Do the western Himalayas defy global warming?

Ram R. Yadav,[1] Won-Kyu Park,[2] Jayendra Singh,[1] and Bhasha Dubey[1]

Received 8 April 2004; revised 25 June 2004; accepted 5 August 2004; published 1 September 2004.

[1] Observational records and reconstructions from tree rings reflect premonsoon (March to May) temperature cooling in the western Himalaya during the latter part of the 20th century. A rapid decrease of minimum temperatures at around three times higher rate, as compared to the rate of increase in maximum temperatures found in local climate records is responsible for the cooling trend in mean premonsoon temperature. The increase of the diurnal temperature range is attributed to large scale deforestation and land degradation in the area and shows the higher influence of local forcing factors on climate in contrast to the general trend found in higher latitudes of the northern Hemisphere. *INDEX TERMS:* 1610 Global Change: Atmosphere (0315, 0325); 1620 Global Change: Climate dynamics (3309); 1625 Global Change: Geomorphology and weathering (1824, 1886). **Citation:** Yadav, R. R., W.-K. Park, J. Singh, and B. Dubey (2004), Do the western Himalayas defy global warming?, *Geophys. Res. Lett.*, *31*, L17201, doi:10.1029/2004GL020201.

1. Introduction

[2] Instrumental climate records show that global mean temperature has increased by 0.6 ± 0.2°C over the last century with the 1990s being the warmest decade and 1998 and 2002 the two warmest years since the start of the instrumental records in 1856 [*Jones and Moberg*, 2003]. Based on mean temperature estimates derived from high-resolution proxies this warming has been shown to be unprecedented since AD 200 [*Mann and Jones*, 2003] and is attributed to anthropogenic forcing of climate. Climate simulation models also show that the anomalous late 20th century warmth could only be explained when contribution from anthropogenic factors is taken into account [*Crowley*, 2000; *Hegerl et al.*, 2003]. However, this warming may not be apparent in areas where local forcing factors play a dominant role.

[3] Climate in high altitudes of the western Himalayan region is poorly known due to logistical difficulties in maintaining observational networks at high elevations. However, natural archives like lake deposits, ice cores and tree rings from the region provide opportunity to gain high-resolution proxy climate records. Here we report a tree-ring width based premonsoon temperature reconstruction using precisely dated tree ring samples from an ensemble of series longer than 500 years. This represents so far the longest record of premonsoon temperature variability for the western Himalayan region and can be used to evaluate the 20th century temperature variations in context of the past 775 years.

2. Materials and Methods

[4] The sites from which our samples originated are dry with similar ecological settings, although partitioned by orographic barriers. Pure Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don) trees grow on steep slopes with thin soil cover. Widely spaced trees characterize all sites with almost no ground vegetation except thin grass cover during the summer monsoon season. The openness of stands minimizes individual variations in tree-ring sequences induced by inter tree competition. To preserve low frequency variations in the final chronology, we only used individual series exceeding 500 years in length from 16 distantly located sites (Figure 1). Conservative standardization approach was used to remove age related growth trend from the tree-ring data. The ring width measurement series were standardized with a straight line of either negative slope or no slope. However, in case of samples when there appeared to be anomalous low frequency trends different from the common pattern of the rest of tree series cubic smoothing splines with a 50% frequency-response cut off width equal to two-thirds of the series length was used [*Cook and Peters*, 1981]. In case of such 23 series spline length varying from 330–800 years was used. In total, 60 radii from 45 trees were selected to develop the mean chronology. Statistical features of the mean chronology such as r_{bar} and expressed population signal (EPS) [*Wigley et al.*, 1984; *Cook and Kairiukstis*, 1990] show that the chronology is suitable for dendroclimatic modeling back to AD 1226 (Figures 2a and 2b).

