



Temperature variations recorded in *Pinus tabulaeformis* tree rings from the southern and northern slopes of the central Qinling Mountains, central China

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The Qinling Mountain range constitutes a critical boundary for climate and vegetation distribution in eastern central mainland China owing to its importance as a geographic demarcation line. In this article, cores from 88 Chinese pines (*Pinus tabulaeformis*) from the southern (MW site) and northern (NWT site) slopes of the Qinling Mountains were used to reconstruct seasonal temperature variations. During the calibration period, significant correlations were found between ring width and the mean temperature from prior September to current April of 0.76 at the southern slope, and between ring width and the mean May–July temperature of 0.67 at the northern slope. The subsequent temperature reconstructions span 1760–2005 for the northern site and 1837–2006 for the southern site. Prior to the mid-20th century, low September–April temperatures were, in general, followed by high May–July temperatures, probably reflecting variations in the winter and summer monsoon. However, since the mid-20th century, both records show trends of a more pronounced increase in September–April temperature on the southern slope. The results provide independent support for the interpretation that recent warming is unusual in nature, coinciding with the observed record. The results compare well with tree-ring based reconstructions from the surrounding regions, suggesting regional signals in the Qinling Mountain reconstructions.

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The Qinling Mountains (32°30'N–34°45'N and 104°30'E–112°45'E) are an east–west oriented 1500 km long mountain range in central China. It is an important geographic demarcation line and the most critical boundary for climate and vegetation distribution in central mainland China owing to its west-to-east alignment, separating semi-arid area and humid regions. Because of its size, high elevation and east-to-west arrangement, the Qinling Mountains constitute a huge physical obstacle for north and southward movement of air masses and are thus critical to the distribution of climate and life zones in eastern parts of China. Climate conditions between the southern and northern slopes are quite different (Yan 2006). In general, the southern slopes are warm and humid, and in recent years frequent flooding has occurred in connection with strong Asian monsoon, causing loss of human life and property damage. On the northern slopes, however, it is relatively cool and dry, and drought is the main threat to agriculture. Since the 1950s, there has been an obvious trend towards warmer and drier climate in the Wei River basin, and water shortage has come to seriously impact on human society. Many studies of climate and environment change have been carried out

in the Qinling Mountains and adjacent regions, among these several dendrochronological studies (Hughes *et al.* 1994; Shao & Wu 1994; Liu *et al.* 2001; Liu & Shao 2003; Garfin *et al.* 2005; Yan 2006; Dang *et al.* 2007; Rosenfeld *et al.* 2007). These include reconstructed April to June precipitation variability in the eastern part of the mountains for the past 400 years (Hughes *et al.* 1994), and a reconstruction of early spring temperatures for the central part of the mountains (Liu *et al.* 2001). However, no study has yet compared climate variability on the southern and northern slopes of the mountains in a long-term context.

In this article, we present two temperature reconstructions from northern and southern slopes, respectively, and analyse the climatic differences between southern and northern slopes for the past 200 years.

Materials and methods

Study area, sampling and chronology development

Samples were collected at three sites from Nan Wutai (NWT) on the northern slope of the Qinling Mountains

