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Long-term climate variability over monsoon Asia as revealed by some proxy sources

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सार - विभिन्न स्रोतों से प्राप्त हुए प्रतिपत्री आँकड़ों के आधार पर एशिया के मानसून क्षेत्रों में जलवायु की विभिन्नता पर अधिकांशतः चतुर्थ महाकल्प के दौरान किए गए अध्ययनों की समीक्षा की गई है। एशियाई क्षेत्र की मानसून प्रणाली की प्रक्रियाओं के साथ् ही साथ महासागर तलछटों, हिमक्रोड जैसे विश्वस्त स्रोतों के विविध प्रकार के प्रतिपत्री आँकड़ों की उपलब्धता और ऐतिहासिक दस्तावेजों को समझने के लिए उत्पन्न हुए जिज्ञासा ने इस क्षेत्र में पुराजलवायविक अध्ययनों को प्रोत्साहित किया है। विविध स्रोतों से प्राप्त प्रतिपत्री आँकड़ों के आधार पर लगाए गए अनुमानों से सम्पूर्ण मानसून प्रवाह के साथ हिमनद और अन्तः हिमनद अवस्थाओं के अच्छे संबंधों का पता चलता है। उष्ण तथा गीले पर्व् को साधारणतः अच्छे ग्रीष्मकालीन मानसून से पहचानते है, जबकि मानसून की गतिविधियाँ थंड एवं शुष्क कालखंड में कमजोर पाई गई है। डेन्ड्रों जलवायविक पुनः कल्पन के आधार पर 17 वीं शताब्दी के आरम्भ में अखिल भारतीय स्तर पर मानसून वर्षा की प्रवृति में किसी प्रकार झुकाव नही पाया गया तथा बडे पैमाने पर अंतःवार्षिक विभिन्नता देखी गई जोकि 20 वी शताब्दी के मौसमी आँकडों से प्राप्त मानसून वर्षा में भी पाई गइ है। इस क्षेत्र के ऐतिहासिक प्रमाण तत्कालीन जलवायु परिवर्तन की सूचना का प्रमुख स्रोत हैं।

ABSTRACT . Studies on climate variability over the region of monsoon Asia mostly during the Quaternary, based on various sources of proxy data have been reviewed. Increasing interest to understand the processes of monsoon system over the Asian region as well as the availability of data from variety of reliable proxy sources such as, ocean sediments, ice cores and historical documents have encouraged the palaeoclimatic studies in this region. Inferences drawn from the multiproxy sources indicate good association of glacial and inter-glacial phases with over all monsoon flow. Warm and wet periods are generally characterized by strong summer monsoon, where as, weak monsoonal activities were observed during cold and dry periods. All India monsoon rainfall since early 17th century based on dendroclimatic reconstructions shows trend-less nature with large interannual variability as seen in the instrumental record of recent century. Historical evidences over this region are a potential source of information on contemporary climate change.

Key words – Climate variability, Monsoon Asia, Proxy sources, Quaternary, Holocene.

1. Introduction

The knowledge of climate variability over the period of instrumental records and beyond on different temporal and spatial scales is important to understand the nature of different climate systems and their impact on the environment and society. Asian monsoon has attracted global attention due to its important role in the changing global climate. Most of the observational and numerical simulation studies on climate are based on instrumental record of about a century and efforts are being made to use this information to understand the natural variability of Asian monsoon system and to identify processes and forcings that contribute to this variability.

Though the palaeorecords of monsoon over India and other parts of Asia are not systematically synthesised, few sparse studies based on different proxy sources and scales are useful to bring out some prominent features of long-term climate change. Well established time series of Indian monsoon rainfall from instrumental record prepared from dense network of meteorological stations covering a period of more than a century is available on regional scale as well as for India as a whole (Parthasarthy *et al.* 1995). Optimizing the number of stations, an appropriate statistical model has been used to extend the series further back to early nineteenth century (Sontakke *et al.* 1993). Temperature data over the country has been documented for about a century and analyzed to see the trend of temperatures, particularly for the last two decades (Rupa Kumar *et al.* 1993; Hingane *et al.* 1985). All these studies indicate highly variable trendless behaviour of Indian summer monsoon rainfall with epochal nature. The temperature over Indian region show increasing trend of about 0.4 per hundred years. The increasing tendency of mean temperature is mainly contributed by maximum temperature as minimum temperature is more or less trendless during the current century. It is indicated by available data that the components of Indian monsoon and related global and regional oceanic and atmospheric parameters are operational in Low Frequency Modes (Pant *et al*, 1988a).