[5] Meteorological records from high elevation stations are not available in the Himalayan region. The high spatial variability in precipitation due to complex topography limits the use of rainfall data from distant weather station for calibrating the response function of our chronology to interannual rainfall variability. However, unlike precipitation, temperature records from high and low elevation stations in the western Himalaya show high spatial coherence which enabled us to prepare a regional mean temperature series by averaging data from nine weather stations (Figure 1) in the western Himalaya. Regional mean temperature series (1901–2000) was produced by merging mean temperature anomalies (relative to 1961–1990 mean) of stations using arithmetic mean. This mean temperature series was then used for dendroclimatic modeling.

[6] The correlation between prewhitened mean ring width chronology and monthly temperature variables of the dendrochronological year (October of the previous growth year to current year's September) showed strong significant negative relationship with premonsoon (March to May) temperature. High temperatures during early summer lead to internal water deficit in the early growing

[1]Birbal Sahni Institute of Palaeobotany, Lucknow, India.
[2]School of Forest Resources, College of Agriculture, Chungbuk National University, Cheongju, Republic of Korea.

Copyright 2004 by the American Geophysical Union.
0094-8276/04/2004GL020201

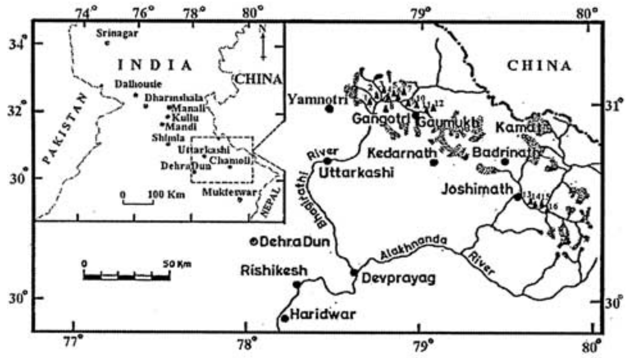

Figure 1. Location of tree-ring sites (filled numbered triangles), and meteorological stations (center dotted circles) used in present study.

season due to increased soil moisture loss by evapotranspiration. The temperature series covering the whole 20th century was split to carry out verification tests of the calibration model [*Fritts*, 1976]. To test the robustness of the calibration model, several calibration-verification periods within the 100-year periods of climate data were tested (Table 1). The 1960–2000 calibration model captures the highest percentage (44%) of the premonsoon temperature variance and was thus chosen for reconstructing premonsoon temperature back to AD 1226. Although other models also showed significant verification statistics (Table 1).

3. Discussion and Conclusions

[7] The premonsoon temperature reconstruction for the last 775 years shows pronounced interdecadal variations superimposed on the interannual variations (Figure 2c). Since the 16th century, the reconstructed temperature shows higher variability as compared to the earlier part of the series (AD 1226–1500), reflecting unstable climate during the Little Ice Age (LIA). Similar variations were also recorded in juniper tree-ring chronologies from central Tibet [*Braeuning*, 2001]. Historical records on the frequency of droughts, dust storms and floods in China also show that the climate during the LIA was highly unstable [*Zhang and Crowley*, 1989]. Decadal variations in our reconstruction show consistent patterns with other temperature reconstructions from Asian mountain regions (Figures 3a–3e) [*Briffa et al.*, 2001; *Esper et al.*, 2002a; *Cook et al.*, 2003] and high-latitudes in the northern Hemisphere (Figure 3f) [*Esper et al.*, 2002b]. Discrepancies can probably be partly explained by different seasonal response of the proxy data used in different reconstructions. The cool episodes noted in our reconstruction around 1573–1622, 1731–1780, 1817–1846 represent the LIA cooling in the western Himalaya. Temperature decline commenced after 1560s and reached to extremes between 1590s–1610s. This cool episode coincides with the extension of glaciers in Himalaya and Karakoram [*Rothlisberger and Geyh*, 1985] and represents the onset of LIA in the western Himalaya. Although data from other regions indicate that the LIA was a global scale phenomena [*Grove*, 1988], there exist regional temporal offsets and differences in the magnitude of cooling. The most wide spread cooling has been recorded during late 16th and early 17th centuries [*Bradley and Jones*, 1993; *Briffa et al.*, 2004]. The Karakoram (Figure 3e) and Tien Shan records [*Esper et al.*, 2002a, 2003] show protracted cooling in the 17th century. North Siberia was cool during the 16th and first half of the 17th century. However, this period of cool summers is not evident in eastern Siberia [*Briffa et al.*, 2001]. The second cool episode, noticed in our reconstruction between 1730s–1770s is contemporaneous with cooling in Nepal, Tibet, central Asia and Karakoram (Figures 3a–3e) [*Briffa et al.*, 2001; *Esper et al.*, 2002a; *Cook et al.*, 2003]. However, the relative warmth during the 1700s indicated in other northern hemispheric records [*Mann et al.*, 1999; *D'Arrigo et al.*, 1999] reinforces the relevance of regional climate forcing. Cooling during 1820s–1850s in the western Himalaya coincides with central Asia and Karakoram [*Briffa et al.*, 2001; *Esper et al.*, 2002a], however, Nepal and Tibet experienced cool episodes during first two decades of the 19th century [*Briffa et al.*, 2001; *Cook et al.*, 2003]. Tree-ring proxies from Mongolia and high-latitude of northern Hemisphere indicate the coolest phase of the LIA during this century [*Mann et al.*, 1999; *D'Arrigo et al.*, 2001].

