Precipitation reconstruction using ring-width chronology of Himalayan cedar from western Himalaya: Preliminary results

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Himalayan cedar (*Cedrus deodara* (D. Don) G. Don) due to its long age and wide ecological amplitude in the Himalayan region has strong dendroclimatic potential. A well replicated ring-width chronology of it, derived from the ensemble of tree-ring samples of two adjacent homogeneous sites, has been used to reconstruct precipitation for the non-monsoon months (previous year October to concurrent May) back to AD 1171. This provides the first record of hydrological conditions for the western Himalayan region, India during the whole of the 'Little Ice Age' and latter part of the 'Medieval Warm Period'. The reconstruction revealed the wettest and the driest non-monsoon months during the fourteenth and the thirteenth centuries, respectively. The seventeenth century consistently recorded dry non-monsoon months in the western Himalayan region. Surplus precipitation, especially more pronounced since the 1950s, is recorded in the current century.

1. Introduction

The Himalayan region is of paramount climatic importance for its role in modulating regional and extra-regional atmospheric circulation. But so far our understanding of the climate of the region is largely based on limited and patchy instrumental records. Generally, the instrumental records are for less than a century in length, and in many cases in inhospitable areas records may only be available for a few decades. As a result, our perspective on climate variability, both spatial and temporal, is quite limited. Interestingly, the meteorological data show distinct spatial heterogeneity in the Himalayan region. Srinagar temperature data show increasing non-significant trend in the current century (Borgaonkar *et al* 1994) contrary to the decreasing non-significant trend for Shimla (Borgaonkar *et al* 1996). Such a heterogeneous behaviour of climate in the Himalayan region makes it very important for developing better understanding of the intricacies of the climate change behaviour. For such studies long-term high-resolution climate data with very precise dating control are needed. Tree-rings are one of the valuable high-resolution surrogate records of environmental variations and could be used to supplement the instrumental records for several centuries. Dendroclimatic aspect of tree-ring studies in India was first started at the Indian Institute of Tropical Meteorology, Pune towards the end of 1970s (Pant 1979, 1983). Since then several other studies have been carried out in this direction. The ring width and density chronologies of some species have been used to develop temperature reconstructions (Hughes 1992; Borgaonkar *et al* 1994, 1996; Yadav *et al* 1997, 1999; Yadav 1998). But the precipitation reconstructions so far carried out in this region are few and restricted to around two centuries only (Hughes 1992; Borgaonkar *et al* 1994). In this study tree-ring chronology of Himalayan cedar has been used to reconstruct total precipitation of the non-monsoon months (previous year October to concurrent year May) extending back to AD 1171 for the western Himalaya, India. This makes the first attempt to reconstruct hydrological conditions for this region covering the entire span of the 'Little Ice Age' and the latter part of the 'Medieval Warm Period'.

Keywords. Tree rings; Himalayan cedar; *Cedrus deodara*; precipitation reconstruction; western Himalaya; India.

