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# LONG RANGE FORECASTING OF ONSET OF DROUGHT CONDITIONS IN TROPICS AND SUBTROPICS

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## PREFACE

Tropical and sub-tropical droughts have a devastating effect on food production and economy of the nations. Therefore, the prediction of droughts, well in advance, is of considerable practical value for wide range of interests, especially for agriculture and hydro-electric power production. As droughts do not occur all of a sudden and are the ultimate consequences of a set of prevailing weather sequences, their probability for occurrence can be predicted with some confidence. A number of attempts have been made in this direction by many workers in the recent past.

The National Institute of Hydrology established the Atmospheric Land Surface Modelling Division in 1986 with the major objective of carrying out studies and research on coupled atmosphere-land surface processes. In the present report an attempt has been made to review the long range forecasting of onset of drought conditions based on teleconnection and links with various meterological parameters.

The report has been prepared by Dr. Divya, Scientist 'B' and Shri M.K. Sharma, Research Assistant, in the Atmospheric Land Surface Modelling Division.

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## ABSTRACT

Droughts of great magnitude in various tropical and sub-tropical regions have been a matter of concern in the recent past. Their socio-economic consequences have resulted in the studies and research on predicting the droughts well in advance. The long range prediction of droughts has been based on the analysis of various meteorological events that usually prevail before the drought occurs.

The present note deals with the long range forecasting of onset of drought conditions in tropics and subtropics with special emphasis on forecasting of Indian monsoon, the ill distributed rainfall accompanying which results in droughts over different parts of India. The meteorological conditions in tropics and subtropics have been emphasised in the note and the physical linkages of various parameters as atmospheric circulations, surface temperature, sea surface pressure and temperature, El Niño and Southern Oscillation, sunspot cycles and snow cover with drought conditions have been discussed. The techniques applied in long range forecasting of rainfall in tropics, specially in India have been reviewed.

# 1.0 INTRODUCTION

Droughts result from scanty and ill-distributed rainfall and form one of the serious natural calamities which frequently inflict some part or the other of the world. Deficient rainfall causes havoc in many ways to people and livestock affecting adversely the agricultural production and resulting in lowering of water levels in reservoirs as well as in hydro-electric dams and underground water. Sometimes a drought may be so severe that famine may ensue.

The intensity of drought depends upon the magnitude of moisture deficit which is triggered by failure of rains. The nature of drought depends upon the amount and distribution of rainfall and its matching with the water need. The droughts may be classified in three broad types - meteorological, hydrological and agricultural. Meteorological drought occurs when there is a significant (more than 25%) decrease from normal precipitation over an area. This drought, if prolonged, results in hydrological drought with marked depletion of surface water and consequent drying up of reservoirs, lakes, streams/rivers, cessation of spring flows and fall in ground-water levels. An agricultural drought occurs when soil moisture and rainfall are inadequate during the growing season to support healthy crop growth to maturity, and cause extreme crop excess and wilt.

Landsberg (1974) summarising the global research work on droughts pointed that no radical one sided trends or well defined cycles of rainfall can be identified to enable forecasting of droughts. Droughts do not occur all of a sudden as floods do, but are usually the ultimate results of a set of weather sequences that require extended periods of time to develop (Linsley et al, 1959). There exist tele-connections and link of drought conditions with features as atmospheric circulations , surface temperatures, sea surface temperature, sunspot cycles and snow cover. Based upon these pnysical quantities long range forecasts, valid for periods longer than seven days-a month, a season or even more, are made.

Droughts of great magnitude are common in many tropical regions. The occurrence of droughts in various tropical regions during the recent past and their severe socio-economic consequences have led to efforts and studies in predicting the droughts of great magnitudes in tropical regions well in advance. In tropical regions, the spatial and temporal variations of Indian climate have specially drawn the attention of the researchers throughout the globe. An extensive work has also been carried out on long range prediction of Indian monsoon as linked with various meteorological parameters.

In the recent years evidences for global warming due to increasing concentrations of greenhouse gases have been found. The global warming is likely to have impacat on meteorological parameters, which in turn, are expected to cause major changes in hydrological cycle. The frequency of droughts may (though the certainty is not yet clear) also change as a consequence of global warming.

In the present note, a review has been carried out on physical linkages of different parameters as atmospheric circulations, sea surface temperatures, ENSO, sunspot cycle, and snow cover with drought conditions in tropics and sub-storpics with special reference to India. The techniques applied in long range forecasting of rainfall in India have also been dealt with. Special emphasis has been given to the possibility of alteration in frequency of droughts due to strengthening of greenhouse effect.

## 2.0 REVIEW

### 2.1 Meteorological Conditions in Tropics/Subtropics

The latitude domain of the tropics and sub tropics is taken in a generous sense in meteorology. Delimitation by tropics of cancer and capricorn has astronomical meaning and for meteorological purposes $30^{o}$ N and $30^{o}$S are considered as approximate boundaries of the tropics. However, no rigid limits are applied. The subtropics are transitional in climatic character between tropics and middle latitudes, lying approximately between $25^{o}$ to $40^{o}$ on both sides of the equator. It borders the tropics on its equatorward side and contacts the temperate group on its poleward frontier.

Research on the tropics in the past decade has developed an increasing appreciation of the large time and space scales and has turned its focus on the dynamics of the climate. The broad pattern of climates of the earth is, in large measure, determined by general circulation of the atmosphere (Fig.1). The surface air rising from the region of strong solar heating - the doldrums, which is a belt of weak horizontal pressure gradient within equatorial region, flows both north ward and south ward towards poles. This wind at high levels is turned to the right in the northern hemisphere and to the left in the southern hemisphere reaching a maximum speed at an average latitudes of $30^{o}$ and is known as subtropical jet streams. At about $30^{o}$ latitudes, in the region known as horse latitudes, it subsides having cooled by its journey northward and southward and splits into two currents, one

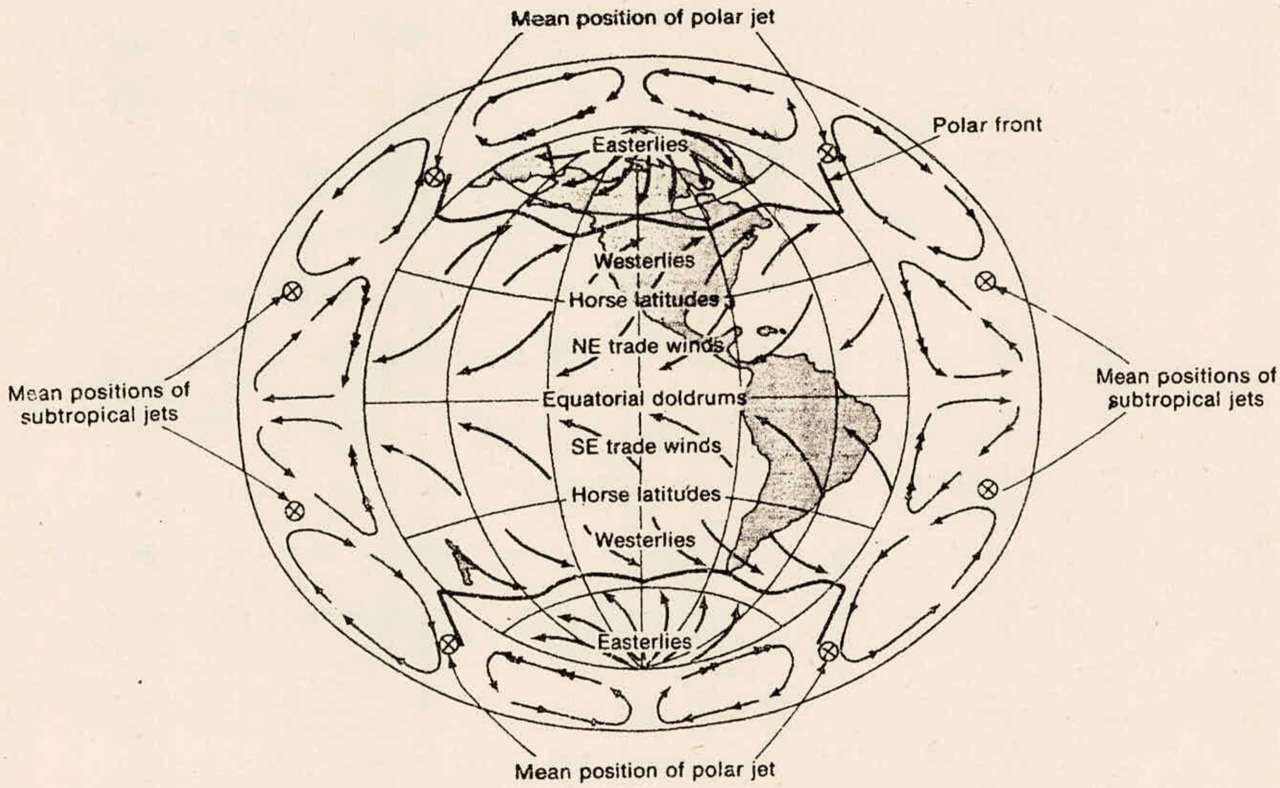


Fig. 1: Schematic representation of the general circulation of the atmosphere

moving southward as the northeast trade winds in the northern hemisphere (northward as south east trade winds in the southern hemisphere) and the second continuing north eastward (southeast ward in the sourthern hemisphere). The trade winds from both hemisphere converge into the equatorial trough, the intertropical convergence zone (ITCZ). The descending air at horse latitudes moves poleward at low levels but the flow is deflected by coriolis force. The winds have a westerly component and are known as westerlies. As the warm poleward moving air reaches a latitude of $40^0$ to $60^0$ it encounters a cold flow from the pole and as a result a boundary known as the 'polar front' is formed between the two masses of air. Poleward of the polar front are the polar easterlies which bring the cold arctic and antarctic air from the polar regions towards the polar front.

Thus, two primary zones of rising air and hence the principal areas of precipitation in the tropics and in the regions of the polar front are observed. Complementing these regions are the zones of descending air and hence relatively light precipitation - in the horse latitudes and near the poles. It has already been noted that the major deserts of the world are found in horse latitude.

Precipitation is unevenly distributed in most parts of the earth throughout the year. The seasonal variation of precipitation can be traced ultimately to the seasonal differences in the heating of the atmosphere. The latitudinal shifting of the one of maximum heating and the accompanying

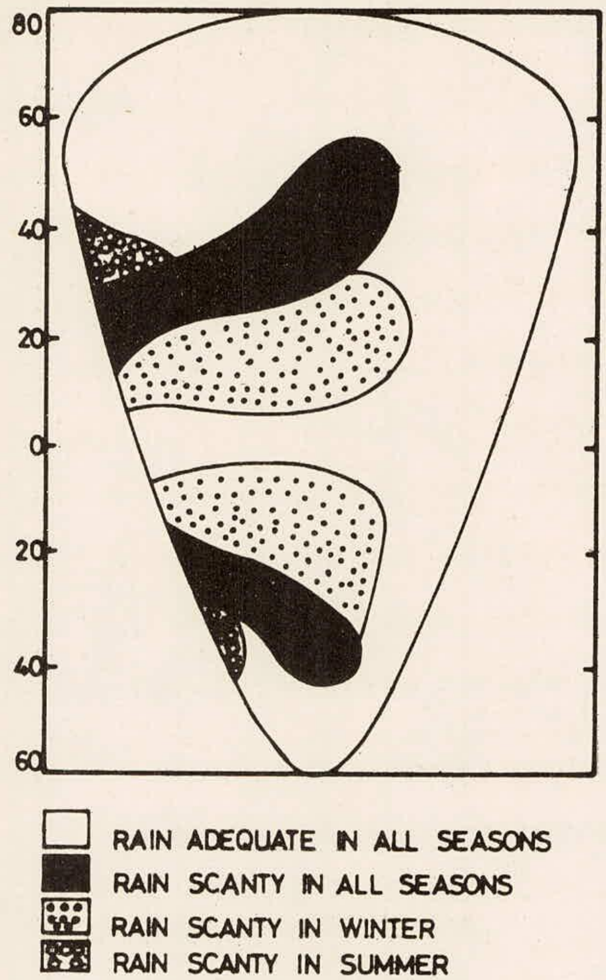


Fig.2: Broad aspects of seasonal precipitation on the hypothetical continent.

migration of the zonal wind belts has a major influence on the seasonal march of precipitation. The broad aspects of seasonal character of precipitation on the hypothetical continent are shown in Fig. 2.

The equatorial latitudes and the entire eastern portion of the continent have rainfall in all seasons. In the western and central part of the continent, on either side of the tropical wet area, are the regions with high-sun (summer) rains or winter dry regime. Poleward of the winter dry regime are the areas which have scanty rainfall in all seasons and on the west side of the continent towards the pole of winter dry region are the small regions where the summer are dry but winters have adequate rains.

Table-1 shows the system of climatic groups and climatic types for tropics and subtropics.

Table-1: CLIMATIC GROUPS AND CLIMATIC TYPES FOR TROPICS AND SUBTROPICS

| Groups of climate | Types of climate | Pressure system and wind belt (Summer | Winter) | Precipitation |
|---|---|---|---|---|
| Tropical humid | Tropical wet | ITC, doldrums, equatorial westerlies | ITC, doldrums, equatorial westerlies | Not over two dry months |
| | Tropical wet and dry | ITC, doldrums, equatorial westerlies | Driertrades | High-sunwet (Zenithal rains low-sun dry) |
| Sub-tropical | Subtropical dry summer | Subtropical high (stable east side) | Westerlies | Summer drought winter rain |
| | Subtropical humid | Subtropical high (unstable) west side) | Westerlies | Rain in all seasons |

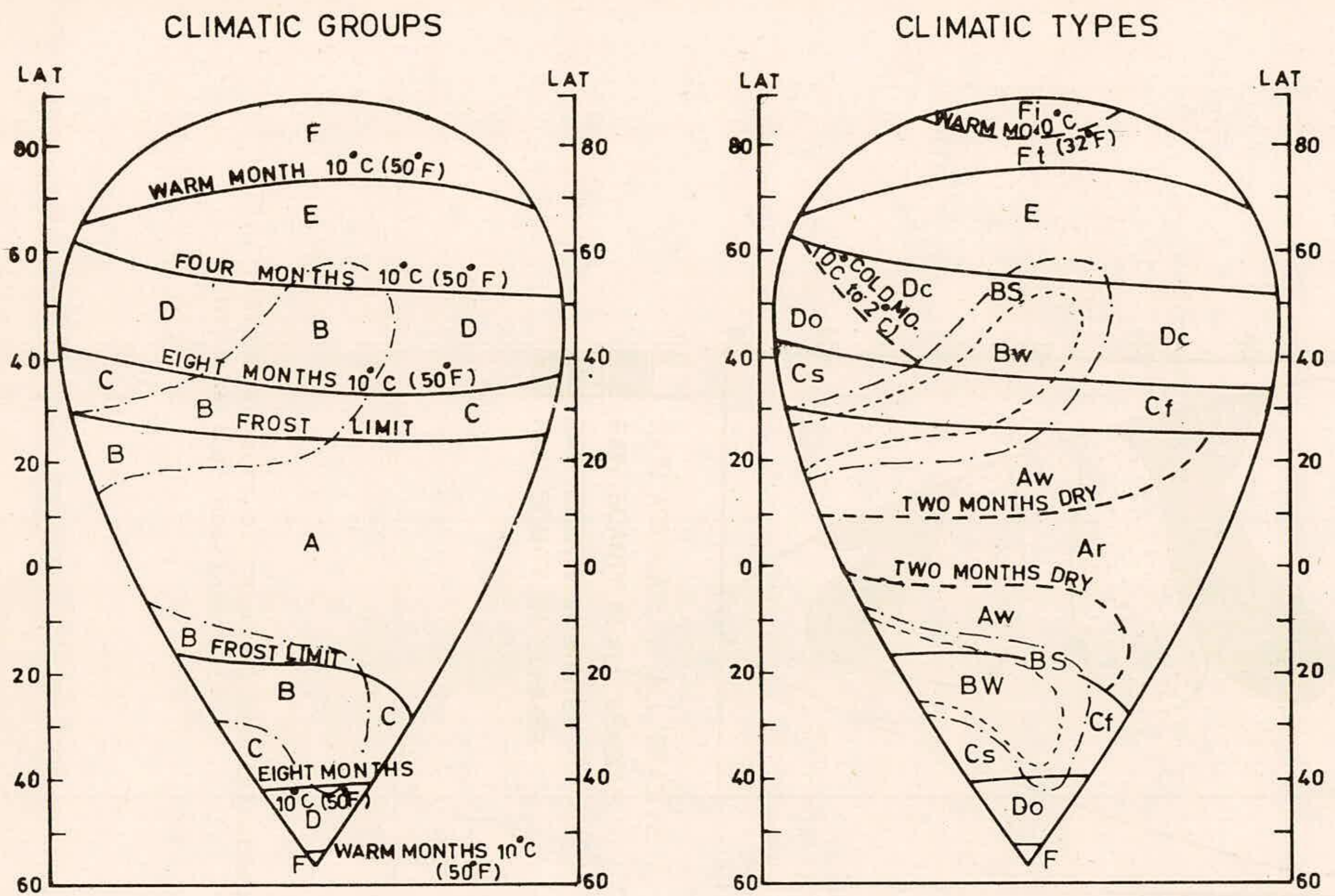


Fig.3: Climatic groups and types on a hypothetical continent. (Trewartha and Horn, 1980). The abbreviations are defined as follows -

A-tropical, Ar-tropical wet, Aw-tropical wet and dry
C-subtropical; Cs-substropical dry summer, Cf-subtropical humid
D-temperate, Do-oceanic, Dc-continental
E-Boreal
F-Polar; Ft-tundra, Fi-ice cap
B-Dry; Bs-semi-arid, Bw-arid.