The aforesaid studies are based on the climatological data of only plane stations of India excluding Himalaya. However, the understanding of climate variability over Himalaya is especially important being the greatest mountain barrier on the earth where, polar, tropical and mediterranean influences interact and it plays a prime role in maintaining and controlling the monsoon system over the Asian continent. The common limitation of many of the climate variability studies over the Himalayan region is the lack of sufficient climate data from high altitude locations. Climate variability studies over Indian Himalaya, Nepal Himalaya and Tibetan Plateau region (Borgaonkar, 1996; Seko and Takahashi, 1991; Li and Tang, 1986) are mostly based on very specific localities and short period data. However, climate of the Himalaya based on reasonably long record of about a century from about 15 stations over Indian Himalaya do not show any long-term trend in rainfall. The temperature records reveal slightly increasing tendency. The significant change is observed generally around AD 1940.

Even then the fact remains that the climatic anomalies such as occurrence of glacial phases, transitions of glacial and interglacial periods and variability of monsoon as reflected in the frequency and intensity of droughts needs to be examined with a data set much longer in extent. In this context the efforts are continuing in India and other parts of Asia on building the proxy climate records. In this article, the information on past climate changes over the monsoon Asia derived from various proxy sources on different time scales have been systematically reviewed.

2. Historical Climate Records

Documentary historical evidences are very important to get some information about contemporary climate change. However, these evidences are generally found scattered in many places and languages with varied interpretation, information is vague and fragmentary on many occassions. A systematic and logical approach in interpreting historical evidences is crucial to extract the valuable information on past climate. Historical records in India and China are relatively long compare to other parts of Asia which represent informative evidences of past climate. Primary efforts of Chu (1973), Zhang and Crowley (1989) established one of the best data set of historical records. Chu (1973) developed a 5000 year record of climate change over China through extensive analysis of historical writings. These are based on phenological observations, for example, timing of recurrent weather dependent phenomenon, such as dates of flowering of shrubs on arrival of migrant birds or distribution of chemically sensitive organisms. His conclusions indicate that, 3000 years ago annual mean and winter temperature around Yellow river was 2° to 5°C higher than at present. He also observed oscillation of 400-800 years with annual mean variation of about 1°C during last 3000 years. A detailed review of Zhang and Crowley (1989) of Chinese historical records give climate related information since AD 1000. Their inferences indicate that cool periods of Little Ice Age were more variable, with increased droughts and floods. Decadal and centennial scale climate fluctuations were significant with temperature variations of the order of 1°C to 1.5°C. These inferences agree with climate at many other places in Northern Hemisphere.

In India, historical climate evidences are mostly related to monsoonal rain, for example, occurrence of drought or flood, no harvesting due to lack of rain or good food grain production etc. Pant *et al*. (1993) attempted a systematic study to extract climate related information for the last 1000 years from historical records of various climatic zones of India. Many historical evidences are indicative of droughts and floods leading to famine conditions. They reconstructed large-scale drought events for past 1000 years. Relatively low frequency of occurrence of droughts was observed during AD 900-1600. This may be due to inadequate availability of related historical information which accounts only for severe and significant events or perhaps a overall good monsoon of the medieval warm period. Since AD 1600 frequency of droughts is relatively higher and drought events are more or less randomly distributed. (Fig. 1). The Holocene climatic changes over northwest India from archaeological evidences and lake pollen data indicate warm and humid climate with frequent floods between 10,000 and 4500 years BP (Pant and Maliekal, 1987).

3. Dendroclimatic Studies

Many long-lived trees grow with annual ring structure. Climatic information recorded by trees growing in stressful forest environments can be extracted from the size, structure and chemical composition of these annual growth rings. The precisely dated tree-ring series from such trees provide a wealth of information about climatic and environmental changes over the past few centuries and in some cases even to few thousand years on short-term scale (*i.e.* annual) to inter-decadal and even century