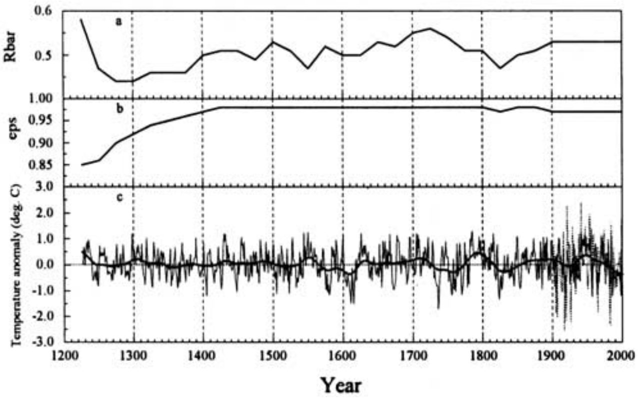

Figure 2. (a) Running r_{bar}; (b) running EPS. The r_{bar} and EPS are measures of common signal strength among the individual tree ring series included in a chronology. The moving window for computing these statistics is 100 years with 25 years overlap; (c) mean premonsoon temperature anomalies for AD 1226–2000 relative to the 1961–1990 mean. The dotted curve represents instrumental data superimposed over the reconstruction. Bold line represents a smoothing spline with a 50% frequency cut off of 50 years.

Table 1. Summary of Calibration and Verification Statistics[a]

Calibration			Verification				
Period	r	R^2	Period	r	T Value	Sign Test	RE
1901–1950	0.45[b]	19%	1951–2000	0.59[c]	3.120[d]	34/16[d]	0.295
1951–2000	0.60[c]	35%	1901–1951	0.44[b]	2.815[d]	30/20	0.141
1901–1959	0.42[b]	16%	1960–2000	0.65[c]	3.387[d]	30/11[d]	0.412
1960–2000	0.68[c]	44%	1901–1959	0.41[b]	2.786[d]	37/22[d]	0.143
1901–2000	0.51[c]	25%					

[a] r – Pearson correlation coefficient, R^2 - variance accounted for by the calibration model adjusted for degrees of freedom, T value, sign test, RE- reduction of error statistic (details described by *Fritts* [1976]).
[b] $p = .001$.
[c] $p = .0001$.
[d] $p = .05$.

