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Late-Summer Temperature Reconstruction of the Eastern Himalayan Region Based on Tree-Ring Data of *Abies densa*

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Abstract

Tree-ring analysis from *Abies densa* growing at the treeline in the Eastern Himalayan region reveals that temperature during late summer (July–September) plays a significant role in controlling the growth of this tree. Mean temperature of each year for these three months has been reconstructed based on this ring-width data. This record goes back to A.D. 1507; however data prior to A.D. 1757 are questionable because they are based on only one sample. The reconstructed temperature series for the last 237 yr shows annual to multiyear fluctuations punctuated with cool and warm periods. The warmest and coolest 10-yr periods of the entire span occurred in 1978–1987 (+0.25°C) and 1801–1810 (−0.31°C), respectively.

Introduction

The Himalaya covers a vast area extending from the northeast to the northwest part of the Indian subcontinent. It exhibits diverse ecosystems owing mainly to varied temperature and precipitation in relation to latitude and topography. Three broad zones, especially in terms of distribution of precipitation, can be recognized: extreme eastern predominantly monsoons; central, both monsoon and western disturbances; and northwestern, under major influences of western disturbances. Several tree-ring studies have been made to explore potential trees and sites (Bhattacharyya et al., 1988, 1992; Bhattacharyya and Yadav, 1990, 1992, 1996, 1999; Bilham et al., 1983; Hughes and Davies, 1987; Ramesh et al., 1985, 1986; Yadav and Bhattacharyya, 1992) as well as to reconstruct seasonal climate (Borgaonkar et al., 1994, 1996; Hughes 1992; Yadav et al., 1997, 1999) from the last two zones. However, for the first zone (the eastern part of the Himalaya) practically no high-resolution climate data are available. The dendrochronological applicability of some conifers of this region has only recently been discussed (Bhattacharyya et al., 1997; Chaudhary et al., 1999). The present study is the pioneering attempt in the Eastern Himalaya to illustrate the potential of tree-ring-width proxy data of *Abies densa*, a subalpine conifer of this region, in supplementing the instrumental records that go back several decades.

Material Collection

Abies densa is distributed from the Central Himalaya to Eastern Tibet (Dallimore and Jackson, 1966; Sahni, 1990). Tree-ring samples were collected from this species in two sites located far from one another (Fig. 1) near treeline at elevations ranging from 3300 to 3900 m. Both sites receive much rainfall: total annual precipitation is about 1250 to 2000 mm at both sites, and about 70–80% of it comes during the monsoon months from June to September. Snow falls during winter and spring.

Two increment cores per tree, one each on opposite sides at breast height, were collected, except in a few cases when only one core was collected because one side was not approachable owing to a steep slope. One site, Yumthang (YUM), is located in the northwestern part of Sikkim at an elevation of 3880 m and is characterized by subalpine conifer-broad leaved forest. *Abies* and *Rhododendron* are the main elements, with the former having higher stand density. From this site 46 cores from 27 trees were collected from trees attaining 10 to 15 m in height and 1 to 2.5 m in girth, growing on moderate slopes. The other site, T-Gompa (TGA), is in the northwestern part of Arunachal Pradesh. Conifers at this site grow mostly on thin soil cover over gneissic boulders at elevations ranging from 3390 to 3680 m. Moss and lichens growing on trees as well as on rocks are common. *Juniperus indica* is mostly confined on the south-facing slopes, whereas *Abies densa* dominates on north-facing slopes. Only a few isolated fir trees attain large size and huge girth; most of the old trees have been cut down, although some have been left owing to interior rot. From this site 54 cores from 29 trees were collected.

Chronology Preparation

Tree rings are very distinct in *Abies densa*, showing the gradual transition of cell sizes (large to small) from early wood to late wood and with a distinct boundary demarcation made by the early wood cells of each subsequent year. Traumatic resin ducts in some cores may be misread as true rings (Fig. 2), but this problem was solved through cross-dating. Each ring in every core was dated to the calendar year of its formation using the cross-dating technique (Stokes and Smiley, 1968). Ring widths of each dated core were measured using an increment-measuring stage with 0.01 mm precision, coupled with a microcomputer. These measurements and dates were then checked using the computer program COFECHA (Holmes, 1983). The cores for which errors appeared were reexamined to evaluate the sources of the errors, and corrections were made. COFECHA was run again on the corrected measurements to check occurrence of any further errors. Ring-width data were standardized using the program ARSTAN (Cook and Kairiukstis, 1990), which removes growth trends related to age and stand dynamics while retaining the maximum common signal to form tree-ring indices. ARSTAN removes trends by fitting a curve to each series to model biological growth and dividing out the growth model. Chronologies are then computed as a robust estimation of the mean value function. A residual chronology is derived by performing autoregressive modeling on the detrended ring measurement results in a chronology in which low-order autocorrelation has been removed (Holmes, 1992). In the present study, a 40-yr cubic spline method was used for detrending the series; that is low-frequency variations of greater than 40 years were removed. The residual two tree-ring chronologies (Fig. 3), one from each site, were used for this study. YUM has the longer chronology, extending from A.D. 1504 to A.D.

