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# HOMOGENEOUS REGIONAL SUMMER MONSOON RAINFALL OVER INDIA : INTERANNUAL VARIABILITY AND TELECONNECTIONS

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**Abstract**

Five homogeneous regions of the Indian summer monsoon rainfall have been delineated, based on the rainfall characteristics and its association with regional/global circulation features, using rainfall data of 29 meteorological sub-divisions. These homogeneous regions are (i) Northwest (NW); (ii) West Central (WC); (iii) Central Northeast (CNE); (iv) Northeast (NE) and (v) Peninsula (PN). Statistical analysis of the rainfall series of these regions for the 120-year period 1871-1990 has been made to understand their mean and variability characteristics as well as teleconnections.

All-India monsoon rainfall is highly and positively correlated with all the homogeneous regions except the NE region. Further, NE region is anticorrelated with three of the four other regions while the two regions NW and WC and WC and PN are very strongly related among themselves. The 31-year moving averages of rainfall anomalies over NW and WC regions are below average continuously during 1897 to 1930 and above average during 1931 to 1970. During these periods standard deviation shows high and low values respectively.

Correlations of these five homogeneous regions with 12 circulation parameters show that NW and WC are significantly related with all of them while the CNE and PN regions are significantly related with only a few and NE region shows no significant relationship with any one of them. The monsoon rainfall was very much below average during El Nino years and excess during La Nina years, except for NE region, which shows the opposite relationship. It is also noticed by superposed analysis that during the year succeeding El Nino the monsoon rainfall was substantially above average while during the year following La Nina event it was below average.

## 1. Introduction

Studies in understanding or prediction of the interannual variability of the summer monsoon seasonal (June through September) rainfall over India have so far mainly focussed on the country as one unit, i.e., All-India (Krishna Kumar et al., 1995). However, for a country as vast as India, with the inherent spatial variability of monsoon activity, there are large regional differences in the monsoon rainfall variability which are of important consequence for practical applications. For instance, the rainfall of meteorological sub-divisions in the northeastern parts of the country is poorly or even negatively correlated with the rest of the country (Parthasarathy, 1984b). Starting from the early work of Walker (1924) to the recent studies of Shukla (1987), Gregory (1989), Prasad and Singh (1988, 1992), Gadgil et al. (1993), Srivastava and Singh (1993) and Iyengar and Basak (1994) it has been well recognised that the rainfall over several sub-divisions of India could be grouped together to obtain areal averages for large homogeneous regions and various attempts have been made in this direction. However, there are some limitations to the classifications suggested so far. Therefore, an effort has been made in the present study to analyze the sub-divisional monsoon rainfall series of India and to group them into homogeneous macro-regional units with similar rainfall characteristics and similar association with global/regional circulation parameters. This regionalization is also expected to optimize the seasonal prediction potential of monsoon rainfall over different regions.

## 2. Details of data

All-India (India taken as one unit) and the 29 different sub-divisional mean summer monsoon (June to September) rainfall data sets have been prepared by properly area-weighting the rainfall at 306 well distributed raingauges over plain regions of contiguous meteorological sub-divisions. Parthasarathy (1984a) and Parthasarathy et al, (1987, 1990) have provided listings of the data from the year 1871 onwards. Recently, Parthasarathy et al, (1992a, 1994, 1995) have updated these data series to the year 1995 based on less number of stations as the monthly rainfall data of 306 stations are not readily available after the year 1990 onwards.

The data of the relevant circulation parameters are obtained from the World Weather Records, Monthly Climatic Data for the World and the records of India Meteorological Department (IMD), Pune.

## 3. Homogeneous monsoon rainfall regions of India

To group the 29 sub-divisions into homogeneous regions, with an aim to arrive at an optimum area having similar rainfall and circulation characteristics of each region, the following criteria have been adopted : (i) Contiguity of the constituent sub-divisions (ii) Percentage contribution of monsoon rainfall to the annual amount, (iii) Coefficient of Variability (CV) of monsoon rainfall, (iv) inter-correlations of sub-divisional rainfall series, (v) Characteristics of Principal Components of the sub-divisional rainfall and (vi) relationships between sub-divisional monsoon rainfall and regional/global circulation parameters.

Contribution to the annual rainfall, statistical characteristics and intercorrelations of sub-divisional monsoon rainfall have been presented by Parthasarathy (1994a, 1984b). There are 18 sub-divisions over central, northwestern and northeastern regions whose monsoon rainfall accounts for more than 80 percent of the annual amount. The monsoon rainfall accounts for less than 60% of the annual rainfall over a small area of south Peninsula. The inter-correlations of 29 sub-divisional monsoon rainfall show that the neighbouring sub-divisions are highly positively related. The rainfall over west Bengal, Orissa, Bihar and UP state sub-divisions is not significantly related with that over the other sub-divisions. The two sub-divisions of Assam state are negatively related with the other sub-divisions.

Principal Component Analysis (PCA) has been applied to the sub-divisional monsoon rainfall series of India by Hastenrath and Rosan (1983), Parthasarahy (1984a), Shukla (1987) and Kulkarni et al.(1992). They examined the spatial patterns of the loadings of the dominant Principal Components (PCs). The first eight PCs are considered to be necessary and sufficient to describe the dominant spatial modes of Indian monsoon rainfall, which put together, contribute about 75% to the total variance of the series. The cumulative variance explained by the first four PCs is 52 percent. The first PC shows negative loadings over the entire country except the northeastern parts. The second PC shows a dipole type structure with positive loadings over U.P. State and negative over Maharashtra state. The third PC shows negative loadings over western half of India and positive over eastern half of the country. The fourth PC shows positive loading over U.P., Bihar, West Bengal and Assam State and negative over rest of the country. These four PCs represent the most important physical patterns contained in the rainfall data set.

The correlations between various circulation parameters and 29 sub-divisional rainfall series during 1951-80 for twelve parameters were presented by Parthasarathy et al. (1993). These 12 parameters can be grouped into four types of atmospheric forcings on the Asian monsoon system. The parameters representing circulation conditions over Asian/Indian region (Yasunari, 1991, Thapliyal, 1990; Parthasarathy et al., 1991; Krishna Kumar et al., 1992; Mooley and Munot, 1993 & Yang et al., 1996) show high significant CCs with Northwestern and central sub-divisions. The parameters representing the cross-equatorial flow (Parthasarathy, et al., 1988 & Lau and Yang, 1996) show good CCs with central and north Indian regions. The parameters representing Pacific Ocean Circulation, i.e., El Nino/Southern Oscillation (Pant and Parthasarathy, 1981; Rasmusson and Carpenter, 1983; Ropelewski and Halpert, 1987; Khandekar, 1991; Verma, 1994; Singh, 1995 & Mooley and Munot, 1996) show significant CCs with Northwestern, Central and Peninsular regions.

On the basis of the criteria discussed above and consideration of the results in several publications referred to above, the 29 sub-divisions have been grouped into five contiguous homogeneous regions as shown in Fig. 1. The monthly weighted average rainfall for the period 1871 to 1990 is obtained for each of the five homogeneous regions and All-India by taking the areas of the constituent subdivisions as the weights. The NorthWest (NW) region consists of six subdivisions in the states of Gujarat, Rajasthan, Punjab and Haryana, with total area of 634, 272 sq. kms. The biggest region is the West Central (WC), having an area of 962,698 sq.kms with eight subdivisions along the west coast and in the central parts of India in the states of Maharashtra and Madhya Pradesh. The Central North

East (CNE) region adjoining WC consists of five sub-divisions of the states Uttar Pradesh, Bihar and Orissa, with an area of 573,006 sq.kms. The smallest region of area 267,444 sq. kms is the Northeast (NE) with four sub-divisions of the eastern states of India, West Bengal and Assam. The Peninsular (PN) region consists of six sub-divisions of the south Indian states Andhra Pradesh, Karnataka, Tamilnadu and Kerala with an area of 442,632 sq. kms. On an average, each raingauge in the basic data represents about 100x100 kms area in all the five regions.

## 4. Statistical details of five homogeneous regions

Table 1 gives the statistical details of monsoon rainfall for the period 1871-1990 for five homogeneous regions and All-India. The monsoon (June through September) rainfall series of the five regions is found to be homogeneous, Gaussian distributed and free from persistence. The NE region has the highest average monsoon rainfall of 1419 mm (69% of annual) with a CV of 8.5%, while NW region receives the lowest rainfall of 490 mm (90% of annual) with a CV of 27%. The regions WC, CNE and PN receive 933 mm, 1002 mm and 659 mm respectively with CVs of 13.5%, 11.2% and 14.8%. The number of runs about the median indicate that there is no significant trend or oscillation in the rainfall series of the five homogeneous regions.