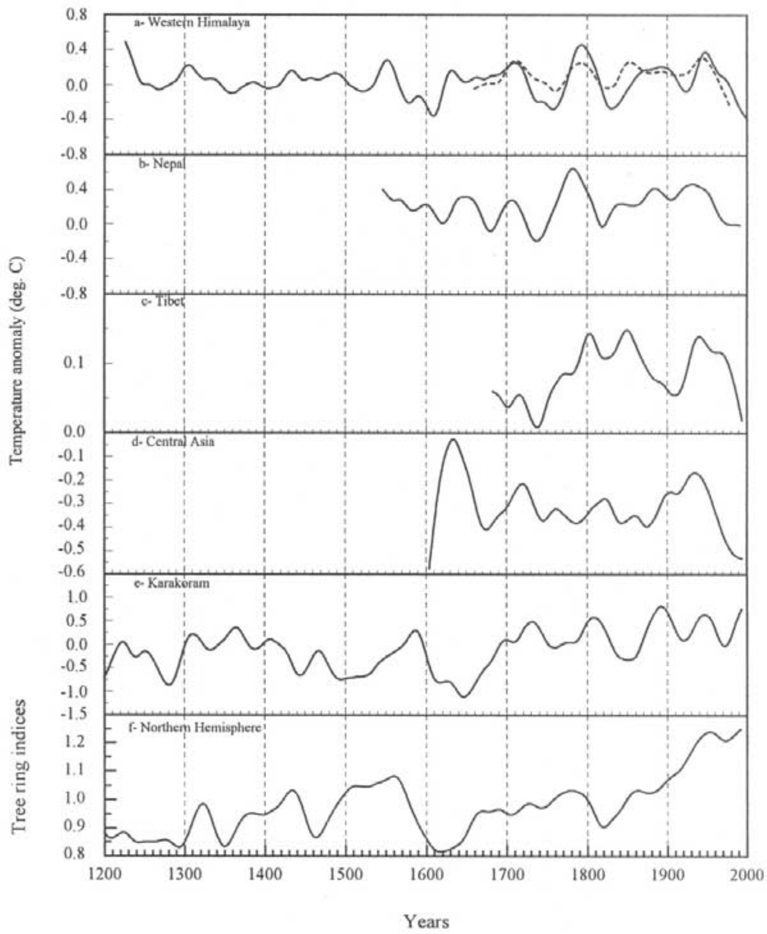

Figure 3. Reconstructed temperature anomalies (relative to the 1961–1990 mean unless otherwise specified) filtered with a smoothing spline with a 50% frequency cut off of 50 years; (a) premonsoon temperature reconstruction for the western Himalaya (present), dashed line is April–September (July excluded) temperature reconstruction for the north western Himalaya- anomaly relative to 1951–1980 mean [*Hughes*, 2001]; (b) February–June temperature reconstruction for Nepal [*Cook et al.*, 2003]; (c) April–September for Tibet [*Briffa et al.*, 2001]; (d) April–September for Central Asia [*Briffa et al.*, 2001]; (e) annual temperature for Karakoram- relative to 1000–1993 mean [*Esper et al.*, 2002a]; (f) Temperature responsive RCS chronology for northern Hemisphere [*Esper et al.*, 2002b].

[8] The 1944–1953 recorded the warmest 10-year mean in the whole span of our temperature reconstruction. Thereafter, temperatures decreased again. The cooling recorded during latter part of the 20th century is in agreement with the instrumental records (Figures 3a and 4a). Tree-ring based temperature reconstructions from other Asian mountain regions like Nepal [*Cook et al.*, 2003], Tibet and central Asia [*Briffa et al.*, 2001] also document cooling during last decades of the 20th century. However, other high-resolution climate proxies from high-latitudes of the northern and southern Hemispheres indicate unprecedented warming in the 20th century [*Mann and Jones*, 2003].

[9] The divergent temperature trend between the high latitudes and the Himalayan region in latter part of the 20th century led us to analyse premonsoon maximum and minimum temperature records from the western Himalaya. Monthly temperature anomalies (relative to 1961–1990 mean) of three weather stations (Dehra Dun, Mukteswar, and Shimla) covering the entire 20th century were used to develop a mean temperature series (Figures 4a–4c). The maximum temperature shows a steady warming trend throughout the 20th century (Figure 4b). In contrast, the minimum temperature shows an increasing trend up to 1950s and decreases thereafter (Figure 4c). This pronounced cooling in minimum temperatures since 1960s outbalances the warming trend in maximum temperatures and leads to a slight cooling trend in mean temperatures after 1950s (Figure 4a). Similar cooling trend in minimum temperature since 1960s was earlier reported over large part of north-western India [*Kumar et al.*, 1994]. Contrary to the western Himalaya, minimum temperatures over large parts of the globe increased even at higher rates as maximum temperatures [*Easterling et al.*, 1997].

