Western Himalaya Trees Growth Study and its Association with Droughts in India: A Case Study

Somaru Ram*, H.P. Borgaonkar and S.S. Nandargi

Indian Institute of Tropical Meteorology, Pune-411008, India

Abstract: Tree ring-width index chronology based on a well replicated tree core samples from the western Himalaya showed significant positive relationship with standardized precipitation potential evapotranspiration (SPEI) and standardized soil index (SSI) during summer season (April-June). However, SSI that describes the drought index over the region is found more compatible with tree growth variations than SPEI in controlling the annual ring-width patterns. It shows high temporal stability with trees growth compared to SPEI. The results showed that the SSI which is an indicator of drought index has strong localized effects on patterns of annual tree growth and forest dynamic, working as booster in limiting of trees growth over western Himalaya.

Keywords: Western Himalaya, Conifer, Tree-ring width index, standardized soil index, standardized potential evapotranspiration index.

1. INTRODUCTION

Tree-ring width parameters are the good proxy in the absence of long-term observed climatic data over western Himalaya. It provides the valuable information to understand the climatic factors responsible for variations of trees growth. In this pursuit, tree–ring analysis of conifer trees from the western Himalaya has been carried out to study the long-term climate variability / change during the past several centuries over region [1-6]. They showed that tree growths over western Himalaya are governed by rainfall and temperature. Epochal warming and cooling during Little Ice Age (LIA) were observed in region [4-5].

Moreover, other studies also indicate that tree growth over the region may be impacted by not only temperature and rainfall amount, but also by potential evapotranspiration, moisture index, vapor pressure and Palmer Drought Severity Index (PDSI), which have significant role in tree growth processes [7-11]. They revealed that tree growth at different locations is mainly influenced by the availability of soil moisture of the region. However, despite of all these studies, climate variability and its possible causes for longer time scales are not well understood to society due to limited study of tree growth-climate relationship. Most of the studies on climate variability/change are restricted with rainfall and temperature over western Himalaya. So, in the present study, standardized soil (SSI) and potential evapotranspiration index (SPEI) were used in relation to tree-growth variations to better understand of how trees growth in this region responds to drought indices.

2. MATERIALS AND METHODS

2.1. Tree Ring-Width Data

Tree-ring width data of Jangla (31°22′ N, 78°10′E), western Himalaya, India has been used from International tree-ring data bank (http://www.ncdc.noaa.gov/paleo/treering.html) to re-investigate the tree growth climate relationship. Total 40 tree core samples in the present study were considered. COFECHA program [12] for missing and datings errors was used to check the dated ring-width measurements. The series inter correlation is 0.637, which revealed good agreement among the core samples. Their standardization process, tree ring chronology preparation and statistics have already been discussed in a previous study [13-14]. In the present study, their details (species, elevation, total time span, time span expressed population signal (EPS)> 0.85, mean sensitivity, mean sample segment length, AR (1), autocorrelation order 1 etc. are summarized in a Table **1**.

2.2. Climate Data

Monthly standardized soil index and standardized precipitation potential evapotranspiration index [15-16] were used from nearby grid boxes for the period 1949-2008 and 1901-2013 respectively, from climate research unit (CRU TS3.23) [17]. The grid boxes (31.25°N, 78.25°E; 31.75N, 78.25E; 31.25N, 78.75E; 31.75N, 78.75E; 30.75N, 77.75E) considered in relation to tree growth variation over western Himalaya is a representatives of meteorological station in absence of

*Address correspondence to this author at the Indian Institute of Tropical Meteorology, Pune-411008, India; Tel: 020 25904357; Fax: +91 020 25865142; E-mail: somaru@tropmet.res.in

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Table 1: Chronology Summary Statistics

Site Name	Series	Species	Elevation (m)	Total Time Span	EPS>0.85[a]	MS[b]	AR(1)[c]	MSSL[d]	AC1[e]
Jangla	40	*Cedrus Deodara*	3000	1538-2004	1725	0.30	1	202	0.08

[a] The first year that EPS (expressed population signal) shows greater than o.85 [22].

[b] Mean sensitivity measures the proportion of high-frequency variation retained in the chronology [28].

[c] Auto regressive process selected by the Akaike Information Criterion to remove Autocorrelation.

[d] Mean sample segment length (average numbers of year per sample).

[e] Auto correlation order 1.

observed data [10, 18, 19]. Detailed calculations for SPEI (precipita-tion minus potential evapotranspiration) and SSI are available in [15-16] and in [20, 21] respectively.

