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Reconstruction of heat index based on tree-ring width records of western Himalaya in India

Somaru Ram*, H.P. Borgaonkar

Indian Institute of Tropical Meteorology, Pune 411008, India

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ABSTRACT

To study climate variability/change, the tree-ring width index chronologies of two species (*Cedrus deodara* and *Pinus roxburghii*) of the western Himalaya was determined. The first principal component (PC1) prepared using the three-site tree-ring width chronologies of the western Himalaya was found to be negatively correlated with the heat index and positively with the Palmer Drought Severity Index (PDSI) and moisture index from February to May as representative of the regional climate. The correlation coefficient of PC1 with the heat index, PDSI, and moisture index for the period 1901–1988 was estimated to be −0.60, 0.37, and 0.59, respectively, which were highly significant at 0.1% level. The result shows that increasing the heat index may enhance transpiration and evaporation over the western Himalaya, which may cause insufficient moisture at the root zone of the trees. Based on the tree-ring data, the heat index of spring season (February–May) was reconstructed back to AD 1839. The reconstructed heat index showed the longest warm periods during 1952–1963 and 1966–1976 in the 20th century.

1. Introduction

The mountain ranges over the Himalaya pose the highest topography barrier on the earth's surface. This region shows a diverse ecosystem mainly due to varied rainfall and temperature (Yadav et al., 2009). Yet, due to the lack of empirical and proxy records, the long-term climatology of the Himalayan region is not well understood in spite of its relevance to human society. Thus, to determine the long-term climate variability/change over the Himalayan region, several tree-ring width studies in this region have been performed in relation to climate, that is, rainfall and temperature. These studies showed that tree-ring width could be a valuable proxy for the reconstruction of climate, particularly rainfall and temperature, back to several centuries (Singh and Yadav, 2005; Singh et al., 2000, 2006, 2009; Yadav and Singh, 2002; Yadav et al., 2004, 2009; Yadav, 2009; Pant et al., 1998, 2000; Hughes, 1992; Borgaonkar et al., 1999; Ram and Borgaonkar, 2013, 2014a).

Moreover, other studies from the Himalayan region demonstrated a significant correlation between tree-ring width chronologies and the Palmer Drought Severity Index (PDSI) (Cook et al., 2010; Sano et al., 2012; Ram 2012; Ram and Borgaonkar, 2014b). They showed the important role of moisture availability at the root zone of the trees. However, the role of heat and moisture index in tree growth processes in the western Himalaya for a longer period has not yet been studied, except for rainfall and temperature. Thus, to determine the long-term variability in heat and moisture index, a chronology with sufficient sample replication were used here to reconstruct the heat index for the first time for the western Himalaya. It is hoped that such climatic information may help further our understanding of the past behavior of heat index over the region.

2. Material and methods

2.1. Tree-ring data

Multi-species residual tree-ring chronologies of the western Himalaya were used from the website http://www.ncdc.noaa.gov/paleo/treering.html/ to reinvestigate the tree growth–climate relationship (Fig. 1). Fig. 1 represents the three tree-ring width index chronologies, namely Ghansali (▲1), Kanasar (▲2) and Tuni (▲3). The total three-site tree-ring chronologies were considered in the present study, and their details (length, species, elevation, total time span, time span expressed population signal (EPS) > 0.85, mean sensitivity, mean sample segment length, AR (1), etc.) are summarized in Table 1. The MSSL (average number of years per sample) of the three chronologies ranges from 117 to 160 years. The Kanasar chronology has high MSSL compared with the other

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* Corresponding author.
E-mail address: somaru@tropmet.res.in (S. Ram).

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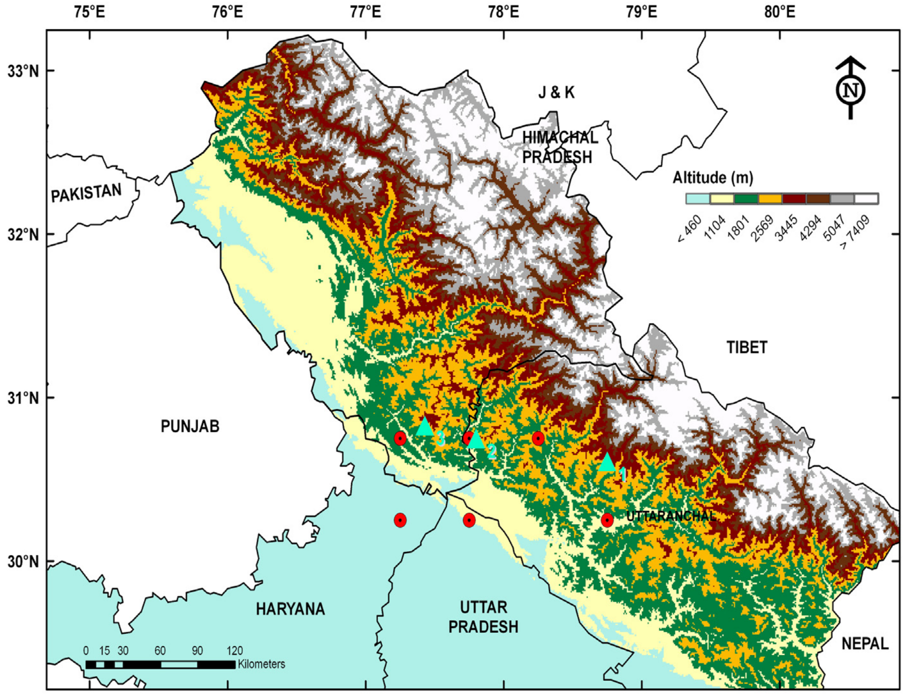