Table 2 shows the inter-correlations of All-India (AI) monsoon rainfall and five homogeneous regions. The NE regional monsoon rainfall is either negatively or poorly correlated with the other regions, as expected. Further, the NW regional monsoon rainfall does not have any association with the central northeast (CNE) and northeast (NE) regional monsoon rainfall. The region WC is very strongly related with NW and PN regions. All the regions are having significant CCs at 0.1% level with All-India rainfall except NE region.

A monsoon rainfall year can be classified as excess (wet or flood) when $R_i \geq \overline{R} + S$ and deficient (dry or drought) when $R_i \leq \overline{R} - S$, where $R_i$ is the rainfall of the ith year, $\overline{R}$ the mean (period 1871-1990) and S standard deviation. This classification is considered to be rational for the tropical regions with high spatial and temporal variation of rainfall, with the crop growth and water requirement and management tuned to long-term mean and variability characteristics of that region (Parthasarathy et al., 1992b). Figures 2(a) to 2(f) show All-India and five regional monsoon rainfall series, 1871-1995 expressed as percentage departure from long term mean (1871-1990) further the top panels in figures also contain a five-point low-pass filter curve (Tyson et al., 1975). The low-pass curves (top panels in Figs. 2) show generally increasing tendency in AI, NW and WC regions during 1901 to 1960; and during 1921 to 1950 in CNE and NE regions; further decreasing in the same period (1921-50) at PN region. The variability was low during 1901 to 1950 in all these regions. The low-pass curve was above normal during 1871-1900 in almost all regions and oscillatory in PN and NE regions. The curve was below normal after 1960 in CNE and NE upto 1980 whereas it is oscillatory in other regions.

Tables 3 and 4 show decade-wise dry and wet years for All-India and five homogeneous regions during the period 1871-1990. The number of dry years varied from 18 to 21 and wet years 16 to 22 over these five regions. All-India recorded 22 dry and 19 wet years during this period. The dry years are three or more in five decades 1901-10, 1911-20, 1961-70, 1971-80 and 1981-90 in All-India, NW and WC. It is observed that dry years (two or more) are common during the present three decades 1961-90. However during the three decades 1921-50, the dry years are rare in All-India and five regions. The wet years were more frequent in the decades 1891-1900, 1941-50, 1951-60, 1961-70 and 1971-80. In the four decades 1901-40 relatively less dry and wet years were noticed over different regions. In the present 30-year period (1961-90) the frequency of dry and wet years is relatively high. It may be noted from Table 3 that (i) 1972 was dry year for all-India and for all the five regions, (ii) 1918 was dry years for all India and for all the regions except northeast India, and (iii) 1877, 1899, 1905, 1911, 1951, 1965, 1968, 1974 are dry years for all India and for all the regions except two of which one was northeast India. Table 4 brings out that (i) there was no wet year common to all-India and the five homogeneous regions, (ii) 1956 was a wet year for all-India and for four regions, and (iii) 1974, 1978, 1892, 1893, 1894, 1917, 1942, 1947, 1961, 1975 and 1988 were wet years for all-India but only over three regions.

Decadal averages of rainfall (see middle panels in Figs 2(a) to 2(f)) anomalies of NW, WC and All-India show remarkably similar patterns of positive and negative anomalies alternating every three decades. However, the decadal anomalies are randomly distributed in CNE, NE and PN regions. It can also be seen that low rainfall periods are associated with high variability (CV) in almost all regions. During four continuous decades 1921-60 the decadal variabilities of all the regions were below the long-term variability; however in CNE it is during 1881-1920. In general, during the present three decades (1961-90) the decadal variability is close to the long-term variability or even above, in almost all regions except in NW region.

Further examination of this variability by using 31-year moving average of anomalies shows (see bottom panels of figs 2(a) to 2(f)) that the rainfall anomalies over NW, WC and All-India are below average continuously during 1897 to 1930 and above average during 1931-70 suggesting a quasi-cycle of about 70-years. During the period of low rainfall the standard deviation shows relatively high values and vice versa. The CNE and NE regions show above normal rainfall anomalies during 1910-35 and below normal during 1936-70. The PN region shows below normal anomalies during 1919-45 and above normal afterwards.

## 5. Regional and global teleconnections of Homogeneous regional rainfall series

Correlation Coefficients (CCs) between the various regional/global parameters and the five homogeneous seasonal monsoon rainfall series for the period 1951-80 are presented in Table 5. Monsoon rainfall of All-India, NW and WC regions is significantly related with almost all the 12 circulation parameters considered. None of the CCs is significant in the case of NE region. CNE region shows significant CCs with five parameters while the PN region shows only 3 significant CCs. Thus, it can be inferred that the NW and WC regions account for most of the relationship of the circulation parameters with the all-India summer monsoon rainfall. Therefore, these parameters can be used for reliable prediction of regional monsoon rainfall only over these two regions.

The El Nino-Southern Oscillation (ENSO) and the Indian monsoon are important components of the coupled ocean-atmosphere-land system, these interactive low-frequency phenomena regulate the short-term variability of the Earth's climate to a great extent. Thus a detailed examination has been made of the association between all-India as well as homogeneous regional monsoon rainfall with El Nino/La Nina events during the 120-year period 1871-1990. We have delineated the El Nino/La Nina years based on the classification adopted by Rasmusson and Carpenter (1983), Quinn and Neal (1987), Diaz and Markgraf (1992) and Wilby (1993). During this period, there were 28 strong and moderate El Nino events and 22 La Nina events. Table 6 gives the statistical details of monsoon rainfall during El Nino/La Nina events. Student's t-test has been applied to determine the statistical significance of the differences between the normal monsoon rainfall and the composite mean rainfall of El Nino/La Nina years. Monsoon rainfall was below normal by 2 to 20 percent during El Nino, and the student's t-value is significant at 5% level or above in all regions except NE region. During La Nina years, the departures are all positive but they are statistically significant only for all-India and PN monsoon rainfall. To understand the association between La Nina/El Nino events and the monsoon rainfall on an year-to-year basis, the percentage departure of rainfall from the long-term average (1871-1990) for All-India and five homogeneous regions for each of the years 1871-1990 have been examined in detail. It is observed that during La Nina years 70% of the events are associated with positive rainfall anomalies of which about 30% are wet rainfall years, except in CNE and NE regions where only 50% of the La Nina events are associated with positive departures. During El Nino years the departures are negative in 80 to 90% occassions, out of which 50% were reported as dry years; however, NE region reported only 60% of El Nino years as having negative departure, the top panels in Figure 2(a) to 2(f) in a way reflect these features.

The relationship between ENSO and All-India monsoon rainfall has been documented by many previous studies (for details refer to Kane, 1990; Bhalme et al., 1990; Mooley, 1996 and Kripalani and Kulkarni, 1996). To gain a better insight into the regional monsoon rainfall and El Nino/La Nina associations, superposed epoch analysis has been applied as described below. The superposed epoch analysis has been earlier used by Bradley et al. (1987) to find the relationship between ENSO signal and surface temperature and precipitation variations over the Northern Hemisphere. Similar technique was also used in Indian rainfall studies by Ananthakrishnan and Parthasarathy (1984) and Parthasarathy and Sontakke (1988). By taking the year of El Nino/La Nina occurrence event as lag zero (lag 0), composite means of monsoon rainfall departures are computed for the years corresponding to lags-4 to lags+4 (four years before to four years after the occurrence of the event i.e., lag 0), for All-India as well as the homogeneous regional rainfall series. This procedure maximizes the signal in the monsoon rainfall, if any, due to the multi-year lead/lag influence of the ENSO system. Figs. 3a to 3f show the results of superposed epoch analysis for All-India and five homogeneous regions. The rainfall was considerably below normal during El Nino year and jumped to significantly above normal during the year succeeding the El Nino event, in all regions except CNE and NE. The rainfall during La Nina year was quite above normal while in the following year it showed below normal value, in almost all regions except CNE and NE. It can be inferred that El Nino and La Nina events have definite and significant effect on Indian regional monsoon rainfall, the rainfall being above normal during the La Nina years and below normal during the succeeding year, and vice versa in the case of El Nino years.