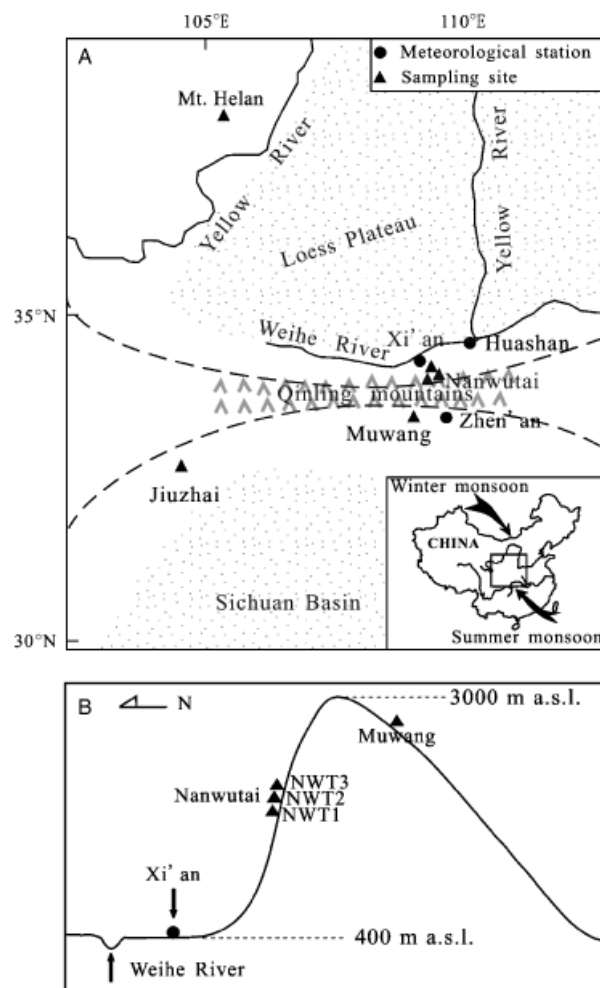


Fig. 1. A. Location of the sampling sites and meteorological stations. B. Different elevations of sampling sites along the profile of the Qinling Mountains.

(Fig. 1) at elevations from 1500 to 1600 m a.s.l. in May 2006: NWT01 (18 trees), NWT02 (12 trees) and NWT03 (26 trees). In October 2006, 32 trees were sampled from Mu Wang (MW) at 2100 m a.s.l. on the southern slope of the Qinling Mountains (Fig. 1). In order to optimize comparison between the southern and northern slopes, one single tree species, the Chinese pine (*Pinus tabulaeformis*), which is also the dominant tree species, was sampled at all sites. At the NWT sites, pines grow on thick soils (c. 40–50 cm) within a disconnected to open canopy on slopes of c. 50°. At the MW site, pines grow in an open canopy (20–30 m distance between trees) in thin and nutrient-poor soil; most trees grow on the rocks. In general, two cores were sampled with an increment borer from each tree for ring-width measurement, but for trees believed to be of old age (about 1/3 of the sampled trees), 3 cores were collected, where the third core will be used for stable isotope analyses. In the laboratory, the tree-ring samples were surfaced, cross-dated, and ring widths measured, with a precision of 1/100 mm, following standard

dendrochronological procedures (Stokes & Smiley 1996). The cross-dating was validated using the COFECHA software (Holmes 1983), and cores with any ambiguities were excluded from the further analysis. The average rates of absent rings in the samples at NWT and MW are <1%. All individual tree-ring series were detrended and standardized to form ring-width indices using the ARSTAN software (Cook & Kairiukstis 1990; Dendrochronology Program Library). During this process, undesirable growth trends, related to age and stand dynamics but unrelated to climatic variations, were removed from each series. To preserve the maximum common signal related to climate, each ring-width measurement series was standardized conservatively, using only negative-exponential or straight-line curve fitting. The individual index series from each site were then combined into a single chronology by computing a bi-weight robust mean. The resulting tree-ring index chronologies preserve much of low frequency signals (Cook & Kairiukstis 1990).

The mean sensitivity, a measure of relative difference in widths between adjacent rings, was 0.21 for NWT and 0.14 for MW. The first order auto-correlations were 0.53 and 0.67 for NWT and MW respectively, indicating that the tree-ring growth of Chinese pine in one year is to some degree influenced by its growth the preceding year. Since the correlations between the NWT were high ($r = 0.66\text{--}0.77$, $n = 190$, $p < 0.0001$), the three NWT sites were combined to create a new chronology named NWT.

Subsample signal strength (SSS; Wigley *et al.* 1984) was used to assess the adequacy of replication in the early years of the chronologies. SSS is a measure of the quality of the tree-ring index curve, where values close to 1 are achieved when the included trees reflect a hypothetical mean curve for the population; this is achieved either if the trees display strong common growth variability or if there is a large number of samples. To utilize the maximum length of the tree-ring chronologies and ensure the reliability of the reconstructions, we restricted our analysis to the period with an SSS of at least 0.75. This threshold corresponds to a minimum sample depth of 10 trees for the NWT (from 1825) and 9 trees for MW (from 1857). The statistical features of the NWT and MW chronologies are listed in Table 1.

