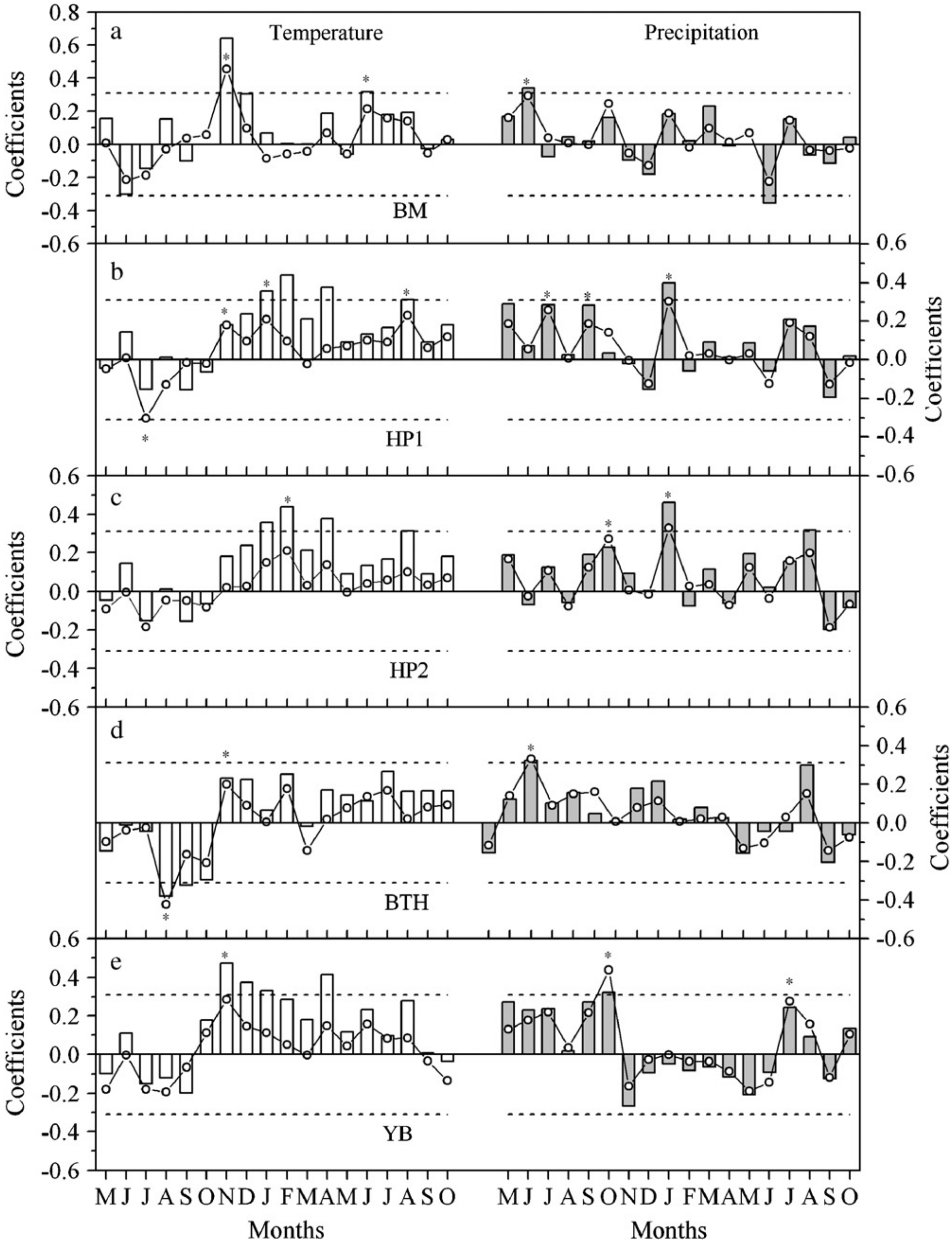

Fig. 4. Correlation (columns) and response (dot-lines) functions coefficients between radial growth and regional monthly mean temperature and total monthly precipitation. Correlations are computed from previous year May to current year October over 1958–2003. Horizontal dashed lines denote the 95% significance level of the correlation. Asterisks denote significance ($p < 0.05$) of response function based on bootstrapping tests.

growth. January precipitation shows a significant positive influence on ring width at sites HP1 and HP2. Possibly, winter precipitation enhances soil moisture which enhances available moisture resources for tree growth during the early growing season. In general, correlation coefficients between individual ring-width chronologies and monthly climate data are relatively weak, but temperature has a higher influence on tree growth at these subalpine sites than precipitation.

