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 Kinner 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 climatic change in the high mountain ranges.

Tree-Ring Data

Fig. 1 Tree-ring site locations ( ) from Western Himalaya (shaded polygon), ( ), near Kinner. Dark circles are meteorological data stations used in the analysis. Big circles ( ) are Shimla (SR), Srinagar (Gangotri), 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 Kinner and Gangotri regions of Western Himalaya.

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 a.s.l and show high spatial coherence 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 1871-2000 (Dashed lines) and recent four decades 1961-2000 (Solid lines).

Fig. 5 Annual highest values of daily maximum and minimum temperatures of Shimla (SR), Srinagar (Gangotri) (SR), Shimla (SRI) and Mukteswar (MKT) for the period 1970 to 2000.

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 36 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 (Meyerswadi et al., 1986; 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.