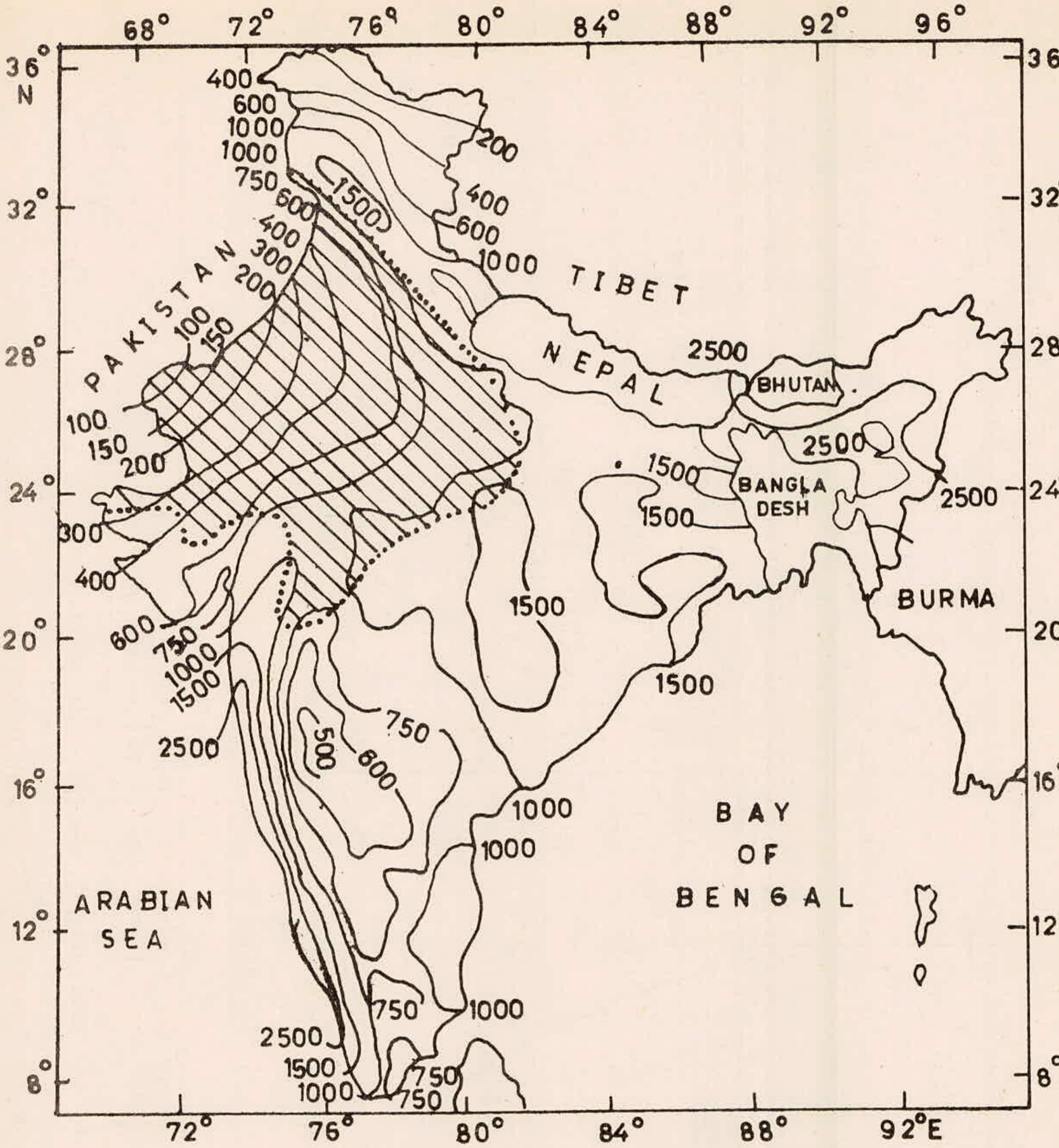


Fig.4: Annual isohyetal map of India (shaded region shows the annual temperature range of more than 48 °C.)

The tropical atmosphere is characterised by high temperature and abundant moisture content. It has no frost. Within this group two main types of climate are identified (Fig.3)- tropical wet climate with a wet season of 10 to 12 months in length and the tropical wet and dry type with predominantly zenithal or summer rains and low sun dry season of over 2 months. The tropical wet type coincides well with the ITC equatorial trough and equatorial westerlies. The tropical wet and dry type is alternately under the influence of ITC - equatorial westerlies during high sun and of dry trades and subtropical anticyclone during low sun.

The subtropical climate is characterised by sub tropical dry summer typically situated on the western side and subtropical humid on the eastern side of the continent. The three main features of this climate are: 1) a concentration of the year's modest amount of precipitation in winter season, while summers are dry 2) warm to hot summers and unusually mild winters and 3) abundant sunshine and meager cloudiness, especially in summer.

In the tropical region, the problem of trends and periodicity in Indian climate has received special attention of the scientists all over the globe. The most spectacular feature of the Indian climate is the summer monsoon which provides about 75% to 90% of rainfall from June to September. Fig. 4 depicts the annual isohyetal map of India. The rainfall during non-monsoon months is associated with the westerly system entering the region. The extreme land sea thermal contrast that prevails during the season profoundly influences the pressure distribution and as a result a semi-permanent low pressure system reaching over Pakistan and adjoining areas, controls the atmospheric circulation driving the moist air from the southern hemisphere into the northern hemisphere.

Many investigators have studied the relations between Indian monsoon rainfall and El Niño, Southern Oscillation phenomena (ENSO), suggesting the existence of link between them (Sikka, 1980, Pant and Parthasarathy, 1981, Bhalme et al, 1983; Rasmusson and Carpenter, 1983, Shukla and Paolino, 1983; Mooley and Parthasarathy, 1983). Cadet and Diehl (1984), studying the long term interannual variability of the surface fields over the Indian ocean found the fluctuations of different surface parameters related to the activity of the summer monsoon.

## 2.2 Physical Linkages of Various Parameters with Drought Conditions

There exists inter annual variability in the combined atmosphere-hydrosphere system which results in changes of

atmospheric and oceanic circulation and extreme events - especially rainfall anomalies-leading to droughts or foods in regional areas. With circulation changes and regional climate anomalies are associa. 1 the large-scale long term surface pressure seesaws between key regions of the tropics which are related to rainfall and temperature fluctuations.

Links between the Himalayan snow cover and the onset of summer monsoon in India has also been reported in literature (Blanford, 1884; Hahn and Shukla, 1976; Dickson, 1984; Dey and Kathuria, 1986).

The earliest climate prediction efforts in the tropics were made in India (Blanford, 1884). Livezey and Jemison (1977), Nicholls (1980) and Preisendorfer and Mobley (1982) reviewed the limited success of long range forecasting in the mid-latitudes. Charney and Shukla (1981) suggested that climatic variability in the tropics should be morepredictable because it is in large part due to slowly varying anomalies of the lower boundary of the atmosphere. However, Nicholls', (1980) comprehensive review is still unable to quote climate prediction work proper for the tropics. Major break throughs in this direction were achieved in the early 1980's.

### 2.2.1 Mid and Upper Troposheric and Lower Stratospheric Circulations:

The most important process for droughts formation is a large scale interlatitudinal air exchange, where the transformation of air moving from higher to lower latitudes is characterised by intensive heat flux and the lack of moisture flux. The dry warm air formed in these cases never bears rains and results in extraordinary evaporation. Being persistently involved into an anticyclonic circulation this air can bring a severe drought.

Jagannathan (1960) in his comprehensive review listed the various elements/areas chosen for prediction including upper air winds between 2 and 8 km over India apparently used to a limited extent since the 1920's. He discussed the varying correlations over the decades between the various surface and upper air parameters and Indian monsoon rainfall and concluded that none of the factors show any consistent relationship. However, the forecast failures were attributed to long term changes of spatial correlations.

The drought year of 1972, when drought was spread over Africa, North India and East Europe, was characterized by anomalous circulation on a global scale by different workers (Murakami, 1975, Krishnamurti et al. 1975). Kanamitsu and Krishnamurti (1978) showed that the global tropical motion field during 1972 in the upper troposphere was quite anomalous on planetary scale. Murakami (1978) found that 200mb zonal mean flow in summer 1972 near India was exceptionally stable. The studies by Murakami (1974,1975, 1978), Krishnamurti et al.(1975) and Kanamitsu and Krishnamurti (1978) have shown that variations in the behaviour of the monsoon are simultaneously evident in the upper tropospheric thermal and circulation anomalies. If these anomalies can be found to occur before the monsoon is established, their existence would aid in the long range forecasting of monsoon activity. Verma (1980) calculated the anomalies of 300-100 mb thickness from the monthly mean values of geopotential height (gpm) at New Delhi, Bombay and Calcutta during the period from 1968 to 1977 (Fig.5).

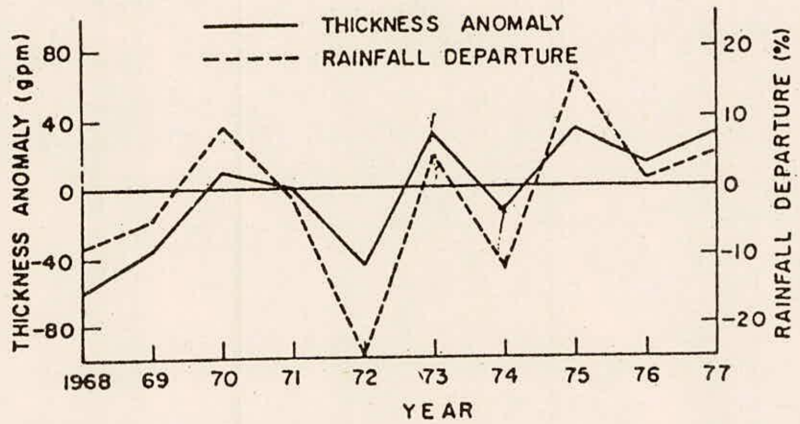


Fig. 5 - Variation of 300-100 mb thickness anomaly (gpm) averaged for New Delhi, Bombay and Calcutta for April and percentage departure of monsoon rainfall for India (Verma, 1980)

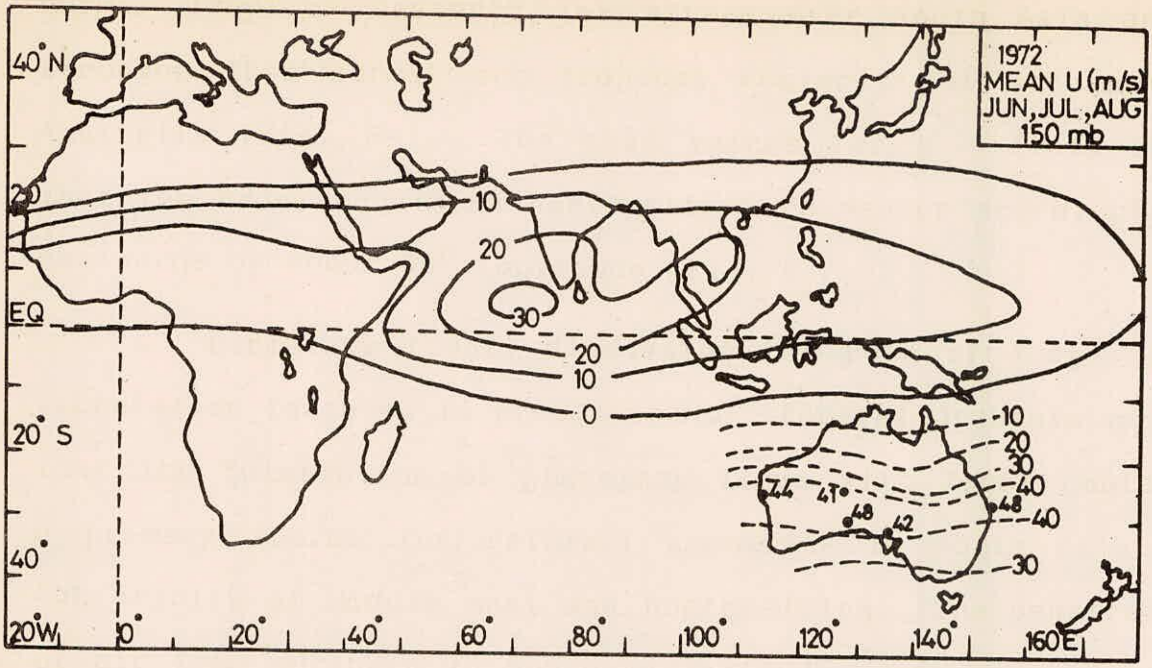


Fig. 6(a) : Mean u field for June to August, 1972
easterly u field (dashed lines show westerly field for Australia)

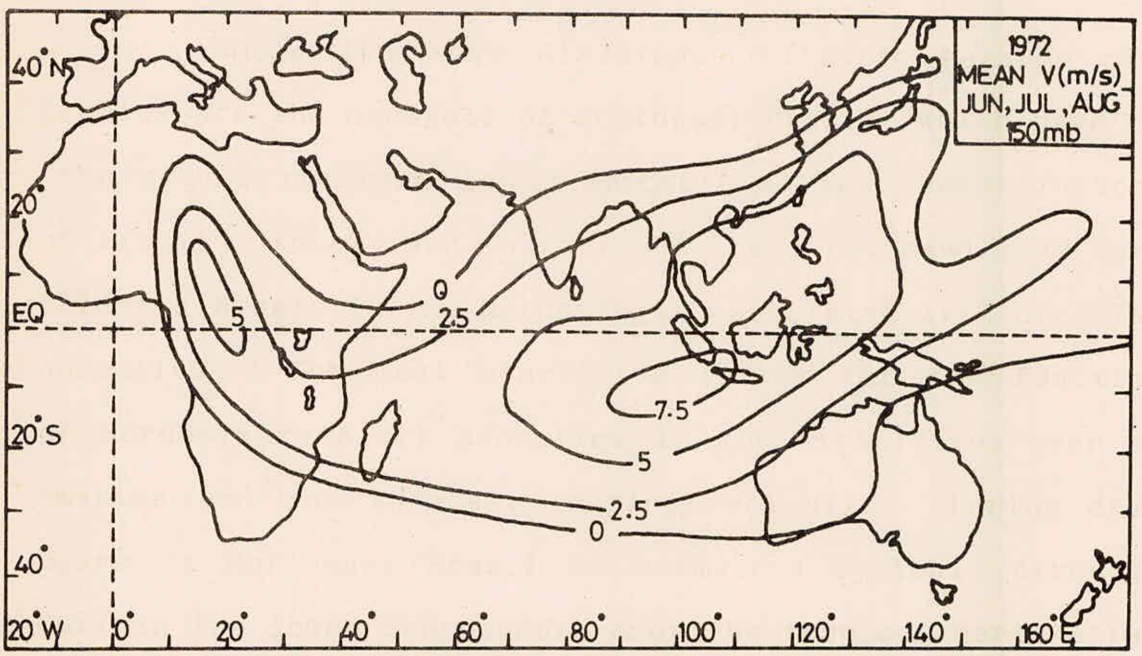


Fig. 6(b) : Mean v field for June to August, 1972;
northerly v field only (Saeed, 1983)

He concluded that a warmer (cooler) upper troposphere over northern India during the pre-monsoon period is linked with above normal (below normal) rainfall acativity during dthe ensuing summer monsoon over India.