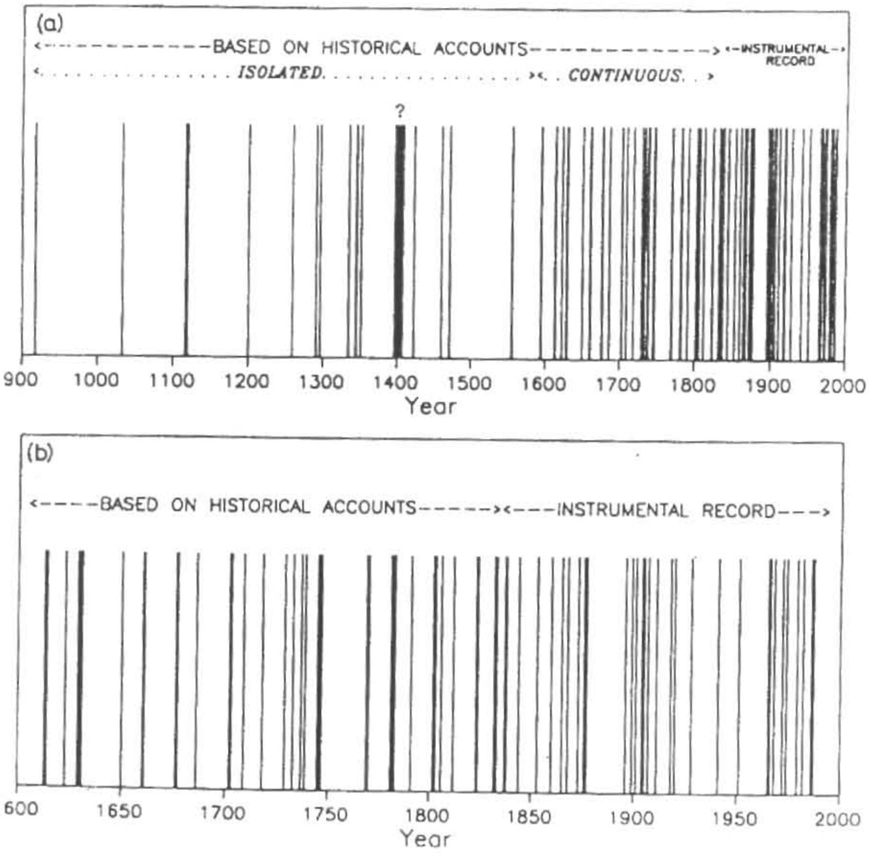


Fig. 1. Occurrence of large-scale droughts over India during AD 900-1991. Historical records were sporadic and isolated up to AD 1600 (a). Frequency of occurrence of drought events were relatively higher and randomly distributed (b) (after Pant *et al.* 1993).

scale. When a large number of tree-ring chronologies are available for a region and they are demonstrated to represent the effect of specific climatic variable like temperature, rainfall etc., these parameters can be reconstructed backward for a much longer time. The spatial anomalies in tree growth/ climatic elements may be mapped and used to deduce the climatic anomalies over a wider geographical region. Long tree-ring chronologies based on Bristlecone Pine from California and Oak from Europe provide calibration for the Holocene climate variation (LaMarche, 1973; Pilcher *et al.* 1984). Tree-ring data also show a potential source of information on severe floods, earthquakes, volcanic eruption, glacier advance and retreat and, ecological disturbance such as fire outbreaks (Hughes, 1991).

The Asian regions extending south into Australia and New Zealand provide large forested areas with tropical, sub-tropical and alpine type of vegetation. Many trees over this region have been demonstrated as potential source of tree-ring data. Tree-ring studies in Europe and North America have been established many decades back, however, within the Asian continent, the dendroclimatic studies have been initiated during the last two decades to look into the climatic and environmental changes, including those related to the Asian monsoon and El Nino/ southern oscillation (ENSO) over the past few centuries.

Wide network of well replicated cross-dated chronologies are already developed from various parts of Asia. Tree-ring studies from Russia (Vaganov *et al* 1995; New Zealand (Nortan, 1983; 1987; Nortan *et al.* 1989) and Tasmania (Cook *et al*, 1991) have been used to reconstruct summer temperature in most cases and river flow and precipitation in few. Considerable progress have been made in dendroclimatic reconstructions of growing season climate (temperature and precipitation) generally covering the last 300-500 years from China, Tiwan, Korea, Japan, the Nepal Himalaya and far east of Russia (Wu, 1992; Hughes *et al*, 1994; Sweda, 1994; Yasue *et al*,

