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Dendroclimatological Investigation of High Altitude Himalayan Conifers and Tropical Teak In India

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ABSTRACT: A wide tree-ring data network from Western Himalayan region as well as from Central and Peninsular India have been established by the Indian Institute of Tropical Meteorology (IITM), Pune, India. This includes several ring width and density chronologies of Himalayan conifers (*Pinus, Picea, Cedrus, Abies*)covering entire area of Western Himalaya and teak (*Tectona grandis* L.F.) from central and peninsular India. Many of these chronologies go back to 15th century. Tree-ring based reconstructed pre-monsoon (March-April-May) summer climate of Western Himalaya do not show any significant increasing or decreasing trend since past several centuries. High altitude tree-ring chronologies near tree line-glacier boundary are sensitive to the winter temperature. Unprecedented higher growth in recent decades is closely associated with the warming trend over the Himalayan region.

Dendroclimatic analysis of teak (*Tectona grandis*) from Central and Peninsular India show significant relationship with pre-monsoon and monsoon climate. Moisture index over the region indicates strong association with tree-ring variations rather than the direct influence of rainfall. It is evident that, two to three consecutive good monsoon years are capable of maintaining normal or above normal tree growth, even though the following year is low precipitation year.

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Introduction

A better understanding of the climate and environmental changes that occurred during the past few centuries (encompassing the Little Ice Age and Medieval Warm Period) can provide important insights into the rates of regional to global scale changes that are expected to occur within the earth system in the next few decades. This is the main trust of research tasks devised under the stream I of the Past Global Changes (PAGES) project of the International Geosphere Biosphere Programme (IGBP). Information on climate during the past 1000 years, which is the man's greatest impact on the planet, is vital to understand the various external and internal forcing on the climate and thereby make reliable future projections. In this time frame, the tree-rings, with their inter-annual resolution, have been globally recognized to be the best source of proxy climate data.

Well-dated tree-ring chronologies covering wide geographical area can provide yearly proxy data for studies of climatic and hydrological variations over both space and time (Fritts, 1976). Tree-rings can be crossdated to the exact year or season in which they were formed. Tree-ring chronologies can be developed from measurements along replicated radii sampled from many trees in a limited geographical area. Tree-ring analysis of conifers (*Pinus, Picea, Cedrus, Abies*) from Western Himalaya and teak (*Tectona grandis*) from tropical forest indicate high dendroclimatic potential and can be used to reconstruct pre-monsoon and monsoon climate variability in the past.

In India, preliminary attempts on dendroclimatic analysis for the Indian region have been made by Pant (1979, 1983). He suggested that the trees of Himalayan zone are most appropriate for dendroclimatic research with welldefined growth rings, which generally display a very prominent response to temperature. Analysis of millennium long Juniper (*Juniperous macropoda*) tree-ring width chronology from the Karakoram mountains in western Himalaya revealed the high dendroclimatic potential of the species (Bilham *et al.*, 1983).

Dendroclimatic reconstructions of pre-monsoon climate (temperature and precipitation) over different parts of the Western Himalaya including Kashmir do not show any increasing or decreasing trend since last three centuries. (Bhattacharyya *et al*, 1988; Borgaonkar *et al.*, 1994; 1996, 2002; Hughes, 1992; Yadav *et al.* 1999). Important role of earlywood density parameter of Himalayan conifers in dendroclimatic modeling has been discussed by Pant *et al.* (2000) and Borgaonkar *et al.* (2001). Conifers from Eastern Himalaya (Sikkim, Arunachal Pradesh) have also been shown as potential climate indicators (Chaudhary *et al.* 1999; Bhattacharyya and Chaudhary, 2003).

Few tree-ring based regional temperature reconstructions indicate cooling trend in summer temperature (Hughes, 2001; Cook *et al.* 2003; Yadav *et al.* 2004) and warming trend in annual and winter temperature during recent decades since last 4 centuries (Esper *et al.* 2002; Cook *et al.* 2003). Northern Hemispheric Temperatures derived from high resolution proxies such as tree-ring, ice-cores also indicate unprecedented warming in 20th century since A.D. 1000 (Mann *et al.* 1999). However, these reconstructions do not indicate prominent effect of Little Ice Age (LIA) over the Western Himalayan region.