Table 1. Statistical characteristics of NWT and MW chronologies.

Parameter	NWT	MW
Mean sensitivity	0.2	0.14
Standard deviation	0.26	0.22
First-order autocorrelation	0.53	0.67
Mean correlation between all series	0.34	0.31
Mean correlation between trees	0.34	0.3
Mean correlation within a tree	0.39	0.42
% variance in 1st PC	36.95%	40.28%
Subsample signal strength (SSS) ≥ 0.75 (trees)	1825 (10)	1857 (9)

During the analysis process, to test the homogeneity of meteorological records of Xi'an and Zhen'an, both double-mass analysis (Kohler 1949) and the Mann-Kendall (Mann 1945) statistical methods were used. The Huashan meteorological station (1953–2004, elevation 2064.9 m a.s.l., 34°29'N, 110°05'E) was used as a reference station.

Climatic situation

Since the Xi'an meteorological station (1953–2004, elevation 397.5 m a.s.l., 34°18'N, 108°56'E) is the closest to the NWT sites with a long record, we used these data when comparing the NWT tree-ring data to temperature and precipitation. For MW chronology, the records from the Zhen'an county meteorological station (1958–2004, elevation 693.7 m a.s.l., 33°26'N, 109°09'E) were used for further analyses.

The results of homogeneity showed that both temperature and precipitation records from the Xi'an and Zhen'an stations are homogenous. Figure 2 gives distribution diagrams of precipitation and temperature for Xi'an and Zhen'an records. Obviously, temperature varies synchronously with precipitation in the two regions – cold and low precipitation in winter, warm and more rainfall in summer. Monthly temperature in northern slopes is higher than that in the southern slopes during summer, but slightly lower in winter. The annual rainfall on the southern slope is about 200 mm higher than that of the northern, indicating that it is dry on the northern slope and wet on the southern.

Climatic signals reflected by Chinese pine tree rings

Limiting factors for tree growth on the southern and northern slopes

Correlation analyses showed major differences of limiting factors for tree growth between the northern and southern slopes. The NWT ring-width indices are significantly positively correlated with precipitation in May and June, and negatively correlated with tem-

perature in prior September, the year before growth, February and May to July (Fig. 3). Of all correlations, the highest occurs for May to July temperature, which is the high-growth-rate part of the growing season for trees. The results are fairly consistent with results from previous studies suggesting that the early summer temperatures are the main climatic factors controlling radial tree growth on the northern slope of the Qinling Mountains (Hughes *et al.* 1994; Liu *et al.* 2001; Liu & Shao 2003; Dang *et al.* 2007). Because the ring-width index is significantly positively correlated with May–June precipitation, and highly negatively correlated with May–July temperature, tree growth would reduce and a narrow ring would be produced if the low precipitation occurs under the normal temperature conditions. Thus, it has a meaningful physiological base for the relationship between ring-width indices and climatic factors.

For the MW site, correlations between ring-width indices and precipitation are generally weak, except prior November and April (Fig. 3). However, ring widths are significantly and positively correlated with temperatures in each month from previous September to current July. When temperatures are averaged for the whole 8-month period, the correlation reaches 0.761 (d.f. = 46, $p < 0.0001$). The high/low association between temperature/rainfall and tree growth at MW is

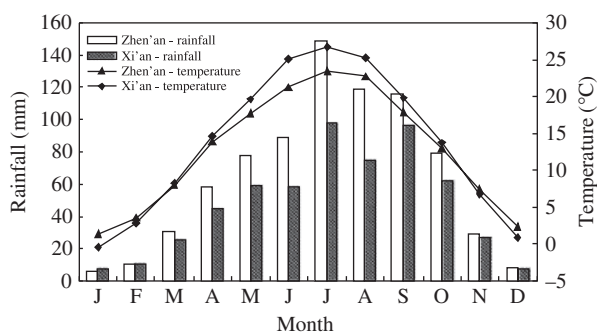


Fig. 2. Monthly total precipitation and mean temperature at the Xian (1953–2004) and Zhen'an (1958–2004) stations.