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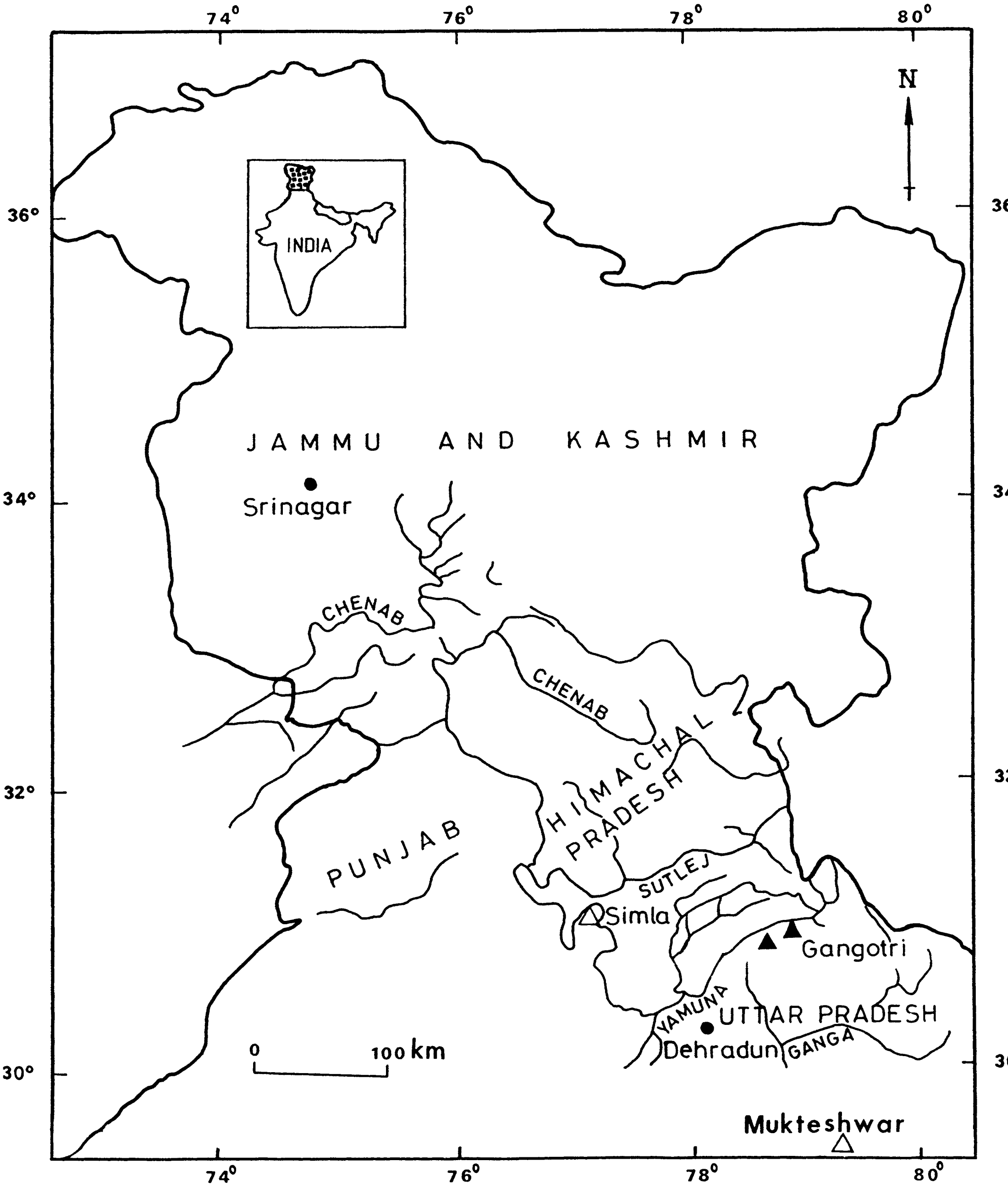

Figure 1. Area map showing the tree-ring sites (filled triangles) and meteorological stations (open triangles) used in the present study.

2. Tree-ring and climate data

Himalayan cedar occurs throughout the western Himalaya from Afghanistan to Garhwal Himalaya in India at elevations from 1200–3000 m. Well drained soils, good amount of winter snow and not too heavy summer monsoon are its primary ecological requirement (Champion and Seth 1968). The best Himalayan cedar forests are found in areas where annual rainfall ranges from 100–175 cm. Due to heavy rainfall it does not grow in the eastern Himalaya beyond Garhwal.

The ring-width chronology of Himalayan cedar (AD 1171–1988), prepared from tree cores collected from two disjunct mature forests in western Himalaya (figure 1), has been used in the present study. Details of the methodology and chronology features are described elsewhere (Yadav *et al* (1999)).

For the climate-growth relationship study a regional average temperature and precipitation series (figure 1) was prepared by merging homogeneous data sets of Mukteshwar (29° 28′N, 79° 39′E, 2311 m a.s.l.) and Simla (31° 10′N, 77° 17′E, 2205 m a.s.l.) supplied by India Meteorological Department, Pune. Monthly variations of temperature and precipitation based on long-period averages (1897–1988) are illustrated in figure 2. The data show that 75% of the annual precipitation is brought by monsoon rains (June to September) and the remaining 25% in non-monsoon months from post monsoon (October and November) to the concurrent year May. Winter and spring