Dendroclimatic studies over the tropical area were initiated by Pant and Borgaonkar (1983). They developed annually dated ring width chronologies of teak (*Tectona grandis*) from Western Ghats of Maharashtra and showed the important role of the postmonsoon precipitation of the previous year of growing season in maintaining moisture availability for the current year's growth. Ramesh *et al.* (1989) reported the variation of stable isotopic ratio of hydrogen (ΔD) in teak with the amount of rainfall and mean maximum temperature to demonstrate its applicability for reconstruction of past climate. Bhattacharyya *et al.* (1992) presented the treering analysis of *Tectona grandis*, *Cedrela toona* and *Michelia champaca* from tropical forests of peninsular India and demonstrated their usefulness in reconstructing the past vagaries of monsoon and drought events. Tree-ring based reconstruction of PDSI for Java, Indonesia gives monsoon drought history of two centuries and influence of ENSO (D'Arrigo *et al.*, 2006.). Such moisture sensitive tree-ring chronologies from tropical region of South and Southeast Asia are capable of capturing ENSO related monsoon droughts.

In this paper, a brief review of dendroclimatic studies carried out at the Indian Institute of Tropical Meteorology (IITM) and few recent analyses of conifers from high altitude, near glacier sites of western Himalaya and teak from central and peninsular India are presented (Figure 1).

Tree-ring Analysis of Western Himalayan Conifers

About 23 ring width index and density chronologies prepared from the conifers *(Pinus, Picea, Cedrus, Abies)* from middle attitude cover the entire area of Western Himalaya from Kashmir through Uttaranchal. Many of these chronologies go back in time to 15th century. Dendroclimatic models based on response function analysis using wide network of tree-ring chronologies and long instrumental records of temperature and precipitation over different parts of Western Himalaya indicate that the summer climate, particularly pre-monsoon temperature and precipitation are highly influencing

Table-1: Correlation table indicating relationship between tree-ring chronologies from Himachal Pradesh and Western Himalayan temperature anomalies of different seasons for the period 1901-2002. (Bold figures indicate significant correlations at least at 1% level)

TR Chronology	DJF	MAM	JJAS	ON
Khoragala	**.41**	-.21	.11	.22
Kothi	**.44**	-.16	-.08	.18
Sangla	**.40**	-.12	-.11	.20
Gurali	**.37**	.18	.12	.11
Kalpa	**.38**	**-.27**	.17	.08

parameters in tree-growth process. This is mainly due to moisture stress condition occurring during the early phase of growing season of the conifers (Borgaonkar *et al.* 1999). These response function models were used to reconstruct pre-monsoon summer climate over western Himalaya since A.D. 1747. Reconstructed pre-monsoon (March-April-May) summer climate (temperature and precipitation) of Western Himalaya do not show any significant increasing or decreasing trend since past 250 years (Borgaonkar *et al.* 1994, 1996, 2002). These reconstructions also indicate that the Little Ice Age phenomenon was not prominent over the Western Himalaya.

High altitude, near glacier tree-ring chronologies from western Himalaya indicate more sensitivity to the temperature variations. Here, we present tree-ring width index chronologies of *Cedrus deodara* D. Don [Himalayan Cedar], and *Picea smithiana* Boiss. from high-altitude, near-glacier sites of Western Himalaya (Figure-2). The tree-ring samples were collected during April-May, 2003 from five locations in Himachal Pradesh (Figure-1). The elevation of the sites ranges between 2900 to

Table 2: Statistics of three teak ring width index chronology

		BOR	TOL	NAR
Full Chronology Period		1884-2001	1654-2001	1481-2003
1	No. of cores (trees)	40 (25)	35 (20)	14 (10)
2	Mean	0.994	0.998	0.998
3	Standard Deviation	0.34	.29	0.28
4	Mean Sensitivity	0.37	0.31	0.29
5	Lag-1 Auto correlation	0.35	.41	0.34
Common Period		1934-2001	1855-2000	1675-1998
6	No. of cores (trees)	35 (22)	31 (18)	12 (9)
7	Mean correlation (variance)	0.30	0.35	0.39
8	Signal to Noise ratio	8.85	7.12	4.61
9	Agreement with population chronology	0.92	0.89	0.84
10	Variance in first eigen vector	35%	43%	42%

Table-3 : Correlation analysis of three teak tree-ring index chronologies with regional temperature (TEM), rainfall (RF) and Palmer Drought Severity Index (PDSI).