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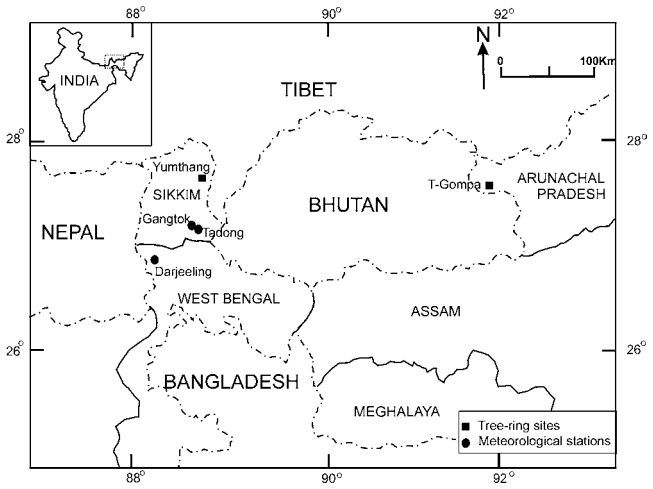


FIGURE 1. Location of tree-ring sampling site and meteorological stations used in the study.

1994, but replication of samples earlier than A.D. 1757 is very poor, while TGA extends from A.D. 1688 to A.D. 1995.

For climatic reconstructions, the most suitable tree-ring chronologies are generally characterized by high mean sensitivity, high standard deviation, low autocorrelation, high signal to noise ratio, high values of common variance, and high correlation between measured series both between and within trees. A chronology with low common variance and high autocorrelation is found where climate is not limiting. The statistics for these characteristics for these two site

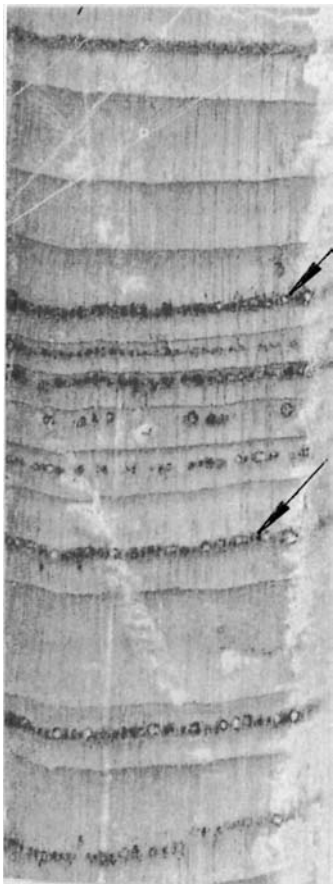


FIGURE 2. Traumatic resin ducts creating "false rings" in Abies densa.

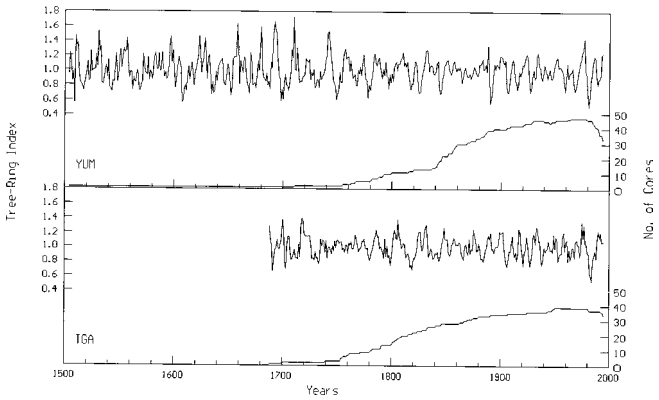


FIGURE 3. Tree-ring chronologies of Abies densa *from Yumthang (YUM) and T-Gompa (TGA), along with the respective sample depth plot.*