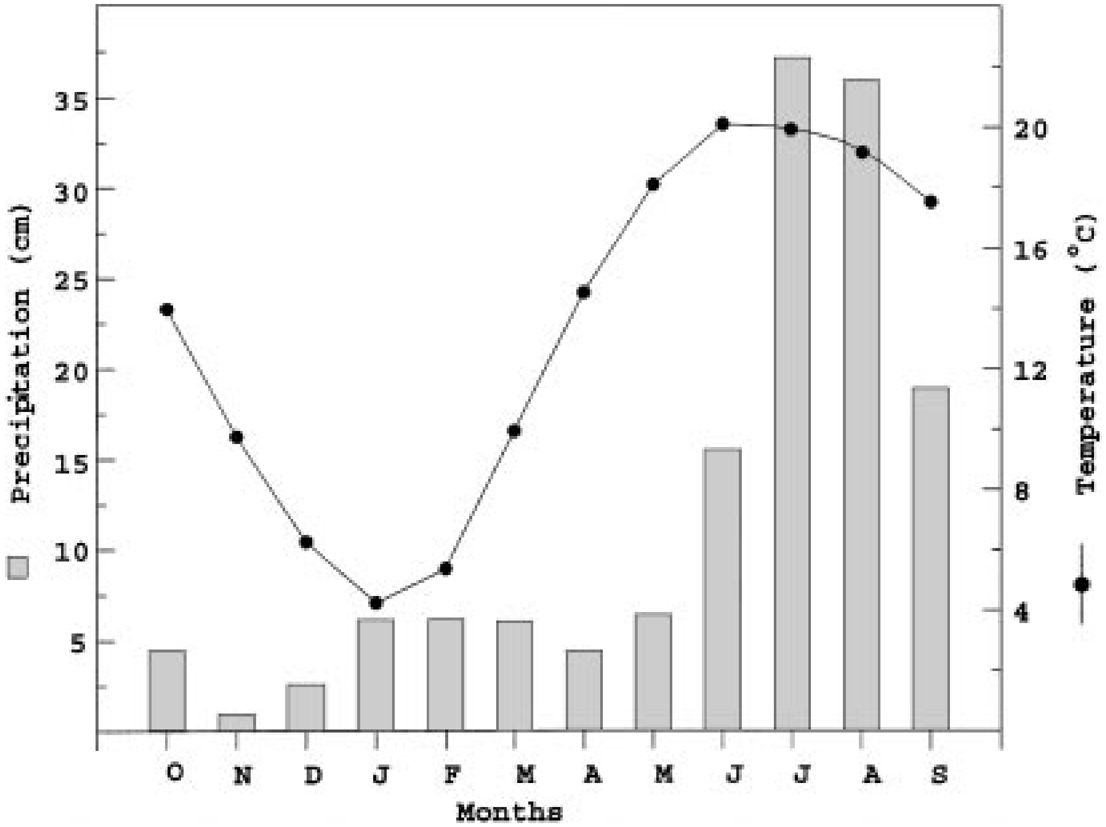

Figure 2. Mean monthly variation in temperature and precipitation during 1897–1988.

together contribute 92% of the non-monsoon months precipitation. The precipitation during non-monsoon months is extra-tropical in origin and associated with the western disturbances as well as with thunderstorm caused by local convective currents. The western disturbances are frequent in winter (6–7 per month). During April–May the frequency of western disturbances comes down to 2 to 3 per month or even less (Dhar *et al* 1984). The precipitation brought by western disturbances gradually decreases from west to east as these disturbances approaching India from the west through Iran, Afghanistan and Pakistan move west to east. January is the coldest month with an average of 5.9°C and June the warmest month with an average of 18.7°C.

3. Calibration, verification and reconstruction

Tree-growth climate relationship using cross-correlation between ring-width chronology and climate data (temperature and precipitation) was used to identify the optimum season and climate variable for reconstruction (figure 3). This indicated a strong positive relationship with precipitation and a negative relationship with temperature during most of the months of the hydrological year (October–September). High temperature coupled with low precipitation appears to be the deterrent factor for tree growth of Himalayan cedar in the study area. As the trees composing the chronology are growing on rocky slopes with thin soil cover they are much prone to desiccation through evapotranspirational losses. The correlations with precipitation and temperature of the prior growth period are stronger indicating that the hydrological regime prior to the growing season is an important preconditioning factor for ensuing growth. The correlation between ring-width index and precipitation of October, December and March–May are statistically significant ($p < 0.05$). The correlations with precipitation and temperature of the monsoon months are weak. This shows that during the monsoon months neither precipitation nor temperature is limiting for growth in this area. Strong ring-width relationship with temperature and precipitation exhibited in the present study shows that the network of chronologies developed from similar sites could emerge as valuable proxy of temperature and precipitation.