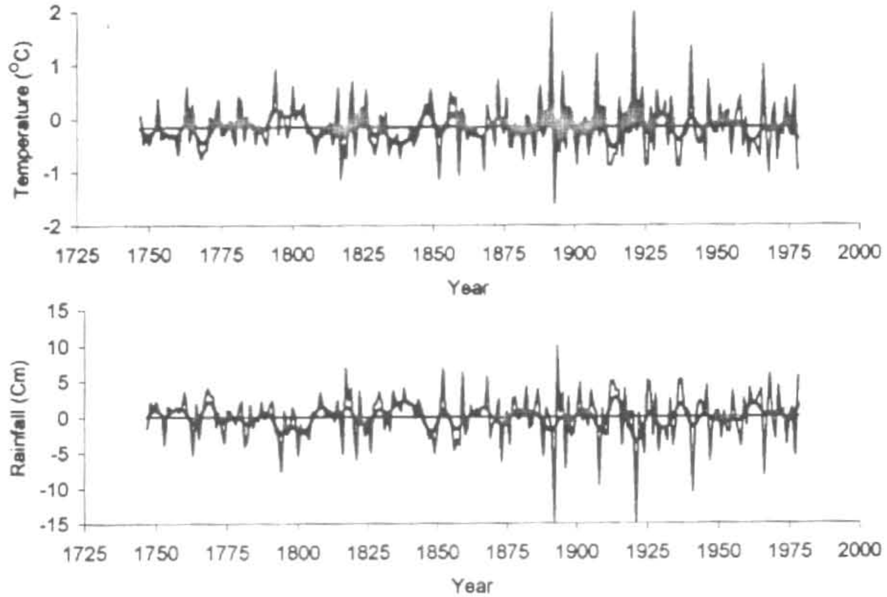
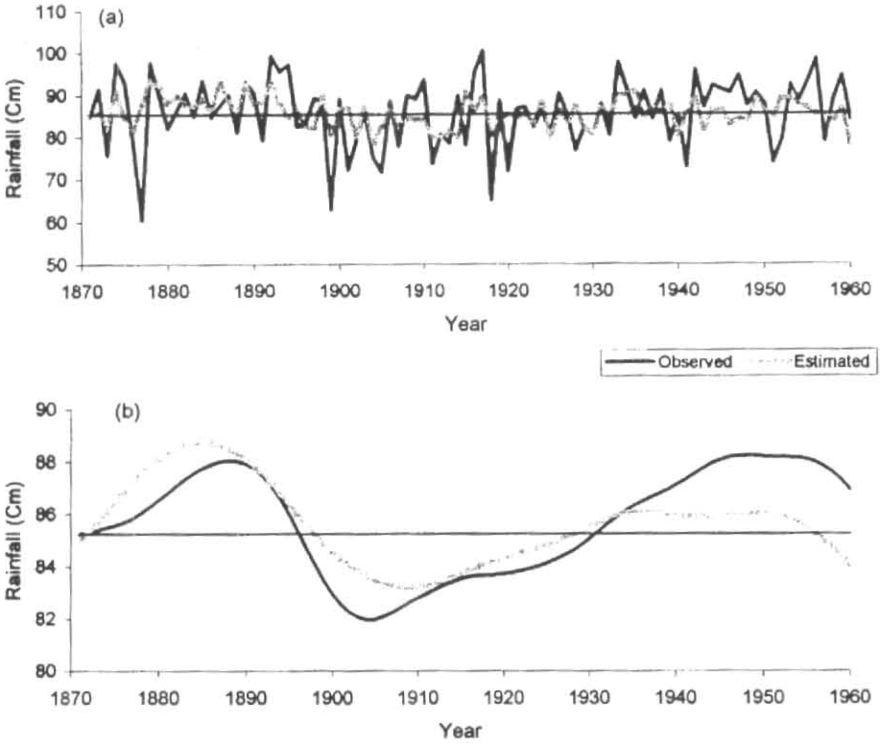


Fig. 2. Reconstructed pre-monsoon (March-April-May) temperature and rainfall anomalies since AD 1747 over the western Himalaya using tree-ring chronology network. Smooth lines indicate low-frequency variations

1995; Choi *et al*, 1992; Suzuki, 1990). Along with the regional dendroclimatic reconstructions, many researchers have made efforts to examine the climatic expression of global synoptic scale atmospheric phenomenon like ENSO (Lough and Fritts; 1985; 1989; Jacoby and D'Arrigo, 1990), circumpolar vortex circulation (Cook *et al.*, 1991) and southern ocean current patterns on regional climate (Schonwiese, 1992; Xixian, 1992; Ramesh *et al.* 1985, 1986).

In India, extensive work have been carried out to understand the dendroclimatic potential of Himalayan conifers (Pant, 1979, 1983; Pant and Borgaonkar, 1984; Hughes and Davies, 1987; Bhattacharyya *et al.* 1988 and Borgaonkar *et al.* 1999) and tropical trees (Pant and Borgaonkar, 1983; Bhattacharyya *et al.* 1992). *Pinus, Picea, Cedrus* and *Abies* are the genera which provide good quality tree-ring data for dendroclimatic reconstructions. The regional reconstructions over western Himalaya (Hughes, 1992; Borgaonkar, 1996; Borgaonkar *et al.*, 1994; 1996; Pant *et al.* 1995, 1998) give pre-monsoon and summer climate variability since past 300 years. Temporal variations of isotopic ratios (δD, δ^{13}C, δ^{18}O) in tree-rings of the Himalayan conifers are also good indicators to deduce high resolution palaeoclimatic history. (Ramesh *et al.* 1985; 1986).

Dendroclimatic analysis using a wide network of tree-ring chronologies and monthly as well as seasonal data of temperature and precipitation anomalies over western Himalaya indicates a significant relationship between pre-monsoon climate and tree growth. A strong association of pre-monsoon climate with tree growth is mainly due to severe moisture stress conditions occurring during these months (Borgaonkar, 1996; Borgaonkar *et al.* 1996). Pant *et al.* (2000) demonstrated that the pre-monsoon climate is of critical importance to tree growth over the western Himalaya, based on densitometric analysis. They found that the early wood density of the tree rings shows significant response to climate. Calibration equation based on instrumental record of pre-monsoon climate and corresponding tree-ring variations shows very good agreement between reconstructed and observed pre-monsoon climate (temperature and precipitation). Fig. 2 represents the reconstructed pre-monsoon temperature and precipitation using earlier part of tree-ring data in the calibration equation. The reconstructions go back to AD 1747, earlier to that the sample size is not sufficient to represent a signal comparable to that of population signal (Wigley *et al.*, 1984). Smooth lines in the figure are low-frequency variations based on cubic spline smoothing at 50% VRF (Variance Reduction Frequency) of 10 years (Cook and Peters; 1981). Both temperature and precipitation series do not show any long-term trend. The reconstructions also reveal that the pre-monsoon climatic conditions during past 250 years were not significantly different than the present climatic conditions. Reconstructions cover later



Figs. 3(a&b). Estimated and observed all India monsoon rainfall. (a) Interannual variations, (b) low-frequency variations using cubic spline smoothing at 30 years cutoff frequency. The estimated values are due to indirect dendroclimatic reconstruciton using southern oscillation index

part of Little Ice Age. It is observed that this phenomenon was not significant in later phase over the western Himalaya.