Kung and Sharif (1980, 1982) used the April upper-air patterns in India - Australia region and sea surface temperature around India in the pre-season to forecast the Indian southwest monsoon rainfall and the onset date in Kerala. They concluded that an early onset date is heralded by low 700 mb height, high 100mb topography and temperature, strong southerly and westerly wind components at 700 mb and strong easterlies at 100 mb over Kerala. An early monsoon onset is also heralded by high 100 mb topography over Pakistan, large kinetic energy at 700 mb over North India, strong southerly 700 mb wind component over Australia and warm Arabian sea waters. Abundant, monsoon rainfall is preceded by strong 100 mb easterly and southerly wind components over the Persian Gulf, warm 200 mb conditions over New Delhi, warm ocean waters at the south tip of India and other factor from diverse regions.

Joseph et al (1981) found southerly meridional wind anomalies in the upper troposphere over India during a year of large scale drought which showed the effect of intrusion of northern hemisphere subtropical westerlies equatorwards and the consequent shift of upper tropospheric circulation features eastwards. Saeed (1983) studied the mean u and v (m/s) wind components at $15^{0}$ mb for the drought year of 1972. He found that the mean u-field at 150 mb shows a weaker than normal tropical easterly jet stream over South Asia and a stronger than normal sub tropical westerly jet stream over Australia (Fig. 6a). The mean values for v - field show that the cross equatorial northerlies are weaker and displaced eastwards by about $20^{0}$ longitude.(Fig. 6b).

Burlutsky (1982) discussing the role of large scale circulation features in prediction of tropical droughts suggested that the interaction of planetary flows with Tibet could be a primary source for rainfall anomalies in south Asia and for aridity of Middle east and north Africa. The penetration of air from northern to southern latitudes under considerable heat flux and under deficit considerable heat flux and under deficit of moisture flux leads to the aridity of climate or to the temporal lack of rainfall and droughts.

Among the most disastrous climatic hazards of the tropics are the droughts of Northeast Brazil, which have haunted the region referred to as 'Nordeste' - the easternmostcorner of Brazil. Kousky and Moura (1981) have reviewed the extreme climatic events in the Nordeste as associated with circulation anomalies. The most conclusive factor for the functioning of Nordeste rainfall anomalies is the circulation over south America and the adjacent tropical atlantic. During drought years in Northeast Brazil an anomalous cyclonic circulation cell in the lower troposphere over the tropical North Atlantic has been observed (Hastenrath, 1985). The Government of Brazil (Consello Nacional de Pesquisas, 1980) is taking an active interest in the possibility of forecasting the droughts.

A sequence of extremely dry years repeatedly in semiarid Sahel zone of west Africa, beginning in the late 1960's and persisting to 1980's, has received considerable attention and has aroused curiosity into the general circulation causes of this disaster. Kidson (1977) found a virtual disappearance of the 850 mb through near $8^{o}$N and weakening of tropical easterly jet above it. This was further confirmed by Kanamitsu and Krishnamurti (1978) for the drought year 1972. The results of Newell and Kidson (1984) showed a stronger West African mid-tropospheric jet during the periods of dry years 1970-73. Lamb's analyses (1978 a,b) also revealed the role of large scale circulation anomalies during drought years.

The seasonal forecasting for the Far east, viz. Hongkong, summer rainfall was suggested by Bell (1976 a,b,1977). There exists a negative correlation between the Irkutsk minus Tokyo pressure difference in January and the Hongkong summer (June-September) rainfall. Low/high index circulations in the early summer follow the high/low index northern hemisphere circulations in January, which in turn are associated with high/low Hongkong rainfall.

Banerjee et al (1978) found correlation between the latitudinal position of the 500 h Pa subtropical ridge acaross $75^{o}$E longitude during April and some index of summer monsoon rainfall. Since 500 h Pa level seperates two different circulation regimes of the upper and lower troposphere it may reasonably be assumed that the position of the ridges are governed by a large number of inputs of the atmosphere. Singh et al (1986) studied the relationship of the 500 h Pa subtropical ridge over the Indian and the west Pacific regions during the premonsoon and the monsoon season with the monsoon rainfall over India. They concluded that the position of the 500 h Pa ridge during April over India is the best predictive correlation with the monsoon rainfall than the northern Hemispheric surface temperature, Southern Oscillation index, Equatorial Pacific SST and EL Niño. When the position of the 500 h Pa ridge over India during April is less than $14^{O}$ N and over Pacific region is less than or equal to $12^{O}$ N, the monsoon rainfall is likely to be deficient and when the position of the ridge is more than $16^{O}$ N, there is a probability of excess rainfall.

The role of antecedent upper air conditions for monsoon rainfall is further emphasized in Thapaliyal's work - (1981,1982) where he has chosen the April latitude position of the 500mb ridge over India as the sole predictor. Fig. 7 shows the time series plots of latitude position of 500 mb ridge along $75^{O}$E over India as input and of rainfall over Indian peninsula as output.

Kruzhkova (1982) analysing the TROPEX-72 data of the tropical troposphere during the drought year 1972 suggested that the anomaly of the height of the 500 h Pa surface was a characteristic for the drought phenomenon and the conditions of atmospheric circulation in 1972, particularly in summer were significantly different from normal; the trade jet streams were shifted by 10 degrees towards the equator.

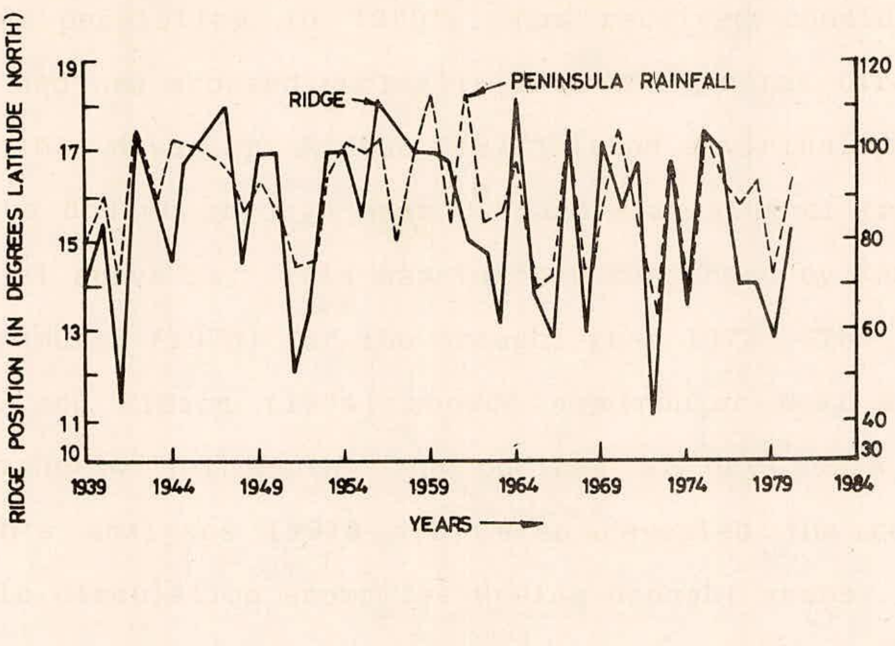


Fig.7: Latitude position of 500 mb ridge along 75°E over India and monsoon rainfall over Indian Peninsula ( Thapliyal, 1981).

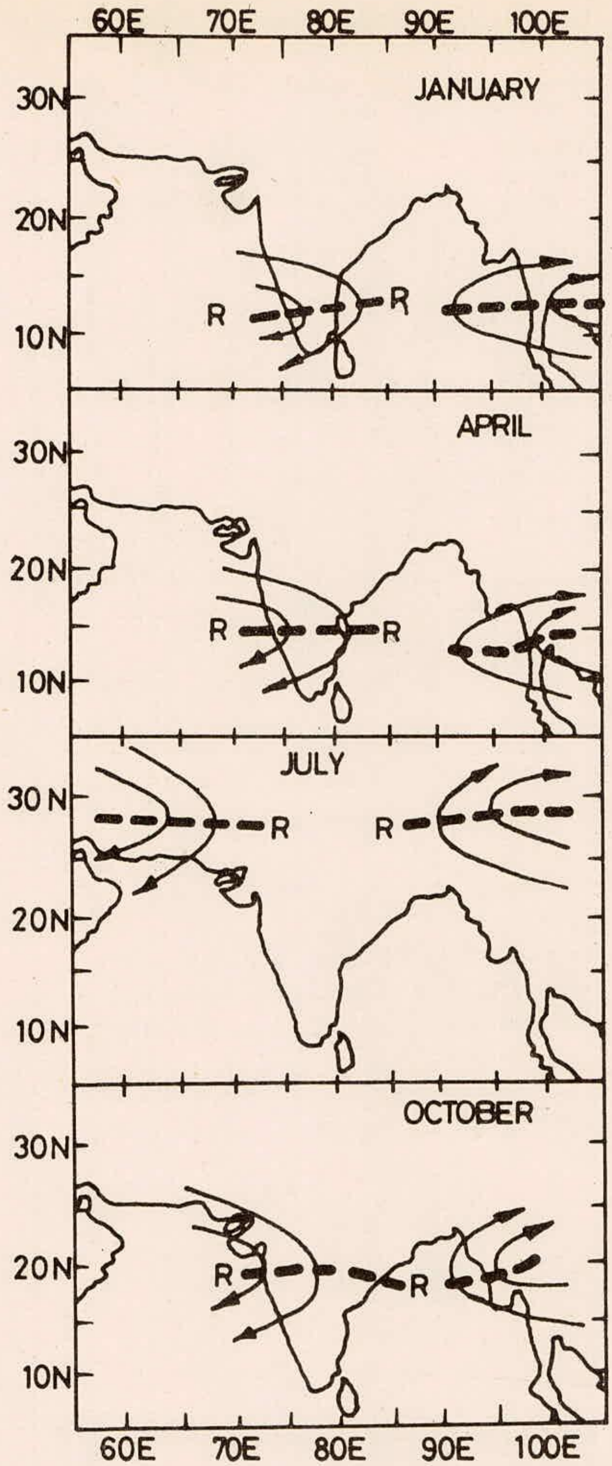


Fig.8: Monthly mean circulation and location of the ridge (R) at 500 mb during January, April , July and October ( Shukla and Mooley, 1987).

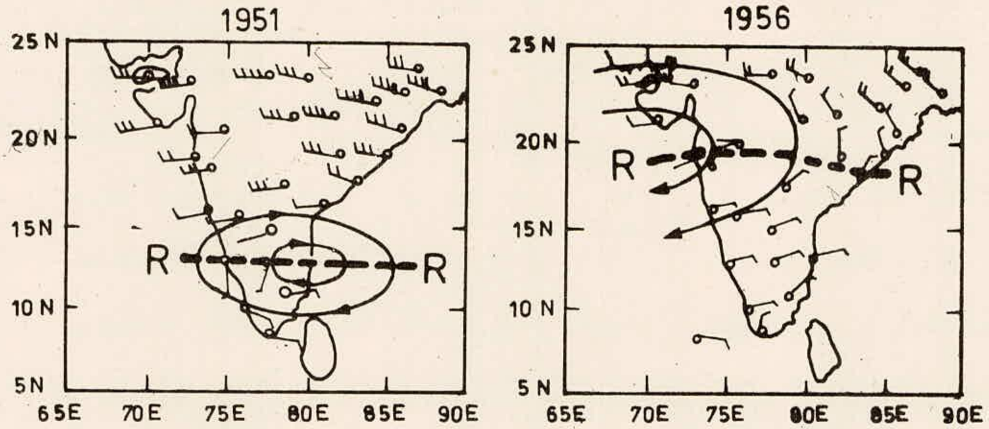


Fig.9: Monthly mean winds in April at 500 mb for the years
1951 and 1956 (Shukla and Mooley, 1987).

The location of the 500mb ridge during the months of January, April, July and October, based on average wind data for the period 1951-65 analysed by India Meteorological Department (1972) are shown in Fig.8. The positions of 500mb ridge along $75^{O}E$ in January, April, July and October are seen at about $11.5^{O}N$, $15^{O}N$, $28.5^{O}N$ (northern most limit during peak of monsoon) and $20^{O}N$ respectively. Figure 9 shows the 500 mb flow for the two years 1951 and 1956, which are characterised for deficient and excessive monsoon rainfall, respectively. The ridge along $75^{O}E$ was at about $12^{O}N$ during April 1951 whereas it was at about $17.5^{O}N$ in 1956. The earlier studies have shown that if the latitudinal position of the 500 mbridge in April is much south (north) of its normal position, the rainfall over India in ensuing monsoon is much below (above normal). Shukla and Mooley (1987) examining the position of 500 mb ridge for the months of April, May, June and July for the period 1948-67 found similar results. They found that the location of 500 mb ridge during most of the drought years was south of its normal position and the position of the ridge was north to the normal position during years with above rainfall. Table 2 shows the Indian monsoon rainfall, April 500mb ridge location along $75^{O}E$ and Darwin mean sea level pressure change from January to April (1939-84).

Studies by Raja Rao and Lakhole, (1978), Mukherjee et al. (1979), Thapliyal (1979) have produced evidence for link between the Indian monsoon and stratospheric zonal winds. Mukherjee et al (1985) using the wind data of 30 mb (24 km)

TABLE 2 : Indian monsoon rainfall, April 500-mb ridge location along 75°E and Darwin mean sea level pressure (SLP) change from January to April(1939-84)

| Year | Rainfall (mm) | Ridge (°N) | Darwin SLP change(mb) | Year | Rainfall (mm) | Ridge (°N) | Darwin SLP change(mb) |
|---|---|---|---|---|---|---|---|
| 1939 | 788.9 | 14.0 | 4.4 | 1963 | 855.2 | 13.5 | 2.6 |
| 1940 | 850.2 | 15.3 | 5.0 | 1964 | 919.9 | 18.3 | 1.8 |
| 1941 | 729.0 | 11.2 | 2.8 | 1965 | 706.8 | 14.0 | 4.9 |
| 1942 | 958.3 | 17.5 | 1.8 | 1966 | 735.2 | 13.5 | 2.4 |
| 1943 | 866.1 | 16.0 | 2.5 | 1967 | 858.6 | 17.5 | 5.7 |
| 1944 | 921.3 | 14.5 | 3.0 | 1968 | 753.7 | 12.5 | 5.6 |
| 1945 | 907.3 | 16.7 | 3.8 | 1969 | 829.3 | 17.3 | 5.1 |
| 1946 | 901.3 | 17.3 | 4.1 | 1970 | 939.4 | 15.8 | 1.8 |
| 1947 | 942.3 | 18.0 | 2.1 | 1971 | 885.8 | 16.7 | 2.2 |
| 1948 | 872.4 | 14.5 | 1.7 | 1972 | 653.2 | 11.0 | 4.8 |
| 1949 | 901.8 | 17.0 | 2.8 | 1973 | 911.6 | 16.7 | 1.7 |
| 1950 | 874.9 | 17.0 | 3.0 | 1974 | 746.9 | 13.5 | 4.8 |
| 1951 | 736.9 | 12.0 | 4.1 | 1975 | 960.1 | 17.5 | 1.3 |
| 1952 | 791.7 | 13.5 | 3.6 | 1976 | 854.7 | 17.0 | 4.8 |
| 1953 | 919.7 | 17.0 | 2.0 | 1977 | 880.5 | 14.0 | 3.4 |
| 1954 | 885.3 | 16.5 | 2.8 | 1978 | 908.0 | 14.0 | 1.9 |
| 1955 | 929.9 | 15.5 | 0.6 | 1979 | 746.0 | 12.5 | 3.7 |
| 1956 | 979.5 | 17.5 | 3.5 | 1980 | 881.0 | 15.0 | 3.8 |
| 1957 | 784.3 | 16.0 | 3.0 | 1981 | 842.0 | 17.0 | 4.8 |
| 1958 | 886.3 | 17.0 | 0.4 | 1982 | 736.0 | 11.3 | 3.8 |
| 1959 | 938.1 | 16.0 | 2.8 | 1983 | 959.0 | 14.5 | 0.3 |
| 1960 | 839.4 | 16.7 | 2.0 | 1984 | 835.0 | 14.8 | 3.0 |
| 1961 | 1017.0 | 15.0 | 1.8 | | | | |
| 1962 | 806.9 | 14.8 | 4.7 | Mean | 857.1 | 15.3 | 3.0 |
| | | | | Std dev | 82.2 | 2.0 | 1.3 |