[10] The human population in the western Himalayan states has increased around three times during second half of the 20th century [*Office of the Registrar General*, 2001]. To meet the needs of growing population agriculture had to be expanded. In Garhwal region, 50% of the area expansion of agricultural land during 1963–1993 took in formerly forested area [*Sen et al.*, 2002]. Increased population and

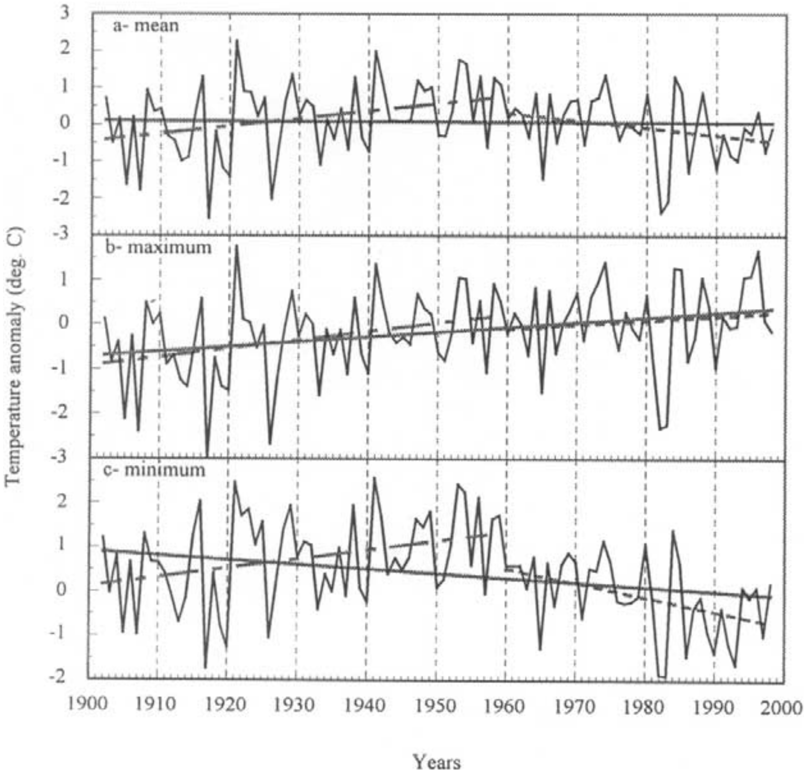

Figure 4. Premonsoon temperature variations over the western Himalaya (observational data). The straight lines represent the linear trend (continuous lines- trend for the 1901–1998, dashed lines for 1901–1959 and 1960–1998 respectively); (a) mean temperature; (b) maximum temperature; (c) minimum temperature.

cattle grazing pressure coupled with the development activities like the construction of roads and hydroelectric power plants have led to large-scale deforestation, causing intense soil degradation and erosion. This led to an increase in barren land from 3.76% of the total geographic area in 1966 to 5.68% in 1991 in the Indian state of Himachal Pradesh (the western Himalaya) alone [*Bhati and Zingel*, 1997]. At lower elevations, large canopy oaks known to promote soil water infiltration have been heavily degraded due to excessive use as fodder and fuel wood in the surrounding of habitations [*Ministry of Environment and Forests*, 2000]. Due to reduction of forest cover, soil water infiltration is greatly reduced and surface runoff increased [*Negi*, 2002]. The removal of tree canopies causes direct heating of the soil surface during daytime followed by intense cooling of moisture deficient low thermal inertia soils by terrestrial radiation loss at night. Thus, the diurnal temperature range increases. The temperature records from Dehra Dun, Mukteswar and Shimla show high correlation coefficients for premonsoon minimum temperatures during 1901–1959 (r = 0.85–0.90). These correlations decrease considerably during 1960–1998 (r = 0.46–0.58). However, correlation coefficients for maximum temperatures among all three stations remained high during both periods (r = 0.84 to 0.91) (Table 2). This indicates that the degree of nocturnal cooling is largely depending on local site conditions, reinforcing our inference that the large-scale deforestation coupled with heavy soil degradation is largely responsible for the recent decrease in minimum temperatures in the western Himalaya.