chronologies are shown in Table 1. Mean sensitivity (MS), a measure of the mean percentage change from each measured yearly ring value to the next, ranges from 0 where there is no difference to 2 where zero value (an absent or missing ring) occurs next to 1 (Fritts, 1976). This MS value in both site chronologies has been found to be low (0.13 for YUM and 0.10 for TGA). Generally under mesic climate conditions in a subalpine-temperate region, conifers have lower MS than in arid sites. Trees growing in such an environment in both Western (Bhattacharyya et al., 1988; Borgaonkar et al., 1996) and the Central Himalaya (Bhattacharyya et al., 1992) also have low values. Autocorrelation is the association between ring width for the year (t–1) and the subsequently formed ring t, t + 1, to t + k. In both chronologies this value is high, which indicates that significant persistence exists in both chronologies. Expressed population signal (EPS) is a measure of the correlation between the mean chronology derived from the core samples and the population from which they were drawn. A value of 0.85 has been put forward as a reasonable threshold (Wigley et al., 1984) and is exceeded here. Strength of signal between trees (common variance) has been estimated by calculating the signal to noise ratio (SNR) (Wigley et al., 1984; Briffa and Jones, 1990). The YUM chronology shows a slightly better SNR than the TGA chronology. The common variance is a mean of the correlation coefficients of all possible pairwise combinations of ring-width index series over the common interval period. This value indicates the variance owing to the common forcing factor of a site, which might be a climatic effect experienced by all trees over a wide area. The correlation between the two sites chronologies for the period (1891–1994) of good sample depth was calculated. There is a good correlation (0.462) between the two standard chronologies, especially considering the fact that the sites are more than 400 km apart. This suggests that

TABLE 1

Statistics of standard tree-ring chronologies at sites Yumthang (YUM) and T-Gompa (TGA)

Statistics	YUM	TGA
Chronology time span (years)	1504–1994 (491)	1688–1995 (308)
No. of radii/trees	50/29	39/26
Mean sensitivity	0.13	0.10
Standard deviation	0.19	0.14
Autocorrelation order 1	0.581	0.498
Common interval (all samples)	1892–1984	1835–1992
Expressed population signal	0.890	0.885
Signal/noise ratio	8.12	7.69
Variance explained	24.16%	32.65%

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regional climate might have a significant role in limiting the growth of this species.

For the subsequent analyses, residual chronology has been considered since it has better correlation between these two sites chronologies.

Tree Growth–Climate Relationship

The lack of high-elevation meteorological stations with records going back more than 50 yr makes tree growth–climate studies at high-elevation tree-ring sites difficult in this region. An attempt has been made to identify growth response in relation to the available climatic records of this region. Three meteorological stations, Darjeeling (27°03′N, 88°16′E), Gangtok (27°20′N, 88°37′E), and Tadong (27°20′N, 88°38′E) (Fig. 1), that have comparatively longer records of monthly mean temperature and precipitation were selected. These three stations are located at an elevation much lower than the two tree-ring sites. Darjeeling is at a comparatively higher elevation at 2265 m than the other two stations, which are located at almost the same elevation, about 1675 m. Temperature data for Darjeeling cover the time span of A.D. 1848 to A.D. 1978, with no records of any months during two intervals: 1854–1881 and 1908–1909. Therefore, temperature data from 1910 onward, with only 4 (months) missing values, have been used in further analyses. The precipitation record extends from 1868 to 1987, with 22 (months) missing values. Both Gangtok (1966–1990) and Tadong (1978–1990) have much shorter temperature and precipitation records than Darjeeling. All missing values in these climatic records were estimated by using the computer program MET of Dendrochronological Program Library (developed by the Laboratory of Tree-Ring Research, University of Arizona, Tucson, U.S.A.). In this program, missing monthly data are estimated by setting the departure of the value from the mean for the month equal to the average departure of the other nearby stations. But since such early records are not available from other stations in this region, the mean of individual months from the Darjeeling data alone was estimated and used to fill the missing values. Correlation matrices were computed for the data of the common period of all three stations. Analysis shows good correlation between the temperature data of Gangtok and Tadong ($r = 0.72$) and Gangtok and Darjeeling (0.51). The correlation between Tadong and Darjeeling could not be calculated since only 1 yr data were common within the available data sets of these two stations. Temperature records from the three stations were merged together with the expectation that replication of data would avoid many problems associated with record inhomogeneity and differing station microclimates and would represent the overall climate of the region. For a better representation of the regional scenario, data from a large number of stations are required, but it is a difficult task for this region owing to the lack of meteorological stations.