For the climate-tree growth relationship study a regional series for SPEI and SSI were prepared by merging the grid point climate data available in and around the sampling area. Standardized precipitation potential evapotranspiration index (SPEI) is a multi-scalar drought index whereas standardized soil index (SSI) is an agricultural drought [20-21]. The SPEI identifies precipitation deficit at various time scales and has zero mean and a standard deviation of one. A sequence of negative (positive) SPEI values indicates that the climatic condition has dry (wet) status over the region. During common period 1949-2008 the correlation coefficients between SPEI and SSI range from 0.40 to 0.74 on the monthly basis, showing significant at 0.1% level.

3. RESULTS

3.1.Chronology Statistics

Total time span and statistics of the residual chronology was shown in Table **1**. The EPS which indicated the quality of chronology statistics was found to be reliable above 0.85 after A.D. 1725 (Table **1**), the threshold values of EPS showed suitability of the chronology for the climatic reconstruction [22]. The mean sensitivity which measures the relative changes from one ring to the next was observed 0.30, showed the amount of high frequency variation retained in chronology. The auto-correlation order1 (0.08) indicate

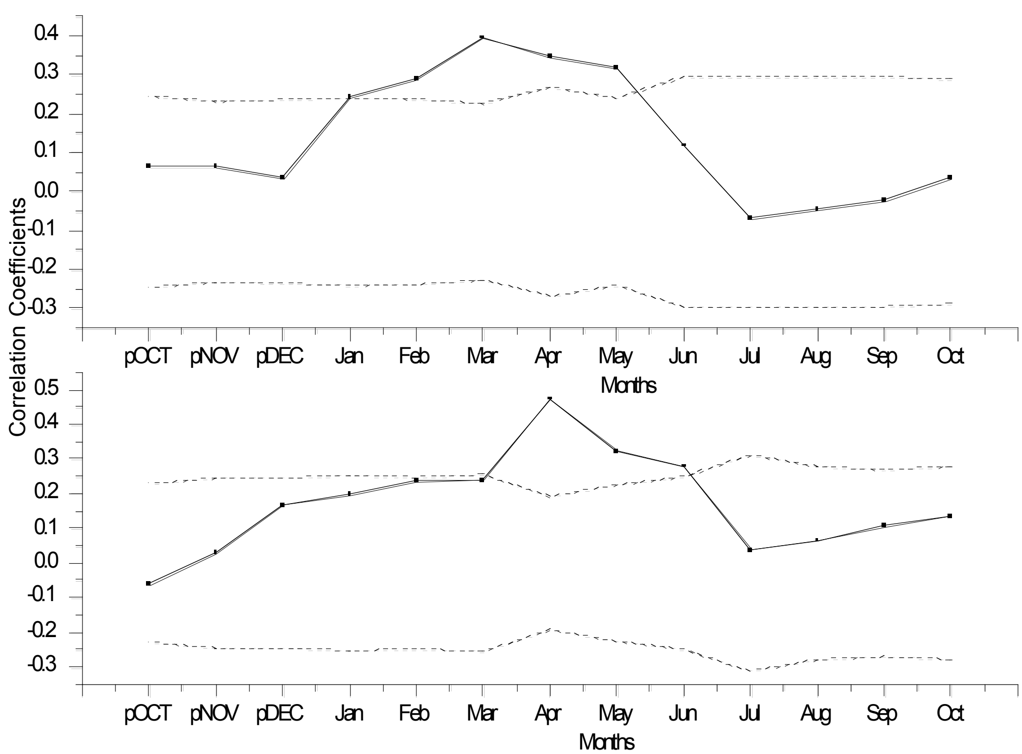

Figure 1: Correlation coefficients between tree ring-width index chronology and SPEI (upper) and SSI (lower) during common period 1949-2004. Dashed lines are significant at 5% level.

the persistence of low frequency signal retained in the chronology. The mean sample segment length (average number of year per sample) of the chronology is 202 years (Table **1**).

3.2. Tree Growth-Climate Relationship

The correlation analysis between residual tree ring-width index chronology and SPEI and SSI for the common period 1949-2004 has been carried out in relation to tree growth variations using DENDROCLIM2002 program [23]. To analysis the tree growth-climate relationship, SPEI and SSI from previous year October (ending of growing season) to current year October (ceasing of growing season) were used with tree growth variations (Figure **1**). Dashed lines in the figure indicate significant at 5% level (Figures **1**). The SPEI (February to May) and SSI (April to June) to current year are positively correlated with tree growth.

