High altitude forest sensitivity to recent warming: A tree-ring analysis of conifers from Western Himalaya, India

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Abstract

An anomalous higher growth during the last few decades has been detected in the multi century tree-ring width chronologies of Himalayan conifers (*Cedrus deodara, Picea smithiana*) from high altitude near glacier areas of Kinnor and Gangotri region of Western Himalaya. These chronologies indicate strong relationship to the mean annual and winter (December-January-February) temperatures of concurrent year. 553 years long master chronology prepared from the five individual chronologies shows few decadal and longer epochs of Little Ice Age (LIA) cooling during A.D. 1453-1590 and A.D. 1780-1930. Suppressed and released growth patterns in the chronology has been observed to be well related to the past glacial fluctuation records of the region. Analysis of instrumental period surface air temperature data over the region indicates significant increasing trend over the last century with a noticeable warming during the recent four decades. The time series of annual highest values of daily maximum and minimum temperatures also show increasing trend. Direct significant relationship of winter temperature to the tree growth is mainly because of moisture availability for a longer period due to higher degree of snow melt. So far the relationship between climate change and the Himalayan cryosphere is not much attended and well understood. In view of this an extensive dendroclimatic and dendroglaciological investigation over high altitude Himalayan region may be useful to enhance our knowledge on snow and ice processes and their relevance to climate in the high mountain ranges.

Tree-Ring Data

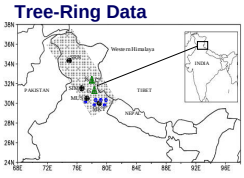

Fig. 1 Tree-ring site locations (▲) from Western Himalaya (shaded portion). G: Gangotri, K: Kinnor. Dark circles are meteorological data stations used in the analysis. Big circles (●) are Srinagar (SRI), Shimla (SIM), Mussoorie (MUS) and Mukteswar (MKT) having both temperature and rainfall data. Small circles (•) indicate only the rainfall stations.

Fig. 2 Tree-ring sampling sites from Kinnor and Gangotri regions of Western Himalaya

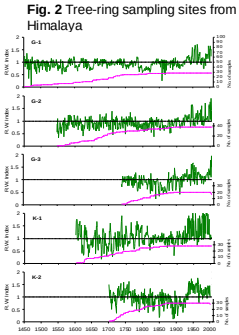

Fig. 3 Tree-ring width index chronologies of Himalayan conifers. G1, G2, G3 are from Gangotri region and K1, K2 are from Kinnor region of Western Himalaya.

Table : Tree-ring sampling sites and data collection

Sr No.	Site Name	Species Name	Location	Elevation (m asl)	No. of cores (trees)	Time span (yrs.)	MS	Common Period (yrs.)	Common Variance (mean R)	SNR	EPS
1	G1 (Gangotri)	Cedrus deodara	31° 17 N 77° 45 E	2950	28(13)	1452-2004 (553)	0.25	1790-2003 (214)	0.37	10.4	0.89
2	G2 (Gangotri)	Cedrus deodara	31° 11 N 78° 50 E	3000	38(18)	1547-2004 (458)	0.28	1840-2003 (164)	0.37	12.1	0.88
3	G3 (Gangotri)	Cedrus deodara	31° 09 N 78° 52 E	2850	20(10)	1730-2004 (256)	0.29	1825-2003 (179)	0.35	8.3	0.87
5	K1 (Kinnor)	Picea smithiana	31° 25 N 78° 14 E	3300	28(14)	1602-2002 (401)	0.32	1803-2001 (199)	0.32	9.4	0.89
6	K2 (Kinnor)	Cedrus deodara	31° 25 N 78° 22 E	3200	30(15)	1701-2002 (302)	0.30	1855-2002 (148)	0.34	10.8	0.89

Climate Data

A century long data of mean surface air temperatures of three stations Shimla, Mussoorie and Mukteswar for the period 1901-2003 were used. These stations are located above 2000 m asl and show high spatial coherency by virtue of their statistically significant inter-correlations in different seasons. The regional mean temperature anomalies based on the data of three stations were computed for five different seasons namely winter (December-February, DJF), spring or pre-monsoon (March-May, MAM), monsoon (June-September, JJAS), post-monsoon (October-November, ON) and annual (Fig. 4). Seasonal anomalies of rainfall based on the data of 9 well distributed and highly inter-correlated stations for the period 1871-2000 over the Western Himalaya were considered in the analysis.