A quantitative relationship between tree growth and climate has been made through response function analysis (Fritts, 1976) where climatic data (generally temperature and precipitation) for different months were used as statistical predictors and ring-width variation as predictands. The sign and magnitude of the partial regression coefficients (PRCs) of the statistical equation were interpreted as response of growth to the particular monthly climatic variable.

For the response function analysis, the equivalent time span (1910–1987) of mean monthly temperature and total monthly precipitation of regional data (mostly of Darjeeling data) and ring-width data from both sites, YUM and TGA, have been selected. The growing period of trees growing near treeline at this region is expected to be around April/May to August/September, so 28 monthly climatic variables were taken (14 months of temperature and 14 months of precipitation) from the previous year's August to the current September as a predictor set for each site in the multiple regression analysis, with the prewhitened tree chronology of the respective sites as the predictand. Selection of the time period, prior August to current September is based on the short time span of the growing season for this tree at both subalpine sites. Prior year's climate has been included to understand the lag effect in tree growth. It has been noted that prior year's climate exerted in the form of store energy to the growth of subsequent years (Fritts, 1976). However, the actual duration of the growing season of *Abies densa* for this region has not been determined by detailed field observations. It has been observed that early wood cells have not formed in the last growth ring attached to bark in all tree-ring samples. These samples were collected during late April and early May, so the commencement of growth in *Abies densa* is likely to be after April. Thus, the short growing period seems to be linked with the drastic decrease in temperature during October, and the resulting cessation of cambial activity.

To avoid the problem of intercorrelation among climatic variables in this analysis, the set of predictor variables used was first transformed into orthogonal eigenvectors using principal component analysis. These orthogonal climate series were then related by multiple regressions to the single-site tree-ring series. The stepwise multiple regressions terminate when the F-quotient for the entering variable becomes less than 1.0. The F-test is used here as a measure of the quotient of the variance reduced by a new variable and the error variance. Use of fewer predictor variables results in both retention of a maximum number of degrees of freedom in the final regression and a reduced amount of error. Once the regression coefficients are calculated, the orthogonal variables are retransformed to the original set of climate variables. Thus, the new set of coefficients, known as the elements of the response function, represents standardized response in terms of current growth to each of the climatic variables and the prior growth. A positive value expresses a direct relationship between variable and tree growth, and a negative value expresses an inverse relationship.

This study shows that at YUM, temperatures during the prior September and the current year's July, August, and September have an inverse relationship, whereas the prior October and current January temperatures show a direct relationship with the tree growth (Fig. 4). Precipitation for the prior and current year's August shows an inverse relationship, but the current year's July has a direct relationship (Fig. 4). The TGA site shows that low temperature during the prior August and October and the current July, August, and September is inversely related to tree growth, while the above-average monthly temperature during the current March and May is directly related to tree growth (Fig. 5). With precipitation, an inverse relationship of the prior August and September and tree growth was noticed (Fig. 5).

The response function analysis reveals that the relationship to climatic variables is not totally the same for the same species growing at these two sites. Correlation to precipitation for only a single month (prior August) was found with a common inverse relationship at both sites. This negative relationship may be an indirect effect connected to the fact that high late-summer mean temperature coincides with higher precipitation, which in turn may have a negative carry- over effect of stored food on the growth of the next year. But why only the precipitation of the prior August, and not other monsoon months, exhibited a negative response is difficult to explain physiologically. A negative relationship with July, August, and September temperature in both sites implies that late-summer temperature is the most significant element controlling growth of *Abies densa* in this region. This inverse relationship is in contrast to the general growth behavior of subalpine conifers, for which increased summer temperature seems to be favorable (Tranquillini, 1964). Increase in temperature might have crossed the threshold limit of the optimum temperature for net photosynthesis at this elevation. It has been noted that the optimum temperature for photosynthesis for the temperate region is generally

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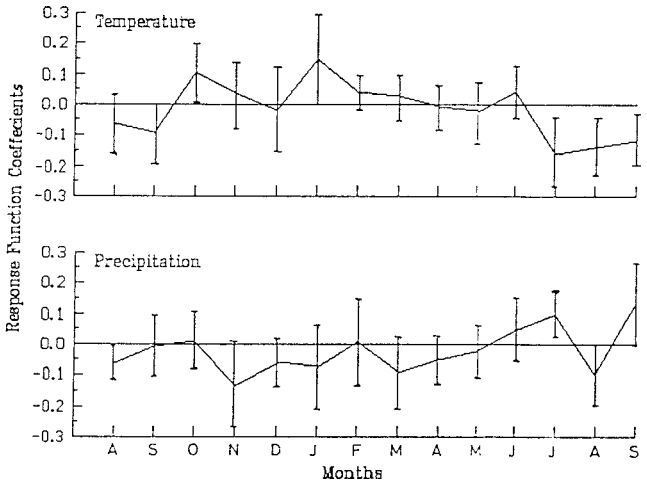