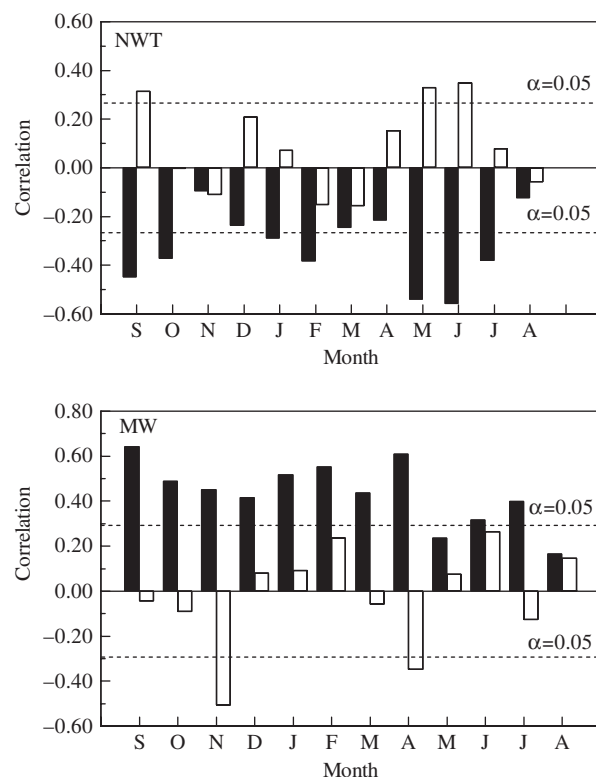


Fig. 3. The correlation between ring-width indices and monthly mean temperature (black bars) and monthly total precipitation (white bars). Meteorological data come from Xian (NWT) and Zhen'an (MW). Horizontal dashed lines are the 95% confidence level.

supported by observations in the field showing that the MW site is quite humid. The correlation analyses for the NWT and MW sites suggest a clear influence of temperatures outside the growing season for pines on the southern slope, while this influence is minimal in the northern slope. The results are consistent with previous studies (Liu & Shao 2003; Dang *et al.* 2007).

Temperature reconstruction of mean May–July temperature in the NWT region

Based on the results of the correlation analysis, we reconstructed May to July mean temperatures for the NWT region. A transfer function was designed as:

$$T_{\text{MJJ}} = -2.620 W_{\text{NWT}} + 26.330 \quad (1)$$

where T_{MJJ} is the mean temperature of May to July and W_{NWT} is the associated NWT tree-ring index for that year. During the calibration period, 1951–2004, the reconstruction tracks the observation very well, with the explained variance 44.4% (43.3% after adjustment for loss of degrees of freedom) in the temperature data. In the model (1), $n = 54$, $r = 0.666$, $F = 41.49$, standard error = 0.74 and $p < 0.0001$. DW = 1.54, which is the Durbin-Watson statistical item for testing of the presence of first-order autocorrelation in the residuals of the regression equation (Durbin & Watson 1950). The comparison between the reconstruction and the observation is shown in Fig. 4 (top).

Because the observation records are too short for an independent verification test to be performed, a bootstrap re-sampling technique (Efron 1979; Young 1994)

was employed here to assess the accuracy of the calibrated regression equations. This method is used particularly for a small data set. For NWT tree-ring-width chronology, the bootstrap results show that after 60 iterations all the statistical items of r , R_{adj}^2 , stand error of estimate, F -value, p -value and Durbin-Watson statistics are close to the values found on the total data set (Table 2).

