Evidence of Secular Variations in Indian Monsoon Rainfall–Circulation Relationships

B. PARTHASARATHY, K. RUPA KUMAR AND A. A. MUNOT

Indian Institute of Tropical Meteorology, Pune, India

(Manuscript received 14 February 1990, in final form 12 March 1991)

ABSTRACT

Detailed correlation analysis of the all-India monsoon rainfall and mean sea-level seasonal pressure at Bombay (19°N, 73°E) up to three lags on either side of the monsoon season during the last 30 years (1951–80) indicates a systematic relationship. The winter-to-premonsoon (March, April, May-December, January, February; MAM-DJF) seasonal pressure tendency at Bombay shows a correlation coefficient (CC) of −0.70 (significant at 0.1% level) with the Indian monsoon rainfall.

Further examination of this relationship over a long period of 144 years (1847–1990), using sliding correlation analysis, reveals some interesting features. The sliding CCs were positive before 1870, negative during 1871–1900, positive in the years 1901–40, and again negative later on, showing systematic turning points around the years 1870, 1900, and 1940. In light of other corroborative evidence, these climatic regimes can be identified as "meridional monsoon" periods during 1871–1900 and after 1940, and as "zonal monsoon" periods before 1870 and during 1901–40, similar to the observation of Fu and Fletcher. It is also observed that the relationship between Bombay pressure and Indian monsoon rainfall becomes dominant when the ENSO variance in Bombay pressure is high and falls apart when the ENSO variance is small.

The paper contains a listing of the long homogeneous data series on all-India monsoon rainfall and monthly MSL pressure at Bombay for the period 1847–1990.

1. Introduction

The importance of the study of monsoons as a problem of global atmospheric circulation has received considerable attention in recent years. It has been recognized by a number of observational studies that the Asian monsoon system, of which the Indian summer monsoon is a major component, plays an important role as a major energy source in the global-scale circulation in middle and low latitudes. Large interannual cycles in the release of latent heat over India and surrounding areas during the summer monsoon season could well affect the associated global circulation patterns. There have been several attempts to determine the variability on decadal and longer time scales of Indian monsoon rainfall during recent years (Parthasarathy 1984; Mooley and Parthasarathy 1984a; Mooley and Shukla 1987; Pant et al. 1988; etc.). Also, Elliott and Angell (1987, 1988) and Fu and Fletcher (1988) reported some interesting evidence of large signals of decadal-scale climatic variations over the Asian monsoon region.

The studies of Hastenrath (1986, 1987), Thapliyal (1987), and Parthasarathy et al. (1988a, 1990b) have established that, for the prediction of all-India monsoon rainfall, local parameters [such as the mean location of the 500 mb ridge at 75°E during April, winter-to-premonsoon seasonal pressure tendency at Bombay, and premonsoon surface air temperatures over the west-central Indian (WCI) region] are correlated with Indian monsoon rainfall, along with other parameters reflecting the ENSO cycle and the meridional circulation over the Indian Ocean region. However, it has not yet been possible to develop a stable long-range prediction scheme because the predictor associations with Indian monsoon rainfall have varied considerably with time, in magnitude as well as direction. It is, therefore, necessary to study these variations with long-period data, in the broader perspective of climate variability over the region. Records of Bombay (Colaba observatory) mean sea-level (MSL) pressure, one of the leading predictors of Indian monsoon rainfall, are available from the year 1847 onward. Because of its relationship to the tropical circulation as well as the Southern Oscillation (Wright 1975), Bombay pressure can be taken as a good tracer for studying the climate variability over this region and its association with the Indian monsoon.

This study examines the behavior of the Indian monsoon rainfall and its relationship with variables derived from the long record of Bombay MSL pressure. Simple linear correlations between various datasets are used to describe the relationships.

Corresponding author address: B. Parthasarathy, Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pune 411 008 (India).