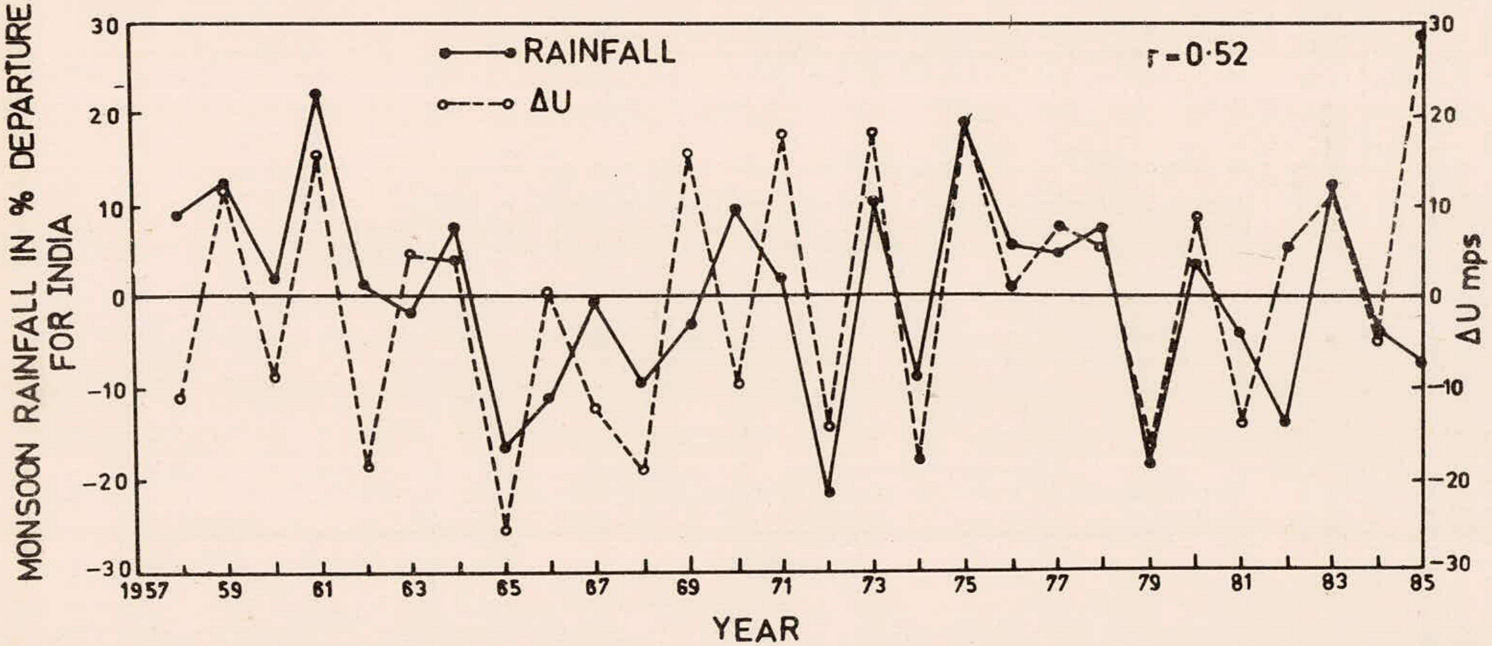


Fig. 10 - The monsoon rainfall for India and the zonal wind anomaly ( Δ U mps) in preceding January for 10mb at Balboa for 1958-85 (Bhalme et al., 1987)

for Balboa ($9^{o}$N, $80^{o}$W) found that during the easterly phase of the zonal wind (June-August) the monsoonal rainfall over India tends to become less than normal. Bhalme et al (1987) examined the zonal wind anamoly at Balboa for 10 mb (30 km) and its correlation with Indian monsoon rainfall. They found that all of the flood years (1959, 1961, 1973, 1975 and 1983) occurred during westerly wind anomalies and 4 out of 5 drought years (1965, 1966, 1972, 1979 with the exception of 1982) occurred during easterly wind anomalies (Fig. 10). The near absence of a drought (flood) year during a westerly (easterly) zonal wind anomaly for January at 10 mb suggested that these anomalies can be used for prediction of non-occurrence of a drought (flood) year for India.

2.2.2 Sea Surface Pressure and Southern Oscillation:

Hildebrandsson (1897) noted an inverse pressure variation between South eastern Australia and Southern South America, which was followed by the work of Lockyer and Lockyer (1902) who had further confirmed the pressure see-saw between Indian ocean and Argentina. Walker (1923, 1924) motivated by the above publications and by his predecessor Sir John Eliot, Head of the India Meteorological Department, who had noted an association between high pressure over Mauritius and Australia and droughts over India, made a comprehensive study of the distant correlations. He recognized three major long term surface pressure see-saws and denoted them by Northern Oscillations (North Atlantic and North Pacific Oscillations) and the Southern Oscillation. Walker and Bliss (1932) found

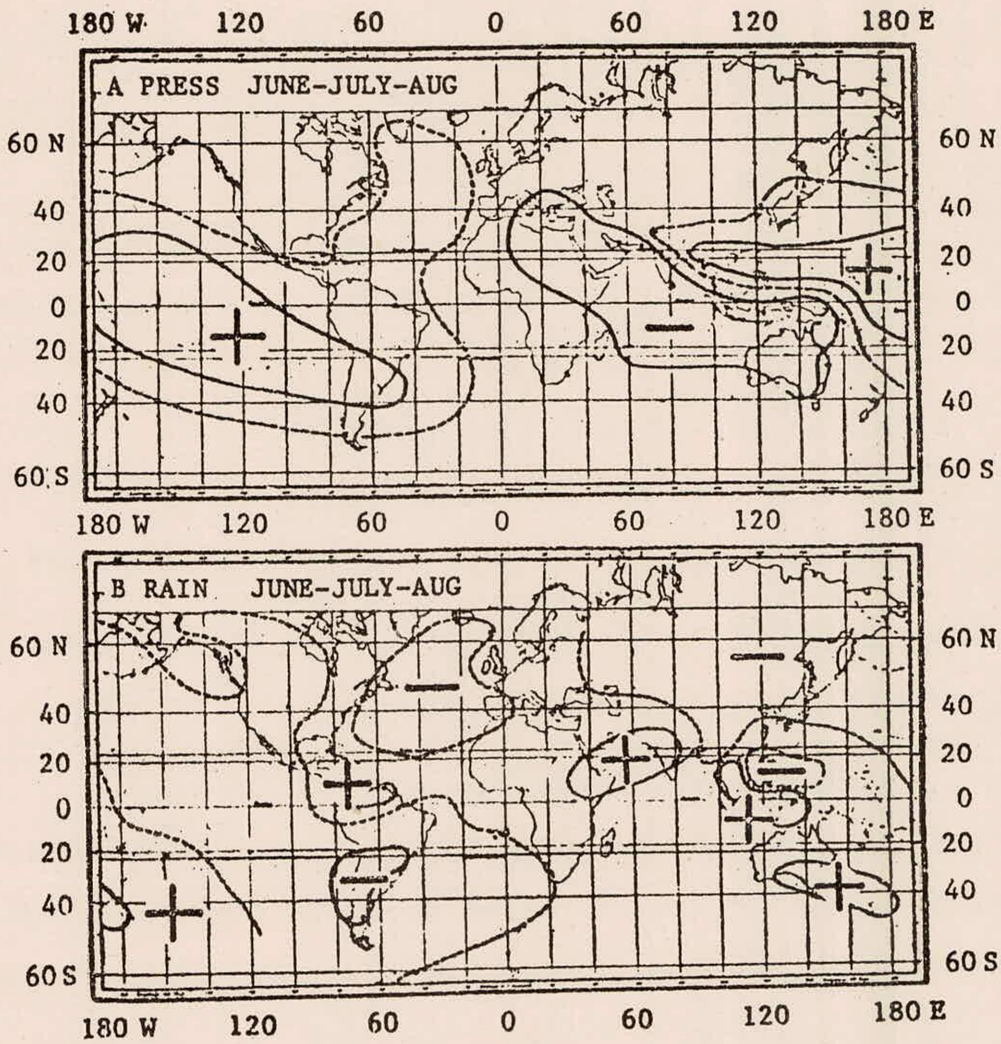


Fig. 11 - Global maps of Southern Oscillations (SO) during June, July and August showing the correlation coefficients between SO index and, a) pressure;b) rainfall (Walker and Bliss, 1932)

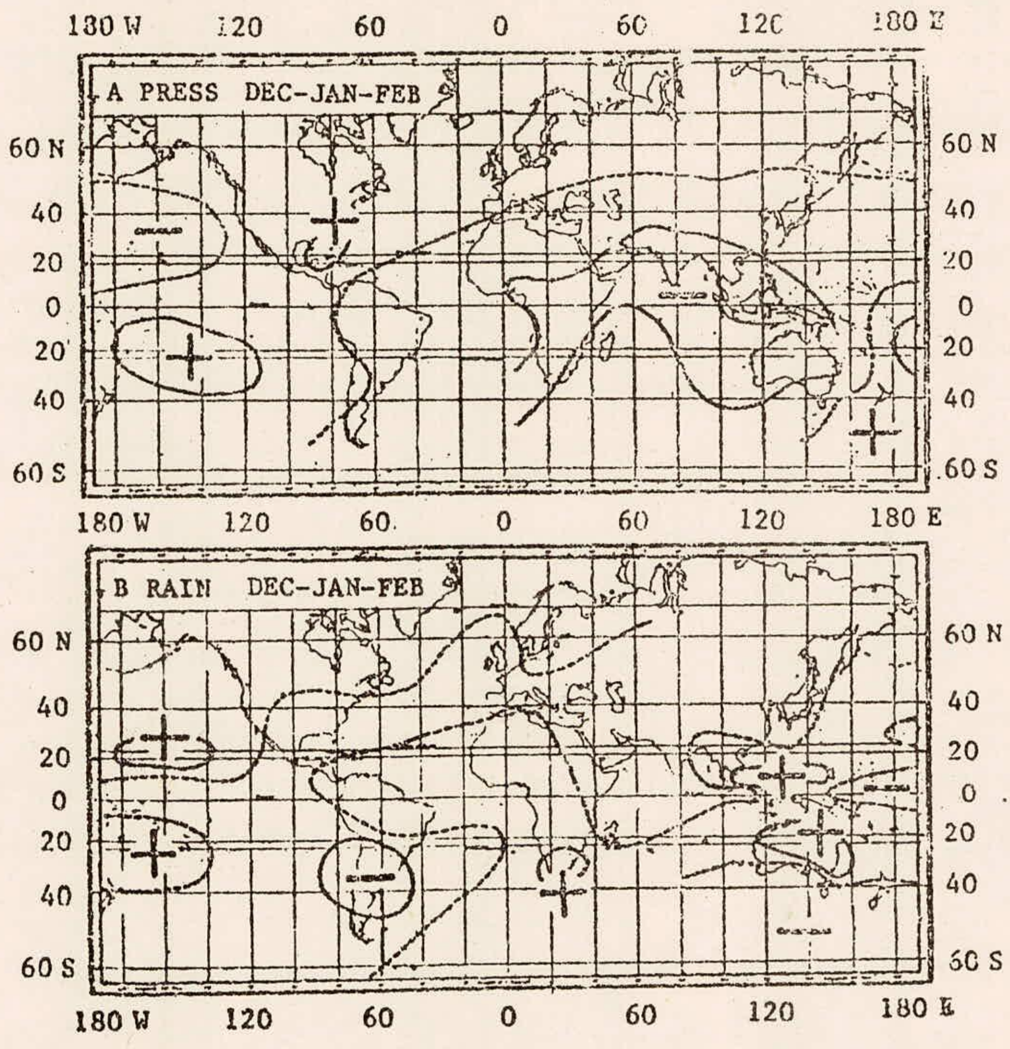


Fig. 12 - Global maps of Southern Oscillations (SO) during December, January, and February showing the correlation coefficients between SO index and, a) pressure;b) rainfall (Walker and Bliss, 1932).

that, when the pressure is high in the Pacific Ocean it tends to below in the Indian ocean from Africa to Australia. This tendency is termed as the Southern Oscillation. This is another ,most significant circulation feature besides the tropospheric circulation which has relationship with the monsoon rainfall. The rainfall varies in oposite direction to the pressure (Fig. 11). Conditions are relatively different in summer and winter (Fig. 12). Walker and Bliss (1932) calculated the index of Southern Oscillation as (Satiago Pressure) + (Honolulu pressure) + (India rain) + (Nile flood) + 0.7 (Manila pressure) - 0.7 (Darwin pressure) - 0.7 (Chile rain) and then found the correlation coefficient of this index with pressure temperature and rain.

Walker and Bliss pursued their studies of the Southern Oscillation with a practical motivation of seasonal forecasting. However, for decades thereafter little attention was given to Southern Oscillation problem. Research into the Southern Oscillation was resumed by Berlage (1957, 1966), Troup (1965), Schove and Berlage (1965), Bjerknes (1966, 1969). Berlage (1957,1966) also found the inverse relation between the air pressure in eastern south Pacific and the greater Australasian region. He called attention for the first time to the tendency of EL Niño events (to be discussed later) to coincide with the phase of the Southern Oscillation and found with some arbitrariness that the periodicity in the operation of the Southern Oscillation represents a typical time scale of 1-5 years. The Southern Oscillation was found by many workers to have an irregular period anything from 1 to 6 years usually averaging between 2 and 3 years (Wright, 1975, Trenberth 1976, Julian and Chervin, 1978).

Southern Oscillation involves both atmosphere and Ocean. The causes for the pressure see-saw in the lower atmosphere resulting in Southern Oscillation - which is instrumental in the alteration of the zonal wind field, are still not well understood. However, its role in climate anomalies in many tropical regions is more obvious. The pressure see saw in south Pacific Ocean and the equatorial Indian ocean are related to the strength of the equatorial zonal east-west circulation in the Pacific ocean called the Walker circulation by Bjerknes (1969). In this zonal circulation the ascending air over Indonesia and descending air in the east Pacific gives rise to surface easterlies and upper westerlies over most of the equatorial Pacific (Krishnamurti, 1971; Krishnamurti et al; 1973, Wright, 1975). The strength of the Walker circulation depends upon the surface water temperature of the equatorial east Pacific Ocean. Wright (1975) found that a weak Walker circulation is associated with a warmer, wetter weather in the equatorial east Pacific and relatively dry conditions in the Indian ocean. With a strong Walker circulation there is a tendency for cloudy, rainy conditions in Indonesia, east Australia and India and dry conditions in the equatorial east Pacific. The Southern oscillation is manifest in many important meteorological variables as, pressure, temperature, wind moisture, cloudiness and rainfall. An extensive survey of literature on the Southern Oscillation has been made by Julian and Cherwin (1978).

The Southern Oscillation Index - a parameter used for prediction of monsoon rainfall in the recent past, has been computed using different combinations of stations by various researchers. As mentioned earlier, Walker (1924) used the index of Southern Oscillation based on the combination of pressure, temperature and rainfall. Troup (1965) refined this index retaining station pressure only and Berlage (1957) used the pressure at Jakarta. The index was derived from a principal component analysis of pressure at several widely spaced stations by Kidson (1975), Wright (1975) and Trenberth (1976), Chen (1982) and Rasmusson (1983) considered the Tahiti minus Darwin pressure as the index of Southern Oscillation. Shukla and Paolino (1983) found that the temporal persistence of Southern Oscillation is highly variable during different seasons, the seasonal auto-correlation being lowest from winter to spring followed by spring to summer. However, its value during the spring season for years of severe droughts is not significantly different from the values of years of heavy monsoon rains. As the correlation coefficient between the Southern Oscillation and the monsoon rainfall is not high, Shukla and Paolino (1983) suggested that the tendency or the phase of Southern Oscillation would be a better predictor than the amplitude. They found that the correlation between a Southern Oscillation index (Darwin Pressure) during spring and monsoon rainfall over India for 81 years period was -0.32.