To identify the optimum season (months) for precipitation reconstruction we used different combinations of total monthly precipitation. The highest correlation was noted with the total precipitation for the previous year October to the concurrent year May. The prewhitened and rereddened chronologies were used to assess their relative strength of the climatic signal. The prewhitened chronology showed a stronger correlation with the non-monsoon months ($r = 0.57$,

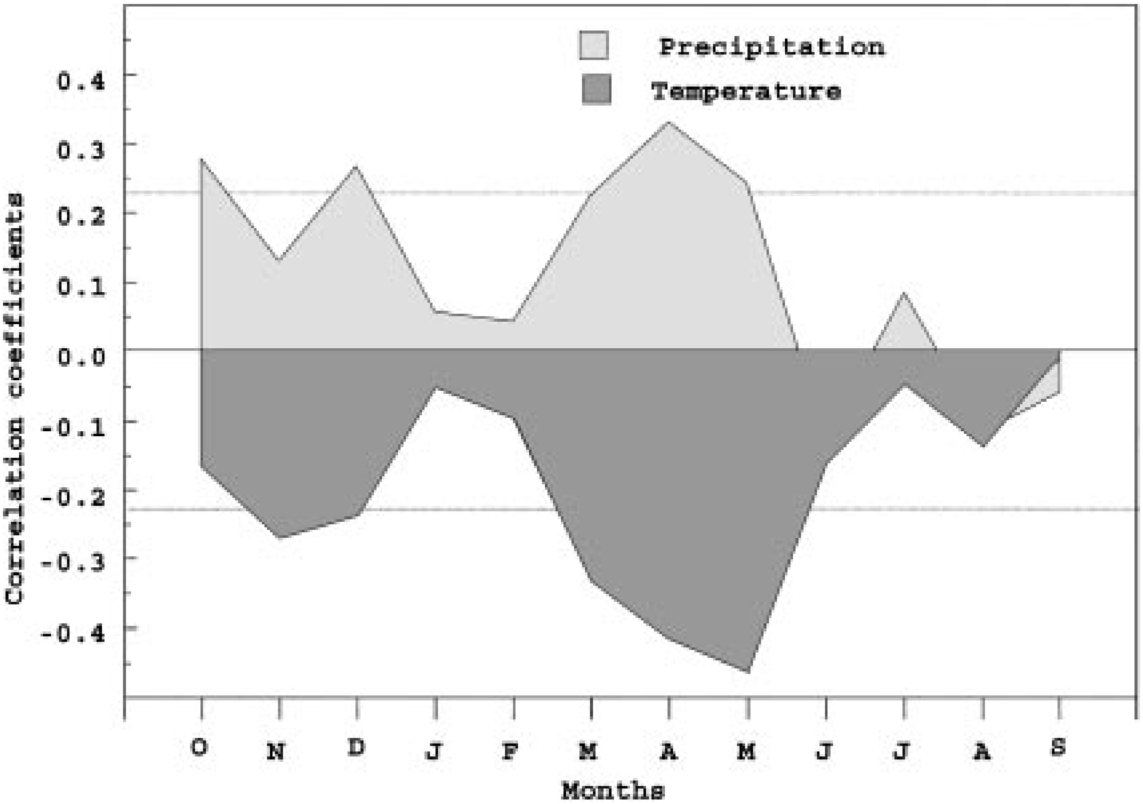

Figure 3. Correlations of monthly precipitation (previous year's October to growth year's September) with Himalayan cedar chronology. The two tailed 95% confidence limits for the correlations are indicated by the dotted lines.