TR Index Chronology		-JJAS	-ON	DJF	MAM	JJAS	ON	ANNUAL
Tolawada (1901-2000)	TEM	-.02	.04	-.04	-.11	-.15	-.14	-.15
	RF	.11	.17	.04	.03	**.28***	**.23***	**.33***
	PDSI	.05	.14	.06	.02	**.29***	**.27***	**.35***
Bori (1901-2000)	TEM	-.14	-.17	-.06	-.13	-.17	**-.18***	**-.20***
	RF	**.19***	.11	-.05	-.08	**.26***	.04	**.27***
	PDSI	.16	**.20***	-.05	.11	**.22***	.11	**.25***
Narangatharai (1901-2000)	TEM	-.16	-.07	-.08	-.14	-.13	.11	-.12
	RF	.16	**.21***	.01	.14	**.24***	.05	**.25***
	PDSI	**.20***	.12	.02	.17	**.26***	-.05	**.29***

*Bold figures with * indicate significant values at least at 5% level*

3450M amsl. The sites are under snow cover during winter and spring. The individual ring width series were subjected to appropriate standardization using negative exponential curve or cubic spline smoothing with wavelength equal to 2/3 of the series length to retain optimum low-frequency signal related to climate (Fritts 1976; Cook *et al.*, 1990). Figure-3 represents five tree-ring width index series from Himachal Pradesh of Western Himalaya. Besides the distant locations of the tree-ring sites with maximum approximate aerial distance about 150 Km, the noticeable feature observed in most of the series is unprecedented surge in tree growth after around A.D 1930. Such anomalous behavior is not observed prior to A. D. 1930. This may be the effect of winter warmth.

We have carried out the correlation analysis of all the three tree-ring chronologies with seasonal temperature and rainfall anomalies of western Himalaya. The seasons are winter (DJF), pre-monsoon (MAM), monsoon (JJAS) and post-monsoon (ON). Seasonal rainfall does not show any coherent significant pattern of relationship common to all the chronologies. Hence we have not presented the rainfall correlations. In case of temperature, the correlation analysis indicates significant positive relationship between winter (DJF) temperatures and three tree-ring index series. Such coherent relationship is not observed with the temperature of any other season. Table-1 gives correlation coefficient values between seasonal temperatures anomalies of Western Himalaya (Pant *et al.*, 2003) and 5 tree-ring index chronologies. The warm weather in winter is believed to be the result in thawing of tissues promoting the subsequent growth which gives a positive relationship between winter temperature and tree growth (Fritts, 1976). Warmer winter releases tree growth resulting wide tree-ring, whereas, cooler winter suppresses the tree growth. A very similar growth pattern was also observed by Singh and Yadav (2000) in *Pinus wallichiana* tree-ring chronology from Gagotri, Western Himalaya and significant positive relationship with winter temperature. They also indicated that the anomalous higher tree growth in recent decades may be the effect of winter warmth. Studies reported that during last few decades many Himalayan glaciers are shrinking. Particularly Gangotri glacier is retreating fast since 1935 (Puri and Shukla. 1996; Sankar and Srivastava, 1999). This matches with the significant increase in winter temperature over Western Himalaya since last few decades and abrupt increasing trend in growth pattern of trees located near the glacier sites. Such significant higher growth in recent years was not observed in middle to low altitude chronologies of Western Himalaya which are away from the direct influence of the glacier activities (Borgaonkar *et al.* 1999). Figure-4 indicates the time series of two tree-ring index chronologies namely KOT and SAN in relation to winter temperature anomalies of Western Himalaya.