## 6. Conclusions

Five homogeneous rainfall series have been prepared for the period 1871-1990, by giving proper area weightage to each of the subdivision merged in the respective homogeneous region; and their rainfall characteristics, variability and teleconnections have been studied. The following are the main conclusions :

i) Northeast region is the wettest homogenous monsoon region, with a mean monsoon rainfall of 141.92 cm (69% of annual) and CV of 8.5%.

ii) The driest homogeneous region is northwest India, which receives 49 cm of monsoon rainfall (90% of annual) with the highest CV of 27%.

iii) The intercorrelations between all-India and four homogeneous monsoon rainfall series are high and positive except those with the northeast region. Two regions, NW & WC and WC & PN are very strongly related among themselves.

iv) The low-pass curve show generally increasing tendency in AI, NW and WC regions during 1901-60, it is above normal during 1871-1900 in all regions and below normal after 1960 in CNE and NE.

v) The number of dry years varied 18-21 and wet years 16-22 in all the regions during 120-year period 1871-1990, however the decades 1901-40 relatively less dry and wet years noticed.

vi) Decadal average of rainfall anomalies of AI, NW and WC show remarkably similar patterns of positive (1871-1900 & 1931-60) and negative (1901-30 & 1961-90) values alternating every three decades.

vii) The 31-year moving average over AI, NW and WC are below average continuously during 1897 to 1930 and above average during 1931-70 suggesting a quasi-cycle of 70 years. The low rainfall show high variability and vice versa.

viii) The 12 circulation parameters considered show strong CCs with the monsoon rainfall of NW and WC regions apart from All-India.

ix) During El Nino year the composite monsoon rainfall tends to be considerably below normal in most regions and excess during the succeeding year. This association is opposite in the case of La Nina year.

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## Figure Legends

| | | |
|---|---|---|
| Fig. 1 | : | Map showing different homogeneous regions of India |
| Fig. 2(a) | : | All-India (AI) summer monsoon (JJAS) rainfall during 1871-1995. Year-to-year percentage departure from mean (top curve); Decadal averages and Coefficient of Variation (middle) and thirty-one year moving average curves of mean and standard deviation (bottom). |
| Fig. 2(b) | : | Same as Fig. 2(a), but for NorthWest (NW) India |
| Fig. 2(c) | : | Same as Fig. 2(a), but for WestCentral (WC) India |
| Fig. 2(d) | : | Same as Fig. 2(a), but for Central NorthEast (CNE) India |
| Fig. 2(e) | : | Same as Fig. 2(a), but for NorthEast (NE) India |
| Fig. 2(f) | : | Same as Fig. 2(a), but for Peninsular (PN) India |
| Fig. 3 | : | Superposed epoch analysis of summer monsoon rainfall with respect to El Nino/La Nina events during 1871-1990. |
| | | (a) All-India (b) Peninsular India |
| Fig.3 (Contd.) | | (c) Northwest India (d) Westcentral India |
| Fig.3 (Contd.) | | (e) Central Northeast India (f) Northeast India. |

Table 1 : Statistical details of homogeneous regions of India for the period 1871-1990

| REGION | Mean cm | Percentage of Annual % | Std. Dev. cm | C.V. % | Range cm | Median cm | No.of runs about the median | Chi-Square Value df 7 | Auto-Correlation Lag+1 |
|---|---|---|---|---|---|---|---|---|---|
| 1. NORTHWEST (NW) | 49.00 | 89.9 | 13.24 | 27.0 | 65.50 | 48.99 | 68 | 3.0 | -0.08 |
| 2. WEST CENTRAL (WC) | 93.32 | 86.3 | 12.59 | 13.5 | 67.88 | 94.90 | 66 | 9.8 | -0.07 |
| 3. CENTRAL NORTHEAST (CNE) | 100.24 | 83.3 | 11.28 | 11.2 | 73.91 | 100.61 | 63 | 8.0 | +0.01 |
| 4. NORTHEAST (NE) | 141.92 | 68.7 | 12.13 | 8.5 | 65.29 | 141.98 | 61 | 4.0 | +0.07 |
| 5. PENINSULAR (PN) | 65.94 | 51.5 | 9.79 | 14.8 | 52.82 | 65.06 | 66 | 5.2 | -0.18 |
| 6. ALL-INDIA | 85.24 | 78.2 | 8.47 | 9.9 | 41.60 | 86.64 | 64 | 11.7 | -0.012 |

Table 2 : Inter-Correlation Matrix of Homogeneous regions of India for the period 1871-1990

| REGIONS | North west | West Central | Central Northeast | Northeast | Peninsular | All-India |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1. NORTHWEST (NW) | 1.000 | | | | | |
| 2. WEST CENTRAL (WC) | .699 | 1.000 | | | | |
| 3. CENTRAL ORTHEAST (CNE) | .243 | .390 | 1.000 | | | |
| 4. NORTHEAST (NE) | -.138 | -.202 | .113 | 1.000 | | |
| 5. PENINSULAR (PN) | .457 | .512 | .095 | -.062 | 1.000 | |
| 6. ALL-INDIA | .822 | .909 | .579 | .002 | .607 | 1.000 |

**Table 3 : Dry (Deficient) years over different regions of India : 1871-1990.**

Dry year = $R_i \leq \bar{R} - S$

| Region / Decade | All-India | Northwest India | West Central India | Central Northeast India | Northeast India | Peninsular India |
|---|---|---|---|---|---|---|
| 1871-80 | 1873,1877 | 1877 | 1877 | 1873,1877, 1878 | 1873 | 1873,1876, 1880 |
| 1881-90 | - | - | - | - | 1884 | 1881, 1884 |
| 1891-1900 | 1899 | 1899 | 1899 | - | 1891,1892, 1896,1900 | 1891, 1899 |
| 1901-10 | 1901,1904 1905 | 1901,1904, 1905 | 1902,1904, 1905 | 1901,1903, 1907 | - | 1905 |
| 1911-20 | 1911,1918, 1920 | 1911,1915, 1918 | 1911,1913, 1918,1920 | 1918 | 1914 | 1911,1913, 1918 |
| 1921-30 | 1928 | 1925 | - | 1928 | 1925 | 1930 |
| 1931-40 | - | 1938,1939 | - | 1932 | - | 1934 |
| 1941-50 | 1941 | 1948 | 1941 | - | - | 1952 |
| 1951-60 | 1951 | 1951 | 1951 | 1951,1954, 1959 | 1957,1958, 1959 | - |
| 1961-70 | 1965,1966, 1968 | 1965,1968 | 1965,1966, 1968 | 1965,1966, 1968 | 1961,1962, 1967 | - |
| 1971-80 | 1972,1974, 1979 | 1972,1974 | 1972,1974, 1979 | 1972,1974, 1979 | 1972,1975, 1980 | 1972,1976 |
| 1981-90 | 1982,1985, 1986,1987 | 1982,1985, 1986,1987 | 1984,1985, 1987 | 1987 | 1981,1982, 1986 | 1987,1990 |
| Total | 22 | 21 | 20 | 19 | 20 | 18 |

**Table 4 : Wet (Excess) years over different regions of India : 1871-1990.**

Wet year = $R_i \geq \bar{R} + S$

| Region<br>Decade | All-India | Northwest India | West Central India | Central Northeast India | Northeast India | Peninsular India |
|---|---|---|---|---|---|---|
| 1871-80 | 1874,1878 | 1878 | 1874,1875 | 1871,1874, 1879 | 1875,1878, 1879,1880 | 1874,1878 |
| 1881-90 | 1884 | 1884 | 1882,1884, 1887 | 1890 | 1886 | 1889 |
| 1891-1900 | 1892,1893, 1894 | 1892,1893, 1894 | 1892,1894 | 1893,1894 | 1893,1899 | 1892,1897 |
| 1901-10 | 1910 | 1908 | - | - | 1905 | 1903,1910 |
| 1911-20 | 1916,1917 | 1917 | 1916,1917 | - | 1918 | 1916,1917 |
| 1921-30 | - | 1926 | - | 1922,1925 | - | 1924 |
| 1931-40 | 1933 | 1933 | 1933,1934, 1938 | 1936 | - | 1938 |
| 1941-50 | 1942,1947 | 1942,1944, 1945,1950 | 1942,1947 | 1942,1943 | 1947 | 1947,1949 |
| 1951-60 | 1956,1959 | 1956,1959 | 1955,1956, 1959 | 1953,1956 | 1953,1956 | 1959 |
| 1961-70 | 1961,1970 | 1961,1970 | 1961,1970 | - | 1966,1968 | 1961,1964 |
| 1971-80 | 1975 | 1973,1975, 1976,1977 | 1975 | 1971,1980 | 1974 | 1975,1978 |
| 1981-90 | 1983,1988 | 1988 | 1983,1990 | 1984 | 1987,1988, 1989 | 1981,1983, 1988,1989 |
| Total | 19 | 22 | 22 | 16 | 18 | 22 |

Table 5 : Correlation between monsoon rainfall (JJAS) of homogeneous regions of India and circulation parameters for the period 1951-80