[11] The pre-20th century mean premonsoon temperature variations in the western Himalaya show a high similarity with other mean temperature records from Asian mountain regions and other high-latitude northern hemispheric areas on interdecadal scale. This coherence breaks apart in the second half of the 20th century, largely due to anthropogenically induced rapid cooling of night temperatures in the western Himalaya which is contrary to temperature trends in higher latitude regions [*Easterling et al.*, 1997]. Although mean temperature is yardstick for the state of climate globally, minimum and maximum temperatures provide

Table 2. Temporal Correlation Structure Between Temperatures (Minimum and Maximum) of Three Meteorological Stations in the Western Himalaya

		Minimum Temperature		Maximum Temperature	
		Stations		Stations	
Period	Stations	Mukteswar	Shimla	Mukteswar	Shimla
1901–1998	Dehra Dun	0.74[a]	0.81[a]	0.88[a]	0.88[a]
	Mukteswar		0.76[a]		0.85[a]
1901–1959	Dehra Dun	0.85[a]	0.90[a]	0.91[a]	0.91[a]
	Mukteswar		0.86[a]		0.84[a]
1960–1998	Dehra Dun	0.46[b]	0.58[c]	0.91[a]	0.87[a]
	Mukteswar		0.53[c]		0.85[a]

[a]p = 0.0001.
[b]p = 0.003.
[c]p = 0.0005.

valuable evidence for local climate forcing. Proxies responsive to maximum and minimum temperatures similar to those reported by *Wilson and Luckman* [2002] would be very useful for climate variability studies under conditions such as reported here from the western Himalaya. We further propose that minimum and maximum temperature records from geographic areas where 20th century cooling is present in proxy temperature records should be analyzed before coming to any conclusion on global trends of current temperature change.

[12] **Acknowledgments.** The work was supported by DST, Government of India [ES/48/ICRP/005/2001]. Part of present work was carried out at Chungbuk National University, Korea under Indian National Science Academy Exchange Fellowship granted to RRY. We sincerely thank Dr. Achim Braeuning for his critical comments on our manuscript.

References

Bhati, J. P., and W.-P. Zingel (1997), Natural resource use pattern in the western Himalayan agriculture: Implications for biodiversity conservation and sustainable development, in *Conservation and Economic Evaluation of Biodiversity*, edited by P. Pushpangdan, K. Ravi, and V. Santhosh, pp. 575–588, Oxford, New Delhi.

Bradley, R. S., and P. D. Jones (1993), Little Ice Age summer temperature variations: Their nature and relevance to recent global warming trends, *Holocene*, *3*, 367–376.

Braeuning, A. (2001), Climate history of Tibetan Plateau during the last 1000 years derived from a network of juniper chronologies, *Dendrochronologia*, *19*, 127–137.

Briffa, K. R., T. J. Osborn, F. H. Schweingruber, I. C. Harris, P. D. Jones, S. G. Shiyatov, and E. A. Vaganov (2001), Low frequency temperature variations from northern tree ring density network, *J. Geophys. Res.*, *106*, 2929–2941.

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

Cook, E. R., and L. A. Kairiukstis (Eds.) (1990), *Methods of Dendrochronology: Applications in Environmental Sciences*, Kluwer Acad., Norwell, Mass.

Cook, E. R., and K. Peters (1981), The smoothing spline: A new approach to standardizing forest interior tree-ring series for dendroclimatic studies, *Tree Ring Bull.*, *41*, 45–53.