Fig. 1. Map showing the study areas of western Himalaya; ▲1 , ▲2 , and ▲3 are the tree-ring width data; ● : grid point data considered for rainfall, temperature, and PDSI.

Table 1
Summary statistics of chronologies.

Site name	Series	Length (year)	species	Elevation (m)	Total time span	EPS > 0.85[a]	MS[b]	AR(1)[c]	MSSL[d]
Ghansali	25	195	*Pinus roxburghii*	2100	1796–1990	1840	0.25	1	130
Kanasar	27	278	*Cedrus deodara*	2200	1711–1988	1850	0.26	1	160
Tuni	29	188	*Pinus roxburghii*	1800	1801–1988	1870	0.24	1	117

[a] The first year that EPS (expressed population signal) was ≥0.85 (Wigley et al., 1984).
[b] Mean sensitivity measures the proportion of high-frequency variation retained in the chronology (Fritts, 1976).
[c] Auto-regressive process selected by the Akaike information criterion to remove autocorrelation.
[d] Mean sample segment length (average numbers of year per sample).

chronologies. The MS, which measures the relative change in ring width from one ring to the next as a measure of the high-frequency variation and climatic responsiveness, ranges from 0.24 to 0.26; The EPS, which measures the statistical quality of a chronology, is found to be above 0.85 after AD 1840 at Ghansali, after AD1850 at Kanasar, and after AD 1870 at Tuni. The threshold value (0.85) of EPS in the chronology indicated the suitability of the chronology for climatic studies, as evidenced by Wigley et al. (1984). Moreover, the number of tree core samples, their standardization processes, and tree-ring chronology statistics with their respective sites have already been discussed in a previous study (Borgaonkar et al., 1999).

The intercorrelation among the site chronologies for the common period 1838–1988 ranges from 0.20 to 0.40, which is significant at the 1% level. Based on their correlation coefficients (CCs), principal component analysis was performed among the chronologies to avoid multicollinearity in data, as evidenced by Ram and Borgaonkar (2014a). The first principal component (Fig. 2), which explained the highest 53% of the common variance in chronologies that regionally shows the effect of climate on tree growth, is discussed later in the paper.

2.2. *Climate data*

Due to the poor network of meteorological stations and limited climatic data over the western Himalaya, the gridded monthly mean temperature, rainfall, and self-calibrating Palmer Drought Severity index (scPDSI) data from the climate research unit (CRU TS3.23) were used in the present analysis (Ian et al., 2014). The grid boxes (30.25° N, 77.25° E; 30.75° N, 77.25° E; 30.25° N, 77.75° E; 30.75° N, 77.75° E; 30.75° N, 78.25° E; and 30.25° N, 78.75° E) nearer to the study area were selected for dendroclimatic analysis (Fig. 1). Based on the strong correlation among the data (Ram and Borgaonkar 2014a, 2014b), a regional series of rainfall, PDSI, and temperature for the study area was prepared by merging the grid box data to determine the tree growth–climate relationship (Fig. 3). In addition, regional moisture and heat index for the study area were computed using the empirical formula (Thornthwaite, 1948; Chhin and Wang, 2005; Ram et al., 2008; Ram and Borgaonkar, 2014a) to determine their impact on tree growth.

The mean monthly variations of regional temperature, heat index, and rainfall during 1901–2014 are shown in Fig. 3, July being the wettest month with an average rainfall of 301.0 mm. The maximum heat index (11.9) and temperature (25.7 °C) were found during June. The minimum heat index (2.5) and temperature (9.2 °C) were recorded in the month of January. More than 75% rainfall over the region is fed by the southwest monsoon (June to September) (Fig. 3).

Mean (X), standard deviation (Std), and trends/year (Tr) for temperature, heat index, rainfall, and moisture index on a monthly basis are shown in Table 2 for the period 1901–2014. Temperatures and heat index significantly increased during February, November, and December. In the case of rainfall and moisture index, a significant decreasing trend was observed during January, March, July,