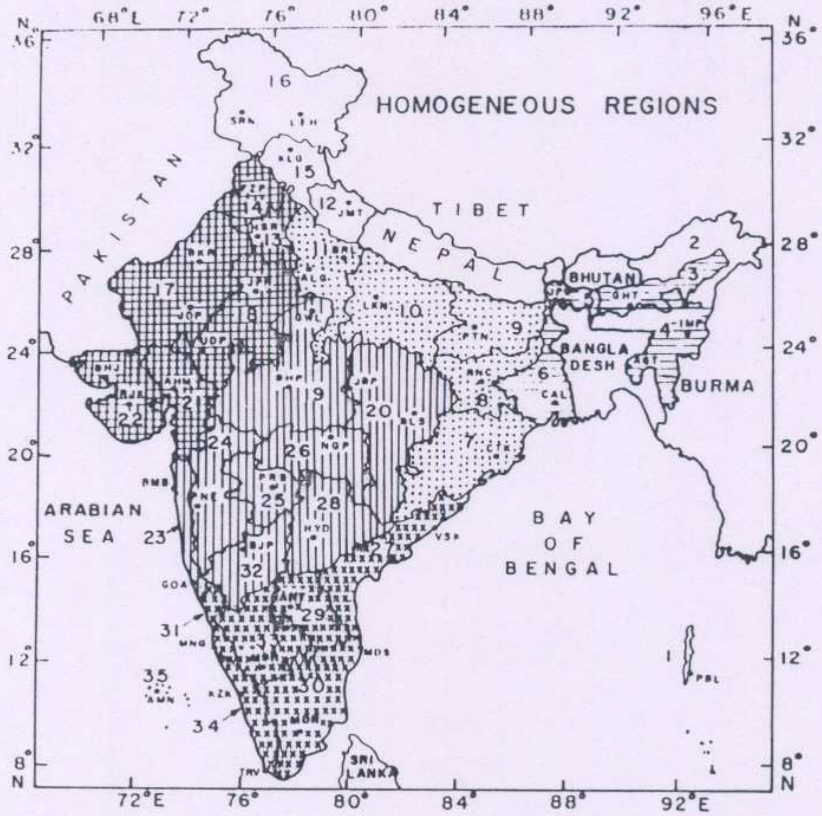
| REGIONS | North west | West Central | Central Northeast | Northeast | Peninsular | All-India |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| WCI Air temp MAM | .49* | .61$ | .42+ | .03 | .17 | .60$ |
| Bombay msl pressure MAM-DJF | -.65$ | -.63$ | -.37+ | -.09 | .53* | -.70$ |
| April 500 mb ridge | .62$ | .64$ | .61$ | .09 | .29 | .70$ |
| Agalega msl pressure MAM-DJF | -.53* | -.41+ | -.17 | .13 | -.31 | -.44+ |
| Nouvelle-Agalega MAM-DJF | .53* | .46* | .31 | -.25 | .07 | .45+ |
| Indian Ocean SST : MAM | .44+ | .55* | .28 | -.21 | .38+ | .51* |
| Darwin msl pressure : MAM-DJF | -.60$ | -.59* | -.33 | -.07 | -.38+ | -.63$ |
| Tahiti-Darwin MAM-DJF | .47* | .39+ | .17 | .03 | .27 | .43+ |
| Pacific Ocean SST : MAM-DJF | -.49* | -.54* | -.26 | .03 | -.28 | -.52* |
| NH Temp DJF | .48* | .47* | .39+ | -.11 | .33 | .52* |
| S. American msl pressure MAM-DJF | -.320 | -.43+ | -.33 | .30 | -.25 | -.39+ |
| 10mb westerly Balboa wind : DJF | -.50* | .66$ | .63$ | -.27 | .33 | .67$ |

$ Significant at 0.1% level
* Significant at 1.0% level
+ Significant at 5.0% level

Table 6 : Details of composite monsoon rainfall during El Nino/ La Nina events for the 120-year period 1871-1990.

| Region | Monsoon Rainfall N = 120 | | | El Nino $n_1 = 28$ | | La Nina $n_2 = 22$ | |
|---|---|---|---|---|---|---|---|
| | Mean mm | Std.Dev. mm | CV % | Departure from Mean (%) | Student's t-value | Departure from mean (%) | Student's t-value |
| All India | 852.4 | 84.3 | 9.9 | -9.4 | -4.56* | 4.8 | 2.16+ |
| Northwest | 490.0 | 131.8 | 26.9 | -20.4 | -3.93* | 9.3 | 1.55 |
| West Central | 933.2 | 125.4 | 13.4 | -10.6 | -3.74* | 5.5 | 1.80 |
| Central Northeast | 1002.4 | 112.3 | 11.2 | -5.1 | -2.14+ | 0.7 | 0.28 |
| Northeast | 1419.2 | 120.8 | 8.5 | -2.1 | -1.12 | 1.1 | 0.56 |
| Peninsular | 659.4 | 97.9 | 14.8 | -11.8 | -3.96* | 11.0 | 3.26* |

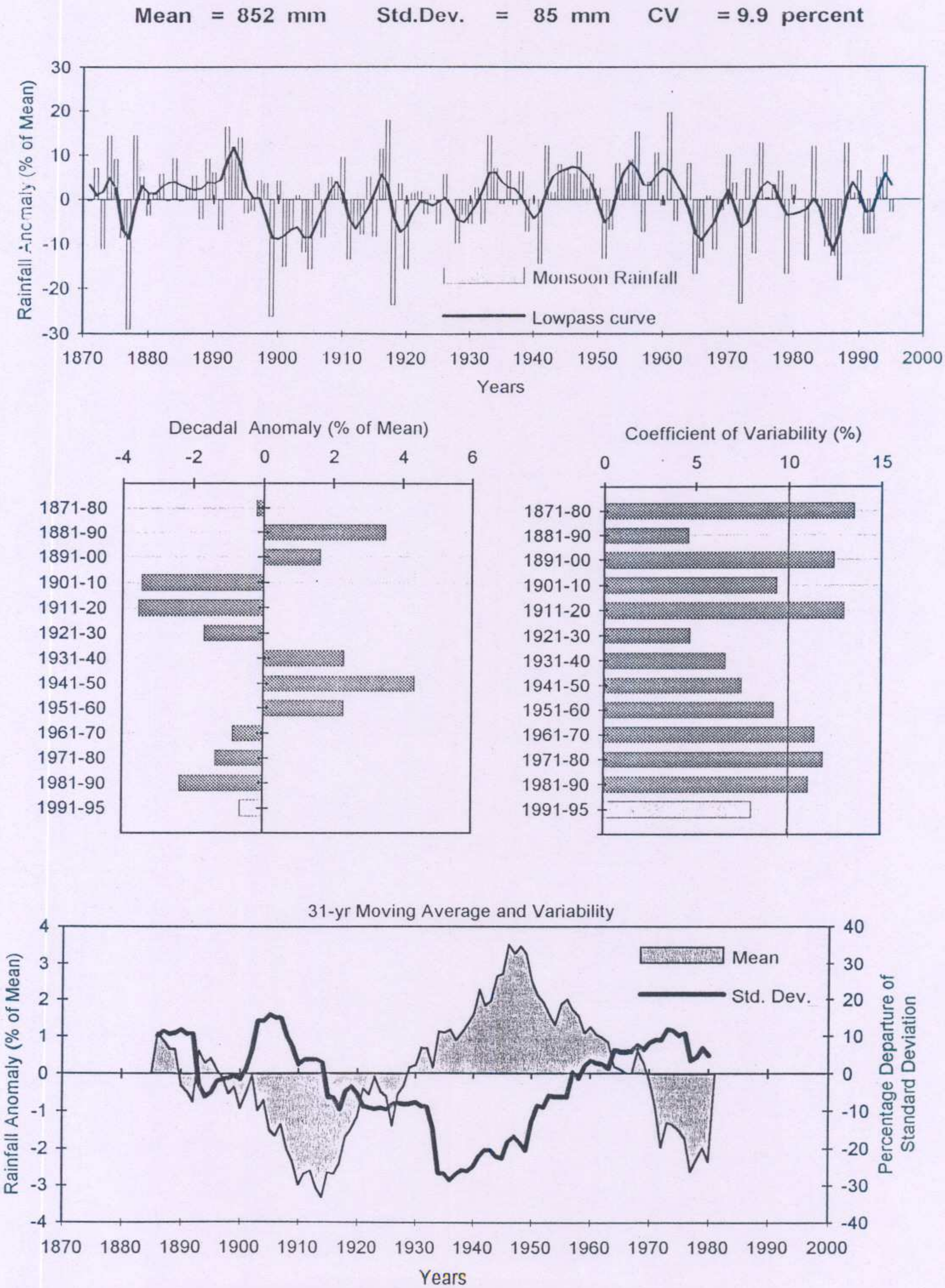
* Significant at 1% level
+ Significant at 5% level




| REGIONS | SUB-DIVISION NUMBERS | |
|---|---|---|
| NORTHWEST INDIA | : 13, 14, 17, 18, 21, 22 | = 6 |
| WEST CENTRAL INDIA | : 19, 20, 23, 24, 25, 26, 28, 32 | = 8 |
| CENTRAL NORTHEAST INDIA | : 07, 08, 09, 10, 11 | = 5 |
| NORTHEAST INDIA | : 03, 04, 05, 06 | = 4 |
| PENINSULAR INDIA | : 27, 29, 30, 31, 33, 34 | = 6 |
| NOT CONSIDERED | : 1, 2, 12, 15, 16, 35 | = 6 |

MAP SHOWING DIFFERENT HOMOGENEOUS REGIONS OF INDIA.

