Chir pine ring-width thermometry in western Himalaya, India

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We have developed the first annually resolved ring-width chronology (AD 1880–2002) of chir pine (*Pinus roxburghii*) from Balcha in Tons valley, western Himalaya. The existence of significant positive relationship between ring-width indices and June–August mean temperature obtained in cross-correlation analysis endorsed the dendroclimatic potential of chir pine chronologies. Using such strong relationship, statistically verifiable first chir pine chronology-based June–August temperature (AD 1880–2001) was reconstructed for the western Himalaya. The calibration model capturing 16% of the variance in instrumental data (AD 1901–1998) showed that the network of such chronologies should help in developing robust temperature records for the western Himalaya.

Keywords: Dendroclimatic potential, *Pinus roxburghii*, ring-width chronology, summer temperature.

TREE-RINGS are one of the high-resolution proxies of climate variables, which are most limiting for the growth of trees over specific sites. In the western Himalaya of India, most of tree species have been found to be responsive to precipitation as moisture is the main limiting factor of tree growth there[1–11]. The temperature records so far developed from the region are indirect as warm conditions exacerbating evapotranspiration lead to soil moisture deficit thereby deterring the growth of trees[12–15]. We report here that the precisely dated growth ring sequences of chir pine (*Pinus roxburghii* Sarg.) provide direct clue to the summer temperature variations.

Chir pine, native to the Himalaya, is a tall, three-needled, monoecious pine with very thick bark often cut in large plates of irregular size. It is found growing in sub-Himalayan tract at elevations ranging from 500 m to 2300 m amsl. The light-loving chir pine prefers to grow in open stands in sub-Himalayan tract from Afghanistan to Bhutan[16]. The tree-ring studies of this species are very few probably due to the rarity of old trees in the forests and also indistinct growth ring boundaries[17,18]. The first ever ring-width chronology of this species growing over a site at 2080 m amsl in west Nepal was successfully developed by Bhattacharyya *et al.*[19]. However, the dendroclimatic potential of this chronology remained unexplored until now. Here we report on the potential application of ring-width chronology of chir pine in developing temperature records for the Himalayan region.

The chir pine often forms pure stands on dry, fire-prone slopes in the western Himalayan region. As it is heavily exploited for oleoresin tapping, old, undisturbed trees are hard to get in the Himalayan region. The chir pine forests are also frequently affected by fires[20]. Occluded resin deposited on oleoresin-tapped tree surfaces, and thick mat of dry needles accumulated on the ground provide highly inflammable fuel load for fire. In the sub-Himalayan region, the chir pine trees are found growing mixed with *Shorea robusta*, *Cedrela toona*, *Anogeissus latifolia* and *Quercus incana* at lower elevations and with *Quercus leucotrichophora*, *Pinus wallichiana* and *Cedrus deodara* at higher elevations. The tree-ring samples for the present study were collected in the form of increment cores from chir pine trees growing disjunctly over wide area in Balcha, Tons Valley, Uttarakhand (Figure 1). For sampling old, healthy trees free of resin tapping were selected. Usually two increment cores from each of the selected trees were taken and after drying at room temperature glued on wooden supports keeping the cross surfaces atop. In total 12 cores from 7 trees were used in this study. The growth ring sequences in core samples were cross-dated using skeleton plot method[21,22] and ring widths measured to 0.01 mm accuracy using linear encoder LINTAB[23]. Very good coherence in growth pattern of trees as revealed in COFECHA[24] (mean $r = 0.63$) and year-to-year similarity in ring-width plots were noticed. This indicates reliable dating of growth ring sequences in chir pine in the sub-Himalayan tract in India and establishes the potential applicability of this species for dendrochronological study.

The ring-width measurement series of individual tree samples were studied for chronology preparation using the program ARSTAN[25]. The ring-width measurement series were detrended using cubic smoothing spline with a 50% frequency response function cut-off width equal to two-thirds of the series length[26]. To minimize the effect of varying sample size in the mean chronology, the variance was stabilized[27]. The ring-width indices were developed after dividing the individual measurement of each year's growth ring by the growth trends of the corresponding year. In order to minimize the influence of outliers, the detrended ring-width measurement series of the respective tree series were averaged to a mean chronology by computing the biweight robust mean[25]. The standard version of the chronology extending back to AD 1880 with the expressed population signal (EPS) of 0.84 (Figure 2)[28] was used in analyses with climate variables. To understand the climate signal in mean ring-width chronology, cross-correlations between tree-ring indices and monthly climate variables (temperature and precipitation) were computed. For this temperature data of Shimla (31°10′N, 77°17′E; 2205 m amsl; 1876–1998)