The correlation calculations between PC#1, which represents the common signal of the spruce chronologies, and regional climate data show a higher number of significant correlations than for the individual chronologies. PC#1 correlates positively with the mean and minimum temperatures from October prior to growth through the current growth year, and the maximum temperature in the winter season

Table 3. Eigenvalues of principal component analysis of the four spruce residual chronologies for the period 1750–2003

Component	Eigenvalue	Variance (%)	Cumulative variance (%)
1	2.19	54.8	54.8
2	0.87	21.8	76.6
3	0.70	17.4	94.0
4	0.24	6.0	100

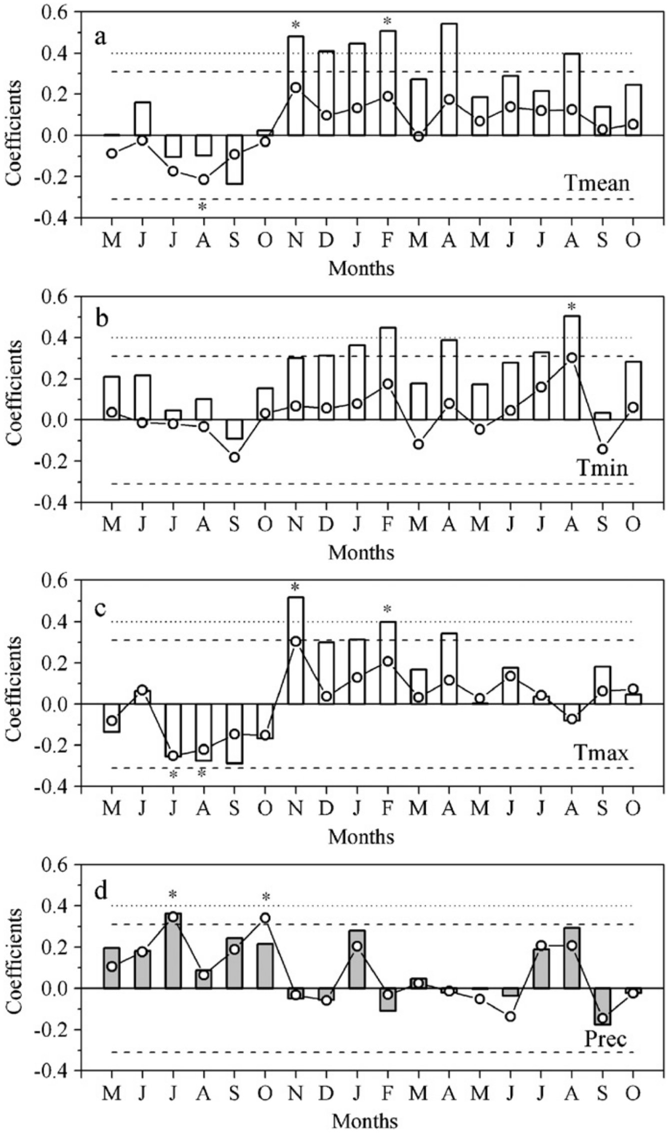

Fig. 5. Correlation (columns) and response (dot-lines) functions coefficients between PC#1 of four spruce chronologies and the regional monthly mean (T_{mean}) (a), minimum (T_{min}) (b), maximum temperature (T_{max}) (c) and precipitation (Prec) (d) from previous year May to current year October over the common period 1958–2003. The horizontal dotted and dashed lines donate the 99% and 95% significance level for the correlation function, respectively. Asterisks denote significance ($p<0.05$) of response function based on bootstrapping tests.

(previous November to April, $r = 0.55$, $p < 0.01$) (Fig. 5). The highest correlation was found between PC#1 and the regional annual mean temperature from previous October to current September ($r = 0.659$, $p < 0.01$), which was therefore reconstructed by using the PC#1 as predictor variable.

Results of response function analyses generally confirm the climate-growth relationships derived from linear correlations for the individual chronologies as well as for PC#1 (Figs. 4 and 5). However, some response function coefficients between ring width and temperature during winter months show a drastic decrease which points to some multicollinearity between temperature records of consecutive months. Except for March, the response for temperature on tree growth remains positive throughout the annual cycle from November of the year before growth until October of the growth year (Fig. 5). Since our final temperature reconstruction includes temperature over the whole year, the multicollinearity between some temperature series is not problematic.