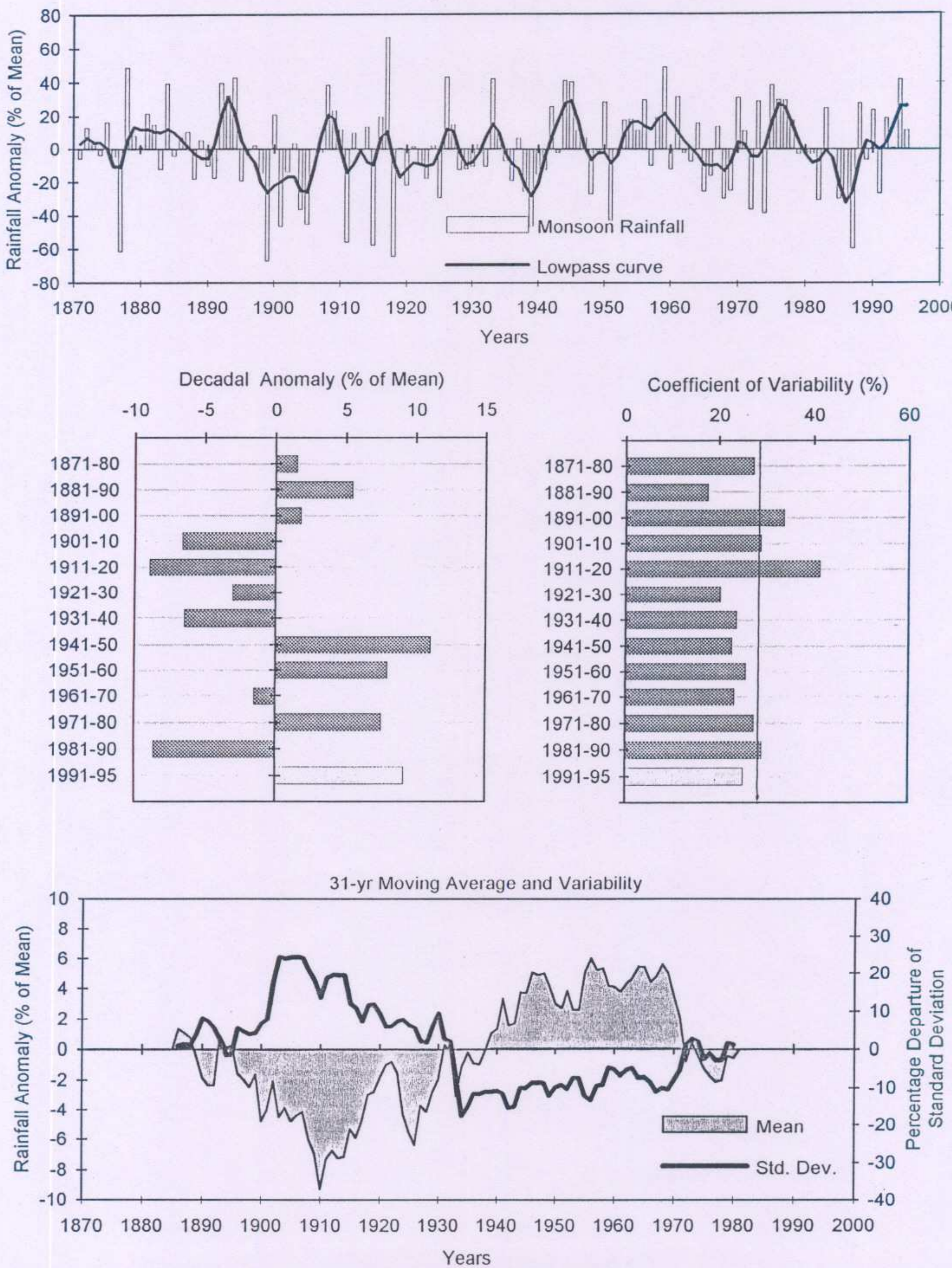
Fig. 1




**All- India Summer Monsoon Rainfall 1871-1995**

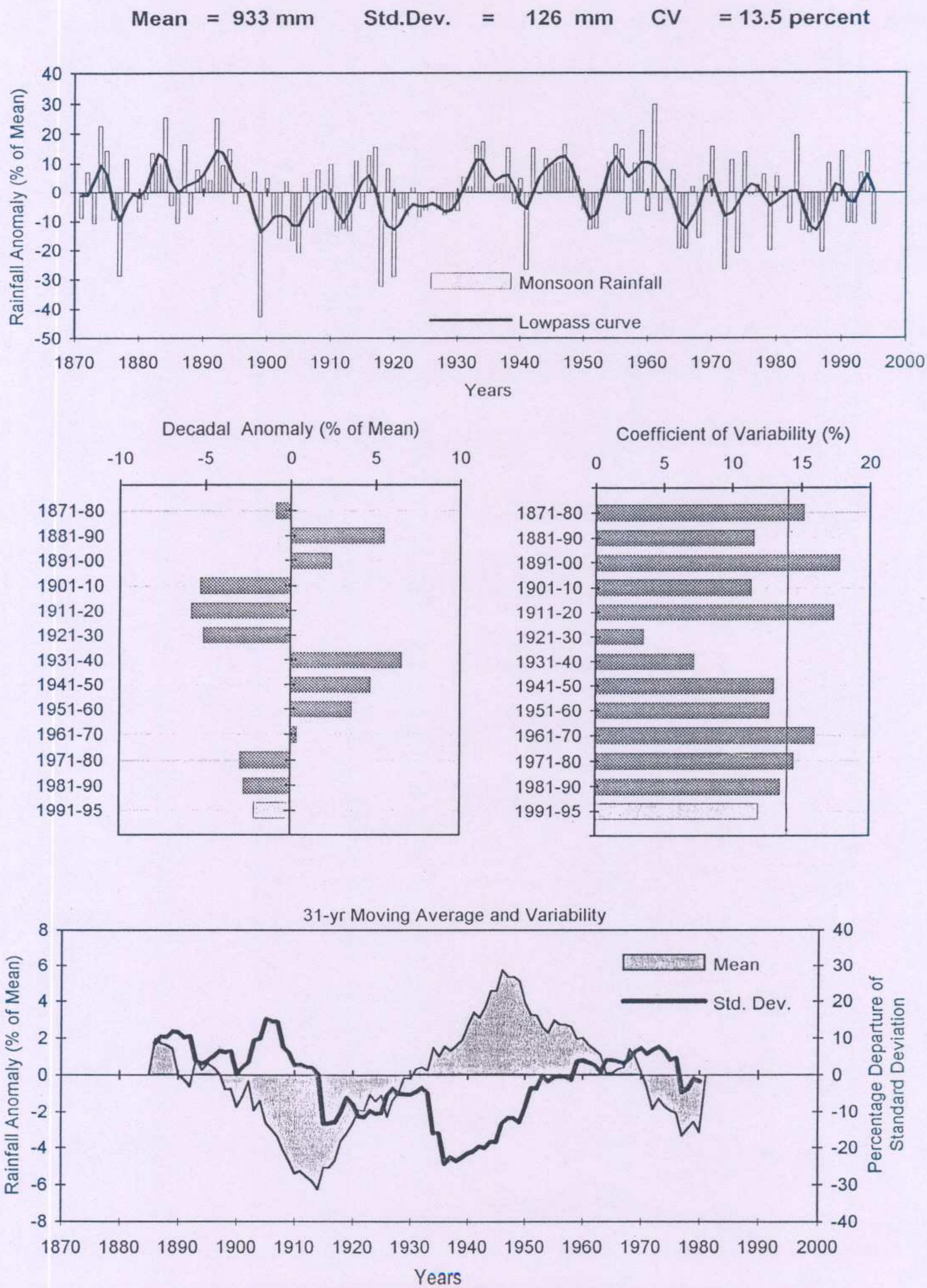
*Fig. 2 (a)*

Mean = 490 mm  Std.Dev. = 132 mm  CV = 27.0 percent