Cook, E. R., P. J. Krusic, and P. D. Jones (2003), Dendroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal, *Int. J. Climatol.*, *23*, 707–732.

Crowley, T. J. (2000), Causes of climate change over the past 1000 years, *Science*, *289*, 270–277.

D'Arrigo, R., G. Jacoby, M. Free, and A. Robock (1999), Northern Hemisphere temperature variability for the past three centuries: Tree ring and model estimates, *Clim. Change*, *42*, 663–675.

D'Arrigo, R., G. Jacoby, D. Frank, N. Pederson, E. Cook, B. Buckley, B. Nachin, R. Mijidorj, and C. Dugarjav (2001), 1738 years of Mongolian temperature variability inferred from a tree-ring width chronology of Siberian pine, *Geophys. Res. Lett.*, *28*, 543–546.

Easterling, D. R., et al. (1997), Maximum and minimum temperature trends for the globe, *Science*, *277*, 364–367.

Esper, J., F. H. Schweingruber, and M. Winiger (2002a), 1300 years of climatic history for western Central Asia inferred from tree rings, *Holocene*, *12*, 267–277.

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

Esper, J., S. G. Shiyatov, V. S. Mazepa, R. J. S. Wilson, D. A. Graybill, and G. Funkhouser (2003), Temperature sensitive Tien Shan tree ring chronologies show multi-centennial growth trends, *Clim. Dyn.*, *21*, 699–706.

Fritts, H. C. (1976), *Tree-Rings and Climate*, Academic, San Diego, Calif.

Grove, J. M. (1988), *The Little Ice Age*, Methuen, New York.

Hegerl, G. C., T. J. Crowley, S. K. Baum, K.-Y. Kim, and W. T. Hyde (2003), Detection of volcanic, solar and greenhouse gas signals in paleo-reconstructions of Northern Hemispheric temperature, *Geophys. Res. Lett.*, *30*(5), 1242, doi:10.1029/2002GL016635.

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.

Jones, P. D., and A. Moberg (2003), Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001, *J. Clim.*, *16*, 206–223.

Kumar, K. R., K. K. Kumar, and G. B. Pant (1994), Diurnal asymmetry of surface temperature trends over India, *Geophys. Res. Lett.*, *21*, 677–680.

Mann, M. E., and P. D. Jones (2003), Global surface temperatures over the past two millennia, *Geophys. Res. Lett.*, *30*(15), 1820, doi:10.1029/2003GL017814.

Mann, M. E., R. S. Bradley, and M. K. Hughes (1999), Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties and limitations, *Geophys. Res. Lett.*, *26*, 759–762.

Ministry of Environment and Forests (2000), State of the forest, *Rep. 1999*, Dehradun, India.

Negi, G. C. S. (2002), Hydrological research in the Indian Himalayan mountains: Soil and water conservation, *Curr. Sci.*, *83*, 974–980.

Office of the Registrar General (2001), Census of India, New Delhi.

Rothlisberger, F., and M. A. Geyh (1985), Glacier variations in Himalayas and Karakorum, *Z. Gletscherkd. Glazialgeol.*, *21*, 237–249.

Sen, K. K., R. L. Senwal, U. Rana, S. Nautiyal, R. K. Maikuri, K. S. Rao, and K. G. Saxena (2002), Patterns and implications of land use/cover change: A case study in Pranmati watershed (Garhawal Himalaya, India), *Mt. Res. Dev.*, *22*, 56–62.

Wigley, T. M. L., K. R. Briffa, and P. D. Jones (1984), On the average value of correlated time series with applications in dendroclimatology and hydrometeorology, *Int. J. Climatol.*, *8*, 33–54.

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

Zhang, J., and T. J. Crowley (1989), Historical climate records in China and reconstruction of past climates (1470–1970), *J. Clim.*, *2*, 833–849.

B. Dubey, J. Singh, and R. R. Yadav, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226007, India. (rryadav2000@yahoo.co.in)

W.-K. Park, School of Forest Resources, College of Agriculture, Chungbuk National University, Cheongju, Republic of Korea.