Tree-ring analysis of teak (Tectona grandis L.F.) From central and peninsular India:

In tropical region of south and southeast Asia number of groups have been working to establish good quality tree-ring data network to understand monsoon variability and related global parameters (e.g. ENSO) in the recent past. In this context, teak (*Tectona grandis* L.F.) from Indonesia, Thailand, Java, India have been demonstrated as a potential source for high resolution spatial reconstruction of climate (D' Arrigo *et al.* 1994; Pumijumnong *et al.* 1995; Murphy and Whetton, 1989; Pant and Borgaonkar, 1983; Bhattacharayya *et al.* 1992; Jacoby and D' Arrigo, 1990). These studies indicate the high potential of teak in reconstruction of monsoon climate. However, a large temporal and spatial network of tree-ring chronologies in this region is needed to understand past variations of monsoon and related parameters.

Teak is ring porous to semi-ring porous wood. Growth rings are distinct, delimited by large earlywood pores. Pores in the earlywood are large, clearly visible to the eye. Transition from earlywood to latewood is gradual. Latewood pores are moderately large to small. Rays are moderately broad, visible to eye. The recent collection (2002 and 2004) of teak tree-ring data includes central and peninsular part of India. More than 500 core samples collected from 24 sites form a wide network of teak tree-ring chronologies. The region is strongly influenced by summer monsoon where more than 75% of total annual precipitation is received during the monsoon months (June-September). Crossdating between the cores from same tree and between different trees of the same site was good over few sites. However, it was poor over some sites. Particularly the sites having trees of large girth but rotten inside showed poor cross-correlations. Forests around such sites indicate decline phase. The frequency of occurrence of false rings is relatively more and confined to both earlywood and latewood zone. Pre-monsoon showers followed by prolong dry spell in beginning of growing season of the teak may cause high frequency of earlywood false rings.

Development of tree-ring index chronologies and their dendroclimatic analyses are in progress. However, here we present few preliminary results of three teak tree-ring chronology namely Tokawada, Bori from central India and Narangthara from peninsular India to discuss the dendroclimatic potential of the species. Three site tree-ring index chronologies were obtained by standard dendrochronological procedures (Fritts 1976, Cook *et al.* 1990). A negative exponential curve or cubic spline smoothing with wavelength of 35% of N, where N is number of rings has been used in the stadardisation procedure to maximize climatic signal and minimize non-climatic noise from each series. Tree-ring chronologies with higher values of mean sensitivity, standard deviation and lower values of autocorrelation are indicators of high dendroclimatic potential of the site (Fritts, 1976). The statistical performance of three teak ring width index chronologies are given in Table 2. Moderately high values of standard deviation, mean sensitivity and common variance (mean correlation among all the tree samples) indicates the high dendroclimatic potential of these three chronologies. Signal to Noise Ratio and Agreement with population chronology show the usefulness of the chronologies in past climate reconstruction. It is also observed that significant Lag-1 auto-correlation which indicates the high persistence in the series can be removed by auto-regressive method (Cook *et al*, 1990). This method also improves the values of common variance and SNR. However, we have presented the results of Standard version of the chronologies (i.e. without auto-regression).

Two long tree-ring width index chronologies are shown in Figure 5. Narangthara, South India is the longest chronology (A.D. 1481-2003, 523 years) of teak produced so far over the south and southeast Asian region. Other long chronology is from Tolawada, Chattisgarh from central India ranging from A.D. 1654-2001 (348 years). Figure 6 shows the significant relationship of Bori chronology with annual rainfall of regional station Hoshangabad (Sikder,2003). The Figure reveals the high association between annual rainfall and ring width variations. Figure 6(b) indicates the low frequency variations between the two parameters. The low frequency variations are obtained by fitting 6^{th} degree polynomial. Low frequency variations of rainfall and tree growth show very similar patterns. This may be due to the carry over effect of moisture in root zone. Higher rainfall during any particular year helps in maintaining the normal growth of the tree in next two-three years even though the rainfall during these years is less. The reverse process is also true when very less rainfall during any particular year creates moisture stress condition at root zone which may continue in next one-two years resulting in below normal tree growth in successive years.