We used the jackknife method to test stability of the transfer function; equation (1). In general, all the statistical items are fairly close to the values found by the original data set and the bootstrap results, indicating that equation (1) is quite stable during the calibration period 1953–2004. However, 1979 was an outlier from the model. If we overlook this year, the explained variance of the temperature rises to 48.4% ($R_{\text{adj}}^2 = 47.4\%$). The observed data show no apparent difference between the May–July mean temperature of 1979 and the 46-year mean. However, the May–June precipitation that year was 58 mm, which is 50% lower than the 46-year average (117 mm). This may have been the cause of the narrow tree ring in 1979. Although 1979 is an unusual year, we do not remove it from the model (1) since we cannot discount the possibility that similar events have happened in the past.

The full May–July temperature reconstruction is shown in Fig. 5 (top) for NWT for the period 1760 to 2005. Periods with temperatures higher than the 246-year mean occurred in the 1787–1822, 1857–1882, 1896–1936 and 1987–2005, while episodes of below average temperatures occurred in the 1823–1856, 1883–1895 and 1937–1986.

Temperature reconstruction of September to April temperatures in the MW region

Based on the above correlation analysis, we reconstructed mean temperatures from prior September to current April for the MW site. The transfer function was designed as

$$T_{\text{SA}} = 3.192 W_{\text{MW}} + 4.895 \quad (2)$$

where T_{SA} is the mean temperature of previous September to current April, W_{MW} is the associated MW tree-ring index for that year. For the period of calibration (1958–2004), the tree-ring/temperature correlation for the September–April period is 0.761. The tree-ring record thus explains 57.9% (56.9% after being adjusted for loss of degrees of freedom) of the variance in the MW temperature. In the model (2), $n = 46$, $r = 0.76$, $F = 60.52$, standard error = 0.65 and $p < 0.0001$. DW = 1.59. The comparison between reconstruction and the observation is shown in Fig. 4 (bottom).

During the verification procedure, all statistical results of bootstrap and jackknife indicate that reconstructed data tracked the observed data very well from 1958 to 2004 (Table 2). Meanwhile, jackknife results show that 1995 was unusual; if this year was

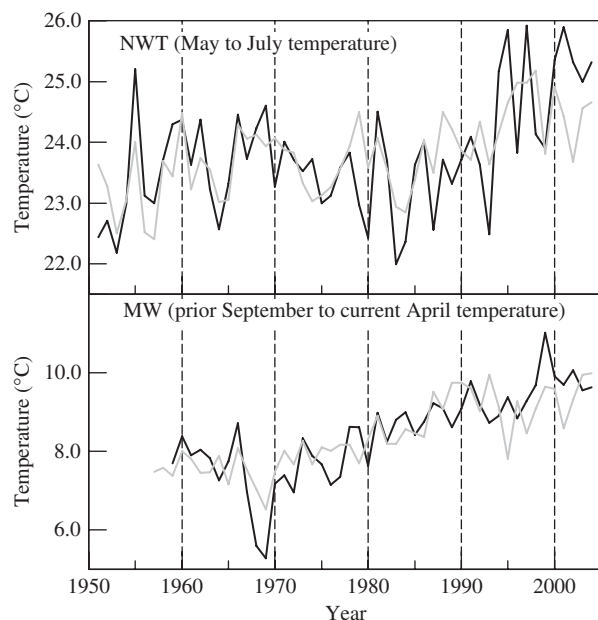


Fig. 4. Comparison between observed (black lines) and estimated (grey lines) temperatures. Horizontal lines are the long-term means. Top: NWT and Xi'an. Bottom: MW and Zhen'an.

Table 2. Calibration and verification statistics for NWT and MW regression.