Table 1. *Regression coefficients (B_0-intercept, B_1-slope) and selected calibration and verification statistics calculated for two sub-periods i.e. 1897–1942, 1943–1988 and whole period (1897–1988). Whole period calibration model (1897–1988) was used for reconstruction. R^2 adj. – the square of the correlation coefficient adjusted for the loss of degree of freedom, R – the Pearson correlation coefficient, RE – reduction of error.* $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Calibration					Verification				
Period	B_0	B_1	F value	R^2 adj.	Period	R	T-value	Sign test	RE
1897–1942	35.3255***	5.8634***	16.801***	0.26	1943–1988	0.529***	2.730**	26/20	0.279
1943–1988	36.7774***	6.3236***	17.081***	0.26	1897–1942	0.526***	3.016**	30/16*	0.276
1897–1988	36.0513***	6.1452***	34.692***	0.27					

1897–1988) and was chosen for calibration and reconstruction.

The concurrent year ring-width index along with index lagged backward and forward ($t-1, t_0, t+1$) was used to assess the relationship with recorded precipitation for the non-monsoon months (Oct_{t-1}–May t_0). The concurrent year ring-width index and not the lagged variables displayed significant correlation with the non-monsoon months precipitation. Therefore, the concurrent year ring-width index was used to calibrate the relationship with precipitation. Cross-calibration (Briffa *et al* 1988) was used to test the fidelity in ring-width and precipitation relationship using simple linear regression. For this the precipitation data were split into two equal halves, i.e., 1897–1942 and 1943–1988. The regression equation accounted for 26% of the variance (R^2 adjusted for loss of degrees of freedom; Draper and Smith 1981) in both the calibration and verification periods (table 1). The calibration models in both the sub-periods produced significant verification statistics (Fritts 1976), i.e., cross-correlation, reduction of error (RE), and product means test values (table 1) except that the sign-test, involving the comparison of the signs of first differences of the series, which failed the significance test (0.05 level) for the sub-period 1943–1988. After cross-verifying the calibration models of both the sub-periods tree-ring and precipitation data were calibrated for the whole period (1897–1988). This showed a marginal improvement in the variance accounted for in the instrumental data (27%). The whole period calibration model was used to estimate precipitation for the early periods covered by tree-ring data. The use of the entire calibration interval enhances the ability of the regression model to reconstruct low frequency variability in precipitation. The

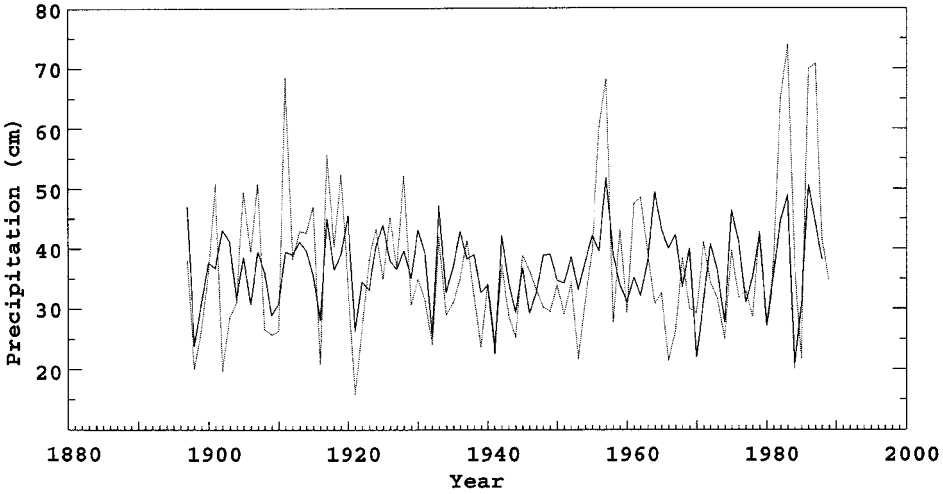

Figure 4. Actual (dotted line) and estimated (solid line) non-monsoon month (October–May) precipitation (cm) anomalies. The whole period (1897–1942) regression model was used to calibrate the reconstruction.

model well reproduces the series used in the calibration (figure 4). However, the dry anomalies appear to be better reproduced than the wet ones. This could be due to the growth promoting role of the moisture supply in the present moisture stressed site.