To look at the effect of soil moisture (function of temperature and precipitation) on the tree growth, Palmer Drought Severity Index (PDSI) has been used (Palmer, 1965). PDSI is a meteorological drought index and it responds to weather conditions that have been abnormally dry or abnormally wet. The PDSI is calculated based on precipitation and temperature data as well as the local available water content (AWC). We have used seasonal PDSI for central India (18 - 24^0 N and 77 - 84^0 E) and south India (8-15^0N and 75-80^0E) extracted from Globally gridded monthly PDSI data set (Dai, A., 2004 and http://www.cdc.noaa.gov). Table 3 indicates the correlation analysis of three tree-ring chronologies with regional temperature, rainfall and PDSI for different seasons for the period 1901-2000. Two chronologies viz. Tokawada and Bori are from central India and Narangathara chronology is from South India. The coherent and significant positive relationship of all the three tree-ring series with rainfall and PDSI during monsoon (JJAS) and annual scale has been observed. General observations on relationship between the teak ring width variations and climate reveal that the low growth years (narrow ring) are significantly associated with deficient rainfall (drought condition) in most of the cases. However normal or above normal rainfall is not reflected as a significant higher growth. This is mainly because of moisture available at root zone of the tree. When the moisture availability reaches to certain threshold value, tree does not respond to additional moisture. However, less moisture at root zone creates the adverse condition for tree growth. Significant positive response of teak tree-ring chronologies with monsoon and annual rainfall and PDSI observed in our analysis is mainly due to the moisture availability during the peak growing season of the teak (May-September). Direct effect of temperature is suppressed due to the monsoon rainfall. The study is in progress to look at the exact role of moisture and temperature in tree growth process and their relationship with monsoon related regional and global parameters such as ENSO/ El Nino etc. with wide network of teak tree-ring chronologies.

Discussion and Conclusions

We have presented tree-ring analysis from two different climate regimes of India. One is from Western Himalayan region where, polar, tropical and Mediterranean influences interact. Other is tropical region which is mainly influenced by the monsoon system. Due to vast altitudinal difference, Western Himalaya experiences sub-tropical, temperate to alpine type of climate. Monsoon currents do not extend to the higher ranges of the Western Himalaya. Therefore, response of climate on tree-ring changes with the location and the altitude of the site. Tree-ring based reconstructions of summer climate (temperature and rainfall) of Indian Himalaya, Tibet, Karakoram region of Himalaya do not show significant increasing or decreasing trend during the past three to four centuries (Borgaonkar *et al.* 2002; Hughes, 2001; Yadav *et al.*, 2004, Brauning and Mantwill, 1994; Wu and Shao, 1995; Espar *et al.* 2002,.). These reconstructions also indicate that the Little Ice Age (LIA) phenomenon was not prominent over this part of the Himalaya. However, few warm and cold epochs were observed over the region.

The analysis of high altitude near glacier tree-ring chronologies presented in this paper indicates the significant positive response with winter temperature rather than the negative relationship of summer temperature as observed in the lower and middle altitude tree-ring chronologies (Borgaonkar *et al.*, 1999; Yadav and Singh, 2002). The positive response of winter temperature to the tree-ring variations is due to winter warmth observed over the region. Instrumental records clearly indicate warming over this region since last century with more prominent increasing trend during last four decades (Pant *et al.* 2003; Bhutiyani *et al.* 2006). Similar patterns were also observed over entire Indian region (Kothawale and Rupa Kumar, 2005), Northern Hemisphere (Mann *et al.* 1999). Tree-ring based reconstructions of Nepal winter (October-February) temperature (Cook *et al.* 2003) and Karakoram annual temperature (Espar *et al.* 2002) show increasing trend in recent decades. Jacoby *et al.* (1996) reported wide annual growth ring pattern in recent years from west central Mongolia in relation to 20th century warming. This probably indicates that the Western Himalaya follows the pattern of global warming in 20th century.