Calibration		Verification	
		Jackknife Mean (range)	Bootstrap (60 iterations) Mean (range)
NWT site			
r	0.67	0.67 (0.64–0.70)	0.66 (0.49–0.78)
R^2	0.44	0.44 (0.41–0.48)	0.44 (0.24–0.61)
R^2_{adj}	0.43	0.43 (0.40–0.47)	0.43 (0.23–0.60)
Standard error of estimate	0.74	0.74 (0.71–0.74)	0.73 (0.59–0.88)
F	41.49	40.79 (35.28–47.9)	41.94 (16.25–77.92)
p	0.0001	0.0001 (0.0001–0.0001)	0.0001 (0.0001–0.0001)
Durbin-Watson	1.54	1.54 (1.27–1.68)	1.50 (1.28–1.57)
MW site			
r	0.76	0.77 (0.65–0.86)	0.76 (0.74–0.79)
R^2	0.58	0.59 (0.42–0.75)	0.58 (0.55–0.62)
R^2_{adj}	0.57	0.58 (0.41–0.75)	0.57 (0.54–0.61)
Standard error of estimate	0.65	0.62 (0.48–0.76)	0.65 (0.61–0.66)
F	60.52	66.01 (32.44–132.72)	59.24 (53.28–69.84)
p	0.0001	0.0001 (0.0001–0.0001)	0.0001 (0.0001–0.0001)
Durbin-Watson	1.59	1.51 (1.13–1.77)	1.58 (1.39–1.75)

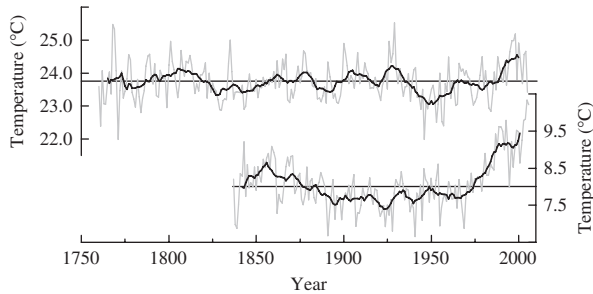


Fig. 5. Reconstruction of the May–July mean temperature for NWT region from AD 1760 to 2005 (top), and the mean temperature from prior September to current April for MW region from AD 1837 to 2006 (bottom). Both reconstructions are based on Chinese pine tree-ring widths. Smoothed lines are the 10-year moving average. Horizontal lines are the long-term means. For the NWT site, a 246-year average is 23.7 °C and for the MW site, a 170-year mean is 8.1 °C.

omitted, the variance would rise from 57.9% to 61.9%. However, for the same reason mentioned above for the NWT site, we keep this year in the model (2). The full reconstruction of September to April mean temperature is given in Fig. 5 (bottom) for MW (1837 to 2006). Two periods, 1837–1875 and 1976–2006, show temperatures higher than the 170-year mean, reflecting warmer early summer. An extended low temperature interval, with temperatures in general below the average, occurred during 1876–1975.

Discussion

The southern aspect of the Qinling Mountains is one of subtropical characteristics with wet summers and mild winters, while the northern slope belongs to a warm-temperate zone with relatively dry summers and cold winters. The southern slopes of the Qinling Mountains are far moister than the northern slopes (Li & Fu 1984),

especially outside winter (Fig. 2). Thus, it is expected that, even though the geographical closeness of the sites, tree growth responses to climate should differ between the north and south slopes. In Fig. 5, in general, two curves show apparently opposite evolution on an annual scale for the entire series, and on decadal scales before 1970, indicating the big difference of climatic variation on the both sides of the Qinling Mountains. The reconstructions suggest that in the past there was an inverse relationship between September–April and May–July temperatures, especially on decadal time scales, so that a cold September–April was followed by warm May–July temperatures, and *vice versa*. However, this relationship seems to break down in the later half of the 20th century, when both reconstructions show an increasing trend from the 1970s corresponding with observed temperatures. As temperatures in this region are highly influenced by the monsoon in both winter and summer, tree-ring data from both slopes of the Qinling Mountains may be used to study past regional monsoon variability in winter as well as in summer.

The two temperature reconstructions, in particular MW, provide independent support for the interpretation that recent warming is unusual in nature (Briffa & Osborn 1999; D'Arrigo *et al.* 2000), where September–April as well as early summer temperatures in the 20th century are the highest throughout both reconstructions. The MW data also suggest that most warming in the central Qinling Mountains area has occurred during winter, which is in agreement with the global trend (Vogelsang & Franses 2005; Ding *et al.* 2006).