Table 4. Statistics of the leave-one-out calibration results for the common period 1959–2003

Period	R	R^2	R^2_{adj}	F	r	Sign test	Pmt	RE
1959–2003	0.659	0.433	0.421	33.0**	0.61	32/13**	2.67*	0.37

R is correlation coefficient; r is the correlation coefficient between the recorded data and the leave-one-out-derived estimates. Pmt is the product mean test. Sign test is sign of paired observed and estimated departures from their mean on the basis of the number of agreement/disagreements; RE is the reduction of error, any positive value indicates there is some sense in the reconstruction (Fritts, 1976).

*Significant at $p < 0.05$.

**Significant at $p < 0.01$.

A linear regression model ($Y = 5.182 + 0.351X$) was developed to reconstruct the annual (previous October to current September) temperature history in the central Hengduan Mountains. As shown in Table 4, the model accounts for 43% of the actual regional temperature variance during the period 1959–2003. The leave-one-out cross-validation method was employed to evaluate the statistical fidelity of this model (Michaelsen, 1987). The model yielded significant verification statistics as measured by sign test and product mean test. The RE value is 0.37, indicating that there is some skill in the derived reconstruction (Fritts, 1976; Table 4). The temperature reconstruction derived from this model shows good agreement with the actual regional temperature (Fig. 6a).

The annual temperature (previous October to September) reconstructed over the last 250 years is shown in Fig. 6b. Although the reconstruction was based on the residual tree-ring chronologies, considerable decadal-scale temperature variability was retained in our reconstruction. Cold episodes occurred around 1810–1820, 1860–1970 and in the 1960–1980s. Warm periods occurred in the 1780s, 1825–1860, 1930–1960, and from 1990 to present.

Discussion

Tree growth near the upper treeline in our study area is mainly influenced by temperature conditions, espe-

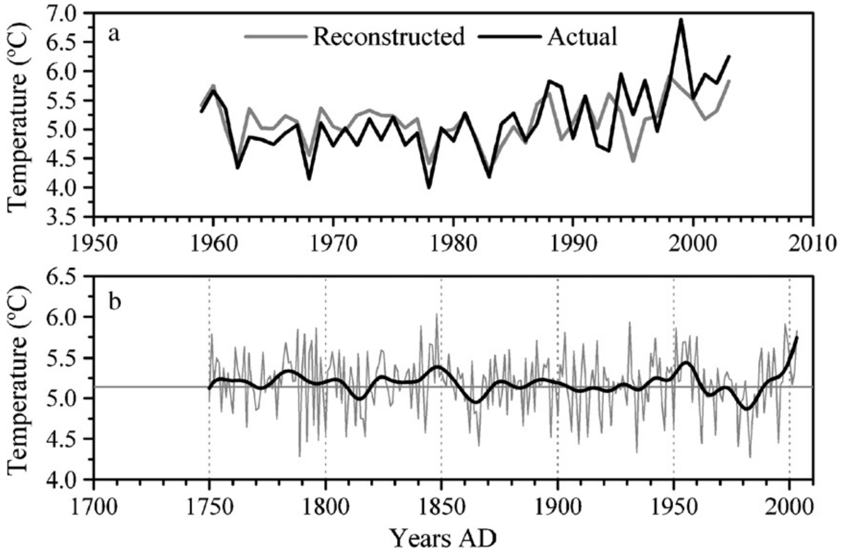

Fig. 6. (a) Comparison of the actual (black line) and reconstructed (gray line) annual (previous October through current September) mean temperature for the common period 1959–2003. (b) Reconstructed annual temperature in the central Hengduan Mountain over the past 250 years. The thin line represents the annual value and the thick line was smoothed with an 11-year FFT-filter (Fast Fourier Transform) to emphasize long-term fluctuations. The horizontal gray line is the actual regional mean temperature for period 1959–2003.

cially in the winter season (Figs. 4 and 5). Ring width of high elevation conifers is often reduced by low winter temperatures as a consequence of bud damage, frost desiccation and reduced root activity due to low soil temperature (Körner, 1998). In addition, after cold winters with delayed snow melt, the following vegetation period is shortened; an early start of winter enhances the consumption of stored carbohydrates, which may lead to a reduced earlywood width in the following year (Bräuning, 2001; Gou et al., 2007).