FIGURE 4. Response function plot for Abies densa *at YUM, with climatic variables from August of prior growth year to current year's September.*

between 15 and 30°C (Meyer et. al., 1973), and at treeline at higher altitude it is around 13 to 20°C (Tranquillini, 1964). Mean temperature during July, August, and September also ranges from 18 to 25°C in the temperate belt of the Eastern Himalayan region; toward treeline it would be lower than this range and seems to be close to the optimum range of photosynthesis. In both sites, *Abies densa* trees are confined to moderate to steep slopes with shallow soil depth, not the most favorable growing conditions. Cool, moist northerly slopes where soil is deep and rich are found to have good tree growths (Dallimore and Jackson, 1966). Thus, under higher temperatures even trees growing in mesic sites might face physiologically water-stressed conditions. During July–September, both temperature and precipitation remain high (Fig. 6) in this region. Higher temperatures might change the water status of the trees, which is a function of the balance between water absorption by roots and transpirational water loss.

Temperature Reconstruction

Late-summer temperature, July, August, and September (JAS), has been found to be the significant element controlling growth of these trees, and this variable was selected for the reconstruction using least square regression. Because of the absence of any biological

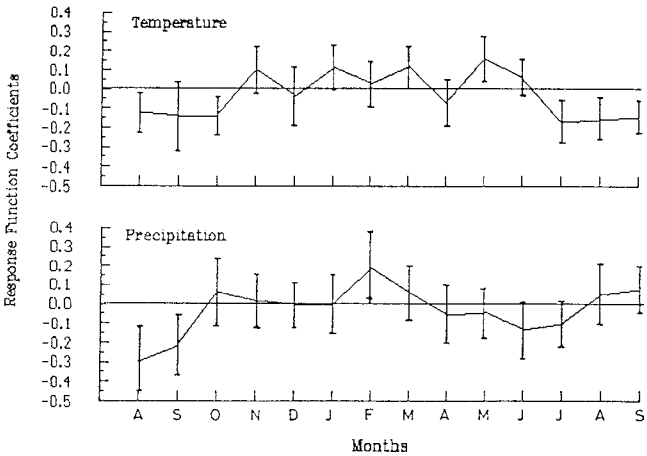


FIGURE 5. Response function plot for Abies densa *at TGA, with climatic variables from August of prior growth year to current year's September.*