Both NWT and Helan Mountain are located in region I on the Loess Plateau (Fig. 1), and therefore, roughly belonging to the same climatic zone. Hence, despite the 800 km distance between them, they may be

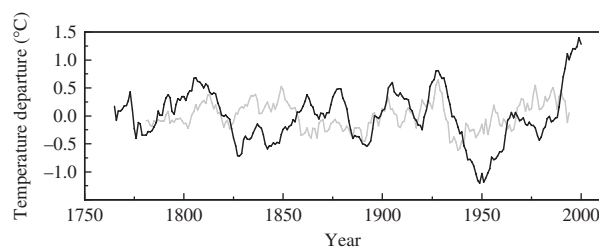


Fig. 6. Comparison between NWT May–July mean temperature (black line) and the Helan Mountain January–August mean temperature (grey line). All curves are smoothed by 10-year moving average.

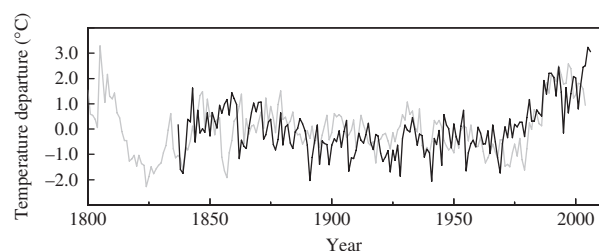


Fig. 7. Comparison between the MW mean temperature from prior September to current April (black line) and Jiuzhai mean temperature from prior November to current March (grey line).

comparable. Figure 6 displays the comparison between NWT May–July mean temperature and Helan Mountain January–August mean temperature (Cai & Liu 2007). Similar fluctuations are seen in long-term variations and in the 1930s, there was a clear temperature decrease at both sites. The warming in the period of 1950 to 1990 is synchronous in both curves. However, after 1990, temperatures over the Helan Mountain show a decreasing trend, while they increase at NWT.

An independent tree-ring based reconstruction from the Jiuzhai region, within region II around the Sichuan Basin (Fig. 1), about 600 km southwest of the MW site (Song *et al.* 2007), was used to assess the MW reconstruction. Both reconstructions represent more or less the same part of the year (Jiuzhai representing November–March temperatures) and time window (*c.* 1800s to 2000). Both records show high co-variability ($r = 0.44$, $p < 0.0001$, d.f. = 170) and the warming trend since the 1970s stands out in both records (Fig. 7). The comparison suggests that the climatic variability in the winter half of the year is similar along the Qinling Mountains. Two sites showed a clear response to global warming during the late 20th century.

Conclusions

We used tree rings, collected from both southern and northern slopes of the Qinling Mountains, to reconstruct seasonal temperature variations in this study. We found that tree growth responds differently to climate at either side of the Qinling Mountains: climatic

conditions of the previous year have a pronounced influence on ring width at the southern slope, while early summer temperatures (and precipitation to some degree) have a strong influence on ring width at the northern slope. Mean May–July temperature for the past 240 years was reconstructed for the northern slope and it corresponds well with an earlier temperature reconstruction from the Helan Mountain northwest of the Qinling Mountains. In addition, prior September to current April mean temperature reconstructed from 1837 to 2006 for the southern slope shows some correspondence with a temperature reconstruction from Jiuzhai southwest of the Qinling Mountains. These results reveal that temperature variations on the northern and southern slopes of the Qinling Mountains represent different seasons of the large-scale climatic variations, likely associated with the summer and winter monsoons, respectively.