Evidence of warm periods in the 1780s and in the 1800s were reported from northeast Tibet (Gou et al., 2007), the Western Himalaya (Hughes, 1992, 2001; Yadav et al., 2004) and Nepal (Cook et al., 2003). The warm period from 1830 to 1850 and the cool period in the 1860s have also been detected by Wu et al. (1988) in our study area. The warm 1850s are consistent with the warm winters in east Tibetan Plateau (Bräuning, 2006) and warm summers in Kashmir, Western Himalaya (Hughes, 2001). Temperature was relatively stable from 1880 to 1940, except for the slightly cool period in the 1910–1920s.

Temperature was relatively low from 1810 to 1820. The coldest year occurred in 1817. A markedly cold spring in 1817 was also reported for the western Himalaya (Hughes, 1992). This may be linked with the volcanic eruption of Tambora (Indonesia) in April 1815. This eruption probably influenced the atmospheric circulation patterns of the monsoonal currents, and has been linked with the strong depression in tree growth in Tibet and Nepal (Cook et al., 2003; Bräuning and Mantwill, 2004,). Instrumental, historical and various tree-ring evidence show widespread cold conditions in 1816, especially in eastern North America and Western Europe and various ice core records invariably show a strong acidity signal associated with this year (Briffa et al., 1998).

Based on instrumental data and other proxies (ice cores, tree rings), Wang et al. (2004) showed that temperature anomalies during the period 1920–1950 are noticeable positive over China throughout the last century, especially in southwestern China and on the Tibetan Plateau. Warm conditions around 1950, and the cool period around 1970 were also reported in West Sichuan (Shao and Fan, 1999) and Tibet (Briffa et al., 2001; Bräuning and Mantwill, 2004). The pronounced negative summer temperature trends from 1970 to 1990 on the Tibetan Plateau are probably the consequence of enhanced cloudiness and rainfall at the upper treeline and thus of increasing monsoon intensity (Bräuning and Mantwill, 2004).

Our reconstruction of temperature variations over the last century is also supported by glacier fluctuation records. Zheng et al. (1999) reported that the Mingyong Glacier of the Meili Snow Mountain (28°29′N, 98°47′E, 6740 m a.s.l.) has retreated by 2 km between 1932 and 1959, then advanced by 830–930 m during 1959–1971 and by 70 m between 1971 and 1982. The terminus of the glacier has retreated by approximately 80 m between 1998 and 2002 and nearly by 110 m from 2002 to 2004 (Baker and Moseley, 2007). The Baishui No.1 glacier of the Jade Dragon Snow Mountain (27°10′N, 100°13′E, 5600 m a.s.l.), southeast of our sampling sites, also advanced by 800 m between 1957 and 1982, and then retreated by 150 m between 1982 and 1997, and by 100 m between 1998 and 2002 (He et al., 2003).

Conclusions

In this paper, a new tree-ring width network was introduced from the central Hengduan Mountains, southwestern, China. Temperature conditions, especially in the winter season, mainly affect the radial growth of trees growing near the upper treeline. A derived linear climate-growth model accounts for 43% of the actual temperature variance. Based on this model, annual temperature variations were reconstructed for the past 250 years. The reconstruction revealed that cool episodes occurred during the 1810s, 1860s, and 1960–1980s. Warm intervals occurred in the 1780s, 1850s, 1940–1960, and in last two decades. During the past 20 years, the strongest increase of annual temperatures during the last 250 years can be observed and are almost at the same level than during the warmest period observed, i.e., around 1950. This temperature maximum will soon be overtopped, if the warming trend observed for the last 20 years will continue. Comparison with other records from nearby regions confirmed the reliability of our reconstruction. However, further investigations are needed to extend the existing chronologies further back in time, and to develop a chronology network more representative for spatial climate variations. Finally, other climatically sensitive parameters like maximum latewood density shall be considered in future analysis.

Acknowledgments

The authors thank Mrs. Iris Burchardt for her aid on ring-width measurements, and Dr. Li Qin-Jun and Zhu Shi-Dan for their assistance in the fieldwork. This work was financially supported by the Natural Science Foundation of China (Grant no. 90302013) and the Max-Planck-Gesellschaft.

References

Baker, B.B., Moseley, R.K., 2007. Advancing treeline and retreating glaciers: implications for conservation in Yunnan, PR China. Arctic, Antarctic, and Alpine Research 39 (2), 200–209.