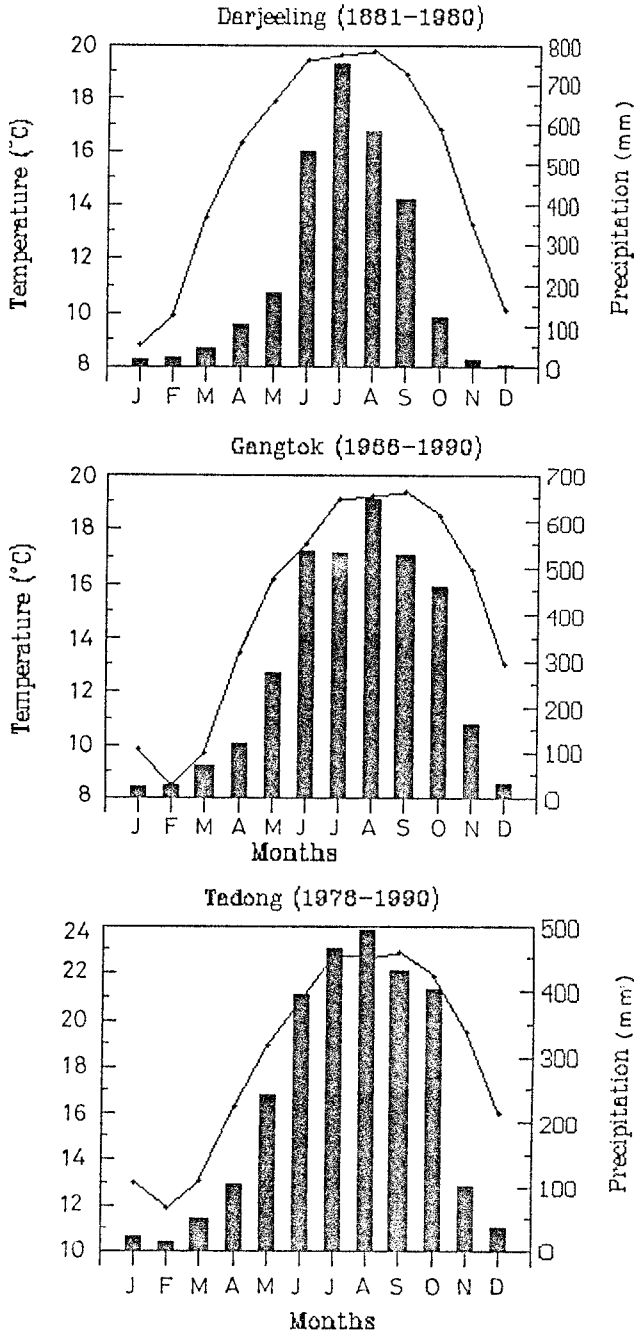


FIGURE 6. Monthly average temperature and precipitation at three meteorological stations of the Eastern Himalaya.

evidence, prior August precipitation was not considered for further analyses in spite of its common negative weight at both sites. For calibration, either a single-site chronology or the two-site chronologies together were taken as predictors, and monthly temperature averaged for JAS either from individual stations or regional data were predictands to find out which model explained more variance. The common period for the climate data was divided into two subperiods (1910–1937 and 1938–1987 for regional data and 1910–1940 and 1941–1978 for Darjeeling data). Three models were used to regress individual chronologies against the mean of late-summer temperature over different time periods: current growth year (t) alone; current year along with prior growth year (t−1, t); and current growth year with following year (t, t+1).

The TGA and YUM chronologies were calibrated with both Darjeeling and the regional data for the current year's JAS temperature

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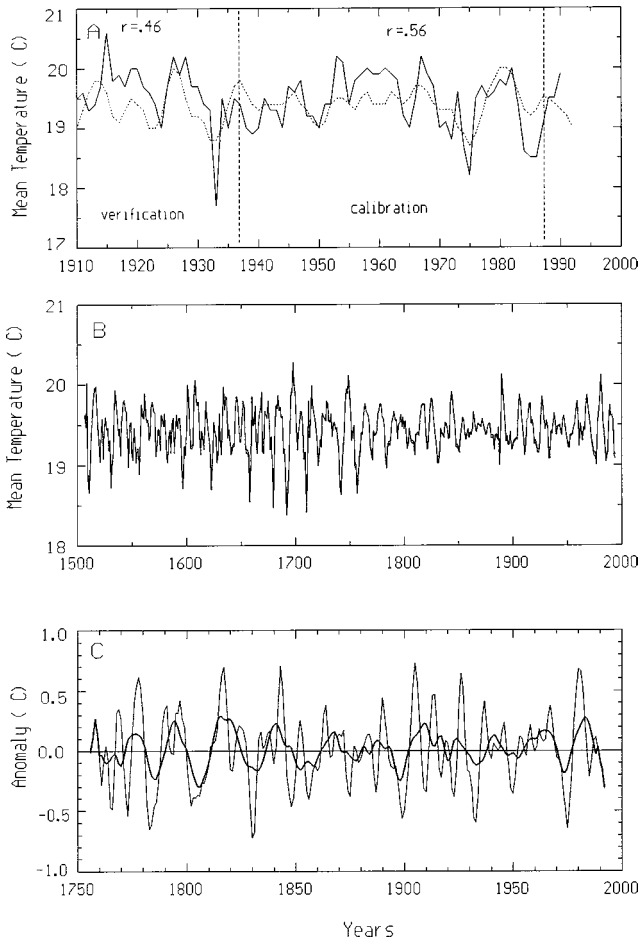


FIGURE 7. (a) Observed (solid line) and reconstructed (dotted line) mean late summer temperature from 1910–1987. The reconstruction was calibrated using 1938–1987 temperature data. (b) Reconstructed mean July–September temperature for the Eastern Himalaya since A.D. 1507. (c) The reconstructed late-summer temperature (A.D. 1757–1994) plotted as anomalies relative to the mean of the fully reconstructed series. The thick line superimposed over the reconstruction is a 10-yr smoothing spline.

