DENDROCHRONOLOGY AN OVERVIEW IN INDIAN CONTEXT

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Tree rings are recorded in many trees growing in wide geographical regions due to seasonal activity of cambium, a meristematic tissue. This ring i.e., growth of the annual increment appears in the form of a crude cone on which cones of proceeding years get stacked. Cross sections through the tree intersect these stacked cones, causing intra-ring variations in cell type attributed to the phase of the growing season (Fig. 1). Dating and analyses of tree rings in varied applications categorized under a specialized branch of science, ***Dendrochronology***. The prefix *dendro* is from the Greek word for tree, *dendron*, and the word *chronology* means the subject that deals with time and the assignment of dates to particular events.

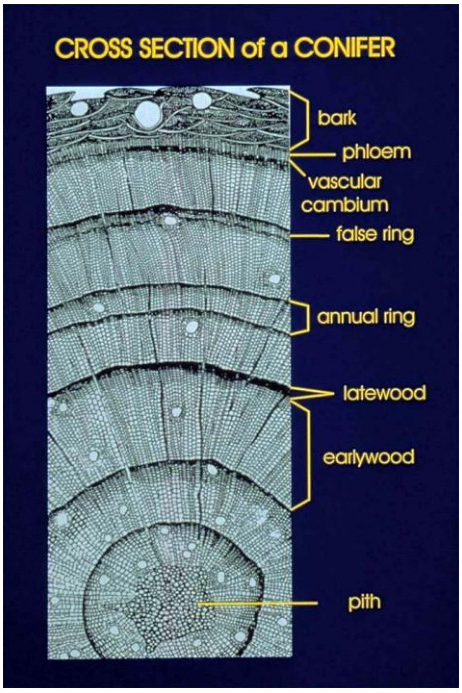

Fig.1 Cross-section of a typical conifer wood *(Photogrpah courtesy of H.C. Fritts, University of Arizona, USA)*

The study of tree ring and its relationships to climate has a long history; perhaps Leonardo da Vinchi was the first to recognize the relationship between tree ring and precipitation as early as 15th century (Stallings, 1937). However, the systematic study of tree rings began with an intuitive insight of an American astronomer, Andrew Ellicott Douglass (1867-1962) who is recognized as the father of Dendrochronology.

Dendrochronology, in relation to its varied applications may be divided into a number of sub fields, several of which focus on its application to problem of environment and climate. The prefix *dendro* is used in conjunction with the name of the particular scientific discipline viz. Climate (Dendroclimatology), Water (Dendrohydrology), Slope Movements (Dendrogeomorphology), Ecological aspect (Dendroecology), Fire (Dendropyrology), Glacier movements (Dendroglaciology), Archaeology (Dendroarchaeology), Tectonic activity (Dendroseismology), Snow (Dendroniveology), Past dynamics of insect populations (Dendroentochronology).

In tree ring analysis the selection of old trees in a region is not an essential criterion but it is desirable to get long information of particular events. World's oldest growing tree, *Pinus longaeva* attaining age of 4600 years is found on moisture stressed site in Eastern California and Nevada in North America (Fig.2). In India, there are reports of old trees growing in many sites but so far the only precisely dated tree attaining maximum age (745 years) is Cedrus deodara from Harshil, Garhwal Himalayas (Fig.3). Other well-known evidence of old tree is a disc of deodar tree stored in wood museum FRI, Dehradun which has 704 rings. There are other trees viz., *Juniperus,* and *Taxus* seem to be very old but exact dates of their tree ring sequences are yet to be determined. In tropics though there might be many trees attained great age but so far *Tectona grandis* and *Cedrela toona* are known to have distinct datable growth rings.