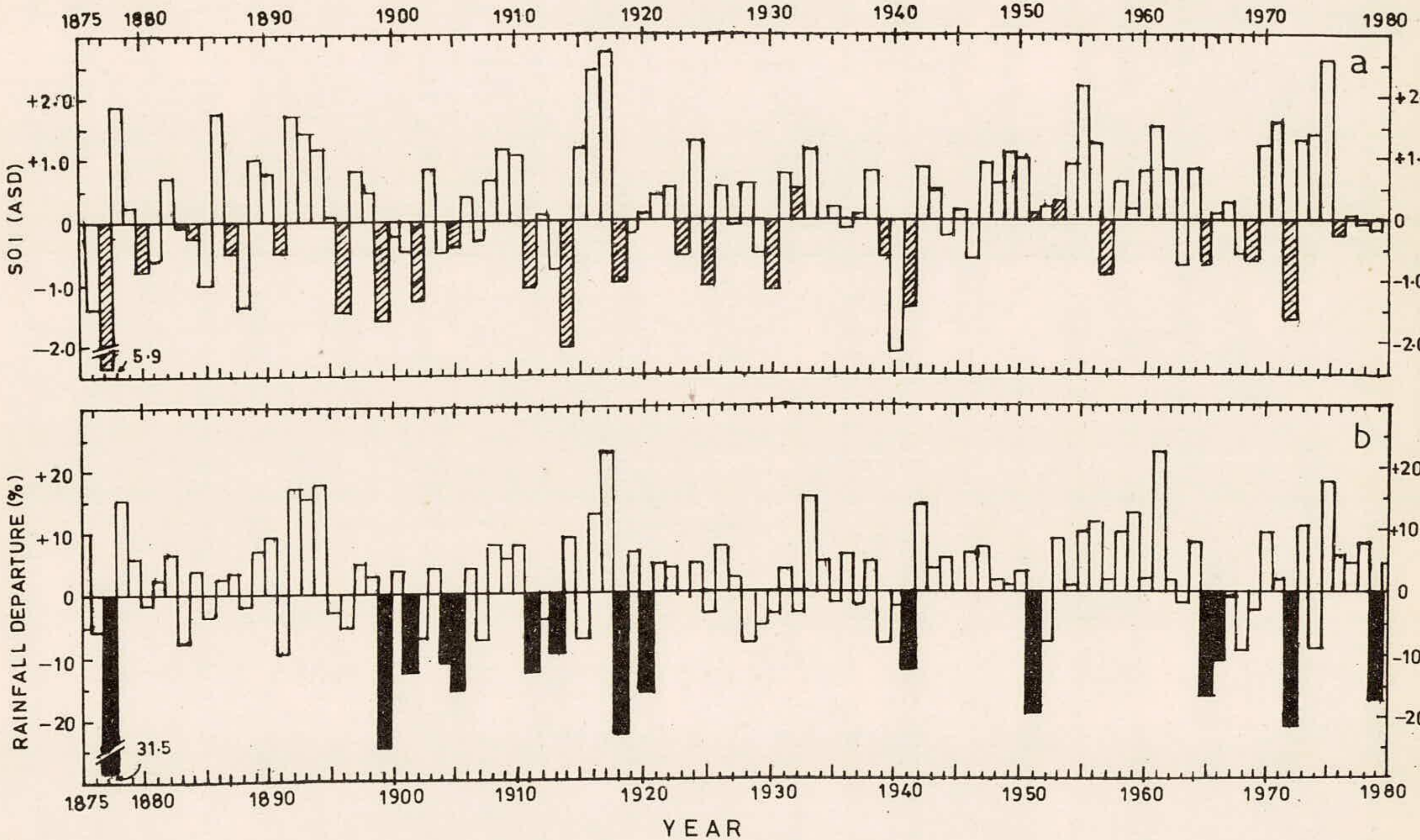


Fig.13: a) The Southern Oscillation index (SOI) for ASO season and El Nino events (stippled pillars) for 1875-1980, b) percentage departure of monsoon rainfall with identified drought years ( shaded pillars) over India ( Bhalme and Jadhav, 1984).

whereas the tendency of the Southern Oscillation (Spring) (March, April and May) (MAM) minus winter (December, January and February) (DJF) sea level pressure for Darwin showed a correlation of --0.46.

Bhalme and Jadhav (1984) analysed the data of 106 years (1875-1980) to find the correlation between the Southern Oscillation index and the monsoon rainfall over India. They found a good agreement between the years of droughts (floods) and large negative (positive) values of the Southern Oscillation index for ASO (August, September, October) season(Fig. 13). They found that 12 of the 15 (80%) droughts occurred during the years of negative Southern Oscillation index.

### 2.2.3 Sea Surface Temperature (SST) and El Niño

In the average annual cycle sea surface temperature of the east and central tropical Pacific off the coast of Peru rises to a maximum around March and April, but in certain years the annual march is greatly enhanced giving rise to a phenomenon known as 'El Niño'. The term refers to the 'Christ child' and reflects the idea that the anomalous warming tends to begin around Christmas time. The El Niño event in the tropical Pacific is recognized as part of natural variability of the coupled ocean-atmosphere system. El Niño is a natural catastrophe as during its occurrence the ecology of the coastal environment is severely disturbed and the coastal areas of Ecuador and, northern Peru suffer under torrential rains. Figure 14 shows the marked interannual variability of SST along the Ecuador Peru coast. The onset

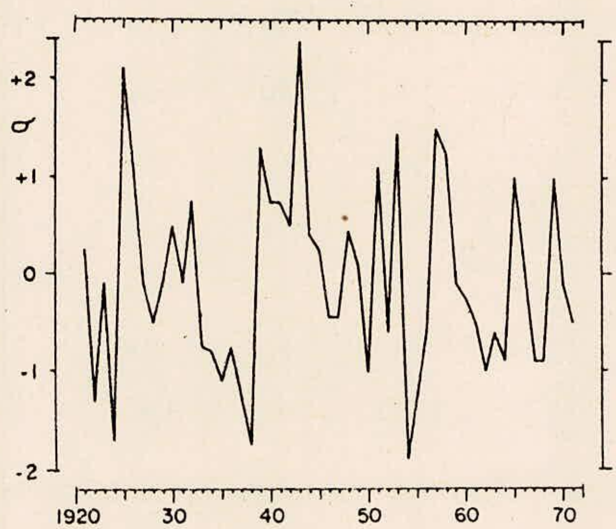


Fig. 14 - Normalised departures o1 mean sea surface temperature along the Ecuador/ Peru Coast ( = 0.8 C) (Covey and Hastenrath, 1978)

years of El Niño type events since the early century are listed in Table 3 (Rasmusson, 1984).

TABLE - 3 ONSET YEARS OF EL NIÑO EVENTS

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1726 | 1821 | 1852 | 1875 | 1896 | 1923 | 1944 | 1972 |
| 1728 | 1824 | 1854 | 1877 | 1899 | 1925 | 1946 | 1973 |
| 1763 | 1828 | 1855 | 1878 | 1900 | 1926 | 1948 | 1975 |
| 1770 | 1829 | 1857 | 1880 | 1902 | 1929 | 1951 | 1976 |
| 1791 | 1832 | 1862 | 1884 | 1905 | 1930 | 1953 | 1982 |
| 1803 | 1837 | 1864 | 1885 | 1911 | 1932 | 1957 | 1983 |
| 1804 | 1844 | 1866 | 1887 | 1912 | 1939 | 1958 | |
| 1814 | 1845 | 1868 | 1888 | 1914 | 1940 | 1963 | |
| 1817 | 1846 | 1871 | 1889 | 1917 | 1941 | 1965 | |
| 1819 | 1850 | 1873 | 1891 | 1919 | 1943 | 1969 | |

The El Niño event is closely related with the planetary scale pressure see saw between the equatorial eastern Pacific and the Indian ocean or the southern oscillation. Hastenrath and Wu (1982) analysed 37 long term upper air stations, numerous surface land stations and ship observations throughout the tropics. They found that the surface pressure in the greater Indonesian region varies inversely to the Eastern to Central South Pacific and broadly parallel with sea surface temperature along the Ecuador/Peru coast. 200 mb variations are more nearly in phase throughout the tropics, but are particularly large over the Eastern to Central South Pacific (Fig. 15).

During the August, September, October (ASO) and November,

Fig. 15(a) - Location map of stations reffered in Fig. 15(b) TA - Tahiti, S-Singapore, E-Equador/Peru

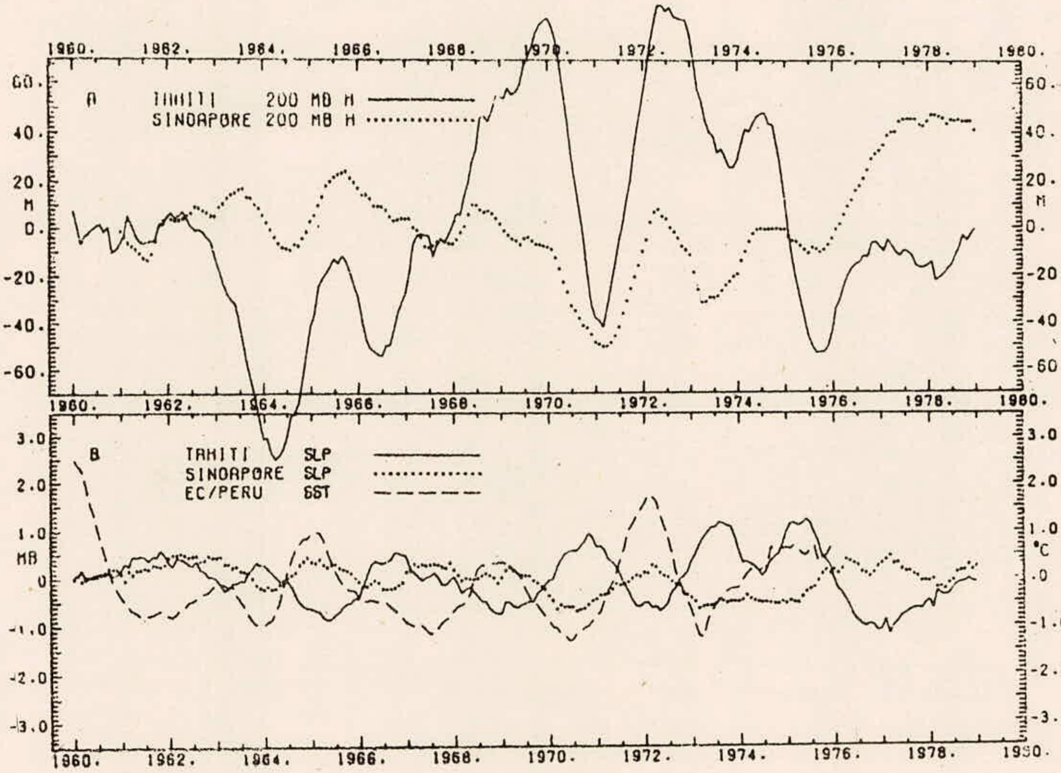


Fig. 15(b) - Annual mean plots of a) 200 mb height variation b) surface pressure and surface temperature variations (Hastenrath and Wu, 1982)

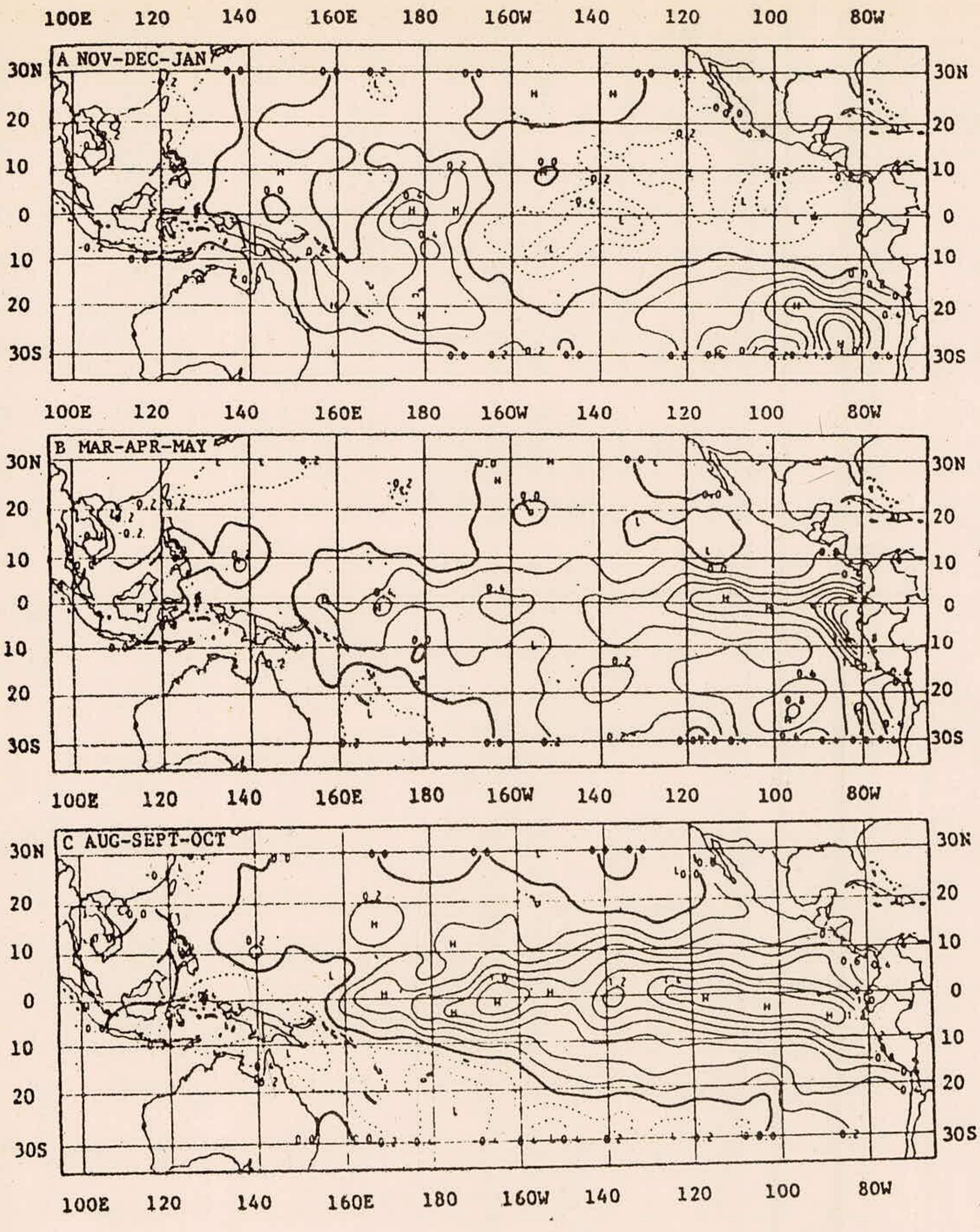


Fig. 16 - Sea surface temperature anomaly ($^{O}$C) pattern of the canonical El Nino during a) NDJ, Preceding b) MAM, peak c) ASO, after El Nino peak, Rasmusson and Carpenter (1982)

December, January (NDJ)(Fig. 16) preceding the El Niño peak, most of the eastern equatorial Pacific is anomalously cold, while the Southern tropical south Pacific and the Western Equatorial Pacific have the positive SST anomalies with a maxima off the Peru coast. During the March, April, May (MAM) peak phase of the El Nino year most of the Eastern tropical Pacific is anomalously warm with maximum departures off the Peru coast and in a band extending from there into the equatorial region of the Eastern Pacific. During the August, September, October following the peak phase of El Nino, pronounced positive sea surface temperature anomalies prevail in the entire equatorial Pacific from the Americas to well west of the dateline. The warm water anomalies spread to the open ocean in a band to the south or near the East Pacific equator and the largest departures are no longer found off the Peru coast.

Many workers have related the El Niño and Southern Oscillation (ENSO) to interannual variability in the tropics (Wyrtki, 1975; Mc Creary, 1976; Quinn et.al. 1978; Tong and Weisberg,1984; Bhalme, 1985; Shukla and Wallace, 1985).

Angell (1981) found a strong relationship between the monsoon rainfall and the equatorial sea surface temperature (SST) anomalies in the following winter, but Rasmusson and Carpenter (1983) showed that the equatorial Pacific SST anomalies have a long life cycle and, since these anomalies are observed even before the monsoon season they can be a potential predictor for the monsoon rainfall. Shukla and Paolino (1983) also observed a close relationship between the El Niño, the Southern Oscillation and the Asiatic summer monsoon.

Palmer and Brankovic (1989) linked the 1988 US drought with the anomalous sea surface temperature. During 1987 there was a moderate El Niño event and in 1988, the conditions in the tropical east Pacific began to swing towards the opposite, 'anti El Niño or Laniña', phase of the event where SST bacame anomalously negative. The anomalous SSTs in 1987 dand 1988 were important in accounting for the reduction in rainfall over the United States in the late spring of 1988. The work of Palmer and Brankovic (1989) was based on the studies by Trenberth et al. (1988), who attributed the drought mainly to the arrival of exceptionally cold water in the tropical Pacific (La Niña) in the aftermath of the warm El Niño event of 1987. Namias (1989) also supported the findings of Trenberth et al. (1988) and Palmer and Brankovic (1989).

2.2.4 Sunspot Cycles and Solar Activity:

The possible relationships between sunspots solar activity and climate were a subject of study soon after the discovery of the 11-year cycle in sunspots by Schwabe in 1843. Sunspots are the temporary dark regions on the surface of the sun, which are associated with strong magnetic activity. The solar activity is the collective name for all types of variations in the appearance or energy output of the sun. The basic measure of solar activity is the number of sunspots visible on the surface of the sun at a given time; more the spots, more active is the sun. Due to wide fluctuations in the daily number of sunspots, the level of solar activity is expressed in terms of monthly or annual mean values. Though the annual mean values of sunspot are known to show a marked and persistent oscillation of approximately 11-years period with alternate maxima of high and moderate intensity, the true length of the cycle is 22 years. The 22-years cycle is supposed to arise as a result of the alternate changes in the polarity of the leading sunspot in a given solar hemisphere in successive 11 year cycles. This 22-year quasi cycle of sunspot activity is often termed as the double sunspot cycle or the Hale sunspot cycle.