individually. Maximum variance was explained by the model t, t + 1 of the YUM chronology when calibrated with regional data. It explained 28.5 and 26.7% variance in the first and second subperiod, respectively. When calibrated with the Darjeeling data, this showed less variance explained in the second subperiod. Briffa et al. (1988) suggested that climatic variance is enhanced by inclusion of multiple chronologies in the prediction equation. We also used ring-width chronologies for the two *Abies densa* sites (TGA and YUM) along with the series of preceding and following growth indices (t – 1, t, and t + 1) as predictors and mean JAS temperature as predictand. Both the chronologies were truncated at A.D. 1757 because their earlier periods (i.e., before A.D. 1757) were based on only one to three cores. Principal component (PC) analysis was used to reduce the six variables (3 each for the 2 sites) and only those PCs that had values of F significant at $P = 0.1$ and further whose cumulative eigenvalue product exceeded unity were selected as predictors in the final calibration equation. In the analysis the first eigenvector explained 44.05% of the total variance and proved to be the only stable predictor of the temperature data. Therefore, the resulting first PC was used as predictor variable in the regression equation. A strong relationship with the regional temperature series was demonstrated for the calibration period 1938–1987 (multiple correlation coefficient = 0.553, F-value = 21.279, $P < 0.001$). The statistical equation thus derived was then used on the whole series of tree-ring indices to obtain corresponding yearly estimates of mean late-summer temperatures (Fig. 7A). These temperature estimates were then validated against the withheld PC data over the 1910–1937 verification period. The results are shown in Table 2. The regression equation accounts for 30.6% of the variance in calibration and 21.1% in the verification. This reconstruction performed less well in the sign test, indicating relative failure to capture high frequency variance. The reconstructed JAS temperature has been shown in Fig 7B and C.

TABLE 2

Calibration and verification statistics for the ring-width chronologies of Abies densa *as predictors of mean late-summer (July–September) temperature*

	Calibration 1938–1987	Verification 1910–1937	Calibration 1910–1937	Verification 1938–1987
Multiple correlation coefficient	0.553**	0.458**	0.458**	0.553**
F-Value	21.279***		5.986*	
R^2	0.306*	0.211*	0.211*	0.306*
R^2 adjusted	0.292	0.18	0.18	0.292
t-value		2.041*		2.952*
Sign test		14/28		37/50*
Reduction of error		0.151		0.281

*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$.

R^2 is the square of the correlation coefficient calculated between actual and estimated data.

t-value is derived using the product mean test. The departures from the actual and reconstructed series are multiplied in each year; the means of negative and positive products are calculated, and the difference between the means is tested with student's t-test.

Sign test = number of agreements/total values; values with the correct deviation (first number) from the mean.

Reduction of error statistic: any positive value demonstrates skill in reconstruction (varies between $-\alpha$ and +1.0).

Reconstructed Temperature and Its Correlation with Other Regions

The temperature records of July–September are extended back to A.D. 1507 (Fig. 7B). In this reconstruction there is markedly greater variability during the period before the A.D. 1757 than after. This variability seems to be an artifact resulting from poorer replication in the earlier part of the chronology. Temperature anomalies relative to the mean of total reconstructed series back to A.D. 1757 will be discussed further because this part is based on good replication of data. The smooth line superimposed on the reconstruction curve shows a 10-yr-filtered version of reconstruction to emphasize the decadal scale fluctuations (Fig. 7C). The filter is a cubic spline passing 50% of the variance in a sine function with a wavelength of 10 yr (Cook and Peters, 1981). The reconstructed curve shows that there are several alternating periods of cool and warm years or episodes. The markedly cool late-summer years are 1782–1786, 1830, 1831, 1899, 1933, and 1975; comparatively much warmer summers are 1777–1779, 1817, 1843, 1904–1906, 1926–1927, and 1980–1982. The years 1905 (+0.72°C) and 1830 (–0.73°C) are the warmest and coolest years, respectively.

The coolest 10-yr period is 1801–1810 (–0.31°C), followed by 1893–1902, 1781–1790, 1827–1836, 1850–1859, 1929–1938, and 1969–1978 The warmest 10-yr mean anomaly is recorded for 1978–1987 (+0.25°C), followed by 1813–1822, 1905–1914, 1837–1846, and 1960–1969. Other than this study, there is no calibrated reconstruction so