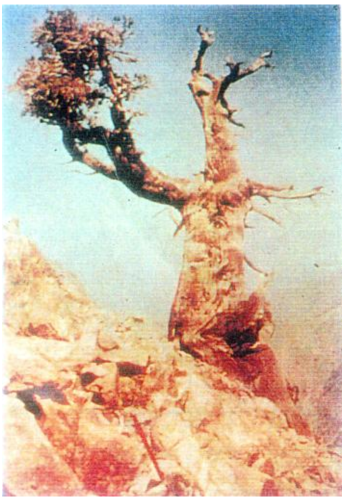

Fig. 2 Pinus longaeva oldest living tree in the world (4600 years)growing in Eastern California and Navada North America (Photogrpah received courtesy ofProf. H.C. Fritts, University of Arizona, USA)

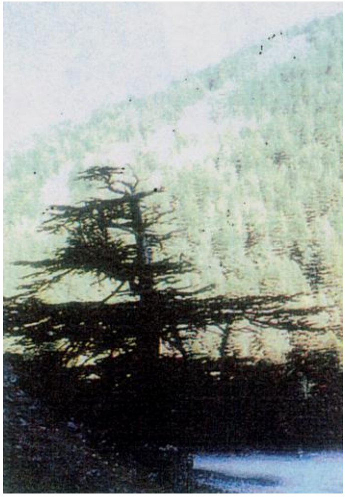

Fig. 3.Cedrus deodara, an oldest dated tree in India (745 years), growing in Harshil, Garhwal Himalayas.

List of trees with probable ages so far known from the Indian region are shown in **Table.1.**

Table 1:

S. No	Species	Region	Chronology span (Years)
	Conifers Taxa		
1.	*Abies densa*	Eastern Himalaya	491years
2.	*Abies pindrow*	Western Himalaya	371years
3.	*Abies spectabilis*	Western Himalaya	437 years
4.	*Larix griffithiana*	Eastern Himalaya	263 years
5.	*Cedrus deodara*	Western Himalaya	Over 1000 years
6.	*Juniperus indica*	Eastern Himalaya	427 years
7.	*Juniperus macropoda**	Western Himalaya	Over 2000 years
8.	*Picea smithiana*	Western Himalaya	260 years
9.	*Pinus gerardiana*	Western Himalaya	600 years
10.	*Pinus kesiya*	Eastern Himalaya	146 years
11.	*Pinus merkusii*	Eastern Himalaya	295 years
12.	*Pinus roxburghii*	Western Himalaya	300 years
		Eastern Himalaya	229 years
13.	*Pinus wallichiana*	Western Himalaya	410 years
		Eastern Himalaya	153 years
14.	*Taxus baccata*	Western Himalaya	345 years
15.	*Tsuga dumosa*	Eastern Himalaya	580 years
	Broad leaved Taxa		
16.	*Cedrela toona*		180 years
17.	*Tectona grandis*		801 years

* Chronology not crossdated

Principle of Dendrochronology:

The fundamental of Dendrochronology is based on following principles (a) the principle of Uniformitarian. (b) The principle of Limiting Factors. (c) The principle of Ecological Amplitude. (d) The principle of Site Selection. (e) The principle of Sensitivity. (f) The principle of cross dating. (g) The principle of Repetition. (h) The principle of Standardization. (i) The principle of modeling growth-Environmental relationship. (j) The principle of Calibration and Verification. The details about these principles have been discussed in Fritts, 1976.

The first criterion in dendrochronology obviously is to select trees producing annual growth rings. A large number of trees grow according to an annual cycle, which begins generally with the opening of leaf bud during March-April or commencement of summer and then ends just before leaf fall or during winter. In response to this cycle, the trees form large thin walled cells (early wood) during early of the growing season and small thick walled cells (late wood) during later part of the growing season. These two types of cells together is known as annual ring. Sometimes, a tree may begin to form latewood towards the end of the growing season, but a new flush of growth may again form early wood cells. This band of latewood between early wood bands, termed a *false ring*, which would ordinarily be classified as a true tree ring however, it is anatomically different from a true tree ring when it is magnified. On the other hand, environmental conditions during some years may be so unfavorable that some trees may not form new wood completely throughout the trunk of the tree, and may result in a *missing ring*. (In reality, this layer of new growth may still be found in the upper portions of the tree where growth is initiated, so this ring is sometimes more appropriately termed a *locally absent ring* in the sense it is not evident in the trunk of the tree). The formation of annual ring is the characteristics of trees growing commonly in temperate and sub-alpine region though some of the tropical trees are also known to produce growth rings. According to Chowdhury (1964) about 25% of tropical trees growing in India produce growth rings, but it is not yet certain whether these growth rings in most of these trees are annual in nature or not.