4. Analysis of the reconstructed precipitation data

The complete reconstruction (AD 1171–1988) plotted as anomalies relative to the mean of the calibration period (AD 1897–1988) is shown in figure 5. The smooth line derived after fitting a cubic spline superimposed on the annual reconstructed data emphasises dry and wet periods on the time scales of 20 years and above. The calibration and verification statistics of two split periods (1897–1942 and 1943–1988) indicate that the reconstructed time series presented here provides valuable information on past precipitation variability during non-monsoon months. There is no other high-resolution proxy record of precipitation for the Himalayan region which could be compared with the present reconstruction. The only precipitation reconstructions prior to this study are of the growing season (April–September by Hughes 1992 and May–September by Borgaonkar *et al* 1994) for the valley of Kashmir which extends back to the latter part of the 18th century.

The reconstructed series display annual to multi-year fluctuations in precipitation of the non-monsoon months. The important feature of the reconstruction is the prolonged wet phase in the latter part of the fourteenth century with a maximum around the 1350s and 1380s. Wet periods recorded during recent decades of the current century, more pronounced since the 1950s (figure 5, table 2), are in well agreement with the instrumental data. The reconstruction has further

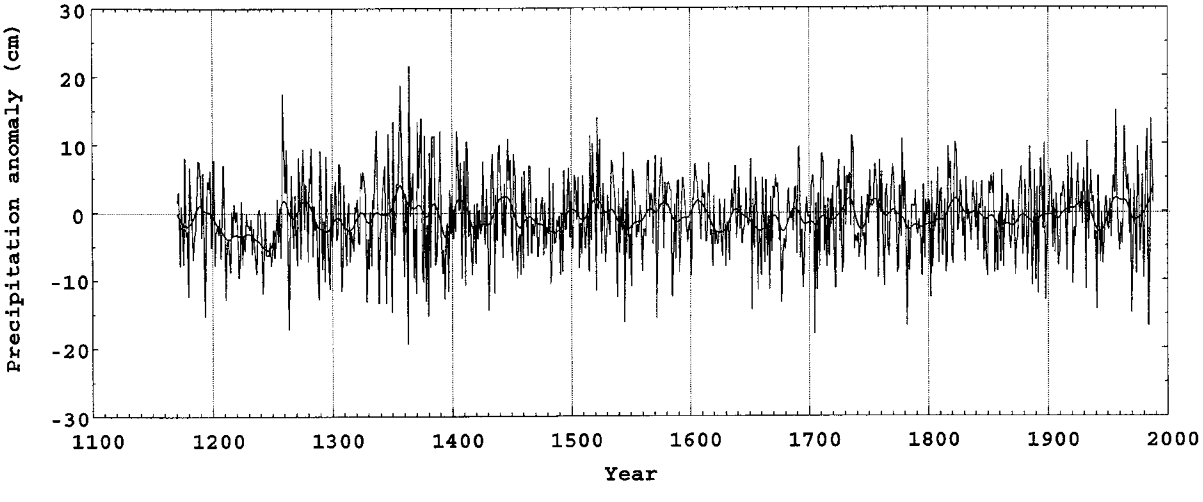

Figure 5. The extended previous year October to concurrent May precipitation reconstruction (AD 1171–1988) plotted as anomalies relative to the mean of 1897–1988 precipitation. Thick line represents the filtered version derived by fitting a cubic spline designed to remove 50% of the variance in a sine function with the wavelengths of 20 years.

Table 2. *Precipitation anomalies (cm).*

a) 20-year mean

Wet			Dry		
Period	Anomaly (cm)	Standard error	Period	Anomaly (cm)	Standard error
1355–1374	3.186	2.334	1233–1252	−5.016	0.734
1434–1453	1.963	1.454	1210–1229	−4.007	0.869
1948–1967	1.825	1.191	1856–1875	−2.885	0.966
1516–1535	1.569	1.540	1472–1491	−2.799	1.001
1564–1583	1.523	1.327	1781–1800	−2.636	1.113

b) 30-year mean

Wet			Dry		
Period	Anomaly (cm)	Standard error	Period	Anomaly (cm)	Standard error
1356–1385	1.871	1.969	1221–1250	−4.470	0.618
1954–1983	1.095	1.261	1652–1681	−2.579	1.074
1817–1846	0.979	0.905	1467–1496	−2.506	0.787
1254–1283	0.965	1.287	1288–1317	−2.331	1.141