2. Details of data

a. Indian summer monsoon rainfall

All-India (India taken as one unit) and 29 different meteorological subdivisional summer monsoon (June through September) rainfall data, prepared by area-weighting 306 well-distributed raingages over the country, have been used here. The reader is referred to Mooley and Parthasarathy (1984a) and Parthasarathy et al. (1987, 1990b) for a detailed discussion of preparing these datasets and their listing from 1871 onward.

The all-India rainfall series in the above studies began in 1871 because of the unavailability of data at all 306 raingages prior to that time. However, from an examination of all of the old rainfall records, we found that a far less dense but well-distributed network of 16 stations [namely, Trivandrum, Madras (Nungambakkam), Shimoga, Bangalore, Hyderabad, Bombay (Colaba), Puri, Calcutta (Alipore), Jabalpur, Deesa, Patna, Kanpur, Guwahati, Gorakhpur, Delhi, and Ferozpur] with reliable data records is available from 1841 onward (Sontakke 1990). The arithmetic average of the monsoon rainfall at these stations has been taken to represent the country's mean, denoted by all-India (A) monsoon rainfall to distinguish it from the original all-India series based on 306 stations. Thus, the all-India (A) series is available for the period 1841–1990 and the all-India series for 1871–1990. The correlation coefficient (CC) between these two series is very high (0.84) for the common period 1871–1990, and the extreme (wet and dry) years also match well. These two series are separately used in the present study. Parthasarathy (1984) and Mooley and Parthasarathy (1984a) established that the all-India summer monsoon rainfall series for the period 1871–1978 was homogeneous, Gaussian-distributed, and free from persistence.

b. Bombay MSL pressure

Mean sea level pressure (0830 Indian Standard Time or 0300 UTC) at Bombay (Colaba observatory: 18°51′N, 72°49′E) is available for the period 1847–1990 from the India Meteorological Department (IMD). A uniform time of observation throughout the data period and constancy of site are ascertained from the observatory records. The data have been preprocessed by IMD by scrutinizing the station records and applying the necessary corrections to make the series homogeneous. As such, there was no need for the type of corrections applied by Wright (1975) and Trenberth and Shea (1987), who obtained the data from various sources like World Weather Records, World Monthly Surface Station Climatology, Monthly Climatic Data for the World, etc., and their periodical updates. The homogeneity of the data, however, was confirmed by applying Swed and Eisenhart's test (runs above and below the median: Swed and Eisenhart 1943; Thom 1966) on the seasonal pressure series.

3. Methodology

To study the association between Indian summer monsoon rainfall and Bombay pressure, the following approach has been used: (i) simple correlation analysis, (ii) compositing of pressure anomalies during the excess (wet) and deficient (dry) years of all-India monsoon rainfall, and (iii) consistency of CCs over long periods by using sliding windows of different widths.

It is conventional to use a period of 30 years for establishing climatic normals and relationships. To understand the temporal characteristics of the relationship between pressure and the all-India monsoon (JJAS) rainfall, the CCs with seasonal pressures of up to 3 lags on either side of the monsoon season (lag − 3, SON; lag − 2, DJF; lag − 1, MAM; lag 0, JJA; lag + 1, SON; lag + 2, DJF; and lag + 3, MAM) have been calculated for the recent period 1951–80. In addition, the seasonal tendency of pressure from the previous winter (DJF) to the current spring (MAM), i.e., lag − 1 minus lag − 2 (MAM–DJF), denoted hereafter as $P_{\text{MAM-DJF}}$, has also been considered for correlation analysis. The importance of this seasonal feature has been demonstrated by Shukla and Paolino (1983), Parthasarathy and Pant (1985), and Parthasarathy et al. (1988a, 1990b).

The persistence (as indicated by the serial correlations of lags 1 to 3) of the datasets involved has been considered in assessing the statistical significance of the correlations, and the degrees of freedom have been reduced wherever necessary, as suggested by Quenouille (1952). However, the serial correlations (up to 3 lags) of almost all parameters are found to be either negative or insignificantly positive (less than 0.2).