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far for this remote, monsoon dominated eastern part of the Himalayan region and probably even no available historical climatic records that could be used for additional verification of the present reconstruction. As mentioned earlier, there are several reconstructions from many sites in the western part of the Himalaya (Borgaonkar et al., 1994, 1996; Hughes, 1992; Yadav et al., 1997, 1999), but most of these are concerned mainly with the reconstruction of spring temperature (March, April, May), except Kashmir. From Kashmir not only late-summer temperature but also other seasonal temperature (April–May) and precipitation (April–September) have been reconstructed since 1780 (Hughes, 1992). There is evidence of spatial coherence between summer temperature reconstructed from the Eastern Himalaya and that recorded from Kashmir. Examples include cooling during 1800, 1820s, 1890s, 1900, 1940s, and 1970s and also warming during 1780s, 1910s and 1960s. However, the relatively cooling periods during the early sixteenth century, mid–seventeenth century, mid–eighteenth century, and 1920s and 1960s reported from the Tibetan Plateau, Trans-Himalaya (Wu, 1992) do not coincide with late summer temperature variations of the Eastern Himalaya. These records do have some association with the spring temperature variations of the Western Himalaya, including Kashmir. In a recent study based on analyses of varied proxy data from the northern hemisphere, it is inferred that the twentieth century was the warmest during the past 1000 yr, with A.D. 1989–1998 and 1998 being the warmest decade and year, respectively (Mann et al., 1999). The present reconstruction which extends up to A.D. 1993, shows that there were three decades of notable warming and also two decades of notable cooling in the twentieth century. The warmest decade recorded was 1978–1987, followed by cooler years in the early 1990s. Analyses of available instrumental records of precipitation and temperature of the Himalaya also suggest that during the twentieth century, increasing temperature and decreasing precipitation were noted only in some pockets, particularly in the Eastern Himalaya (Rupa Kumar et al., 1995). Moreover, long term cooling indicating the Little Ice Age that is believed to cover the time span from the sixteenth to the nineteenth century (Lamb, 1977) may not have been a major event in the Eastern Himalayan region. Though there is evidence of a reduction in late-summer temperature variability from the late 1700s to 1900 in the present study, it does not show any significant negative anomalies over the longer duration. Earlier dendroclimatic analyses from the Western Himalaya (Borgaonkar et al, 1994, 1996; Yadav et al., 1999) also suggest that there is no clear evidence of a Little Ice Age in the Himalayas. Interestingly, the impact of such a cold period has been reported from the adjacent Tibetan Plateau, Trans-Himalayan region (Wu, 1992). Moreover, the present data do not exhibit any clear-cut response to the cooling of the northern hemisphere temperature as a result of the eruption of Tambora, Indonesia in April 1815.

An attempt has also been made to understand whether any link exists between variation of late-summer temperature over the Eastern Himalayan region and El Nino/Southern Oscillation (ENSO) events. In this preliminary attempt, no consistent relationship has been found in the correlation between July–September temperatures of this region with the sea-surface temperature (SST) of different seasons over the eastern equatorial Pacific Ocean. Interestingly, spring temperatures of the Western Himalaya exhibit a negative relationship with the ENSO SST index for June to December and a positive correlation with the average summer monsoon rainfall of India (Yadav et al., 1997).

Discussion and Conclusions

This study is the first attempt at a dendroclimatic reconstruction from the eastern part of the Himalayan region. The growth of *Abies densa* in this region has been found to have a statistically significant relationship with the late-summer temperature (JAS). The late-summer temperature has been estimated back to A.D. 1757, based on well-replicated tree-ring-width data of *Abies densa*. The reconstructed temperature record is characterized by annual to multiyear fluctuations punctuated by cool and warm periods. The warmest and coolest 10-yr periods of the entire span occurred in 1978–1987 (+0.25°C) and 1801–1810 (–0.31°C), respectively. The late-summer temperature reconstruction captured 30.6% of the variance in the recorded data for the calibration period. Though this value is not very high, it may be possible to improve the reconstruction by incorporating more chronologies in the predictor model. A congener of this species, *Abies pindrow*, growing in the Western Himalaya has a similar negative response to late-summer months (Hughes, 1992). July–September temperatures for the Western Himalaya and stations used in this study are fairly well correlated (0.58) for the period 1951–1989. Because of this coherence in regional temperatures, it is expected that fir growth response to climate may also exhibit regional coherence. Thus, combining well-correlated site chronologies and using climatic data from a large number of meteorological stations of both the Eastern and Western Himalaya can enhance climatic signals in future studies and provide better regional climatic records. Moreover, in mesic environment conditions, densitometric data of tree rings are found to be more suitable in extracting climatic information (Parker, 1976; Schweingruber et al., 1978; Hughes et al., 1984) than ring widths, so this is a possible approach to improve reconstruction. Tree-ring analysis of *Abies pindrow* from the Western Himalaya also indicated that isotopic (Ramesh et al., 1985, 1986) and densitometric data (Hughes, 1992) may be more effective in climatic reconstruction.

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