c) 50-year mean

Wet			Dry		
Period	Anomaly (cm)	Standard error	Period	Anomaly (cm)	Standard error
1336–1385	1.250	1.386	1202–1251	−3.950	0.529
1404–1453	0.414	0.949	1284–1333	−2.068	0.818
1917–1966	0.402	0.825	1618–1667	−1.952	0.691

revealed prolonged periods of wet non-monsoon months around 1400s–1440s, 1560s–1600s, 1508–1537, 1720–1780 and 1817–1846. Earlier temperature reconstruction (Yadav *et al* 1999) has shown cool springs during these periods.

The thirteenth century with the exception of a few decades (1250s–1270s) experienced the driest anomaly (figure 5, table 2). The reliability of the reconstruction for this period is less due to the poor replication of samples constituting this part of the chronology. Nonetheless, it is interesting to note that this dry episode, representing part of the 'Medieval Warm Period' (Hughes and Diaz 1994) is coincidental with the retreat of glaciers relative to their modern position to minimum extent in the Himalayan region (Rothlisberger and Geyh 1985). The seventeenth century, usually associated with maximum cooling of the 'Little Ice Age' in the high latitude northern Hemisphere (Lamb 1977), experienced droughts (figure 5, table 2). This seventeenth century drought was the most prolonged period of below normal non-monsoon precipitation in the past 818-year record. The mean spring temperature during this period has been found to have fluctuated above the long-term mean (Yadav *et al* 1999). The other dry episodes recorded in our reconstruction are around the 1450s–1490s, 1770s–1800s and 1846–1875.

The precipitation over the Himalayan region especially during the non-monsoon winter and spring seasons has significant influence on the ensuing summer monsoon rainfall over south Asia (Dey and Bhanukumar 1983; Barnett *et al* 1989; Douville and Royer 1996; Overpeck *et al* 1996; Yang 1996). Extensive and prolonged snow cover has a significant influence on the climatic system through the albedo feedback processes. A large and deep snow cover keeps the soil wet for longer times in spring and summer. This will delay and reduce the heating of land mass which in turn can either delay the onset of summer monsoon or reduce its intensity. The increasing trend in precipitation of non-monsoon months since the last few decades in the current century appears to be coincidental with a decrease in all India summer monsoon rainfall (Parthasarthy *et al* 1994). It has been further postulated that a surplus (deficit) monsoon over India and the vicinity preceded by a lighter (heavier) than normal Eurasian snow cover could trigger an El-Niño (La-Nina) event in the eastern Equatorial Pacific about 12 to 15 months following the surplus (deficit) monsoon season (Khandekar 1991). The existence of such teleconnections indicates that the network of tree-ring data similar to the present one from the Himalayan region should emerge as one of the valuable proxies of the Indian summer monsoon and also El-Niño/Southern Oscillation (ENSO), both of global climatic significance.

5. Conclusions

The correlation analysis between ring-width chronology and climate variables indicated that the precipitation has positive and temperature negative influence on Himalayan cedar growth in the study sites. The strong climate signal in the chronology shows that the Himalayan cedar chronology which developed from similar climate stressed sites could be a valuable surrogate record of both the temperature and precipitation variables.

Tree-ring based precipitation reconstruction for the non-monsoon months (previous year October to concurrent May) covering the entire span of the 'Little Ice Age' and latter part of the 'Medieval Warm Period' has been developed for the first time for the western Himalayan region, India. The reconstruction using a single tree-ring chronology captured 27% of the variance in the recorded precipitation data during the calibration period. This shows that the network of tree-ring data developed from the homogeneous sites should result in robust climate estimates representative of regional scale climate features. Such long-term data will help in understanding the natural climate variability during the 'Medieval Warm Period' and the 'Little Ice Age'. Such background knowledge on long-term climate variability of the period long before the industrial boom are needed for human impact assessment on climate change.

The reconstruction providing a preliminary glimpse of precipitation variability has revealed annual to multi-year episodes of wet and dry periods of non-monsoon months. The protracted intervals of dry and warm conditions occurred during the thirteenth and the seventeenth centuries. The latter part of the fourteenth century was the wettest of the 818-year record.

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