In tropical region of south and southeast Asia number of groups have been working on to establish good quality tree-ring data network to understand monsoon variability and related global parameters (*e.g.* El Nino) in the recent past. In this context, teak (*Tectona grandis*) 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 a, b; Murphy and Whetton, 1989; Pant and Borgaonkar, 1983; Bhattacharayya *et al.* 1992). These studies indicate great capability of *Tectona grandis* in reconstruction of monsoon precipitation. 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.

Variability of all India summer monsoon rainfall (AISMR) since last 400 years have been demonstrated by Pant *et al.* (1988b) using indirect dendroclimatic reconstruction. The influence of Southern Oscillation (SO) on Indian summer monsoon rainfall has been extensively studied and results conclusively establish a significant relationship between the two (Pant and Parthasarthy, 1981; Parthasarthy and Pant, 1984; 1985;). The data of Wright's Index of SO of four seasons namely DJF, MAM, JJA and SON reconstructed back to AD 1602-1960 using tree-ring chronologies from both western-north America and the Southern Hemisphere (Lough and Fritts, 1985) have been used along with all India summer monsoon (June-September) rainfall data from AD 1871-1978 (Mooley and Parthasarthy; 1984) to estimate AISMR back to AD 1602. Figs. 3 (a & b) shows good agreement between estimated and actual rainfall. The reconstructed AISMR for the period AD 1602-1960 is represented in Fig. 4. The smooth line is low-frequency variation based on cubic spline smoothing at cut off frequency of 10 years. The excess rainfall epoch is observed during AD 1610-1635. Other less prominent epochs are also seen in the series which reflect the basic nature of the instrumental rainfall series (Mooley and

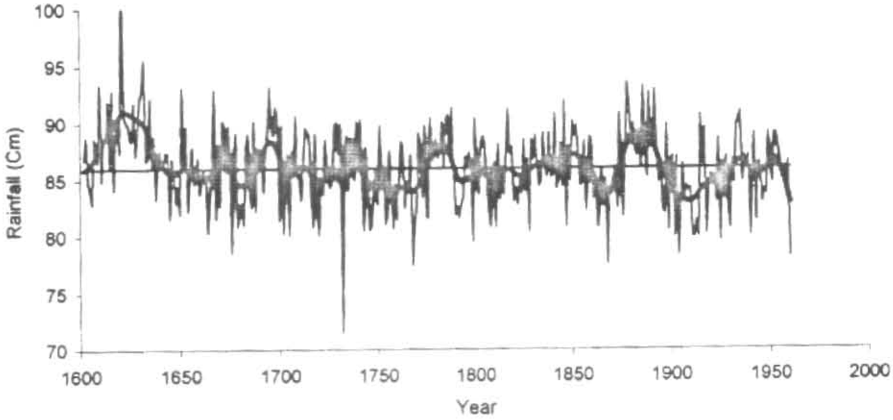


Fig. 4. Reconstruction series of all India monsoon rainfall since AD 1602 alongwith low-frequency variation (Smooth line)

Parthasarthy, 1984). Major drought events noted from historical and other sources during 19th century by Mooley and Pant (1981) have also been matching with the reconstructed series as low precipitation years.

4. Glaciao-Climatic studies

Vast snow cover over Asian mountainous region provides valuable information of past climatic fluctuations. Glacier movements (advancement, stationary and retreating phases), chemical and physical properties of ice cores are useful parameters to investigate the spatial variability of climate in this region. The wide spread occurrence of glaciers in the mountains of central Asia provide variety of sites throughout the central Asia from which multi-parameter ice core records can be recovered. Table 1 represents glacierized surface area in central Asia (Haeberli *et al.* 1989).

Snow cover interacts with global atmosphere by changing the energy regime due to large albedo and net radiation deficit. Extensive snow cover over Eurasia during spring was found to be followed by a longer advanced period of the Indian summer monsoon (Dey and Bhanu Kumar, 1982). The Eurasian and in particular the Himalayan winter snow cover extent and the following Indian summer monsoon rainfall were found to be negatively correlated (Hahn and Shukla, 1976; Dey and Bhanu Kumar, 1983; Parthasarathy and Pant, 1987). Satellite-derived snow cover data over Eurasia have important implication for long-range forecasting of the Indian summer monsoon rainfall (Bhanu Kumar, 1987; Kriplani *et al.* 1996).