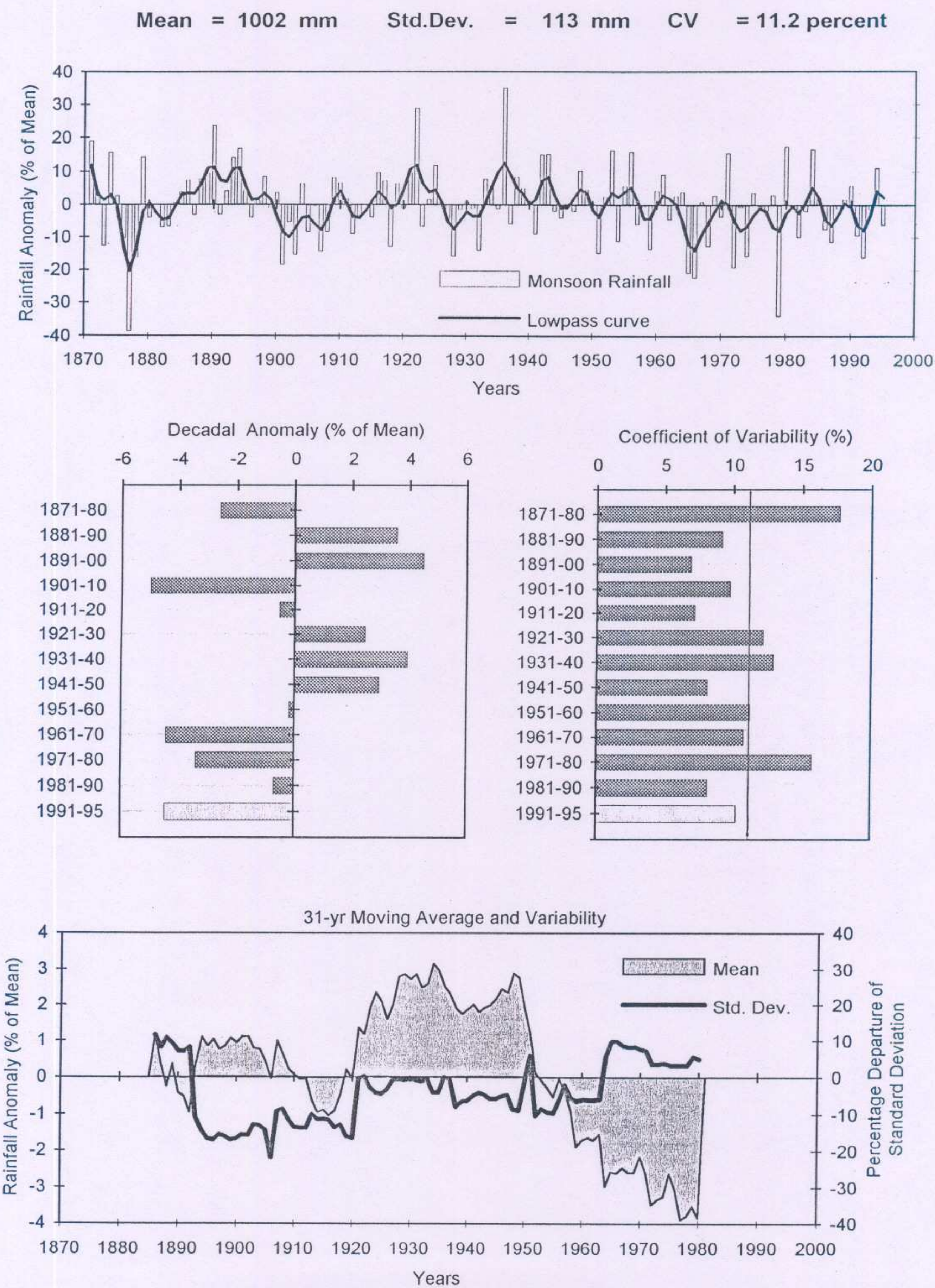

**Northwest India Summer Monsoon Rainfall 1871-1995**

Fig. 2(b)



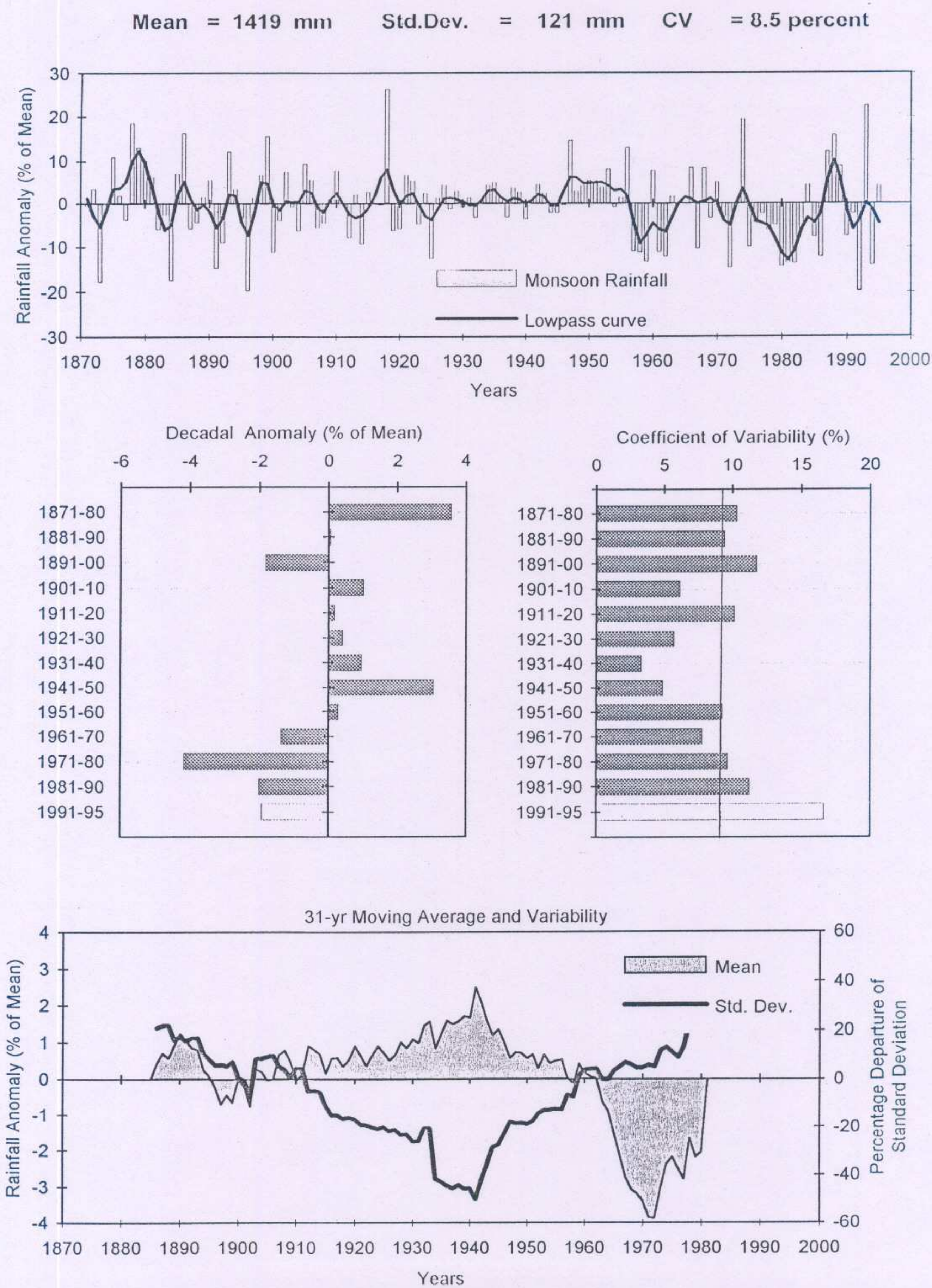

**West Central India Summer Monsoon Rainfall 1871-1995**

Fig. 2 (C)