Several parameters of annual ring (viz., ring width, wood density and isotopes like oxygen-18, deuterium, carbon-14 and carbon-13 in the cellulose of the ring) have been used to study the effects of different environmental factors on tree growth. Ring width is the most commonly used parameter in dendrochronology because width can be studied and measured easily from a finely sanded surface by using dissecting microscope (Fritts, 1976).

The growth of any tree either by diameter or in height is the cumulative effect of genetic and various environmental factors. The genetic or inherent character of a tree regulates the adaptability and responses of trees to various environmental conditions, and to the supply of nutrients, moisture, temperature, light, carbon dioxide and others essential to growths are the products of environment. Width of a ring (diameter growth increment of a year) as influenced by various factors, which can be expressed as below (after Graybill, 1982).

$$R(t) = C+B+D+E$$

In this equation, R is the measured ring width in year t, C is the macroclimate signal common to trees at a site, B is the biological growth curve as determine by increasing age of the tree, D is the disturbances signal that may be due to fire, insect damage, or other disturbances that affected the entire site; and E is the random growth signal unique to each specimen related to genetic or inherent character. The basic principle underlying in the application of tree-width data in the growth/environmental studies can be explained by the above equation. The signal of C and D factors mentioned already are stored in the form of narrow or wide tree ring of the particular year. For the assessment of the effects of any of these factors on tree-growth it is essential first to date the annual rings to the calendar year of their formation. Secondly, to enhance the signal of desired parameters and to singularize its effect it is necessary to eliminate effects of the other, which are considered noise in the analysis. For example in climatic studies effects of B and D should be removed to enhance signal of C. Similarly for understanding the effects of disturbance (D) in tree growth, C and B are to be deleted. The mathematical process "Standardization" which has been described later can remove the effects of 'B' on tree growth. Various criteria and statistical methods have been defined for the study of growth rings, which vary according to the objectives of study (Fritts, 1976).

Site Selection and Sampling:

The selection of site and tree species depends upon the objective of the study. The tree-ring sampling site should be selected on the basis of climate sensitivity, tree age, geographic location, lack of obvious disturbance evidences (such as synchrononized radial growth release, asymmetrical crown, presence of buttresses), homogeneity of site conditions (such as slope, aspects, and parent material), and the suitability of the available species for Dendrochronology. Sample can be obtained in the form of disc from the stumps of already felled trees, from fossil wood in bogs and also from the historical wood found in old wooden buildings. Usually complete cross section of a tree-trunk at breast height (1.4m) is most suitable for tree ring studies. Since cross sections are not easily available, increment corer are usually used to remove a small core (10mm in diameter) without causing the living tree any harm. Generally two cores from opposite direction at breast height of the same tree are collected. The number of trees that should be sampled from a given site depends on the variability in ring widths among the trees. Generally about 10 to 20 trees are sampled from each site on each geographically limited and ecologically homogenous site. (Fritts, 1976). However, the number of samples can be varied depending upon the sensitivity of site, which is indicated by the high variability in tree width and objective to the study. The variability in the ring width indicates the extent how much the tree has been limited by the environmental factors. When the ring-to-ring variability is high, the tree-series contains the good signal of the environment factors influencing the tree growth and is called sensitivity series and is suited for dendrochronological studies (Fritts, 1976)

Laboratory and Analytical Studies:

Dating and Measurement of ring widths:

The tree-cores samples collected from the site should be mounted in grooved wooden stick. The surface of the cores have to make even by cutting by sharp edged razor and smoothed using several grades of sand papers so that cells especially ring boundary become clearly visible to study under microscope. For the study of various climatic and non-climatic factors on tree growth, the growth rings are needed to be assigned to the calendar dates. There is a great chance of making error in dating the growth rings by just ring counting as growth response of trees to the extremes or fluctuations of any environmental factors often results in locally absent of multiple rings. Such anomalies in ring pattern can be detected by cross dating, a procedure through which patterns of narrow and wide rings are matched on a year to year basis within and among trees.