In order to see the strength of the signal during extreme rainfall years in the pressure series, composite values of pressure anomalies (from 1951–80 mean) for lag − 3 to lag + 3 seasons and MAM–DJF have been calculated for years of deficient ($\leqslant \bar{R} - S$) and excess ($\geqslant \bar{R} + S$) all-India monsoon rainfall ($\bar{R}$ is the mean and S the standard deviation) during the period 1951–80. There were seven dry (1951, 1965, 1966, 1968, 1972, 1974, and 1979) and five wet (1956, 1959, 1961, 1970, and 1975) monsoon rainfall situations during this 30-year period, which have also been found to have a definite impact on production of food grains over India (Parthasarathy et al. 1988b).

The consistency of significant CCs over a long period of time has been examined as suggested by Bell (1977) by calculating the CCs over sliding windows of width 11, 21, and 31 years during the period 1847–1990. These window widths are chosen to understand the high-, medium-, and low-frequency changes in the correlation.

4. Relationship between all-India monsoon rainfall and Bombay pressure

The CCs between all-India monsoon rainfall and the different seasonal means of MSL pressure at Bombay (lag − 3 to lag + 3 and MAM–DJF) during the period 1951–80 are shown in Fig. 1a. A systematic change in CC values can be observed from small and positive at lag − 2, two seasons before monsoon, to negative and later to near zero at lag + 3 (the negative CC being significant at 5% level or above for lag − 1, lag 0, and lag + 1 seasons). This systematic variation of CC during the course of the seasons suggests that the large-scale circulation features of the monsoon system may be undergoing a low-frequency transition during anomalous monsoon years. Here $P_{\mathrm{MAM-DJF}}$ shows a CC of −0.70 (significant at 0.1% level) with the monsoon rainfall.

The composite values of seasonal pressure anomalies for lag − 3 to lag + 3 and $P_{\mathrm{MAM-DJF}}$ for extreme years of deficient and excess all-India monsoon rainfall show opposite signs from lag − 3 to lag + 3 (except at lag + 2) and a gradual transition in magnitude with season (Fig. 1b). Here $P_{\mathrm{MAM-DJF}}$ has a value of −0.6 mb during excess years and +0.5 mb during deficient years, the range of 1.1 mb against a standard deviation of 0.5 mb during 1951–80 indicating a good signal of the extreme years of monsoon rainfall during this 30-year period.

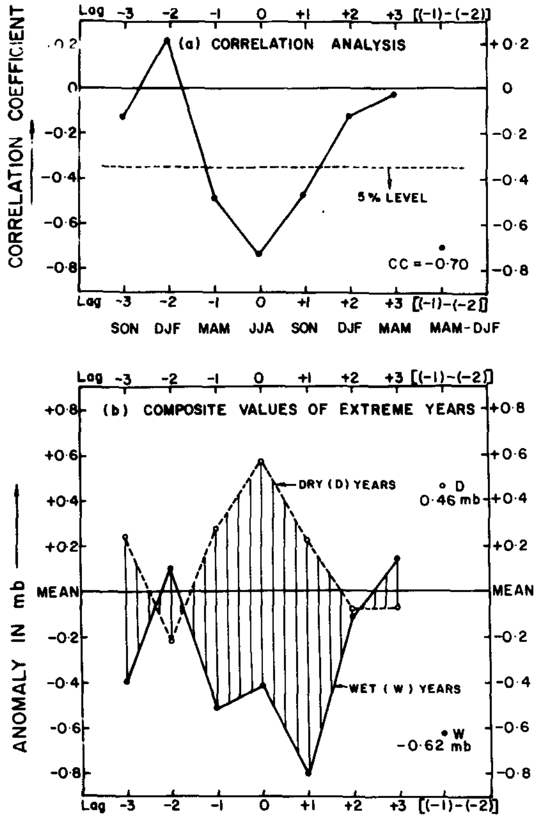

FIG. 1. Relationships between all-Indian Monsoon Rainfall and MSL pressure of Bombay for different seasons during the period 1951–80. (a) Correlation coefficient between the parameters. (b) Composite values of seasonal pressure anomalies for five wet years (1956, 1959, 1961, 1970, and 1975) and seven dry years (1951, 1965, 1966, 1968, 1972, 1974, and 1979) of all-India monsoon rainfall.