TABLE 1

Glacierized area in central Asia

China	56,500 km^2
Pakistan/India	40,000 km^2
Kazakhstan, Tajikistan & Khirgizstan	18,200 km^2
Nepal/ Bhutan	7,500 km^2
Afghanistan	4,000 km^2

Studies of modern glacier fluctuations in the mountains of central Asia have been limited to general observations of advance or retreat of the snout. Very few studies (Mayewski and Jascke, 1979; Mayewski *et al.*, 1980) are available which indicate glacier fluctuations since the beginning of nineteenth century in terms of absolute time scale. They reported the glacier fluctuations on the basis of percentage of advancement, retreating and stationary positions of several glaciers across the Himalaya on yearly scale since AD 1812. These records indicate the fluctuations in dominancy of advance and stationary positions of glacier till AD 1870. During AD 1870 to 1940 random fluctuations in dominancy of retreat, stationary and advance regimes were observed followed by retreating phase in present decades. Mayewski *et al.* (1980) also discussed the relationship between glacial advances from 1890 to 1910 in the Trans-Himalaya and strengthened monsoon circulation pattern.

Analysis of Quaternary sediments along the Kali river in Kumaon Himalaya (Chamyal and Mayura, 1995) indicate advancement and retreating phases of the glaciers. Quaternary glacier advancement have been observed immediately adjacent to the modern Gangotri glacier and further down to the valley of Bhagirathi, northwest Garhwal Himalaya (Sharma and Owen, 1995). Their studies based on optical stimulated dates of 18Ka the Bhagirathi glacial episodes correlates with the last glacial elsewhere in the Himalaya and throughout the world. Evidence of long-term glacier fluctuations in Lahul-Spiti Himalaya (Owen *et al.*, 1995, 1996) is attributed to an increase in aridity throughout the Quaternary due either to global climatic change or uplift of Pir Panjal ranges to the south of Lahul which restricted the northward penetration of south Asian summer monsoon.

Glacio-climatic investigations of Tibetan Plateau (Lehmkuhl and Liu, 1994; Wang, *et al.*, 1995) reveal some information on extent of ice at the Last Glacial Maxima (LGM) and their implications for constructing the palaeomonsoon. According to Kuhle (1987, 1990), the whole of the Tibetan Plateau was covered by a single ice sheet. However, his view on extent of Pleistocene glaciation of Tibetan Plateau is not acceptable by many workers.

5. Ice core Investigations

Analysis of physical and chemical characteristics developed from ice cores provide high resolution and direct view of palaeo-atmosphere of the time scales of decades to hundreds and in many cases to thousands of years. Over Indian as well as central Asian region ice core palaeo-climatic investigation is limited compared to the wide scale studies in the polar regions. Glacio-chemical analysis on vast areas of central Asia (Wake *et al.*, 1993, 1994) indicates that glaciers adjacent to large arid regions (such as those of the northern and western margins of the Tibetan Plateau) contain high concentration of ions and dust particles due to incoming strong dust flow from nearby sources. Glaciers more distance from dust source regions show intermediate levels of major ions and dust, while southern slope glaciers of eastern Himalaya are relatively free from the influence of desert dust. These dust free ice records may have good potential associated with inter-annual and longer scale variability of Indian and Plateau monsoons. Ladakh Himalaya ice cores (Mayewski *et al.* 1983; 1984) indicate significant shift in chemical composition of monsoon water on seasonal to multi-annual scale. Short-term climatic and environmental information since last 2000 years have been derived from isotopic and chemical studies of five glaciers in the Indian Himalaya (Nijampurkar *et al.*, 1982,1985; Nijampurkar amd Bhandari, 1984; Nijampurkar and Rao, 1992).

The $\delta^{18}O$ series and concentration of micro-particles analysed from ice core studies of Dunde Cap, northeastern margin of Tibetan Plateau (Thomson *et al.* 1989) indicates the climatic condition during Holocene and Late Glacial Stage. They suggested colder and wetter climate of Late Glacial Stage than Holocene period as revealed from more negative $\delta^{18}O$ ratio, increased dust content and decreased soluble aerosol concentration during Late Glacial Stage. The transition period is marked by decreasing dust particle content, less negative $\delta^{18}O$ ratios and higher concentration of aerosol around 10,000 years ago. During early Holocene, the region experienced less precipitation. Little Ice Age was not as cold as expected. The period AD 1000 to 1200 was found to be coldest from the study of couple of ice cores over Tibetan Plateau (Thomson *et al.* 1995; Yao *et al.*, 1995).

6. Long-Term Climate Change: Multiproxy Studies

Monsoon, a component of global circulation system, have been a dominant part of the climate over the Indian subcontinent since geological times. Palaeoclimatic records over the region and simulations with climate models show four monsoon maxima occurring during interglacial conditions over the past 1,50,000 years. These maxima are believed to be due to orbitally-produced solar radiation changes and glacier boundary condition changes (Prell and Kutzbach, 1987).