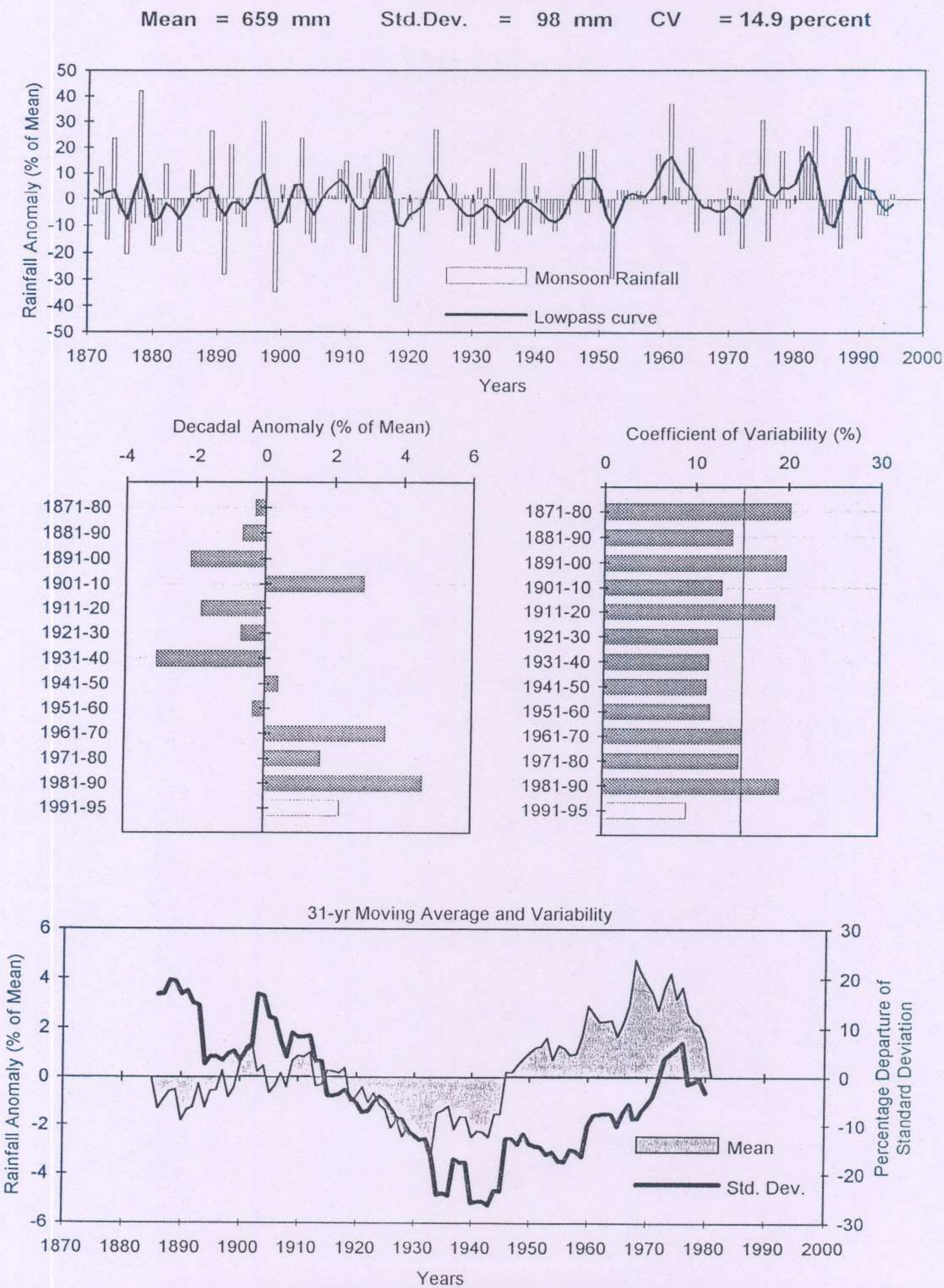

**Central Northeast India Summer Monsoon Rainfall 1871-1995**

Fig. 2 (d)




**Northeast India Summer Monsoon Rainfall 1871-1995**

Fig. 2 (e)




**South Peninsular India Summer Monsoon Rainfall 1871-1995**

Fig. 2 (f)

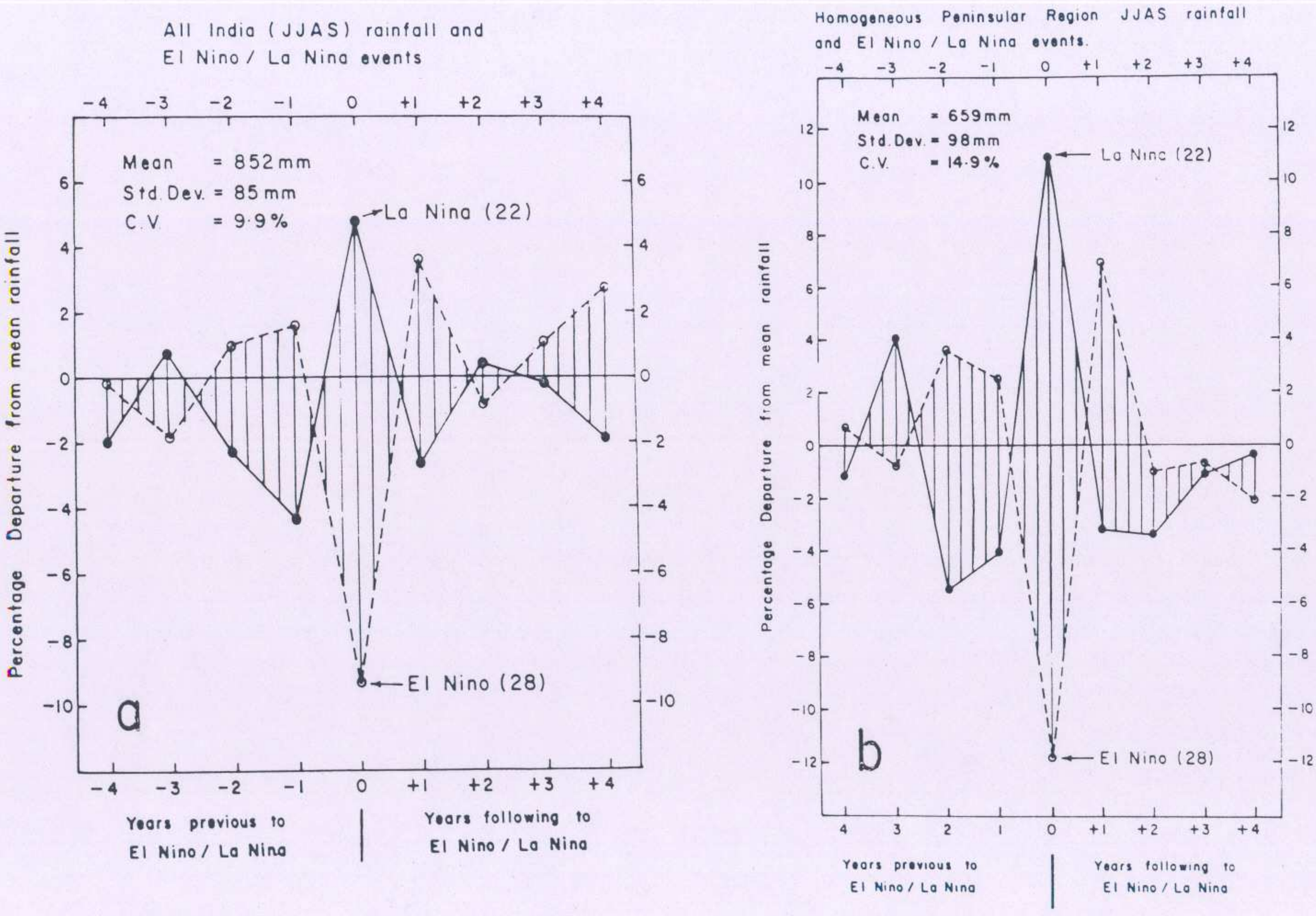

All India (JJAS) rainfall and
El Nino / La Nina events
Mean = 852 mm
Std. Dev. = 85 mm
C.V. = 9·9 %
La Nina (22)
El Nino (28)
a
Percentage Departure from mean rainfall
Years previous to
El Nino / La Nina
Years following to
El Nino / La Nina
Homogeneous Peninsular Region JJAS rainfall
and El Nino / La Nina events.
Mean = 659mm
Std. Dev. = 98mm
C.V. = 14·9 %
La Ninc (22)
El Nino (28)
b
Percentage Departure from mean rainfall
Years previous to
El Nino / La Nina
Years following to
El Nino / La Nina