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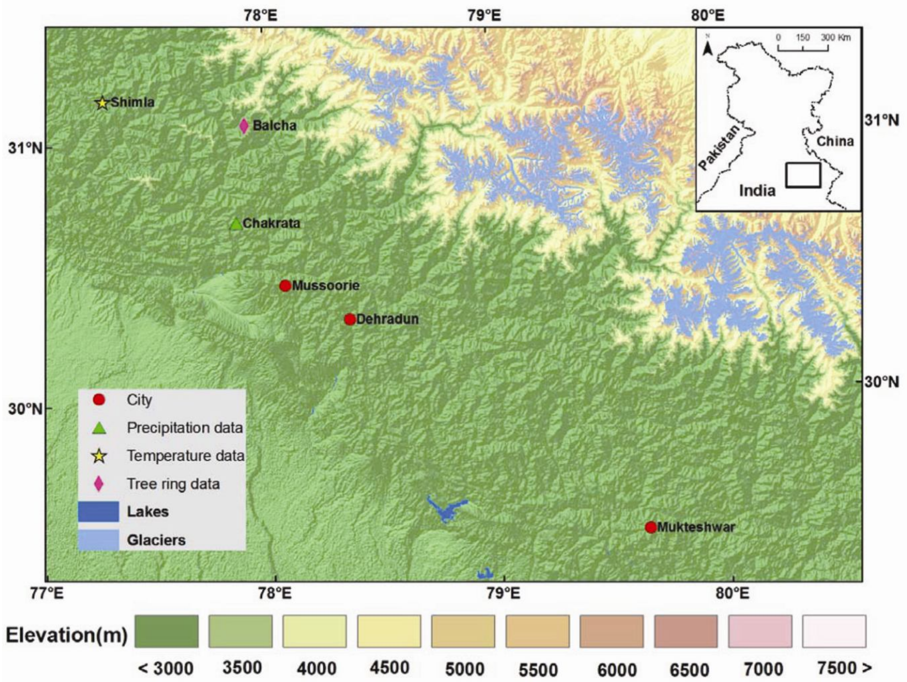

Figure 1. Map showing the location of tree cores sampling site and climate (Shimla temperature and Chakrata precipitation) stations.

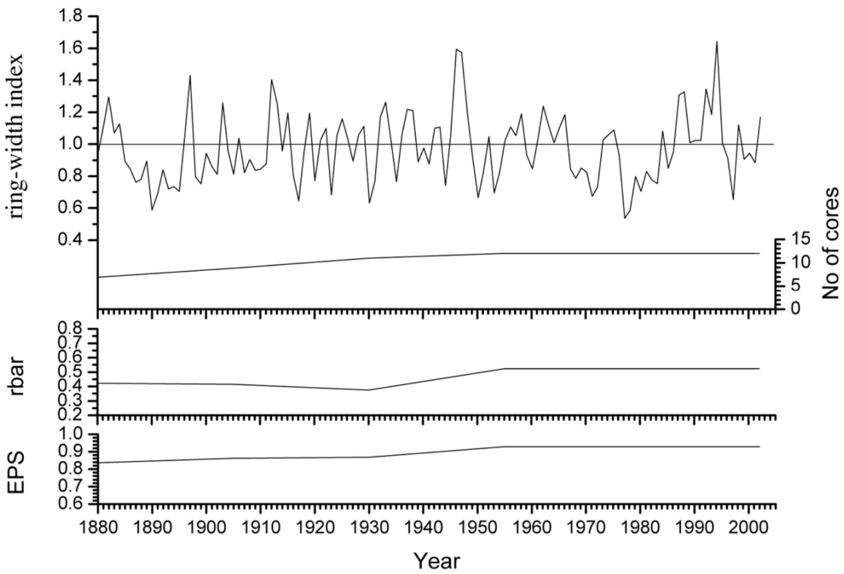

Figure 2. Ring-width chronology (AD 1880–2002) along with the number of samples used in chronology building, expressed population signal (EPS) and rbar statistics.

and precipitation of Chakrata (30°41′N, 77°52′E; 2118 m amsl; 1901–1967) were used. The selection of meteorological data for this study was based on the availability of station data close to the sampling site and also representing the climate regime similar to that over the tree-ring site. The correlations were calculated for the respective common period (i.e. 1901–1998 for temperature and 1901–1967 for precipitation) using monthly climate data from October of the previous growth year to October of the current year (Figure 3).