Physical and Chemical characteristics of lake sediments, ocean sediments, peats, loess and speleothem are potential proxies which offer important information on long-term climate variability of Holocene and beyond. Holocene variations in monsoon rainfall over northwest India have been discussed by Bryson and Swain, 1981; Swain *et al*, 1983; Singh *et al.* 1990 using pollen sequences and lake level data. Hyper-arid condition was observed from Last Glacial Maxima (LGM) to c. 13,000 years BP. This dry climate might be due to low precipitation of summer monsoon and higher winter precipitation than that at present (Singh *et al*, 1990). They also pointed out that the cause of such situation might be because the westerly circulation moved farther south along with weak summer monsoon circulation. Studies of Van Campo *et al.* 1982 of deep sea cores from Arabian Sea also indicated weak monsoon circulation during LGM. Early Holocene (c. 9300-7500 years BP) monsoon precipitation indicates increasing trend and mean annual precipitation during the mid-Holocene (c. 7500-6000 years BP) was about double the modern value (Swain *et al.* 1983; Singh *et al.* 1990). The intensity of monsoon as well as winter precipitation declined after c. 6500 year BP. A decreasing trend continued till further to present level.

Similar patterns of LGM climate have been shown by Sukumar *et al.*(1993) using $\delta^{13}C$ measurements in peat from Nilgiri Hills, southern India. The changes in vegetation type revealed from the $\delta^{13}C$ series corresponds to a specific climate regime. Predominance of tropical grass type vegetation during 20-16 K-years BP clearly indicates a very arid phase during LGM as this type of vegetation grow favourably under low aridity and low soil moisture. This also points to a period of weak southwest summer monsoon during LGM. Spreading of dicotyledonous forest and temperate grass around 11 K-years BP may be the cause of strengthening of summer monsoon circulation. The data also indicate dry condition around 6000 years BP.

The palaeoclimate of the Himalaya on different time scales has been studied by various workers (De Terra and Paterson, 1939; Morris, 1938; Zeuner, 1972; Singh and Agrawal, 1976; Agrawal, 1985; Agrawal *et al.* 1989; Bhattacharyya, 1989). The north-west Himalaya and Kashmir valley received particular attention and were studied using different techniques like lithostratigraphy, magnetostratigraphy, palaeobotanical data, pollen evidences, diatom studies and stable isotopic ratios. Some clues from vertebrates from the sediments were also used to frame the Cenozoic climatic changes of the region. The climatic record of Kashmir valley for the past four million years is well preserved in the Karewa sediments, having an estimated thickness of 1000 meters. Most of the exposures of the Karewas in the valley were fully mapped and their mutual correlations were studied. A reasonable chronological framework of these sequences is now available, having a satisfactory convergence between the different climatic parameters within the limitations of the dating resolution (Agrawal *et al.*, 1989). Up to 3.8 M years BP the climate seems to be warm temperate. From 3.7 to 2.6 M years BP, there was a transition from a sub-tropical type of climate to a cool temperate type, and with some variation in precipitation, cool temperate until 2.2 M years BP. Between 0.6 and 0.3 M years BP, there were three relatively long cold periods. This evidence is based mainly on pollen but is supported by stable isotopic and faunal data. Loesses are unstratified, homogeneous, porous calcareous silt generally wind deposited in periglacial environment and represent cold arid conditions. Palaeosols or buried past soils are generally indicative of warm and humid climate. These loess-palaeosol layers are very good continental palaeoclimatic indicators. These deposits provide climatic information of past 2,00,000 years. There are evidences of 10 palaeosols during this period, out of which 3 palaeosols show greater weathering and may therefore reflect warmer/humid conditions compared to the others. Between 10,000 years BP and present, the pollen profiles show a cold temperate-warm temperate-cool temperate cycle. However, a warming of the valley is indicated around 17,000 years BP.

Recent study of Mazari (1995) based on bog, lake and fluvial sediments in the Spiti valley, Western Himalaya indicate warm and moist phase at 6880 ± 45, 5390 ± 95 and 3150 ± 05 year BP. Around 990 ± 70 and 460 ± 210 years BP, similar patterns were observed. Cold and dry phases occurrred mostly in the intervening time in the mid-Holocene, and also around 1830 ± 140 and 300 years BP. In the valley, human settlements thrived only during periods of climatic amelioration. Around c.18,000 years BP there was an Upper Palaeolithic culture; at c.5000 years BP, Neolithic cultures; at c.1800 years BP a Kushana culture; and at c.1000 years BP historical dynasties (Agrawal *et al.*, 1989). On the whole, the climatic pattern of Kashmir and western part of the Himalaya follows a global trend: the warming up of the Pliocene, the glacial and interglacial oscillations of the Pleistocene etc. However, the Pleistocene cooling was not abrupt but very gradual (Agrawal, 1985).