Importance of cross dating are (a) used to identify the year in which each growth ring was formed (b) to assign an exact calendar dates to each growth ring (c) to solve the problem of absent ring (d) to solve the problem of false ring (e) to identify the cases where two or more apparent rings have been formed during one year (f) ensures accurate dating (g) for the dating of dead wood and archaeological samples. Cross dating is often accomplished by Skeleton plot method, which is very simple and usually used for accurate dating of the growth rings (Stokes and Smiley, 1968). It is the graphic representation of those rings considered important in cross dating. For this purpose narrow rings are taken into consideration. Salient features of Skeleton Plots are: (a) represent growth variation of samples onto separate strips of graph paper. (b) Equalize the absolute scales ring growth. (c) Easily compare growth variation of two or more specimens. To prepare a chronology based on tree rings, the width of dated growth rings need to be measured to the nearest 0.01 mm by using a binocular microscope coupled with a calibrated device (measuring machine) by which the mounted core can be moved across the stage and properly aligned with the cross hair for measurement The accuracy of the crossdating is verified using the computer program COFECHA (Holmes, 1992). It performs data quality control on a set of tree-ring measurements, verifies crossdating among ring measurement series and indicates possible dating or measurement problems. It may also be used to check crossdating among different sites chronologies of same region.

Chronology Building:

For the Chronology preparation the first step is the removal of the overall trends from each tree ring series resulting due to ageing effects of trees and exogenous disturbances. These disturbances could be caused by several factors such as forest fire, insects' attack, disease infestation, earthquake shakes, storms, frosts and others. The effect of these disturbances could be minimized through Standardization, which is accomplished by fitting a growth curve to the ring width series and then dividing the measured value by the curve value at each year. It provides a new series of desirable properties that are later averaged together to transform into tree ring indices series. This new series has a mean of 1.0 and a relatively constant variance (Fritts, 1976; Cook et al, 1990). The averaging of standardized ring width values or indices reduces the amount of variability due to non climatic factors and enhances the ratio of climatic signal to the non climatic signal in the mean chronology.

ARSTAN (Holmes, 1994) is probably the most commonly used computer program to undertake this standardization process. Program ARSTAN produces chronologies from tree-ring measurement series by detrending and indexing (standardizing) the series, then applying a robust estimation of the mean value function to remove effects of endogenous stand disturbances. Autoregressive modeling of index series often enhances the common signal. Extensive statistical analysis of a common time interval provides characterization of the data set.

CLIMATIC RECONSTRUCTION

Tree-ring data show considerable potential to provide annually resolved reconstructions of pre-instrumental climatic conditions. Most but not all of these reconstructions are based on routine statistical approaches involving mainly the concepts of response and transfer functions in routine use (Fritts, 1976; Cook and Kairiukstis, 1990). A number of different statistical procedures e.g. sign test, correlation, multiple regression analysis with or without the identification of the principal component of the population can be used to identify and plot the relationship between climate and tree-ring.

Response Function:

In order to represent the relationships between climate and tree growth, it is necessary to obtain quantitative estimates or models that represent these relationships. Empirical dendroclimatic models describe tree growth as a function of changing climate conditions over a range of time scales and simulate fundamental relationships as accurately as possible based on current knowledge of the growth controlling processes and dendrochronology. The models most commonly describe relationships between ring characteristics and monthly, seasonal, or annual conditions where the basic processes linking causal factors to growth are unknown or poorly defined (Fritts, 1991) To understand which climatic variables are significant in limiting growth of tree, the response function are used. In this analysis monthly climatic variables act as “predictors”(usually temperature and precipitation) and the tree ring indices as the “predictand” to identify which months, or combination of months, are most highly correlated with tree growth.

The response function information can be presented graphically to show the relationship of the predictand and the predictors over time. Response function coefficients that are above zero indicate a positive relationship with climatic variables, whereas coefficients lower than zero indicate a negative relationship with the climatic variables. For each component of the response function that is significant, the percentage of variance explained by the element in the year of interest is indicated by the coefficient value on the Y-axis.

Transfer Function:

Transfer function is opposite to response function; it provides a basis for retrodicting climatic data from tree ring values. Preceding, current, and following ring width indices are used as predictors of the climatic variables. Usually, temperature and precipitation values for those months, which are recorded significant in response function analysis, are considered for reconstruction. The multiple regression equation is used to predict climatic values from ring width indices.