Results of teak tree-ring analysis indicate significant relationship of tree growth with monsoon related parameters. Teak is a tropical species and found over the entire monsoon belt of south and southeast Asian region. Dendroclimatological studies of teak from India, Myammar, Thailand, Indonesia (Pant and Borgaonkar, 1983, Bhattacharyya *et al.* 1992, Murphy and Whetton, 1989, Pumijumnong *et al.* 1995; Jacoby and D' Arrigo, 1990, D' Arrigo *et al*, 1994) proved its suitability to understand the past vagaries of monsoon. Unlike the Himalayan conifers, teak growth is influenced by the amount of the monsoon rainfall. During monsoon season sufficient moisture is available at root zone for longer time period even though the temperature is high. Hence, the effect temperature change on tree growth is not directly visible. However, the moisture index which is the function of temperature and precipitation has been shown to be the more realistic parameter in tree growth climate relationship. D' Arrigo *et. al.* (2006) reconstructed moisture index (PDSI) for Java, Indonesia from tree-ring that refers monsoon drought for last two centuries. A good network of long chronologies of teak from Indian tropical belt will be a potential source to look at the past environment and can be used to reconstruct past drought/ flood indices and vagaries of monsoon since last several centuries.

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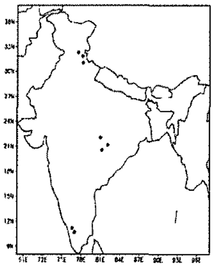

Figure 1 : Tree-ring Dta Network at IITM

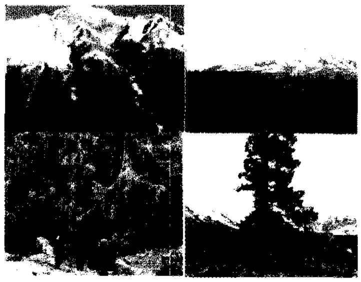

Figure 2: (A & B) Tree-ring sampling site near Sangla glacier, Himachal Pradesh (Alt. 3200M amsl) (C) Tree-ring sampling site near tree-line & glacier boundary. Site : Kalpa, Himachal Pradesh. (Alt. 3450 M amsl) (D) Abies pindrowat upper tree line boundary, Site : Kalpa.

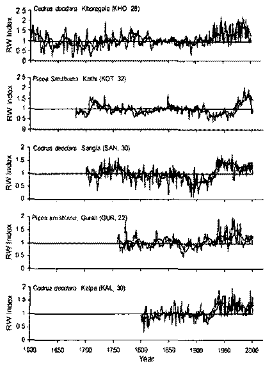

Figure 3 : Five tree-ring width index chronologies from Himachal Pradesh, Western Himalaya, India. Number in the bracket indicates the number of samples included in the respective chronology.

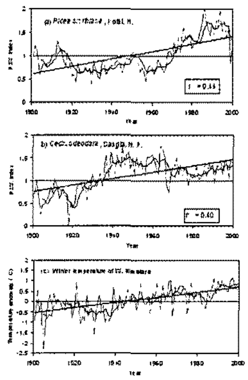

Figure 4 : Tree-ring chronologies at (a) Kothi, (b) Sangla and (c) winter temperature anomalies of western Himalaya. Rab and rac are serial correlations of Kothi and Sanlachronologies respectively with winter temperature of western Himalaya.

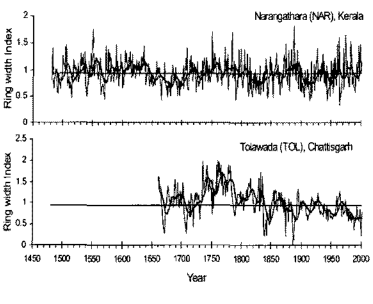

Figure-5 : Long tree-ring width index chronologies from Peninsular India (Narangathara, Kerala) and Central India (Tolawada, Chattisgarh)

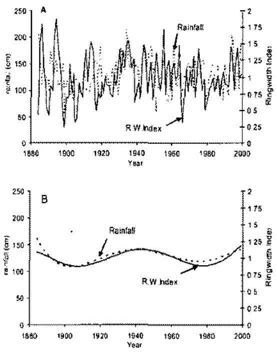

Figure-6 : Tree-ring variations and annual rainfall (a) of Hoshangabad and Bori ringwidth index choronology (b) Low frequency variations.