Palaeoclimatic studies in the central part of the Himalayan ranges, comprising the Nepal Himalaya and Tibetan plateau, have been carried out by Fort (1985) using the analysis of sedimentary and geomorphic data. He concluded that, on the northern side of the Nepal Himalayan Range, warm and alternatively dry/humid climates of late Cenozoic period (~10 myr BP) were progressively replaced by cold climates, which lead to the development of glaciation. Occurrence of first glacial remnants took place fairly late, around middle Pleistocene (1 M years BP), at a time when the range reached an altitude high enough to lie above the snow line. Increasing dryness of this Tibetan side is due to the range uplifting, still active, blocking the advance of monsoon moisture. On the southern side of the Nepal Himalaya, warm climates prevailed all the time, but slight nuances occurred due to rising (temperate tendency) and proximity to relief (increasing contrasts). Rapid strengthening of summer monsoonal circulation was observed around 10-9.5 K years ago from multiproxy data from two lakes of western Tibet (Gasse *et al.*, 1991; Fontes *et al.*, 1993) resulting wet-warm conditions which is further changed to long-term aridity around 4.3 K years ago.

7. Discussion and Conclusions

The palaeoclimatic information based on solar radiation changes induced by orbital variations, changes in glacial boundary conditions to high resolution dendroclimatic investigations and historical evidences give broad inferences about the past climatic condition on different time scales since Cenozoic era to recent past. The studies indicate the occurrence of four monsoon maxima during the interglacial conditions over the past 150 K years

BP. Oxygen isotope studies of Arabian sea sediment cores has indicated lower salinity and weak upwelling roughly during the interglacial phase. Few palynological studies from Karewa sediments of Kashmir and western part of Himalaya follow the global trend. Pollen sequences from the lake-beds of northwest India suggest a cold and dry period with weak monsoon activity during the recent glacial maxima with a peak around 18 K years BP. The signal of glacial-interglacial phases in the northern latitudes have also shown good relationship with the over all monsoon flow. Cold periods of the climatic history have winter like circulation, whereas, warm periods are characterised by a strong summer monsoon flow. A general inferences on climate of Holocene period (10 K years BP) drawn from various proxy sources indicate warm humid climate with frequent floods during 10 to 4.5 K years BP over the northern regions of the subcontinent. However, $\delta^{18}O$ series in ice cores of Tibetan Plateau indicates cold and wet climate of last glacial phase, whereas, less precipitation occurred during early Holocene. Little Ice Age period over Plateau was not as cold as expected.

Historical evidences are also found to be an important source of past climatic information. A systematic analysis of Chinese historical documents gives broad information of temperature variation since mid-Holocene period. Indian historical records are mostly indicative of drought/ flood events, which provide long history of thousand years of drought occurrence. The Asian region has a wide potential source of historical evidences. Systematic and collective efforts are needed to elaborate the possibility of extracting climate related information from many other parts of the region to achieve a broad scenario of climate variability.

High resolution dendroclimatic reconstruction from different parts of Asia give annual to decadal and century scale variations of climate in the recent past. This is an excellent tool to extend instrumental record backward in time for the past few centuries. The pre-monsoon climate of western Himalaya, since mid-eighteenth century reconstructed using wide network of tree-ring chronologies do not show any significant effect of Little Ice Age over the region. Thomson *et al.* (1995) and Yao *et al.* (1995) also indicated similar results from the ice core analysis of Tibetan Plateau that the Little Ice Age was not as cold as expected. Indian summer monsoon rainfall since A.D. 1602 experiences similar characteristics of high inter-annual variability and epochal low-frequency variations as that of instrumental series of Indian summer monsoon rainfall.

Studies based on General Circulation Models (GCM) give better understanding of past monsoon variability and its relationship to various forcing factors (Bryson, 1989; Rind and Overpeck, 1993). The role of Tibetan Plateau in relation to monsoon circulation is very important. The uplift of Tibetan Plateau has led to the evolution of a complex monsoon circulation pattern (Ruddiman and Kutzbach, 1987). Some GCM studies indicate the major role of astronomical forcing in Asian monsoon variability (Kutzbach and Street-Perrott, 1985; Prell and Kutzbach, 1987; Clemens and Oglexby, 1992; Wasson, 1995). Climate model analysis of Hansen *et al.*, (1988) and Meehl and Washington, (1993) indicate that the Tibetan Plateau is likely to warm significantly in response to elevated atmospheric trace gases concentration and this could give rise to stronger summer monsoonal circulation.

Modeling of climate variability on inter-decadal to century time scale is a major research area in the field of climatology. The shortness of instrumental climate records that cover the past 100 years at most, make the study difficult. In the Himalayan/ Tibetan Plateau region the problem is more severe due to lack of long instrumental records. A well dated high resolution palaeoclimatic data offer a means of extending the climate record back in time.

For better understanding of climate variability at different time scales it is important to expand the geographical coverage of palaeoclimatic records. The sources of these records include tree-rings, ice-cores, speleothems, historical records and lake-sediments. By understanding the past monsoonal variability and its relationship to various forcing functions, it is possible to improve our fundamental understanding of the dynamics of the systems. This will be helpful to develop more reliable predictive models of Asian monsoon variability.

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