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References

- Briffa, K. B. & Osbon, T. J. 1999: Climate warming: Seeing the wood from the trees. *Science* 284, 926–927.
- Cai, Q. & Liu, Y. 2007: January to August temperature variability since 1776 inferred from tree-ring width of *Pinus tabulaeformis* in Helan Mountain. *Journal of Geographical Sciences*, doi: 10.1007/s11442-007-0293-5.
- Cook, E. R. & Kairiukstis, L. A. 1990: *Methods of Dendrochronology*. 391 pp. Kluwer Academic Publishers, Boston.
- Dang, H., Jiang, M., Zhang, Q. & Zhang, Y. 2007: Growth responses of subalpine fir to climate variability in the Qinling Mountain, China. *Forest Ecology and Management* 240, 143–150.
- D'Arrigo, R., Jacoby, G., Pederson, N., Frank, D., Buckley, B., Natchin, B., Mijiddorj, R. & Dugarjav, C. 2000: Mongolian tree-rings, temperature sensitivity and reconstructions of Northern Hemisphere temperature. *The Holocene* 10, 669–672.
- Dendrochronology Program Library: <http://www.ltr.arizona.edu/software.html>
- Ding, Y., Ren, G., Shi, G., Guan, P., Zheng, X., Zhai, P., Zhang, D., Zhao, Z., Wang, S., Wang, H., Luo, Y., Chen, D., Gao, X. & Dai, X. 2006: National assessment report of climate change (I): Climate change in China and its future trend. *Advances in Climate Change Research* 2, 3–8.
- Durbin, J. & Watson, G. S. 1950: Testing for serial correlation in least squares regression, I. *Biometrika* 37, 409–428.
- Efron, B. 1979: Bootstrap methods: Another look at the jackknife. *Annals Statistics* 7, 1–26.
- Garfin, G. M., Hughes, M. K., Liu, Y., Burns, J. M., Touchan, R., Leavitt, S. W. & An, Z. 2005: Exploratory temperature and precipitation reconstructions from the Qinling Mountains, North-central China. *Tree Ring Research* 61, 59–72.
- Holmes, R. L. 1983: Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43, 69–78.
- Hughes, M. K., Wu, X., Shao, X. & Garfin, G. M. 1994: A preliminary reconstruction of rainfall in central China since A.D., 1600 from tree-ring density and width. *Quaternary Research* 42, 88–99.

- 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.
- Li, Z. & Fu, B. 1984: Climatic characteristics in the Qinling Mountains. In Compilation group, (eds.): *Collected Paper on Mountain Climates*, 87–96. Chinese Meteorological Publishing House, Beijing.
- Liu, H. & Shao, X. 2003: Reconstruction of early-spring temperature of Qinling Mountains using tree-ring chronologies. *Acta Geographica Sinica* 58, 879–884.
- Liu, Y., Ma, L., Hughes, M. K., Garfin, G. M., Cai, Q., An, Z. & Leavitt, S. W. 2001: Seasonal temperature reconstruction from central China based on tree ring data. *Palaeobotanist* 50, 89–94.
- Mann, H. B. 1945: Non-parametric test against trend. *Econometrika* 13, 245–259.
- Rosenfeld, D., Dai, J., Yu, X., Yao, Z., Xu, X., Yang, X. & Du, C. 2007: Inverse relations between amounts of air pollution and orographic precipitation. *Science* 315, 1396–1398.
- Shao, X. & Wu, X. 1994: Tree-ring chronologies for *Pinus Armandii Franch* from Huashan, China. *Acta Geographica Sinica* 49, 174–181.
- Song, H., Liu, Y., Ni, W., Cai, Q., Sun, J., Ge, W. & Xiao, W. 2007: Winter mean lowest temperature derived from tree-ring width in Jiuzhaigou Region, China since 1750 A.D. *Quaternary Sciences* 27, 486–491.
- Stokes, M. A. & Smiley, T. L. 1996: *An Introduction to Tree-Ring Dating*. 73 pp. The University of Arizona Press, Tucson.
- Vogelsang, T. J. & Franses, P. H. 2005: Are winters getting warmer? *Environmental Modelling & Software* 20, 1449–1455.
- Wigley, T. M., Briffa, K. R. & Jones, P. D. 1984: On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate of Applied Meteorology* 23, 201–213.
- Yan, J. 2006: *Comparable Studies on Environmental Changes in Southern and Northern Qinling Mountains*. 219 pp. China Science Press, Beijing.
- Young, G. A. 1994: Bootstrap: More than a stab in the dark. *Statistical Science* 9, 382–415.