Thus, it may be stated that active monsoon conditions over the country in most cases were preceded by below-normal pressure before monsoon season with a steeper pressure drop from winter to premonsoon, and vice versa. Therefore, $P_{\mathrm{MAM-DJF}}$ at Bombay would have been a useful parameter in the long-range prediction of Indian monsoon rainfall during this period, and the short-period relationship requires further detailed examination in time and space.

On a subdivisional scale (Fig. 2), the CCs are generally negative in all parts of the country and significant at the 10% level or above for the 21 contiguous subdivisions (76% of the area of India). The CCs are significant at the 5% level or above over the region north of 12°N and west of 80°E. Therefore, it can be concluded that the relationship between $P_{\mathrm{MAM-DJF}}$ at Bombay and monsoon rainfall had good spatial coherence over a major part of the country.

5. Consistency of the relationship between all-India monsoon rainfall and $P_{\mathrm{MAM-DJF}}$ at Bombay over a long period

Figure 3 shows the variation of CCs between all-India monsoon rainfall and $P_{\mathrm{MAM-DJF}}$ at Bombay during the period 1871–1990, over sliding windows of widths 11, 21, and 31 years. The CC value is plotted in the central year of the corresponding window. The CCs are generally negative during 1871–1901, positive during 1902–1945, and again negative during 1946–1990; however, the CCs are significant at the 5% level or above only after 1950. It may also be seen that the CCs over windows of 11 and 21 years width are more rapidly fluctuating than those over the windows of 31 years.

The turning points in the signs of the relationship around the years 1901 and 1943, delineating fairly long periods of direct and inverse associations (Fig. 3), have prompted us to extend the data period back to the earliest possible year to obtain further evidence of such changes, if any. For this purpose, we examined the sliding correlations of the all-India (A) rainfall and $P_{\mathrm{MAM-DJF}}$ at Bombay during 1847–1990. The sliding CCs are shown in Fig. 4. It may be noted that this rainfall series is based on fewer stations. It is seen that the 31-year sliding width CCs are positive before 1870 and during 1900–1940, and negative during 1870–1900 and after 1940, showing conspicuous turning points of changeover in the signs of CCs around the years 1870, 1900, and 1940. However, the positive CCs before 1870 are small and insignificant. During the recent period after 1940, the CCs were stronger in the case of all-India monsoon rainfall based on 306 stations (Fig. 3) than those in the case of all-India monsoon rainfall based on 16 stations (Fig. 4).

A high negative value of $P_{\mathrm{MAM-DJF}}$, indicating a steeper pressure drop from winter to spring, generally leads to a lower pressure during the premonsoon months. In view of this, the negative relationships dur-