In dendroclimatology it is a general practice that emperically derived equations which link tree growth variation in climatic time series needs verification from independent data. This can be accomplished by matching the climatic reconstructions with 1) independent meteorological observations 2) historical records or individual observations 3) or other proxy data

DENDROCHRONOLOGY IN THE CONTEXT OF INDIAN SUBCONTINENT:

In India, systematic tree ring research has been started since last two decades. Three-premier Research Institutions viz., Birbal Sahni Institute of Palaeoboatany, Lucknow. Indian Institute of Tropical Meteorology, Pune and Physical Research laboratory, Ahmadabad are the main centers in India for pursuing various aspect of Derochronologiacal studies
A summary of various aspects of tree ring studies carried out in this part of globe has been discussed here.

1.Selection of suitable sites and trees for Dendrochronological study:

Based on several tree ring parameters viz., ring-width (Bhattacharyya *et al*., 1988, 1992; Bhattacharyya & Yadav, 1990, 1992, 1996; Borgaonkar *et al*., 1994; Pant, 1979; Pant and Borgaonkar, 1984; Yadav and Bhattacharyya, 1992, 1994) or isotopic analysis from cellulose of tree ring (Ramesh *et. al*, 1985, 1986) several tree ring sites and taxa have been recorded potential for Dendroclimatic studies from this region. It has been noted that several conifers viz., *Cedrus deodara, Juniperus macropoda, Pinus gerardiana, Taxus baccata,* are found suitable in making long tree ring records (Bhattacharyya *et al*, 1997). However, among these taxa, Pinus *gerardiana* and *Cedrus deodara* are found most promising. Deodar trees growing around Malari, Harshil, and Gangotri, Uttaranchal state; Kistwar, Jammu and Kashmir; and Kinnaur in Himachal Pradesh have been found to be 400-800 years old. Old stands of *Pinus gerardiana* (300-600 years) are common in Kinnaur, and Kistwar. *Juniperus macropoda*, another inner Himalayan conifer, might be the oldest living conifer of this region. Earlier a sample of this tree collected from Hunza valley, Karakoram has been reported to have 1200 rings (Bilham *et al*, 1983) but dating of this sample could not be possible due to lack of cross dating within the radii of same sample. Later, *Juniperus excelsa* and *J. turkestanica* growing at Karakorum, Northern Pakistan has been recorded to have 165-1000 rings and suitability for dendroclimatic analyses have been established (Esper, 2000). It has been noted that during last 500 years that the maximum growth occurred in this tree during 1579-1603 and minimum was between1825-1850 which seem to be linked with the changes of temperature. Junipers growing in the adjacent Tibetan plateau have also been found datable and suitable for dendroclimatic studies (Brauning, 1994). Several conifers growing in diversified ecological conditions of Nepal Himalaya (Bhattacharya *et. al* 1992) and from the Eastern Himalaya (Chaudhary *et. al*., 1999) have been found datable and suitable for tree ring analyses

2.Dendroclimatic Analysis:

The ultimate and the most important aim of the tree-ring analysis are to reconstruct climatic conditions on the centennial, decadal and annual scales from regional tree growth. In India except some meteorological stations, instrumental climatic records do not go beyond 100-150 years. Tree-ring based climatic reconstruction offers a possibility for adding available instrumental records in both spatial and temporal coverage, which is crucial for understanding the contemporary climatic variability. The work carried out so far in this aspect from diversified geographical regions have been summarized here.

i) Western Himalaya:

Hughes and Davis (1987) have made pioneer attempt in climatic reconstruction based on tree ring data of *Abies pindrow* and *Picea smithiana* from the Kashmir valley. Later Hughes (1992) gave detailed reconstructions of mean temperature for spring (April-May), late summer (August-September), and precipitation since 1780AD at Srinagar, Jammu and Kashmir based on width and density of annual rings of *Abies pindrow*. Borgaonkar *et. al*. (1994) have also reconstructed climate especially, summer temperature (May-September) of Srinagar, Kashmir back to eighteenth century. In another study, Borgaonkar *et al* (1996) reconstructed pre monsoon (March-April-May) temperature back to eighteenth century using ring width data of *Cedrus deodara* from Manali, Kufri (Shimla) and Kanasar. Reconstruction of climate long back to 1390 AD was made based on ring width data of *Cedrus deodara* growing at Harshil, Garhwal Himalaya (Yadav *et al* 1999). Most salient features in these studies are the absence of any prominent large magnitude century scale excursions in negative anomalies, which might indicate regional influence of "Little Ice Age". In contrary, 17th century has been found with monotonically warm spring. Moreover, in this region evidence of warming has not been depicted which could be associated with the anthropogenic activities during 20th century. The evidence of such cool spring during this period has also been recorded from this region in another study where April-May temperature has been reconstructed based on combined tree ring chronologies of *Cedrus deodara*, *Pinus wallichiana* and *Picea smithiana* from the Garhwal Himalaya, (Yadav *et al*, 1997). It has been recorded that for the period 1950-1986 mean April-May temperature for the Western Himalaya has negative correlation with ENSO Sea surface temperature (SST) index of June-December (r= -0.49) and all India summer monsoon rainfall data (r= + 0.37). Estimated temperature of April- May based on tree ring data also shows similar correlation but is comparatively lower (r = -0.22, +0.20 respectively, Yadav *et al*, 1997).

Besides there are some other studies, though not directly involved with the climatic reconstruction but are related to the other aspect of the environmental studies. Earlier in an exploratory study it has been reported that growth in *Cedrus deodara* growing in Harshil and *Pinus gerardiana* in Kinnaur are low mostly during years of deficient rainfall and also with years having El-Nino events (Bhattacharyya and Yadav, 1992). These two taxa have been found to be excellent potential to reconstruct long records of droughts in the Western Himalayan Region

ii) Central Himalaya:

Temperature for two seasons, February-June (1546-1991) and October-February (1605-1991) has been reconstructed based on tree ring data of five species of this region (Cook *et. al* 2003). They recorded unusual cold temperature during 1815-1822 in the both reconstructions, and correlated with the eruption of Tambora in Indonesia. Moreover the climatic reconstructions strongly reflect patterns of temperature variability associated with Little ice age and subsequent warming. This study shows that only the October – February season exhibits evidence for late20th century warming, while February –June temperature have actually cooled since1960.

iii) Eastern Himalaya:

The only report of the reconstruction of July- September temperature extended up to 1507 AD is available from this region. This record is based on composite tree ring chronologies of *Abies densa* made from trees growing in two sites, T- gompa and Yumthang in Arunachal Pradesh and Sikkim respectively. Reconstructed data shows no significant change in trend. However some decadal scale fluctuations have been recorded in the reconstructed series. 1760s, 1780s, 1800s, 1830s, 1850s and 1890s are recorded as cool decades with the minimum occurring in 1801-1810 (-0.31 C). Period 1978-1987 (+0.25 C) was the warmest one (Bhattacharyya and Chaudhary, 2003). In another study tree ring data of Larch (*Larix griffithiana),* the only deciduous conifer of this region has been recorded to have significant positive response to May temperature. However prepared Larch chronology is not long enough to extend reconstructed climatic data beyond existing meteorological records. They believed that future collection from undisturbed forest site would help to extend this chronology (Chaudhary and Bhattacharyya, 2000)

iv) Peninsular Region:

It is believed that about 25% of the tropical trees produce growth rings (Chowdhary, 1940). But datability of these rings to the respective years of their formation in most of these trees which is a prerequisite for the dendroclimatological studies are yet to be established. In the attempts made so far two taxa, teak (*Tectona grandis*) and toon (*Cedrela toona*) have been found suitable for such studies. Between these two taxa, teak is widely distributed in peninsular region of India and it has been studied from several sites. These are from dry deciduous forest in Korzi, Andhra Pradesh (Yadav and Bhattacharyya, 1996) from a large number of sites in Central India (Wood, 1996) and moist deciduous forest in Thane, Maharashtra (Pant and Borgaonkar, 1983, Bhattacharyya *et al*., 1992 b). They showed that tree-ring of teak could be valuable proxy data for the reconstruction of monsoon precipitation. Due to large-scale deforestation it is difficult to get old teak trees in their natural forest. A disc stored in the Wood Museum, Institute of Wood Science and Technology, Bangalore has been analyzed for the long tree-ring records from tropical region. It exhibits 801 rings and these rings were dated by comparing the ring width pattern of the other chronology extending from 1872 to 1987 AD prepared from the same species growing in Andhra Pradesh (Yadav and Bhattacharyya, 1996). By cross dating with teak chronology from Andhra Pradesh, this chronology has been dated from 1153-1953 AD. This teak chronology **(**Bhattacharyya et.al. 1999) exhibits low growth during drought years of 1871, 1873, 1876, 1891.1899, 1905, 1918, 1936 and 1937 reported (Parthasarathy *et. al*.1987) in north Karnataka