The correlation study revealed that temperature for all the months, except October–December of the preceding growth year had positive relationship with chir pine growth indices; however, this relationship was relatively stronger for June–August (JA). The growth indices were found to be directly associated with precipitation during October and November of the previous year as well as February, May, July and September of the current year. However, the relationship with precipitation of November of the previous year and September of the current year

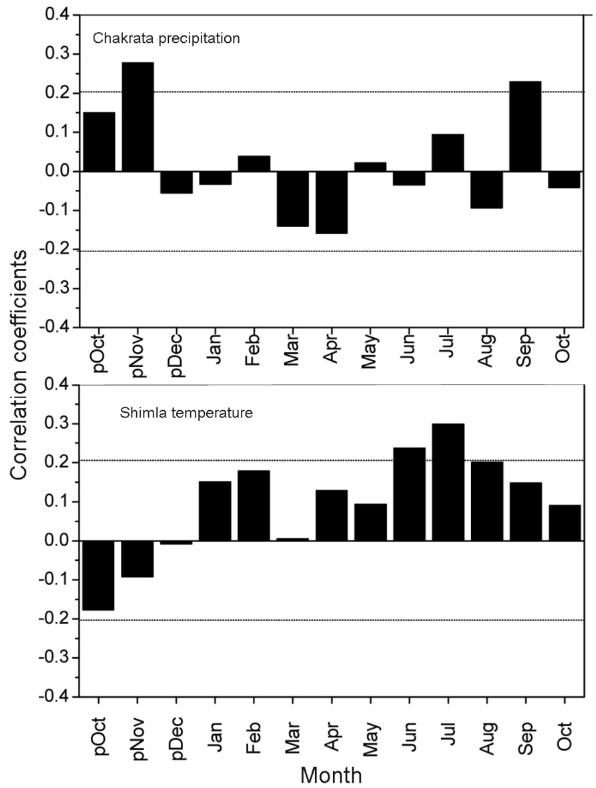

Figure 3. Cross-correlation analyses between ring width indices and monthly precipitation of Chakrata (upper panel) and mean monthly temperature of Shimla (lower panel). The dotted lines represent 95% confidence interval.

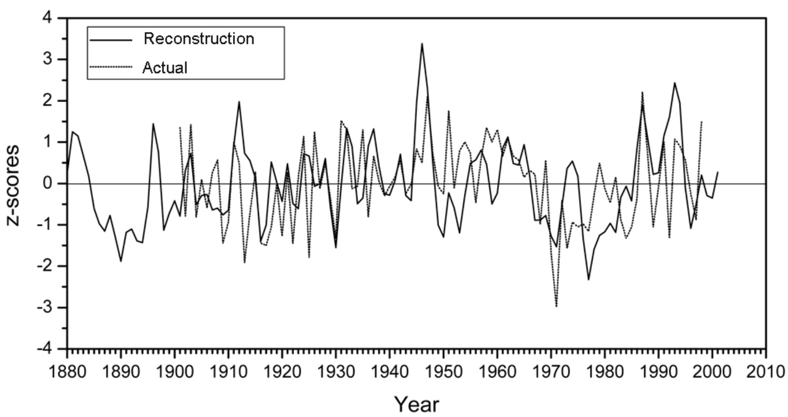

Figure 4. Reconstructed June–August temperature (AD 1880–2001, solid line) and actual temperature (dotted line). Calibration period AD 1901–1998 was used in the reconstruction.

Table 1. Calibration–verification statistics of June–August temperature reconstruction obtained in principal component regression analysis

Calibration		Verification				
Period	ar^2 %	Period	R	T value	Sign test	RE
1901–1949	16	1950–1998	0.42**	2.0*	$31^{+}/18^{-}$*	0.16
1950–1998	16	1901–1949	0.42**	1.3	$34^{+}/15^{-}$*	0.16
1901–1998	16					

Here, ar^2 is captured variance adjusted for degrees of freedom, R is Spearman correlation; RE is the reduction of error (details given in Fritts[22]). $*P < 0.05$, $**P < 0.01$.

was stronger (Figure 3). It is interesting to note that the present ring-width chronology shows direct relationship with the mean monthly temperature during summer in the western Himalaya.

The JA mean seasonal temperature was correlated with the ring-width chronology to understand if statistically reliable calibrations could be developed for reconstruction. The $t0$ and $t + 1$ variables of the standard chronology showed statistically significant relationship with mean JA temperature. The principal component regression analysis involving $t0$ and $t + 1$ chronology variables as predictors and JA mean temperature as predictand was performed to develop the calibration models. The first principal component (PC#1) with eigen value 1.34 capturing 67% of the common variance was utilized in calibrations using simple linear regression model. The split-period calibrations in two equal sub-periods (1901–1949 and 1950–1998) were performed to test the fidelity of the models. The two sub-period calibration models capturing 16% of the variance in the instrumental JA temperature yielded significant statistics (Table 1), except the *T* test which failed in the verification of the 1950–1998 calibration model. As both the sub-period calibration models yielded similar calibration and verification statistics, we used the full length of the instrumental temperature data (1901–1998) for the reconstruction of mean JA temperature back to AD 1880, the period when sufficient sample replication was available (Figure 4). Though there exists considerable similarity in observed and modelled JA temperature data, extreme low and high values are not captured in the present reconstruction. We are optimistic that with the inclusion of more samples in the present chronology as well as more such chronologies in the predictor model should help in developing stronger reconstructions of temperature. It is also expected that this study should provoke tree-ring workers in the region to take aggressive steps in developing chir pine chronologies to get direct record of mean summer temperature.

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