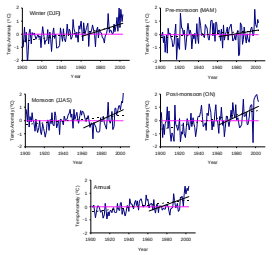

Fig.4 Mean surface temperature series over Western Himalaya for different seasons with linear trends for entire period 1901-2003 (Dashed lines) and recent four decades 1961-2003 (Solid line).

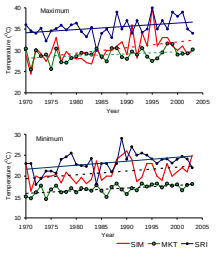

Fig. 5 Annual highest values of daily maximum and minimum temperatures of Srinagar (SRI), Shimla (SIM) and Mukteswar (MKT) for the period 1970 to 2003.

Tree growth – climate relationship

To understand the nature of the tree growth – climate relationship we carried out correlation analysis using individual tree-ring chronologies and seasonal mean surface temperature and rainfall anomalies over the Western Himalaya. The results were presented in Fig. 6 Significant positive relationship of all the tree-ring index series with the winter (DJF) temperature is the characteristic feature of the analysis. Such coherent relationship was not observed with the temperature or rainfall of any other seasons. Annual temperature also shows significant positive response to G1, G2 and K1. Other noticeable feature of the correlation analysis is inverse relationship of temperature and direct relationship of rainfall with tree growth during pre-monsoon (MAM) season. This relationship is significant for G2 and K2.

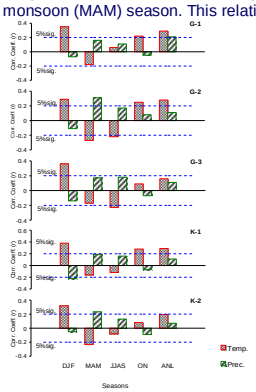

Fig.6 Correlation analysis of five Western Himalayan conifer tree-ring chronologies with seasonal temperature and rainfall of Western Himalaya for the period 1901-2003 and 1871-2000 respectively.

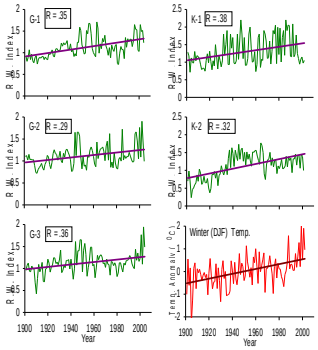

Fig.7 Five tree-ring index chronologies from Western Himalaya and winter (DJF) mean temperature series. 'R' is the correlation of individual tree-ring series with winter mean temperature. All correlations are significant at 1% level.

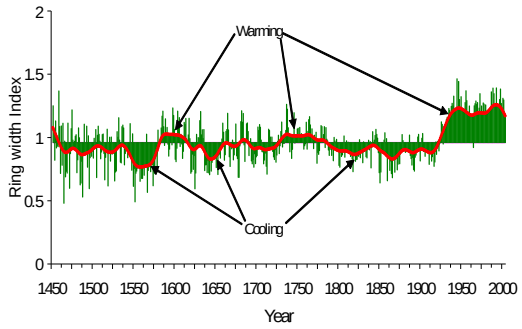

Fig.8 553 years (A.D. 1452-2004) long tree-ring index chronology of high altitude Himalayan conifer from Western Himalaya. Smooth red line is 30 years cubic spline filter.

Conclusions

The anomalous higher growth in the high altitude tree-ring chronologies observed during the past few decades is strongly associated with increasing temperature pattern over the region. Prior to the 20th century, our 553 years tree-ring records were observed to be overall in phase with the contemporary glacial fluctuations over the Himalayan region noticed by the other studies (Mayewaski et al., 1980; Duan and Yao, 2003; Borgaonkar et al., 2009). The increasing trend in temperature was also observed over entire Indian region (Kothawale and Rupa Kumar, 2005), Northern Hemisphere (Mann et al., 1999). This probably indicates that the Western Himalaya follows the pattern of global warming in the 20th century.

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