Fig 2

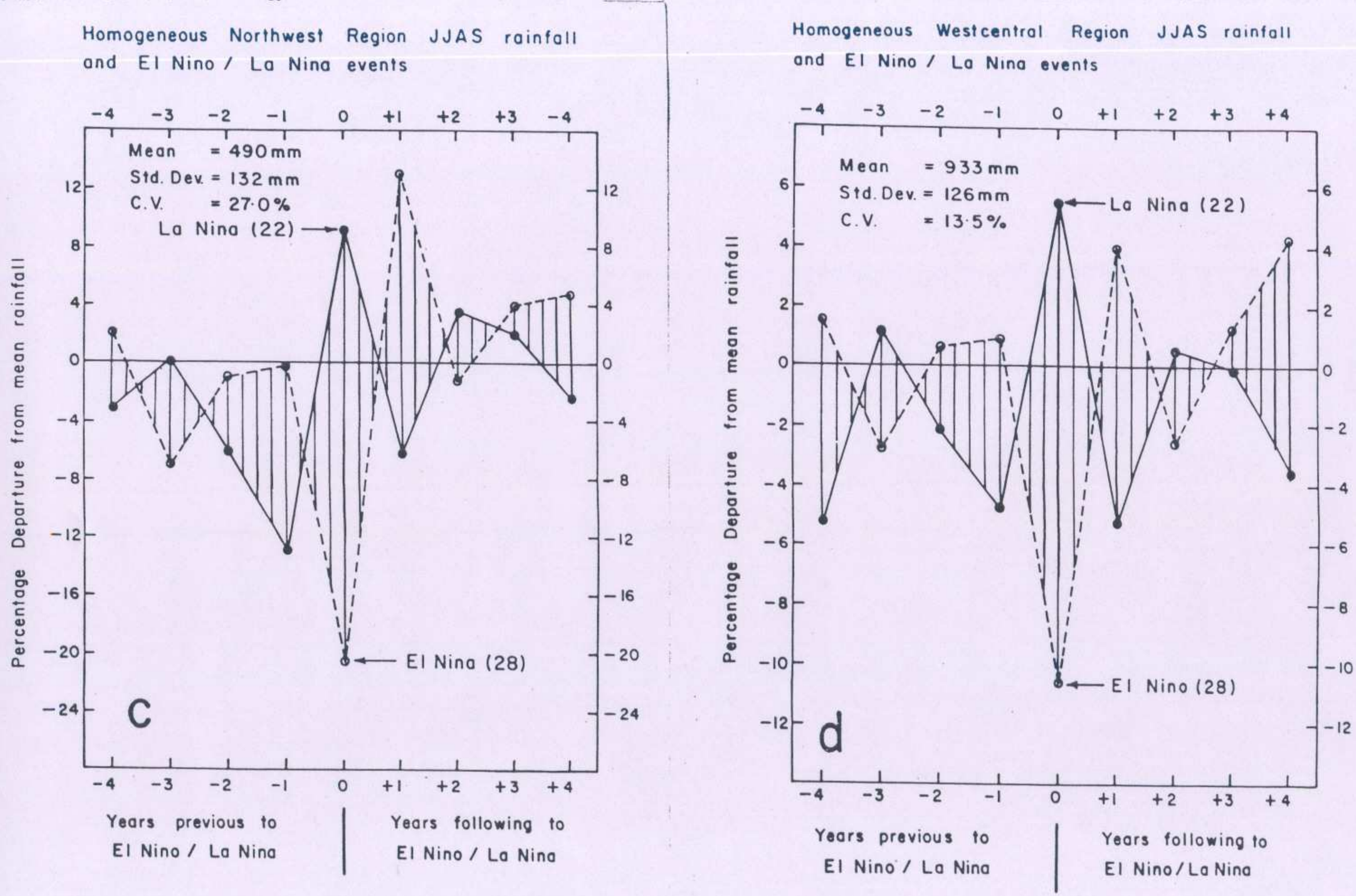

Homogeneous Northwest Region JJAS rainfall
and El Nino / La Nina events
Mean = 490 mm
Std. Dev. = 132 mm
C.V. = 27·0%
La Nina (22)
El Nina (28)
c
Percentage Departure from mean rainfall
Years previous to El Nino / La Nina
Years following to El Nino / La Nina
Homogeneous Westcentral Region JJAS rainfall
and El Nino / La Nina events
Mean = 933 mm
Std. Dev. = 126 mm
C.V. = 13·5%
La Nina (22)
El Nino (28)
d
Percentage Departure from mean rainfall
Years previous to El Nino / La Nina
Years following to El Nino / La Nina

Fig. 3 (cont)

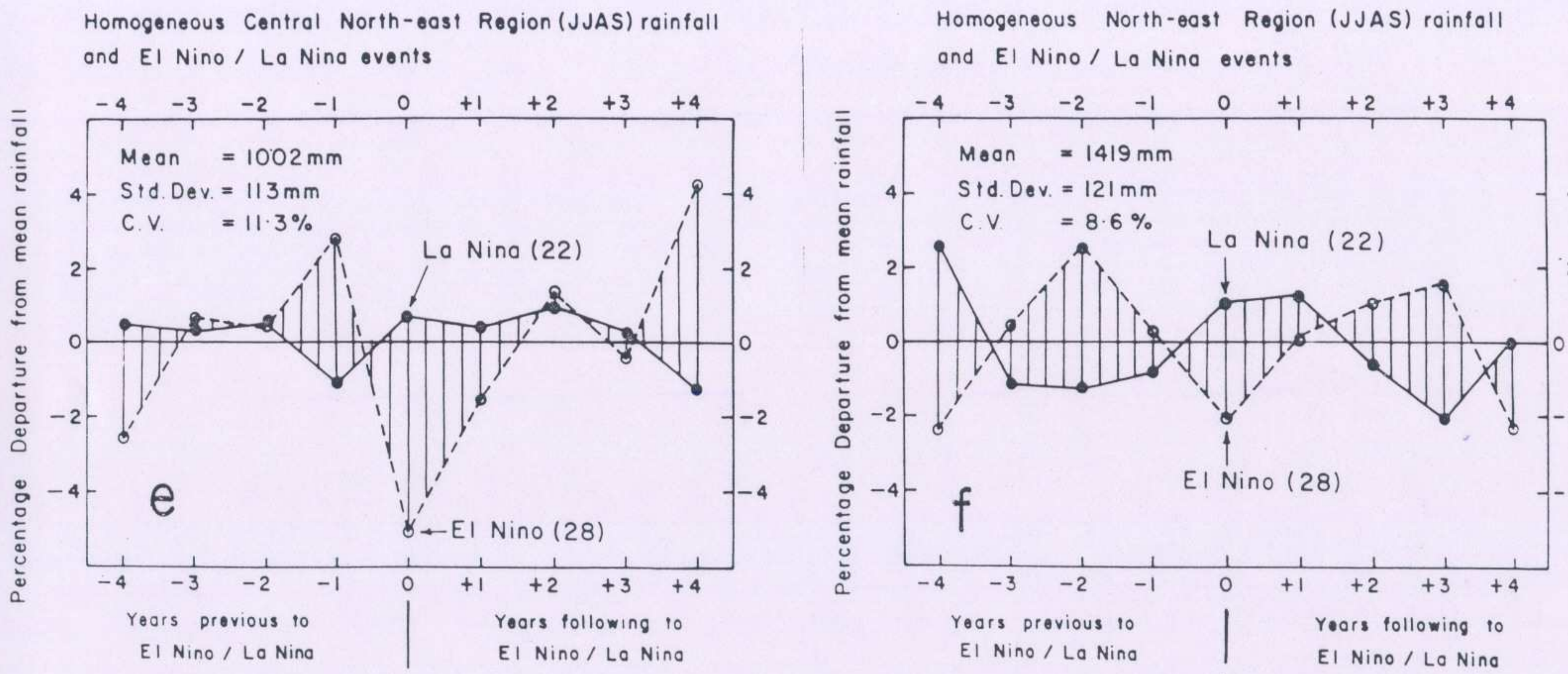

Homogeneous Central North-east Region (JJAS) rainfall
and El Nino / La Nina events
Mean = 1002 mm
Std. Dev. = 113 mm
C.V. = 11·3%
La Nina (22)
El Nino (28)
e
Percentage Departure from mean rainfall
Years previous to El Nino / La Nina
Years following to El Nino / La Nina
Homogeneous North-east Region (JJAS) rainfall
and El Nino / La Nina events
Mean = 1419 mm
Std. Dev. = 121 mm
C.V. = 8·6 %
La Nina (22)
El Nino (28)
f
Percentage Departure from mean rainfall
Years previous to El Nino / La Nina
Years following to El Nino / La Nina

Fig. 3 (cont)