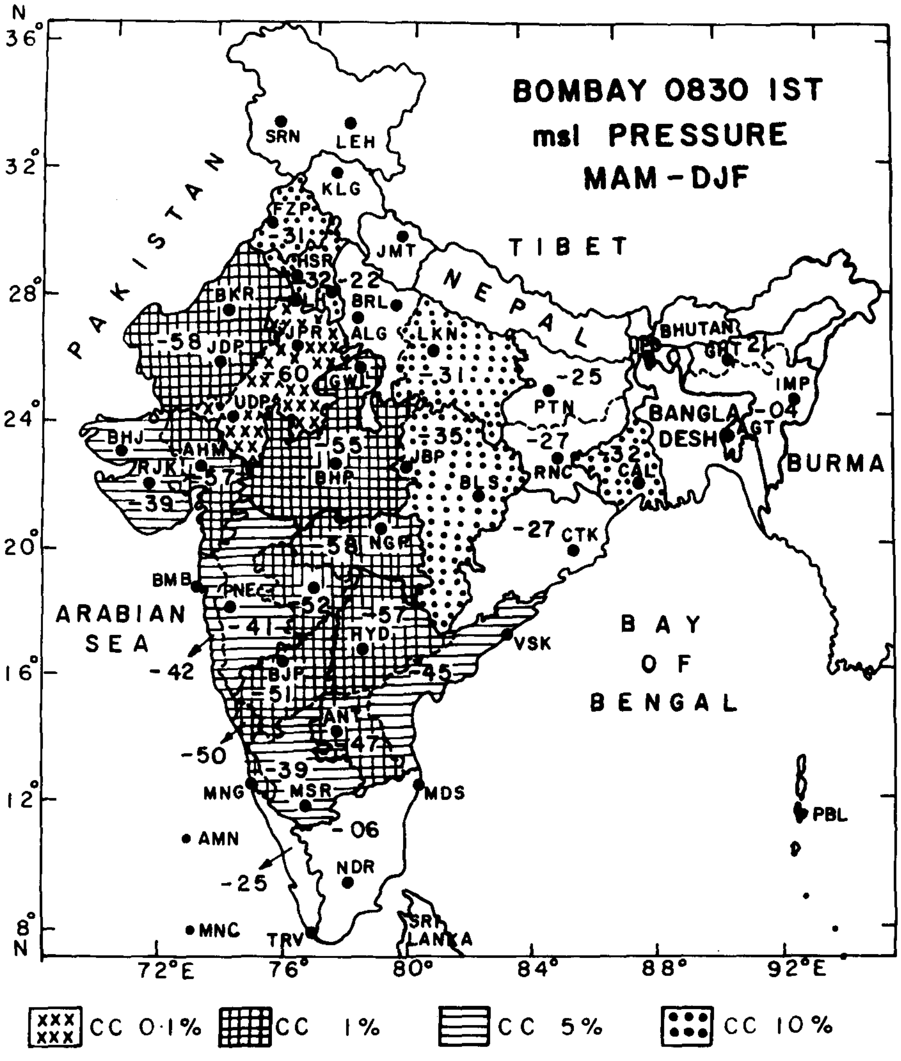

FIG. 2. Correlation coefficients between monsoon rainfall of different meteorological subdivisions of India and MSL pressure tendency (MAM–DJF) of Bombay for the period 1951–80.

ing 1870–1900 and after 1940 are understandable as a lower pressure over the Indian (Asian) landmass during premonsoon months establishes a stronger lower-tropospheric cross-equatorial flow, which in turn transports larger amounts of water vapor into the Northern Hemisphere (Hastenrath 1985). However, during the periods prior to 1870 and 1900–40 Bombay pressure seems to be indifferent or even positively related to monsoon rainfall, which does not correspond with any of the causal mechanisms usually put forth for the development of the monsoon circulation.

Changes in the correlations between Indian rainfall and its predictors were noted quite early by Walker (1910, 1914) and Savur (1931), but a global perspective of such changes was not available at that time. Recent studies have shown marked secular changes in the relationship between the all-India monsoon rainfall and different circulation features such as the Southern Oscillation (Shukla and Paolino 1983; Parthasarathy and Pant 1984; Elliott and Angell 1987, 1988; Pant et al. 1988), sea surface temperature over the tropical Pacific Ocean (Angell 1981; Mooley and Parthasarathy 1984b), mean sea level pressure over equatorial South American regions and snow cover over the Himalayan area (Thapliyal 1987), annual sunspot numbers (Ananthakrishnan and Parthasarathy 1984), surface air temperatures over the west-central Indian region (WCI) (Parthasarathy et al. 1990a), and Northern Hemispheric surface air temperature (Verma et al. 1985). The major turning points in these relationships seem to have some temporal coherence around the years 1900 and 1940. Elliott and Angell (1987, 1988) examined relationships between the Indian monsoon, the Southern Oscillation, and the hemispheric air and sea temperatures for the period 1884–1984 and found a general decrease in correlation between the various