Many workers have found indications of an 11-year cycle in several meteorological variables as temperature, Precipitation, pressure and other parameters (Xanthakis, 1973, King, 1973; Jagannathan and Bhalame, 1973, Curic, 1974; Shapley et al.,1975; Shapley and Krochl, 1977; Bhalme et al., 1979). Evidence has also been found for a 22 year cycle in several meteorological and climatic variables (Willett, 1965; Spar and Mayer, 1973; King, 1975; Roberts, 1975; Dicke , 1979) Mitchell et al. (1979) found evidence of a 22 year cycle in an index of area affected by drought, west of Mississipi river in the United States and suggested that the drought cycle is related to the Hale sunspot cycle. Mitchells results show that the risk of widespread drought west of the Mississipi river is higher in the years following a Hale sunspot minimum than it is at other times during the Hale cycle.

Blanford (1877), Hill (1879), Pogson (1879) and Walker (1915) studied the correlation between the sunspot cycles and excess or deficient rainfall in India. Hill (1879) and Pogson (1879) found linkages between the sunspot cycle and the rainfall. But Blandford (1877) and Walker (1915) suggested that there is no evident relation between rainfall and sunspot. Research in this field was discouraged for a long time because of the conclusion that solar variation had no linkages with the rainfall distribution.

A striking inverse relationship between sunspot cycle and days of excessive heavy precipitation over Tamil Nadu during the Northeast monsoon in the period 1906-1955 was found by Sen Gupta (1957) (Fig. 17). He found in contrast to the previous workers that the drought conditions often approached during sunspot maximum. Koteswaram and Alvi (1969) examining the SW monsoon rainfall of west coast station in India, found that the rainfall series at Trivendrum and Cochin are in opposite phase to sunspots from 1910 to 1940 (Fig. 18).

The studies by Bhalme and Mooley (1979) led to the conclusion that there is a statistically significant tendency of severe or worse drought to occur in the years following the sunspot maximum (Fig. 19). Bhalme and Mooley (1980, 1981) provided convincing evidence of about 22-year cycle in the fluctuations of an objectively defined flood

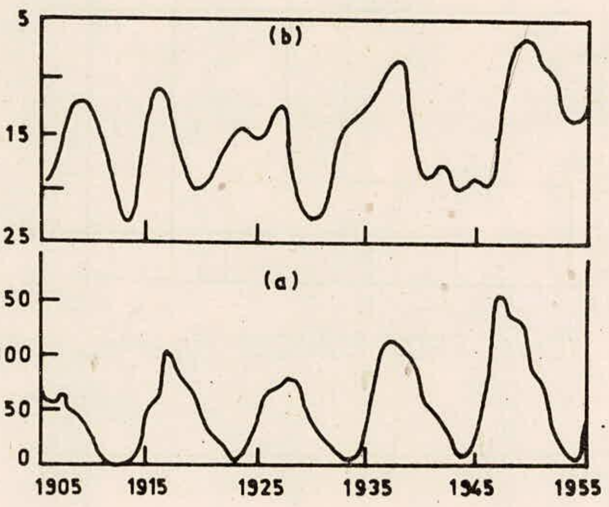


Fig. 17(a) Sunspot number, b) variation of excess daily rainfall over Tamil Nadu state, the reversed ordinate shows the number of days with daily rainfall double the normal value or more, for the period 1906-1955 (Sen Gupta, 1957)

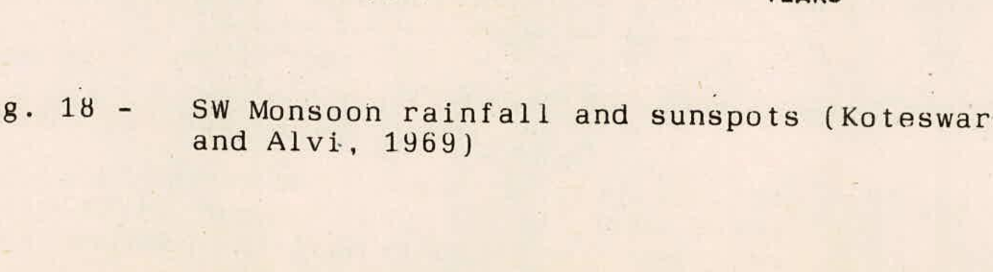


Fig. 18 - SW Monsoon rainfall and sunspots (Koteswaran and Alvi, 1969)

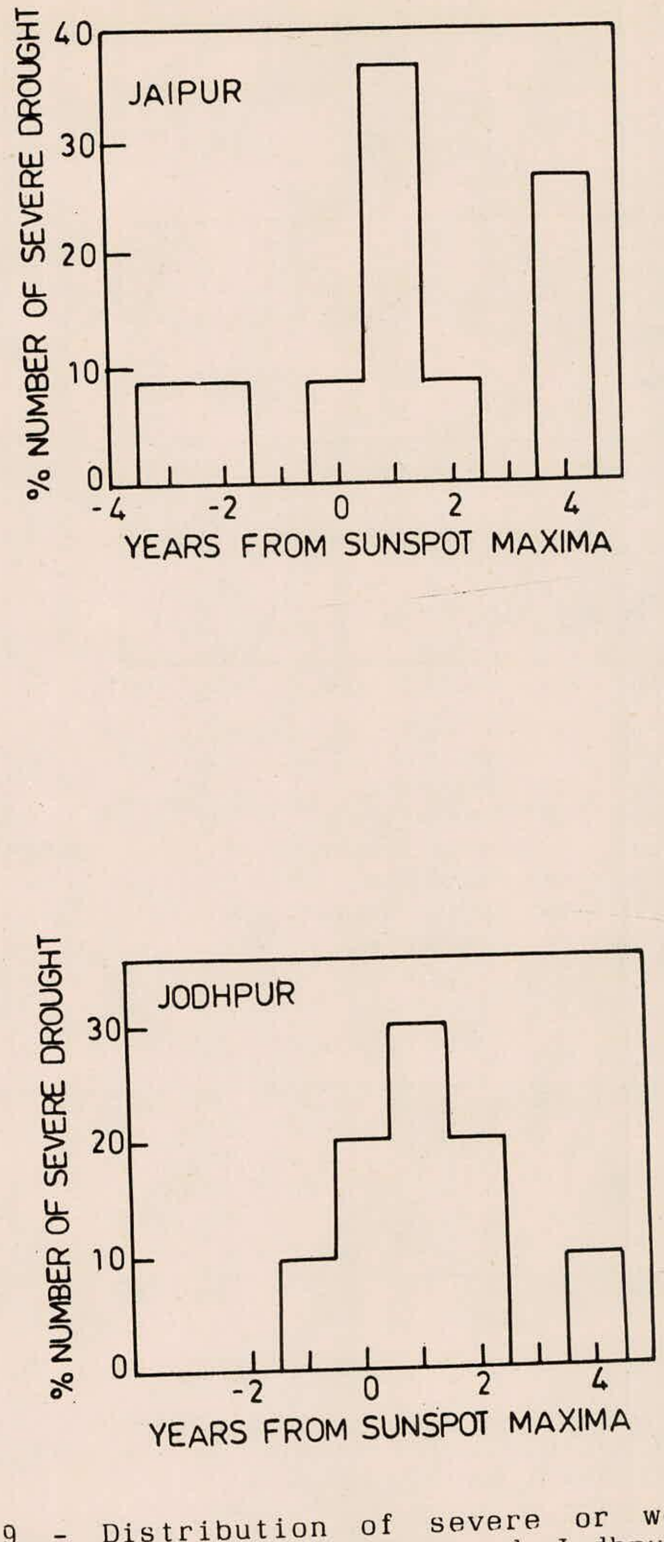


Fig. 19 - Distribution of severe or worse drought years over Jaipur and Jodhpur districts, relative to sunspot maximum (Bhalme and Mooley, 1979)

area over India ( the percentage area of India in a year with monsoon index ) expanding and contracting in phase with the double sunspot cycle. The large scale flood events occurred remarkably in the high amplitude maximum phase of sunspot cycle (Fig. 20). Mitchell et al (1979) also found highly significant rhythm of double sunspot cycle in the drought area over the US Central Great Plains. The large scale drought occurred within two or three years following the low amplitude sunspot maximum. Mitchell et al (1979) established with confidence an association between drought area changes and double sunspot cycle.

Bhalme and Jadhav (1984) illustrated the association between the occurrences of large scale flood events in India and the double (Hale) sunspot cycle for the period 1891-1980 by separating drought and flood years in a single diagram of the sunspot curve (Fig. 21). They found that all of large scale floods (except floods of 1933 and 1975) have tended to cluster consistently in the positive (major) sunspot cycle. This suggested a link between the large scale flood recurrence over India and the double sunspot cycle. The drought events in Fig. 21 are more or less evenly distributed in both positive (major) and negative (minor) sunspot cycles, which suggested that drought recurrence did not exhibit any coherence with the double sunspot cycle.

### 2.2.5 Snow Cover

Blanford (1884) found a negative relation between southwest monsoon rainfall and snowfall of the preceding winter

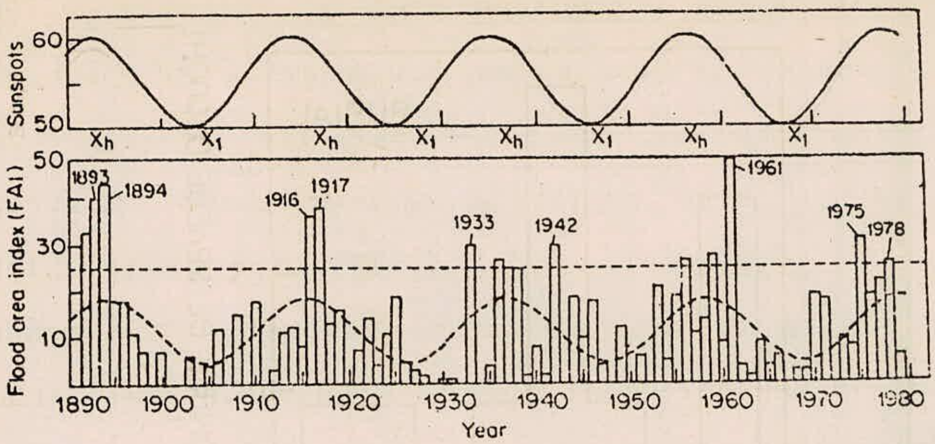


Fig. 20.- Lower: Flood Area Index (FAI), the years of high amplitude sunspot maximum ($X_h$) ., the years of low amplitude sunspot maximum ($X_l$ ) and a wave of 21-year period in FAI series.
Upper: a wave of 21 year period of mean annual sunspot numb;er (Bhalme and Mooley, 1980).

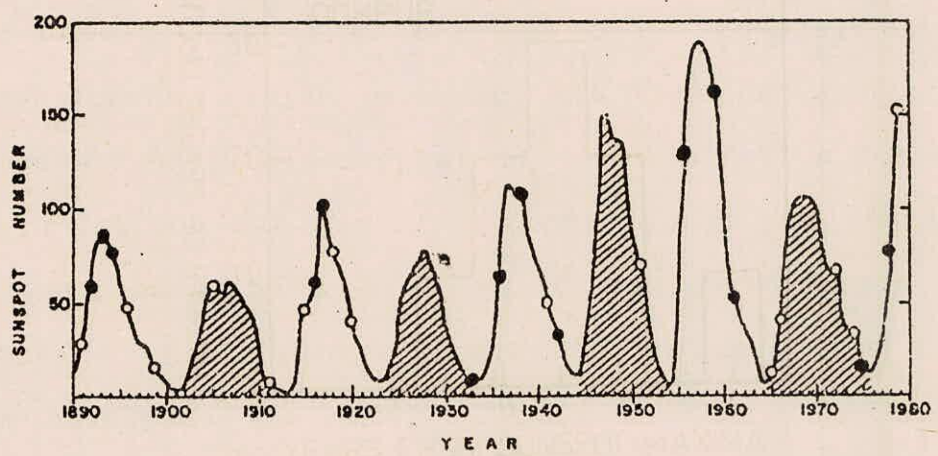


Fig. 21 - Variations in annual mean sunspot number for drought O and of lood years over India. Shaded and unshaded peaks correspond to negative and positive cycles respectively (Bhalme and Jadhav 1984).

in Himalayas. He used this relation in issuing monsoon forecasts from 1882 to 1885. Hahn and Shukla (1976) found a similar relationship between Eurasian winter snow cover and Indian monsoon rainfall. Their findings were based on satellite measurements. Dickson (1984) extending the work of Hahn and Shukla (1976) noted a correlation between Eurasian and Himalayan region snow cover extent and the subsequent Indian monsoon and the subsequent Indian monsoon rainfall. The results of satellite data evaluations concerning a possible relationship between Eurasian spring snow cover and an advance period of the summer monsoon were inconclusive (Dey and Bhanukumar, 1982, 1984; Ropelewski et al. ,1984).

Dey and Kathuria (1986) examined the relationship between Himalayan snow cover extent and the onset of summer monsoon over Kerala, India for the period 1971-81. They used the onset data of summer monsoon, publishied by India Meteorological Department (IMD) and the snow cover extent over the Himalayas was derived from satellite images and Northern Hemisphere snow cover charts. Their study with 11-year data indicated a positive correlation between mean monthly snow cover area over Himalayas for the months February through April and the onset dates of summer monsoon over Kerala (Fig.22). This implied that larger area snow cover over Himalayas was likely to be followed by late onset of summer monsoon over Kerala and vice versa.

## 2.3 Techniques Applied in Long Range Forecasting

As the long range forecasting (LRF) of weather has

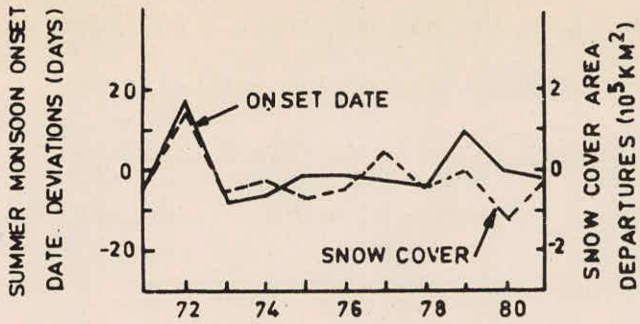


Fig.22 - Mean monthly Himalayan snow cover area (Feb.through April) and the corresponding onset dates over Kerala (Dey and Kathuria, 1986)

a profound socio-economic impact on management of national resources, many countries in the world have started issuing LRF of weather on operational basis. India has the distinction of being the first country in the world for developing LRF techniques for monsoon rainfall over India. The first LRF of monsoon rainfall over whole of India and Burma was issued on June 4th, 1886. The forecast was based on analysis of Himalayan snow cover. Subsequently, India introduced various techniques for LRF as correlation. Multiple Regression (MR), Auto Regressive Integrated Moving Average (ARIMA) and Dynamic Stochastic Transfer (DST). These techniques have also been used by different workers for LRF of rainfall in various countries in the tropics.

Thapliyal (1984,1986) reviewed various LRF techniques used in India for the past hundred years and mentioned that mainly two approaches have been followed for increasing the accuracy of LRF. In the first appraoch the predictors having physical linkages with the Indian monsoon were identified using the correlation approach and were used for LRF of monsoon. But due to temporal variation of the correlation coefficients the accuracy of forecast cannot be increased beyond a certain limit. In the second approach, efforts have been made to increase the accuracy of LRF of monsoon rainfall developing better techniques. Various techniques used in LRF of rainfall over different regions of the tropics/subtropics with special emphasis on Indian rainfall is given in the following section.

2.3.1 Multiple regression technique:

The prediction equation derived from the multiple regression analysis has the form

$$R = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_n x_n$$

Where R is the Predictand or the percentage departure of monsoon rainfall, n is the number of predictors employed in the multiple linear equation, and the coefficients $a_0, a_1 .. a_n$ are determined by the method of least square. The types of possible predictors considered can be divided into two groups-station values and derived values. The former include directly observable atmospheric variable as temperature, sea level pressure and the geopotential heights of pressure surface at individual stations; whereas the latter includes 200-500 mb thickness at individual stations, temperature difference, sea level pressure difference and geopotential height differences between two stations.