4. DISCUSSION AND CONCLUSIONS

Figure **1** shows the correlations coefficients (CCs) between tree ring width index and different drought indices (SPEI, SSI). SPEI reveals the significant positive relationship with tree growth during February, March, April, and May of current year (upper panel). The CCs indicated that soil moisture availability in the early growing season plays a critical role in trees growth processes while late growth season moisture availability is less important (Figure **1**) as supported by Li *et al.* (2007) [24]. In case of SSI, trees growth showed the significant positive relationship with SSI during current year April, May, and June (lower panel). It showed that both SSI and SPEI had somewhat similar effects in developing of trees growth variations.

Based on the relationships given by monthly climatic variables to tree growth variations, a summer season through April to June has been made in relation to trees growth variations (Figure **2**). The significant relationship indicates that summer climate is more compatible to trees growth variations [13]. Both SPEI and SSI were found having statistically significant impact on trees growth during summer season (Figure **2**). It indicates that seasonal climate is more responsible in trees growth process than a single month [10, 25].

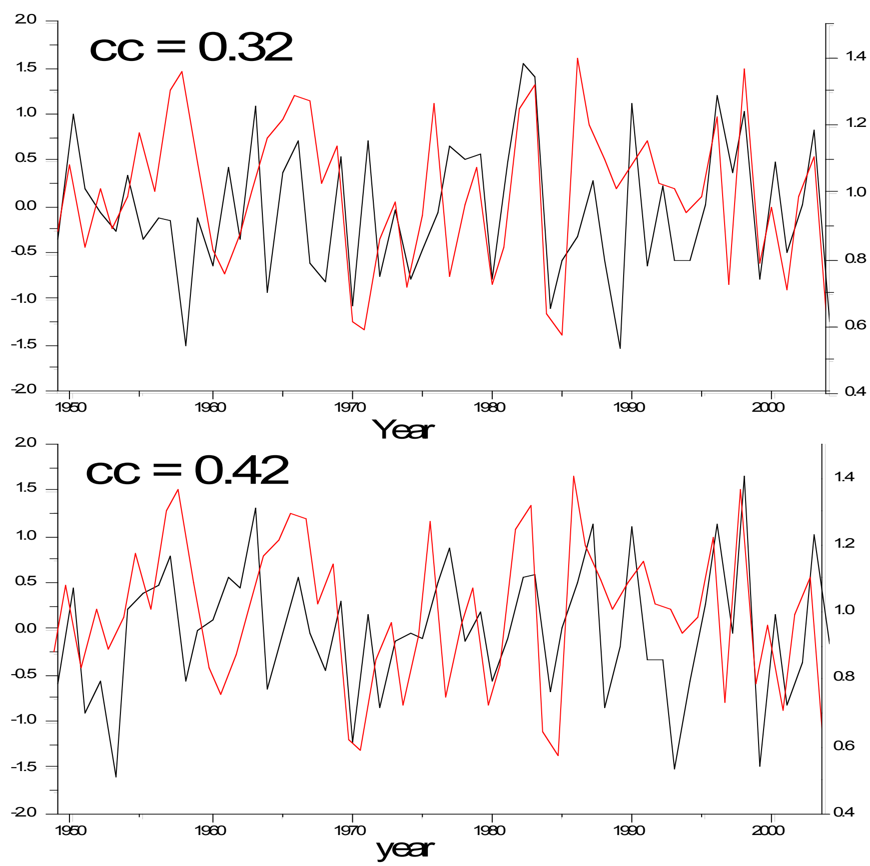

Figure 2: Variations between tree-ring width index (red line) and seasonal SPEI (black line) in upper panel and SSI (black line) in lower panel during summer season (April to June) for the common period 1949-2004. CC is correlation coefficients.