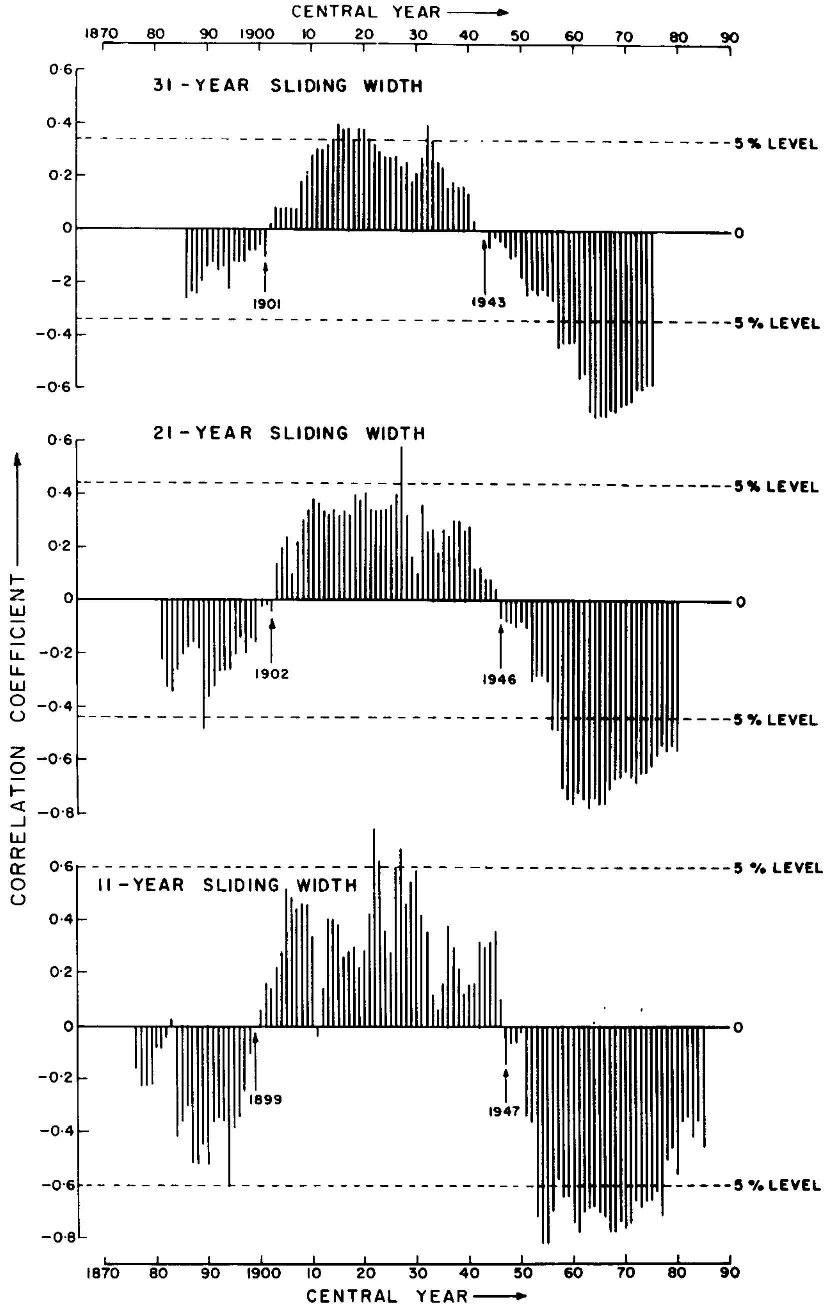

FIG. 3. Variation of correlation coefficient over sliding window of 11, 21, and 31 years, between all-India monsoon rainfall and pressure tendency (MAM–DJF) of Bombay during the period 1871–1990.

datasets between about 1920 and 1950. They suggest that the evidence shows a large change in the circulation some time in the middle of this century.