Sir Gilbert Walker, in 1907 introduced the concept of correlation in LRF and developed a multiple regression formula for LRF of monsoon rainfall over India;

$$\hat{R}_{IB} + 0.30\hat{F}_1 + 0.53\hat{F}_2 - 0.04\hat{F}_4 - 35.0\ \hat{F}_3 \ldots$$

where, $R_{IB}$ is seasonal monsoon rainfall (June to September) over whole of India and Burma, $F_1$ is Himalayan snow accumulation at the end of May, $F_2$ is the south American pressure (spring), $F_3$ is Mauritius pressure (May), $F_4$ is Zanzibar district rain (April and May) and the symbol on the top of alphabet represents departure from its long period normal.

Walker used the above formula with multiple correlation coefficient (MCC) equal to 0.58 for preparing experimental forecasts. Later on he modified the regression formula to issue the forecast for two broad sub-divisions of India viz. Peninsula and Northwest India from 1924 to 1930 and had MCC equal to 0.76. It was later found that the relationship between monsoon rainfall and some of the predictors either ceased to exist or showed considerable decline with the passage of years. Therefore, forecast formulae were revised on several occassions. Thapliyal (1987) revised the formula seven times based on correlation coefficient of individual factors and MCC of the formula. The forecast formula used for Peninsula in 1987 had the MCC equal to 0.83 and is given below.

$$\hat{R}_p = +4.4\hat{F}_5 + 33.9\hat{F}_{13} + 71.3\,\hat{F}_{14} + 41.5\hat{F}_{15} + 13.5$$

where, $F_5$ is South American pressure (April + May) , $F_{13}$ is the location of 500hp$_a$ subtropical ridge over India long 75E longitude during April, $F_{14}$ is Indian east coast temperature (mean minimum for March ,), $F_{15}$ is central India temperature (mean minimum for May). The formula having MCC equal to 0.73 and used in 1987 for forecasting rainfall in Northwest India is -

$$\hat{R}_{NW_1} = 20.7 - 26.5\,\hat{F}_{12} + 18.7\hat{F}_{13} + 13.1\hat{F}_{14} - 16.1\hat{F}_{16}$$

where, $F_{12}$ is equatorial pressure (Jakarta - January to April; Seychelles - February to March, and Port Darwin -March to May) and $F_{16}$ is Argentina pressure (April).

Thapliyal (1986) verified the forecasts issued during the period 1924 - 1982 and calculated the spill score for the regression technique used for monsoon forecasting over climatology (Table - 4). He found that the multiple regression

TABLE-4 : Verification of forecasts issued during 1924-1982 (Thapliyal, 1986 )

| Forecast for monsoon Rainfall over | Percentage of correct forecast obtained from | | Skill score over climatology |
|---|---|---|---|
| | Forecast formula | Climatology | |
| (1) Peninsula | 64.4 | 49.0 | 0.3 |
| (2) Northwest India | 62.7 | 38.0 | 0.4 |

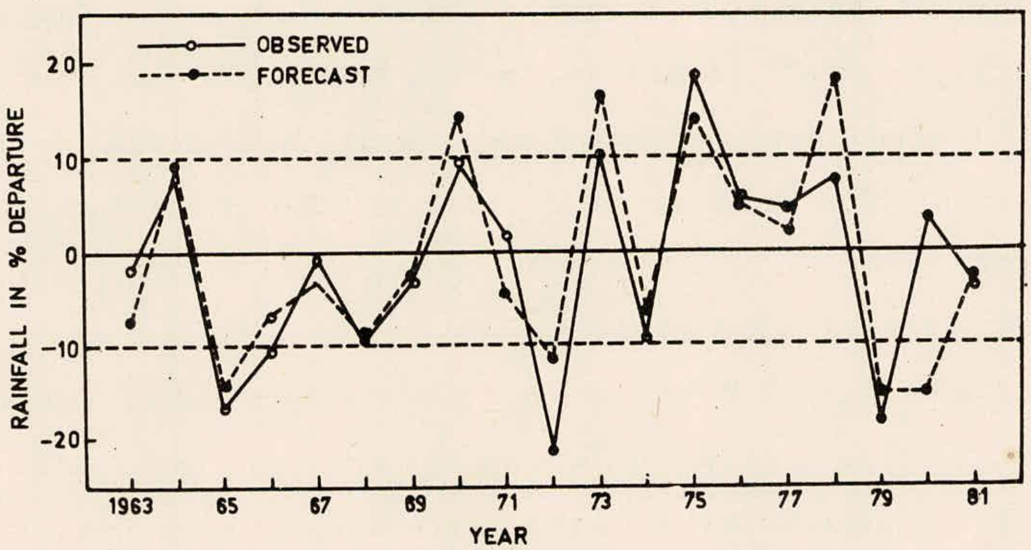


Fig. 23 - Percentage rainfall departures observed and forecast without involving data for the forecast year (Bhalme et al., 1986)

technique had shown positive forecast spill as compared to climatology.

Bhalme et al. (1986) applied the technique of screening - regression analysis (Miller, 1958) to derive the prediction equation for forecasting of monsoon rainfall departures. They selected those predictors from the 121 meteorological predictors for the period 1963-1975 which best explained the percentage departure of monsoon rainfall. The predictor with highest linear correlation with the monsoon rainfall - the sea level pressure at Jodhpur, was chosen first. Partial correlation coefficients, between the predictand each of the remaining predicators - geopotential height of the 850 mb surface at Ahmedabad, surface temperature at New Delhi, geopotential height of the 850 mb surface at Calcutta, and surface temperature at Jodhpur, were then examined. The predictor associated with the highest coefficient was the second one selected. The additional predictors were chosen in a similar manner till no predictor was able to increase the explained variance of the predictand by more than 2 percent. Figure 23 shows year to year observed and forecast monsoon rainfall.

Parthasarathy et al (1988) selecated the predictors in a stepwise fashion from a set of 11 predictors, which in turn were chosen from a pool of 31 predictors, which in turn were chosen form a pool of 31 predictors on the basis of strength of their correlation with Indian rainfall (Table 5) during the period 1951 - 1986. Their results showed that the magni-

TABLE-5 : Correlation Cofficient Between All-India Summer Monsoon Rainfall and Different Parameters for the Period 1951-1980. (Parthasarathy et al, 1988)

| Parameters | Correlation Cofficient |
|---|---|
| SLP parameters | |
| Darwin, MAM-DJF | -0.63‡ |
| Adelaide, MAM-DJF | -0.36* |
| Cordoba, MAM-DJF | -0.40* |
| Buenos Aires, MAM-DJF | -0.40* |
| Agalega, MAM-DJF | -0.44* |
| Plaisane, MAM-DJF | -0.40* |
| Amritsar, MAM-DJF | -0.42* |
| New Delhi, MAM-DJF | -0.43* |
| Jodhpur, MAM-DJF | -0.53† |
| Ahmedabad, MAM-DJF | -0.62‡ |
| Nagpur, MAM-DJF | -0.55† |
| Bombay, MAM-DJF | -0.74‡ |
| Trivandrum, MAM-DJF | -0.63‡ |
| Minicoy Islands, MAM-DJF | -0.49† |
| Cape Town, SON | -0.43* |
| Darwin, DJF | +0.39* |
| Darwin, MAM | -0.44* |
| Tahiti-Darwin, MAM-DJF | +0.43* |
| Santiago-Darwin, MAM-DJF | +0.52† |
| Nouvelle-Agalega, MAM-DJF | +0.45* |
| 1/2(Cordova+Buenos Aires), MAM-DJF | -0.40* |
| SST parameters | |
| Pacific SST region II, MAM | -0.40* |
| Pacific SST region I, MAM-DJF | +0.40* |
| Pacific SST region II, MAM-DJF | -0.51† |
| Pacific SST region III, MAM-DJF | -0.52† |
| Indian Ocean SST region II, MAM | +0.39* |
| Indian Ocean SST region III, MAM | +0.51† |
| Surface air temperature parameters | |
| Asian air temperature region I, MAM | +0.50† |
| Asian air temperature region II, MAM | +0.49† |
| Asian air temperature region III, MAM | +0.37* |
| Circulation parameters | |
| April 500-mbar ridge at 75°E | +0.70‡ |

MAM-DJF denotes the time series of normalised seasonal differences from northern winter to spring. SON stands for the preceding fall.

* Significant at 5% level.

† Significant at 1% level.

‡ Significant at 0.1% level.

tude of the regression coefficients remained relatively stable, although the changing rank of individual predictors in different periods appeared to be an important feature.

Nicholls' (1983) constructed a linear single parameter regression model of Jakarta September-November rainfall versus Darwin August pressure during 1951-69. He used this relationship to predict the Jakarta September-November rainfall during each of the years (1970-80) (Fig.24). The correlation coefficient between predicted and observed rainfall was 0.66. Multiple regression models have also been developed to forecast the rainfall in Northeast Brazil, Subsaharan drought, rainfall in Southern Africa and Kenya (Hastenrath, 1985).

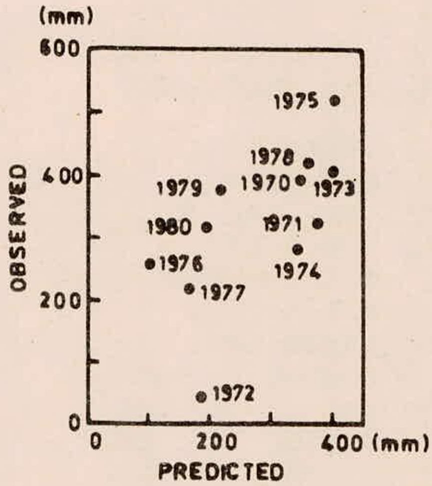


Fig.24: Predicted and observed September-November Jakarta rainfall in 1970-80 (Nicholls,1983).

TABLE - 6 ANALYSIS OF 15 PARAMETERS FOR LEF OF MONSOON
(Gowarikar et al, 1989)

| | | Temperature | | | | | | Wind | | | Pressure anomaly (SOI) | | | | Snow-cover | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Monsoon condition | *El Nino* in current year | *El Nino* in previous year | Northern India (March) | East coast of India (March) | Central India (May) | Northern hemisphere (Jan & Feb) | 500 hPa ridge (April) | 50 hPa ridge-trough extent (Jan & Feb) | 10 hPa (30 km) westerly wind (Jan) | Tahiti-Darwin (Spring) | Darwin (Spring) | South America, Argentina (April) | Indian Ocean Equatorial (Jan-May) | Himalayan (Jan-March) | Eurasian (Previous Dec) | No. of parameters favourable/Total No. of parameters |
| | | (–) | (+) | (+) | (+) | (+) | (+) | (+) | (–) | (+) | (+) | (–) | (–) | (–) | (–) | (–) | |
| 1951 | D | F | U | U | U | F | U | U | | | U | U | U | F | U | | 3/12 |
| 1952 | N | F | U | U | U | F | F | U | | | F | U | U | U | F | | 5/12 |
| 1953 | N | U | U | F | F | F | F | F | | | U | U | U | U | F | | 6/12 |
| 1954 | N | F | F | F | F | F | U | F | | | F | F | U | F | U | | 9/12 |
| 1955 | N | F | U | F | F | F | F | F | | | F | F | F | F | F | | 11/12 |
| 1956 | N | F | U | F | U | F | U | F | | | F | F | F | F | F | | 9/12 |
| 1957 | N | U | U | U | U | U | U | F | | | U | U | U | U | U | | 1/12 |
| 1958 | N | F | F | F | F | F | F | F | U | U | U | U | F | U | F | | 9/14 |
| 1959 | N | F | U | F | U | F | F | F | F | F | F | F | F | F | U | | 11/14 |
| 1960 | N | F | U | U | U | U | F | F | U | U | F | F | F | F | F | | 8/14 |
| 1961 | N | F | U | F | F | F | F | U | F | F | U | U | F | F | U | | 9/14 |
| 1962 | N | F | U | U | U | U | F | U | F | U | F | U | U | F | F | | 6/14 |
| 1963 | N | F | U | U | U | U | F | U | F | F | F | F | F | F | F | | 9/14 |
| 1964 | N | F | U | F | F | U | U | F | F | F | F | F | U | F | F | | 10/14 |
| 1965 | D | U | U | U | U | U | U | U | U | U | U | U | U | U | U | | 0/14 |
| 1966 | D | F | F | U | F | U | F | U | F | F | U | U | F | U | F | | 8/14 |
| 1967 | N | F | U | U | U | U | U | F | F | U | F | U | U | F | F | F | 7/15 |
| 1968 | D | F | U | U | U | U | U | U | U | U | F | U | U | F | U | U | 3/15 |
| 1969 | N | F | U | F | F | F | U | F | F | F | U | U | F | U | F | U | 9/15 |
| 1970 | N | F | U | F | F | F | F | F | F | U | U | U | F | U | F | F | 10/15 |
| 1971 | N | F | U | U | U | U | U | F | F | F | F | F | F | F | U | F | 9/15 |
| 1972 | D | U | U | U | U | F | U | U | U | U | U | U | F | F | U | U | 3/15 |
| 1973 | N | F | F | U | F | F | F | F | F | F | U | U | F | U | U | U | 9/15 |
| 1974 | D | F | U | F | F | U | U | U | U | U | F | F | U | F | U | U | 6/15 |
| 1975 | N | F | U | U | F | F | F | F | F | F | F | F | F | F | U | F | 12/15 |
| 1976 | N | U | U | F | F | U | F | F | F | F | F | U | U | F | F | U | 9/15 |
| 1977 | N | F | F | F | F | U | U | U | F | F | U | U | F | U | F | F | 9/15 |
| 1978 | N | F | U | U | U | F | F | U | U | F | F | U | U | U | F | U | 6/15 |
| 1979 | D | F | U | U | U | U | U | U | U | U | U | U | U | U | F | U | 2/15 |
| 1980 | N | F | U | F | F | F | F | U | F | F | U | U | F | U | U | F | 9/15 |
| 1981 | N | F | U | F | F | U | F | F | F | U | U | U | U | U | F | F | 8/15 |
| 1982 | D | U | U | U | F | U | U | U | U | F | U | U | U | U | F | U | 3/15 |
| 1983 | N | F | F | U | F | F | F | U | F | F | U | U | F | U | F | U | 9/15 |
| 1984 | N | F | U | U | U | F | F | U | F | U | U | U | U | U | F | F | 6/15 |
| 1985 | N | F | U | F | F | F | U | U | F | F | U | F | F | F | U | F | 10/15 |
| 1986 | D | F | U | F | F | U | F | U | U | U | U | U | F | F | U | U | 6/15 |
| 1987 | D | U | U | F | U | U | F | F | U | U | U | U | F | U | F | U | 5/15 |
| 1988 | N | F | F | F | F | F | F | U | F | F | F | F | U | F | F | F | 13/15 |

NOTE : ve and —ve signs indicate direct and inverse relationship of predictors with monsoon; N and D indicate normal and deficient monsoon rainfall; F and U indicate favourable and unfavourable signals from predictors for normal monsoon.

TABLE-7 : Inferences based on signals from 15 parameters for the period : 1951-1987 (Gowarikar et al ,1989).

| Percentage of parameters favourable | No. of occassions | Subsequent monsoon condition | |
|---|---|---|---|
| | | Normal | Deficient |
| 90 (11 out of 12) | 1 | 1 | 0 |
| 80 | 2 | 2 | 0 |
| 70 | 6 | 6 | 0 |
| 60 | 18 | 18 | 0 |
| 50 | 21 | 20 | 1 |
| 50 | 16 | 7 | 9 |
| 40 | 12 | 3 | 9 |
| 30 | 7 | 1 | 6 |
| 20 | 6 | 1 | 5 |
| 10 | 2 | 1 | 1 |
| 0 | 1 | 0 | 1 |

### 2.3.2 Parametric and Power Regression Technique

As the accuracy of multiple regression models is not always very satisfactory, Gowarikar et al. (1989) suggested parametric and power regression models for predicting monsoon rainfall over India well in advance. The parametric model gives a qualitative forecast whereas the power regression model gives a quantitative forecast.

In the parametric model Gowarikar et al. (1989) analysed 15 regional and global meteorological and oceanic parameters from the data of the period 1951-1987 which were divided into four main groups - temperature, pressure, wind and snow cover (Table 6). These parameters were selected on the basis of their possible physical linkages with the monsoon rainfall over the country, out of which some were inter-related. Inferences on subsequent monsoon rainfall based on signals from 15 parameters are given in table 7. The percentage number of parameters favourable in each year since 1951 are shown in Fig. 25. It was observed that wherever more than 70% parameters showed favourable signals, the monsoon rainfall was normal. The model was used for LRF of monsoon of 1988 when 87% of the parameters were observed to be favourable. This led to the conclusion that monsoon rainfall in 1988 would be normal and actually it was 119% of the normal.