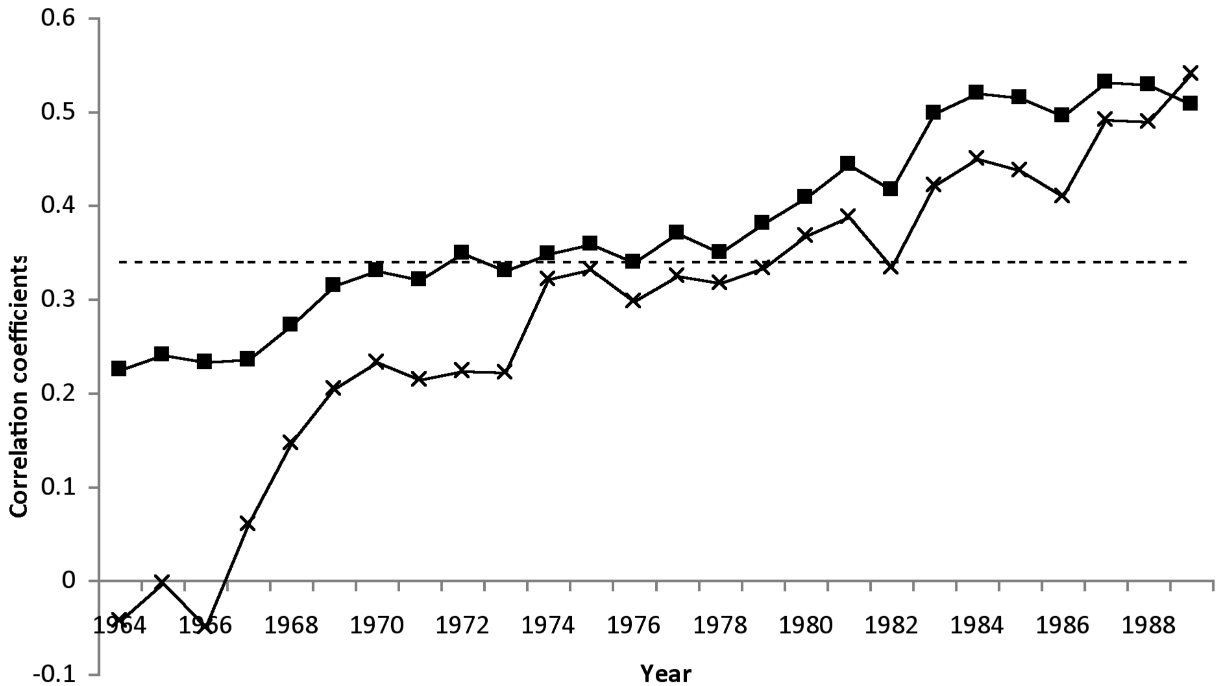

Figure 3: 31 sliding correlation coefficients between index and SPEI (×) and SSI (▪) during 1949-2004. Dashed lines are significant at 5% level.

However, to see the long-term variations of climatic condition (SPEI, SSI) on trees growth variations, a 31year sliding correlation analysis was performed between tree ring chronology and summer climate (April to June) during common period 1949-2004 (Figures **3**). There is constantly significant relationship between chronology and SSI from 1972 onwards (Figure **3**). But, the relationship during recent few decades is strengthened as compared to early period and showed the constantly increasing CCs (significant at 5% level) (Figure **3**). Whereas, SPEI showed the significant CCs after 1979 onwards with tree growth, but strengthened the CCs during recent few decades. However, SSI showed the higher correlation with trees growth variations throughout period than SPEI (Figure **3**).

However, the possible causes for strengthening the relationship during recent few decades were not known well, but increasing intensity of global warming in the recent past few decades over the region might be one of the reasons [24, 26, 27, 13] which reduce the insufficient soil moisture at root zone of the trees. Significantly increasing winter temperature during recent few decades might enhance water movement into trees growth variations as evidenced by Ram (2012) [8]. Thus, the increasing temperature, moisture and carbon dioxide at high altitude during recent few decades can make favorable condition to get enhancement in photosynthesis activity of trees growth [28]. Hence, trees with more carbon dioxide in the atmosphere are likely to grow more rapidly, at high altitude [29]. Also, it showed that the persistent of winter's low temperature for long period at high altitude might be detrimental for photosynthesis and respiration [30]. Moreover, large-scale land transformations and disturbance in natural resources in recent few decades over the Indian region may be one of the possible reasons which may alter the tree growth-climate relationship as evidenced by Tian *et al*. (2014) [31].

This study is based on a single site tree ring–width data but has potential to monitor the past drought history. The results showed that long time series of tree–ring growth are one of the best source of proxy data for reconstructing past records of drought index, which can provide to society to understand the past drought history on inter annual to decadal time scales during the past few centuries in absence of the long-term climatic data.

The existent of strong significant relationship between tree growth and SPEI and SSI showed that SPEI and SSI look to be reconstructable by using a wide network of tree ring chronologies from western Himalaya, thus extending drought indices other than rainfall and temperature would be useful for better understanding of long-term climate variability / change on local and regional scale at high-altitude regions, in absence of sparse and short period of meteoro logical data.

This type of research work would be more useful for society for monitoring drought impacts on forest management, agricultural, water resources, and hydroclimatic variations over the region. Thus, long-term proxy record climate over south Asia may provide better environmental information to identify drought impact on local and regional scale during the past several centuries and millennia.

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