Biondi, F., Waikul, K., 2004. DENDROCLIM2002: A C++ program for statistical calibration of climate signals in tree-ring chronologies. Computers and Geosciences 30 (3), 303–311.

Bräuning, A., 1994. Dendrochronology for the last 1400 years in Eastern Tibet. Geojournal 34 (1), 75–95.

Bräuning, A., 2001. Combined view of various tree ring parameters from different habitats in Tibet for the reconstruction of seasonal aspects of Asian Monsoon variability. Paleobotanist 50, 1–12.

Bräuning, A., 2006. Tree-ring evidence of 'Little Ice Age' glacier advances in southern Tibet. The Holocene 16, 369–380.

Bräuning, A., Mantwill, B., 2004. Summer temperature and summer monsoon history on the Tibetan Plateau during the last 400 years recorded by tree rings. Geophysical Research Letters 31, L24205.

Briffa, K.R., Jones, P.D., Schweingruber, F.H., Osborn, T.J., 1998. Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature 393, 450–455.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Harris, I.C., Jones, P.D., Shiyatov, S.G., Vaganov, E.A., 2001. Low frequency temperature variations from northern tree ring density network. Journal of Geophysical Research 106, 2929–2941.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., 2004. Large-scale temperature inferences from tree rings: a review. Global and Planetary Change 40, 11–26.

Chang, D.H.S., 1981. The vegetation zonation of the Tibetan Plateau. Mountain Research and Development 1 (1), 29–48.

Cook, E.R., 1985. A Time-Series Analysis Approach to Tree-Ring Standardization. Dissertation, University of Arizona, Tucson, AR, USA.

Cook, E.R., Kairiukstis, A. (Eds.), 1990. Methods of Dendrochronology: Applications in the Environmental Sciences. Kluwer Academic Publishers, Dordrecht.

Cook, E.R., Peters, K., 1997. Calculating unbiased tree-ring indices for the study of climatic and environmental change. The Holocene 7, 361–370.

Cook, E.R., Krusic, P.J., Jones, P.D., 2003. Dencroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal. International Journal of Climatology 23, 707–732.

Diaz, H.F., Bradley, R.S., 1997. Temperature variations during the last century at high elevation sites. Climatic Change 36, 253–379.

Easterling, D.R., Horton, B., Jones, P.D., Peterson, T.C., Karl, T.R., Parker, D.E., Salinger, M.J., Razuvayev, V., Plummer, N., Jamerson, P., Folland, C., 1997. Maximum and minimum temperature trends for the globe. Science 277, 364–367.

Esper, J., Cook, E.R., Schweingruber, F.H., 2002. Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. Science 295, 2250–2253.

Fritts, H.C., 1976. Tree Rings and Climate. Academic Press, London, 567pp.

Gou, X.-H., Yang, M.-X., Peng, J.-F., Zhang, Y., Chen, T., Hou, Z.-D., 2006. Maximum temperature reconstruction for Animaqing Mountains over the past 830 years based on tree-ring records. Quaternary Sciences 26 (6), 991–998 (in Chinese, with English abstract).

Gou, X.-H., Chen, F.-H., Jacoby, G., Cook, E.R., Yang, M.-X., Peng, J.-F., Zhang, Y., 2007. Rapid tree growth with respect to the last 400 years in response to climate warming, northeastern Tibetan Plateau. International Journal of Climatology 27, 1497–1503.

He, Y.-Q., Zhang, Z.-L., Yao, T.-D., Chen, T., Pang, H.-X., Zhang, D., 2003. Modern changes of the climate and glaciers in China's monsoonal temperature glacier region. Acta Geographica Sinica 58 (4), 550–558 (in Chinese, with English abstract).

Hughes, M.K., 1992. Dendroclimatic evidence from the western Himalaya. In: Bradley, R.S., Jones, P.D. (Eds.), Climate since A.D. 1500. Routledge, London, pp. 415–431.

Hughes, M.K., 2001. An improved reconstruction of summer temperature at Srinagar, Kashmir since 1660 AD, based on tree-ring width and maximum latewood density of *Abies pindrow* [Royle] Spach. Palaeobotanist 50, 13–19.

Jacoby, G.C., D'Arrigo, R.D., Davaajamts, T., 1996. Mongolian tree rings and 20th-century warming. Science 273, 771–773.