The parametric model developed by Gowarikar et al. (1989) is purely qualitative where equal weightage is given to all the 15 parameters. But the relationship between the monsoon rainfall with individual parameter is non-linear.

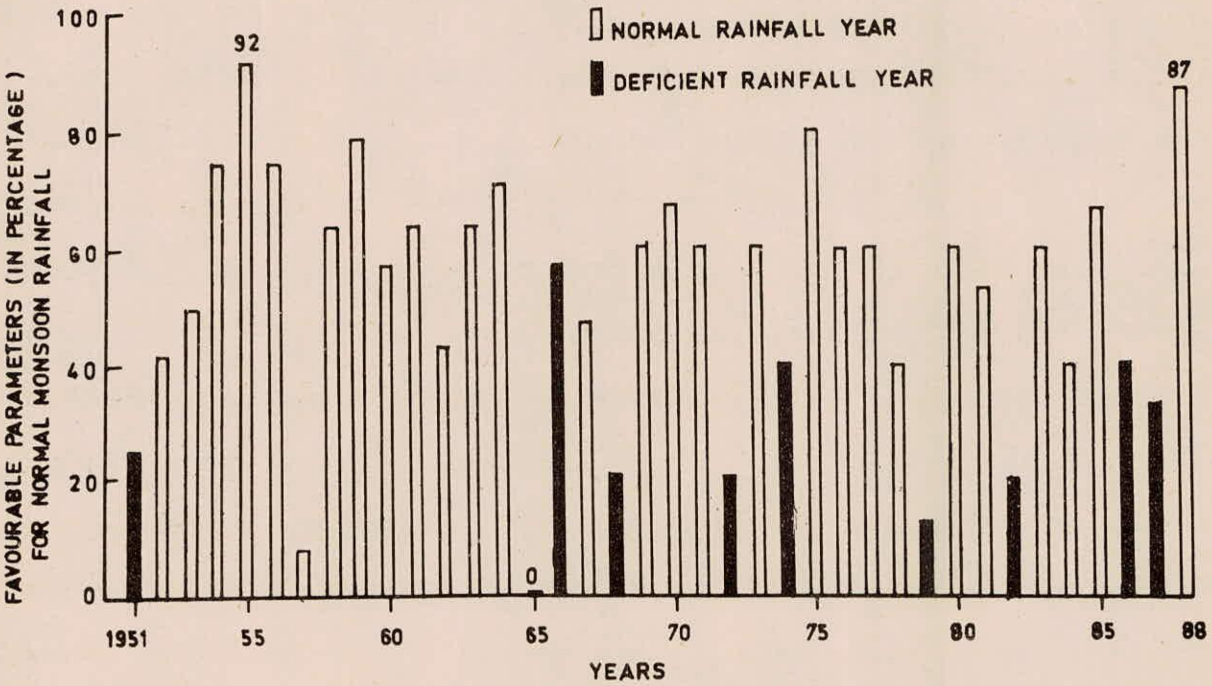


Fig. 25 - Year to year variation in number of favourable parameters and monsoon rainfall over India (Gowarikar, et al, 1989)

For example, in 1957, the 500 hPa ridge was the only favourable parameter out of 12 parameters but still the subsequent rainfall was normal. Gowarikar et al (1989) formulated a power regression model where they determined the magnitude of influence of each parameter. They used, a curvilinear equation of the form

$$R = c_0 + \sum_{i=1}^{15} c_i X_i^{p_i}$$

where R is the monsoon rainfall ever India, $X_1$, $X_2$..... $X_{15}$ are different parameters and $c_s$ and $p_s$ are the model constant. The model constants were derived using the 23 years data (1958-80) and the final equation had the form

$$R = 621.0 + \sum_{i=1}^{15} c_i X_i^{p_i}$$

The parameters were arranged in order of their decreasing correlation coefficient with monsoon rainfall. It was found that the performance of power regression models could best predict the droughts of 1982, 1986 and 1987 during the independent test period of 1981-88. Fig. 26 shows the performance of linear regression model and power regression model during the period (1975-88). The analysis suggested that the power regression model is superior to multiple regression model not only on account of its better performance but also on its capacity to utilise some part of the nonlinear relationship for prediction.

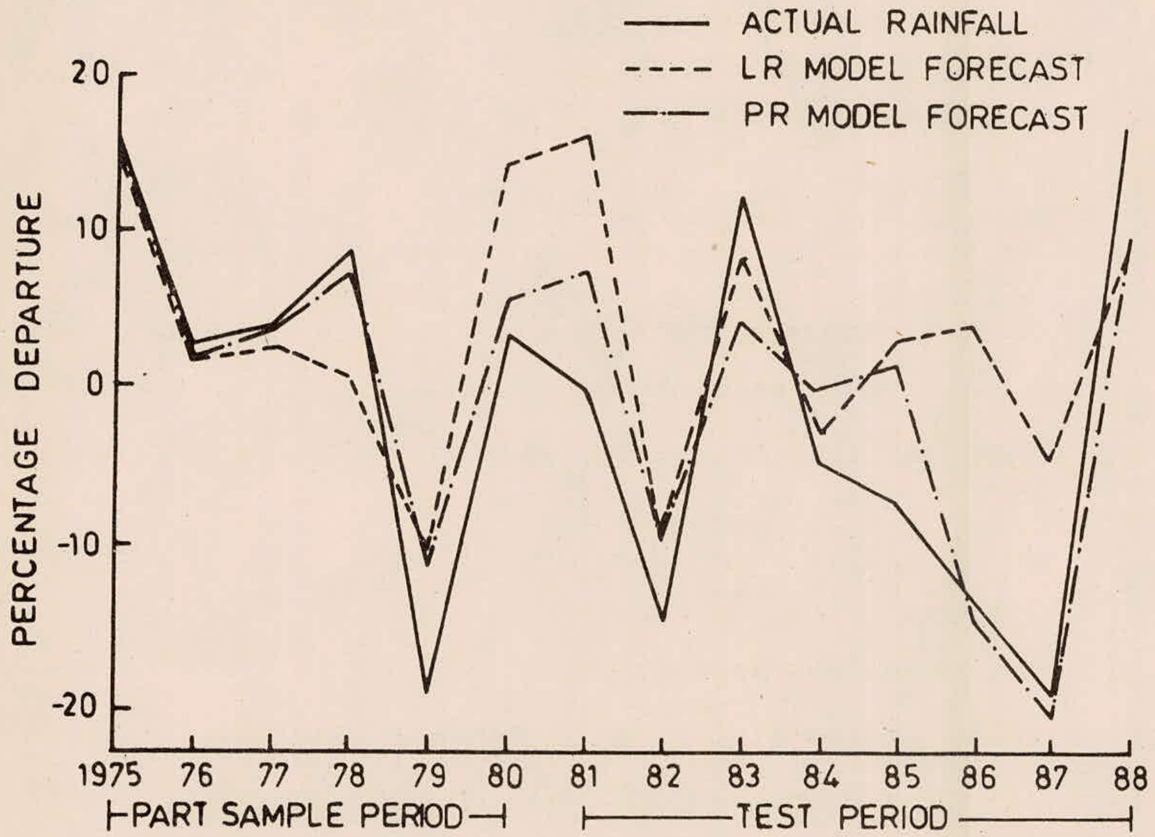


Fig. 26 - Performance of linear regression (LR) and power regression (PR) models during part sample period (1975-1980) and test period (1981-1988) (Gowarikar et al., 1989)

### 2.3.3 ARIMA Technique

In the last decade, experiments have been carried out with ARIMA (Auto Regressive Integrated Moving Average) technique in India and abroad (Delleur and Kavvas, 1978; Jackobson, 1979; Wenjie et al, 1980 ; Hongxing et al., 1986; Thapliyal, 1981; 1986). The ARIMA technique fits the model to the past data and projects forward a single time series like rainfall, temperature etc.

The general form of model is denoted by ARIMA (p,d,q) which can be represented as follows (Box and Jenkins, 1976).

$$\phi(B)\ W_t = \theta(B)\ a_t$$

where

$$W_t = (1-B)^d Z_t$$

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 \ \ldots \ - \phi_p B^P$$

$$\phi(B) = \theta_o - \theta_1 B - \theta_2 B^2 \ldots \theta_q B^q$$

$Z_t$ is the original non stationary time series, $W_t$ is stationary time series derived from $Z_t$, B is backward shift operator, p is the highest order of auto regressive term, q is the highest order of moving average term, d is the highest number of time for which original non stationary series is to be differenced, a is the random shock, and $\theta_s$ and $\phi_s$ are unknown constants.

Thapliyal (1986) found that the model of the kind of ARIMA (1,1,1) fits well to the rainfall data of Peninsula and Northwest India. He used the following equations in the over Peninsula and Northwest India.

$$Z_t = 0.94\ Z_{t-1} + 0.06\ Z_{t-2} + a_t - 0.85\ a_{t-1}$$

where $Z_t$ is monsoon rainfall series of Peninsula and a are random shock.

$$Z_t = 0.87\, Z_{t-1} + 0.13\, Z_{t-2} + a_t - 0.89\, a_{t-1}$$

where $Z_t$ is monsoon rainfall series of Northwest India.

The above model forecast have shown some skill over random and climatological forecasts. However, their performance has not been found better than those obtained from the multiple regression technique. Thapliyal (1986) also used the multiplicative form of ARIMA model for forecasting monthly rianfall with considerable success.

### 2.3.4 Dynamic Stochastic Transfer Technique:

Thapliyal (1982, 1984) and Barnett and Somerville (1983) suggested that the combination of deterministic and statistical approaches might improve the accuracy of operational LRF. The general form of the Dynamic Stochastic Transfer (DST) model is represented as follows (Thapliyal, 1981, 1982)

$$Y_t = \frac{w(B)}{\delta(B)}\, x_{t-b} + \frac{\phi(B)}{\theta(B)}\, a_t \qquad ; \quad b \geqslant 0$$

where $w(B) = w_0 - w_1 B - w_2 B^2 \,..........\, w_s B^s$

$$\delta(B) = 1 - \delta_1 B - \delta_2 B^2 \,..........\, \delta_r B^r$$

$\phi(B)$ and $\theta(B)$ have already been defined in eqns, $Y_t$ and $x_t$ are the output (say, monsoon rainfall over India) and input (say, a meteorological predictor, $a_t$ is random shock or white noise.

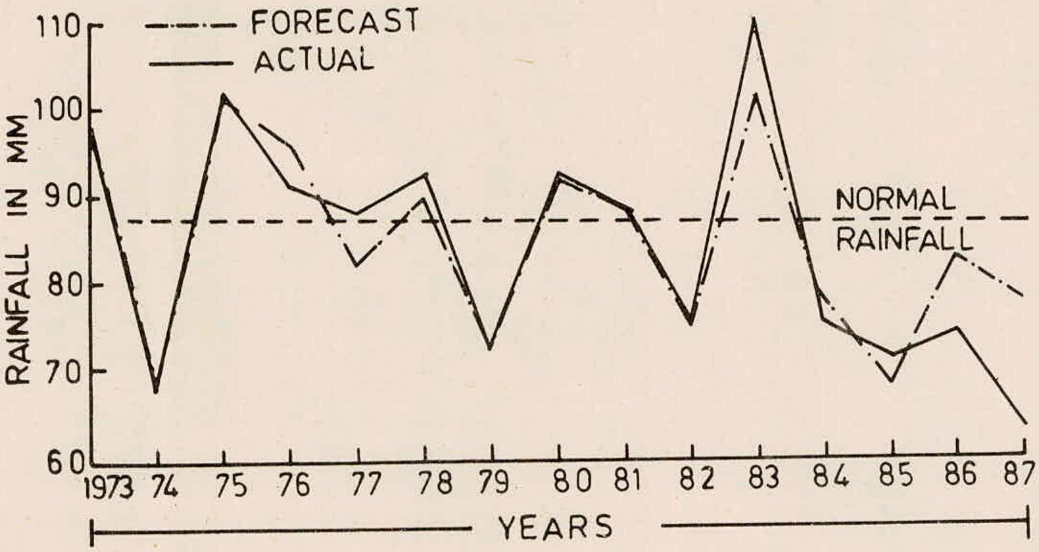


Fig. 27 - Verification of DST Model Forecast for Peninsula (Thapliyal, 1988)

Fig. 27 shows the forecast of rainfall for Peninsular India together with the actual rainfall. The DST model has correctly predicted the droughts in 1979, 1982, 1984 and 1985. However, the model could only predict the sign of the deficiency in 1986 and 1987 and not the actual amount of deficiency.

Table-8 gives the LRF issued by India Meteorological Department.

Table: 8: Long Range Forecast prepared issued by India Meteorological Department

| S.No. | Long Range Forecast for | Technique(s) used | Forecast issued in Ist week of | Forecast Area |
|---|---|---|---|---|
| 1. | Monsoon onset | MR | March | Kerala(Southern most state) |
| 2. | Rainfall during entire monsoon season (June to September) | DST AND MR | May<br>June | NW India & peninsula |
| 3. | Rainfall during Second half of monsoon season (August & Sept.) | DST AND MR | Aug. | -do- |
| 4. | Precipitation during winter season(January to March) | DST AND MR | Jan. | NW India |
| 5. | Rainfall during each calander month | ARIMA | Each month | All 31 met. sub div. of India |

## 3.0 GREENHOUSE EFFECT AND FREQUENCY OF DROUGHTS

Recent investigations have provided ample evidence for global warming due to the increasing concentration of trace gases as Carbon dioxide, Oxone, Nitrous oxide, Methane and Chlorofluoro carbons. As a consequence, the strengthening of the 'greenhouse' effect' may have considerable impact on various meteorological parameters, which in turn may influence the hydrological cycle and water availability.

Beran (1989), reviewing the processes and future of drought, mentioned that the estimates of general tendencies relative to current climate can be obtained from first principles, from climate modelling and from palaeoclimates. Some of the estimates mentioned by Beran (1989) are as follows - 1) The drought incidence may increase in the medium term, 2) In most parts of India and south-east Asia there will be a change towards dried winters and wetter summers, 3) the US corn belt will become drier at the outset but will later become more humid than today. The state of art models are unable to answer precisely the most urgent question - will the climatic change produce more or fewer droughts? The models have however, provided us the information on possibility of more frequent severe events in the future.

## 4.0 REMARKS AND RECOMMENDATIONS

Droughts, one of the extreme natural calamities, do not occur all of a sudden. These are usually the result of a number of weather events that prevail for extended periods of time before the drought occurs. The prevailing weather events include the mid and upper troposheric and lower stratospheric thermal and circulation anomalies, the pressure seesaw in South Pacific Ocean and the equatorial Indian ocean and Southern Oscillation, rise in sea surface temperature of the east and central tropical Pacific along the Peru Coast and El Niño, 11-and 22-year sunspot cycles; and extent of snow cover in the preceding winter. These physical quantities have been used for long range forecasting of onset of deficient rainfall conditions (or drought conditions) in the tropics and subtropics.

In India the early efforts in the latter part of the last century relied heavily on winter snow accumulation in the Himalaya as a telltale factor for Southwest monsoon rainfall. Later on other parameters from various parts of the tropics-particularly pressure and rainfall were added in early years of 20th century. New predictors were introduced including the upper-air parameters viz;April latitude position of 500mb-ridge over India, for long range forecasting of monsoon rainfall by India Meteorological Department.

In Indonesia, pressure was suggested as a sole predictor for monsoon rainfall. Various methods have been tried over the decades to predict the droughts of Northeast Brazil-on the basis of circulation anaomalies in Brazil-tropical Atlantic sector. For estimation of future rainfall anomalies in Subsaharan Africa, Kenya as well as for Southern Africa extrapolation of time series behaviour has been proposed. The forecasts of summer rainfall in Hong Kong have been issued for many years based on January pressure difference of Irkutsk minus Tokyo.

Various techniques as multiple regression, parametric and power regression, ARIMA, dynamic and stochastic transfer are being used for long range prediction of seasonal rainfall in different countries of tropics and subtropics. The combination of extensive diagnostic analysis with statistical methods as multiple regression may provide greater skill. The choice of good predictors on the basis of general circulation diagnostics appears essential. Numerical models have also been suggested in the past years as a possible tool in climate prediction. However, a sound empirical understanding seems a prerequisite for the design of realistic numerical models. For increasing the accuracy of prediction of onset of monsoon rainfall in India, some important considerations which need further investigations are: development of prediction equations for a number of homogeneous areas of India, rather than the development of only one equation for the whole area, inclusion of snow cover over north, west India, premonsoon activities of western disturbance over nothern India and, wind at different levels, for derivation of prediction equation.

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