3.Tree ring in glacial fluctuations:

Tree ring data has also been found useful tool in understanding the glacial fluctuations. Tree ring data of *Pinus wallichiana* growing in the sub alpine region of the Kinnaur Himachal Pradesh (Bhattacharyya and Yadav, 1996) and *Betula utilis* (work in progress) around Gangotri Glacier have been found good indicators of glacial behaviour of this region. This study indicates that tree growths are low during the years having positive glacial mass balance or glacial advances reported during recent past in the Himalayan and Trans Himalayan region. Tree ring analyses reveal that recent rapid retreat of the Gangotri glacier might have some association with the increase of winter temperature (Singh and Yadav, 2000)

4. Tree ring and isotopic analysis:

Ramesh *et. al* (1985, 1986) found that the isotopic analyses from tree ring have great potential in the climatic reconstruction. They observed that the stable isotope ratios of Oxygen, Hydrogen and carbon have coherent variations along different radii in a single tree, between two trees of the same species and among different species of trees that grow in the same micro climate. The common isotopic signals are correlated to the instrumentally measured climatic parameters

5. Tree ring in Paleoseismology:

Besides climate, tree rings analysis offers an important tool for the study of Palaeoseismic events. The synchronic occurrence of earthquake signature in tree ring data from wide spread areas along the activity fault zones could be utilized to date the palaeosiesmic events Severely damaged tree may exhibit several changes in growth pattern, like growth suppression, growth eccentricity and reaction wood. Long-term information on occurrence of strong earthquakes going back to few centuries would help in understanding the recurrence behavior of catastrophic earthquakes. A preliminary investigation of tree growth /earthquake relationship from a *Kail pine* (*Pinus wallichiana*) from Agora, which was badly affected by Uttarkashi earthquake. October 1991 suggest that growth rings were commonly found to be narrow in 1992, the year subsequent to the earthquake events. This earthquake occurred in the end of the growing season (October) when tree growth in most of the trees in the Himalayan region ceases. Therefore its effect was notice only in tree rings produced during the subsequent years The tilted trees also showed the formation of eccentric growth rings, i.e. narrow rings on the upslope side of the stem in comparison to wider contemporary rings of the lean side which clearly testifies the potential of such studies in the Himalayan region (Yadav and Bhattacharyya. 1994)

Future direction:

A network of climatically sensitive tree ring chronologies from trees growing in contrasting climatic zone of North west and eastern part of the Himalaya and Peninsular India would be of great significance in understanding the detailed climatic dynamics of the Indian subcontinent in global perspective. Particularly, the long tree-ring records from tropical region would be of great relevance for the analyses of monsoon climatic variability in longer time scale. For the longer climatic record, extensive efforts need to be made in the collection of tree ring sample from the new geographical area and selection old trees for making millennium long tree ring records. The problem of getting a large number of samples from older tree could be substantiated by the collection of samples from wood used in different purposes from both Himalayan and tropical forest sites. The analysis of tree growth /climate relationship from these chronologies would help to extend existing meteorological records long back. This long data would be useful in understanding monsoon variability and to analyze its long-term teleconnection with other climatic phenomenon like Eurasian snow cover and ENSO events.

Tree-ring studies carried out so far from India has taken mostly ring-width into consideration but recent studies elsewhere has shown that other parameters such as density, isotope, cell size, vessel area etc. also have equal or sometimes, more importance in deciphering and reconstructing past climatic changes as well as other aspects of environmental, ecological and geomorphological studies. These tree ring parameters should be applied not only for the detailed understanding temporal aspect of the multi seasonal climatic changes of India but also solving other environmental issues, which has great relevance to society.

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