Jin, L.-Y., Qin, N.-S., Gou, X.-H., Chen, F.-H., Li, J.-B., 2005. Series of spring maximum temperature in southern Qinghai Plateau and analysis of its variations during the last 450 years. Quaternary Sciences 25 (2), 193–201 (in Chinese, with English abstract).

Jones, P.D., Hulme, M., 1996. Calculating regional climatic time series for temperature and precipitation: methods and illustrations. International Journal of Climatology 16, 361–377.

Kang, X.C., Graumlich, L.J., Sheppard, P.R., 1997. A 1835 a tree-ring chronology and its preliminary analysis in Dulan region, Qinghai. Chinese Science Bulletin 42 (13), 1122–1124.

Kohler, M.A., 1949. On the use of double-mass analysis for testing the consistency of meteorological records and for making required adjustments. Bulletin of the American Meteorological Society 30, 188–189.

Körner, C., 1998. A re-assessment of high elevation treeline positions and their explanation. Oecologia 115, 445–459.

Liu, X.-D., Chen, B.-D., 2000. Climatic warming in the Tibetan Plateau during recent decades. International Journal of Climatology 20, 1729–1742.

Luckman, B.H., Wilson, R.J.S., 2005. Summer temperatures in the Canadian Rockies during the last millennium: a revised record. Climate Dynamics 24, 131–144.

Mann, M.E., Bradley, R.S., Hughes, M.K., 1998. Global-scale temperature patterns and climate forcing over the past six centuries. Nature 392, 779–787.

Michaelsen, J., 1987. Cross-validation in statistical climate forecast models. Journal of Applied Meteorology 26 (11), 1589–1600.

Osborn, T.J., Briffa, K.R., Jones, P.D., 1997. Adjusting variance for sample size in tree-ring chronologies and other regional mean timeseries. Dendrochronologia 15, 89–99.

Rinn, F., 2003. TSAPWin: Time Series Analysis and Presentation for Dendrochronology and Related Applications, Version 0.55 User Reference, Heidelberg, 76pp.

Shao, X.-M., Fan, J.-M., 1999. Past climate on west Sichuan plateau as reconstructed from ring-widths of dragon spruce. Quaternary Sciences 1, 81–89 (in Chinese, with English abstract).

Stokes, M.A., Smiley, T.L., 1968. An Introduction to Tree-Ring Dating. The University of Chicago Press, Chicago/London, 73pp.

Wang, S.-W., Zhu, J.-H., Cai, J.-N., 2004. Interdecadal variability of temperature and precipitation in China since 1880. Advances in Atmospheric Sciences 21 (3), 307–313.

Wigley, T., Briffa, K.R., Jones, P.D., 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. Journal of Climate and Applied Meteorology 23, 201–213.

Wilson, R.J.S., Luckman, B.H., 2002. Tree-ring reconstruction of maximum and minimum temperatures and the diurnal temperature range in British Columbia, Canada. Dendrochronologia 20 (3), 257–268.

Wu, X.-D., Lin, Z.-Y., Sun, L., 1988. A preliminary study on the climatic change of the Hengduan Mountains area since 1600 AD. Advances in Atmospheric Sciences 5 (4), 437–443.

Wu, X.-D., Sun, L., Zhan, X.-Z., 1989. A preliminary study on reconstructing past climate in the middle Xizang Plateau by using tree-ring data. Acta Geographica Sinica 44 (3), 334–342 (in Chinese, with English abstract).

Yadav, R.R., Park, W.-K., Singh, J., Dubey, B., 2004. Do the western Himalayas defy global warming? Geophysical Research Letters 31, L17201.

Yang, B., Bräuning, A., Shi, Y.-F., 2003. Late Holocene temperature fluctuations on the Tibetan Plateau. Quaternary Science Reviews 22, 2335–2344.

Yao, T.-D., Qin, D.-H., Xu, B.-Q., Yang, M.-X., Duan, K.-Q., Wang, N.-L., Wang, Y.-Q., Hou, S.-G., 2006. Temperature change over the past millennium recorded in ice cores from the Tibetan Plateau. Advances in Climate Change Research 2 (3), 99–103 (in Chinese, with English abstract).

Zheng, B.-X., Zhao, X.-T., Li, T.-S., Wang, C.-Y., 1999. Features and fluctuation of the Melang Glacier in the Mainri Mountain. Journal of Glaciology and Geocryology 21 (2), 145–150 (in Chinese, with English abstract).