The positive correlation between premonsoon pressure and monsoon rainfall prior to 1870 and during 1900–40, which belies the conventional theory of associating the strength of cross-equatorial flow with the activity of monsoon, may be due to other types of large-scale circulations dominating the system. This can be broadly visualized as the meridional circulation becoming weaker and the zonal circulation becoming stronger in the monsoon region. In this connection, it is interesting to note that there was a weakening of the trade winds in the eastern Pacific during the late 1930s followed by a warming of the sea surface, and the anomaly spread across the Pacific in the early 1940s in a pattern resembling a slow El Niño–Southern Oscillation (ENSO) event (Cooper et al. 1989).

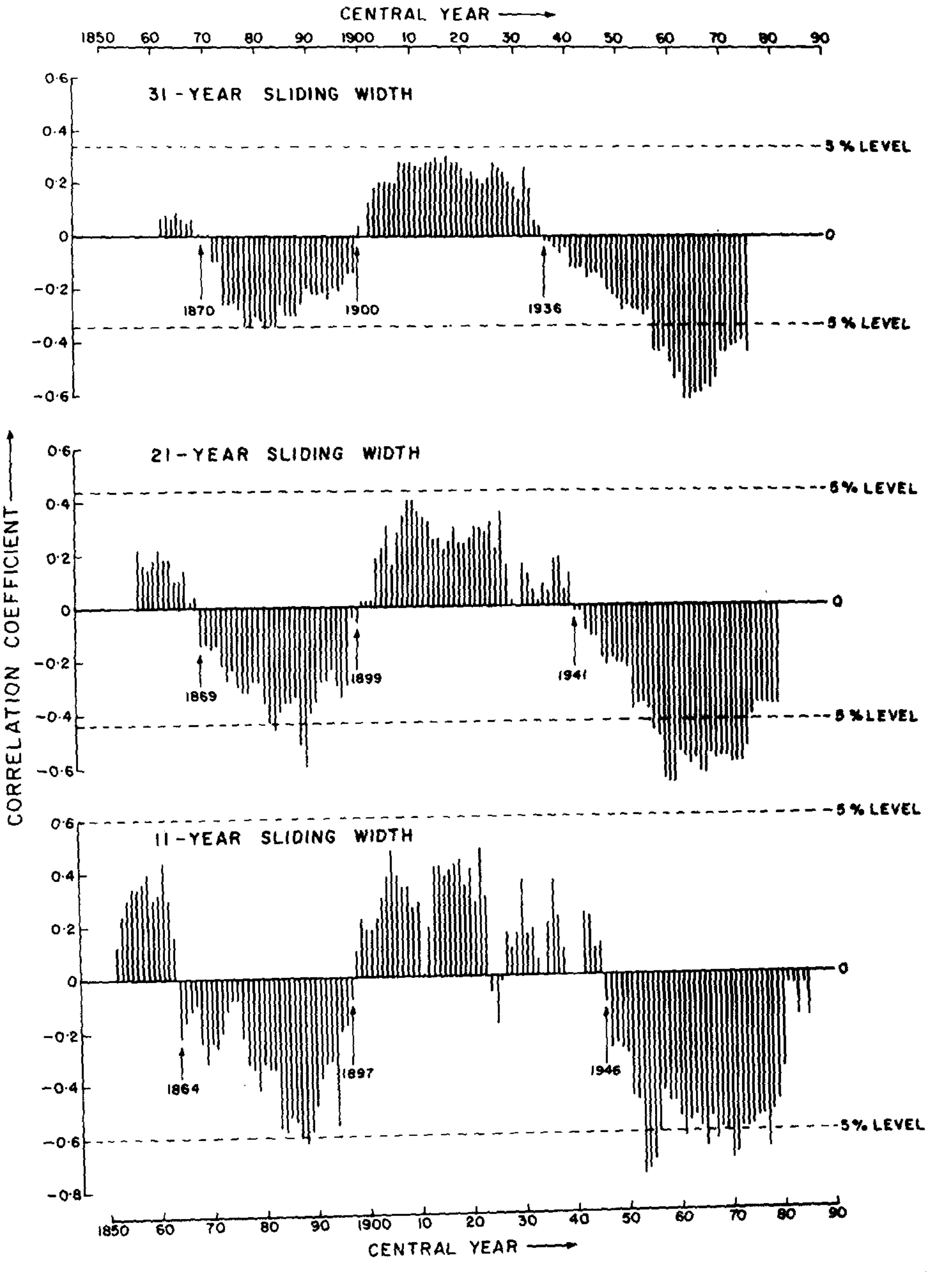

FIG. 4. Variation of correlation coefficient over sliding window of 11, 21, and 31 years, between all-India (A) monsoon rainfall (average of 16 stations) and pressure tendency (MAM-DJF) of Bombay during the years 1847-1990.

In a recent study, Fu and Fletcher (1988) identified large climatic variations in the Asian monsoon region by examining the zonal and meridional components of surface winds (COADS) during the monsoon months (June, July, and August) for the period 1860-1960 over the Arabian Sea, the Bay of Bengal, and the equatorial buffer zone in the Indian Ocean (0°-5°S, 40°-100°E). They concluded that the relative dominance of the two wind components had been undergoing significant decadal-scale variability, more dominantly in the Bay of Bengal (Fig. 5). The cumulative curves of the anomalies of the zonal component during June through August over the Bay of Bengal and the all-India monsoon rainfall anomalies show a striking inverse relationship (Fig. 6). Based on these associations, they identified distinct climatic regimes in wind components with changes around the years 1875, 1900, and 1940. The period 1875-1900 is characterized by what they call the "meridional monsoonal period" and the period 1900-1940 by the "zonal monsoonal period" over the Indian Ocean (Fig. 7), which are also synchronous with the high and low epochs of the Indian

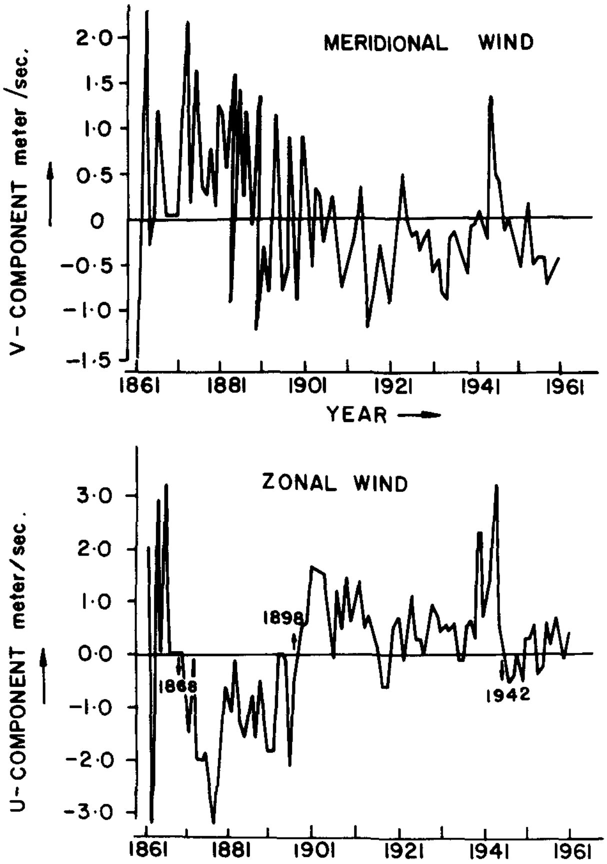

FIG. 5. Monsoon winds (*U* and *V* components) in the Bay of Bengal monsoon current from June to August for the period 1860–1960. (After Fu and Fletcher 1988).

monsoon rainfall. It has also been observed that, during the zonal monsoonal period, dry years were more common than during the meridional monsoonal period, when wet years were more common in India. In the present study, changes in the signs of correlations around 1870, 1900, and 1940 may be reasoned to be a part of the large-scale changes in the climatic regimes over the Indian Ocean and Pacific Ocean areas.

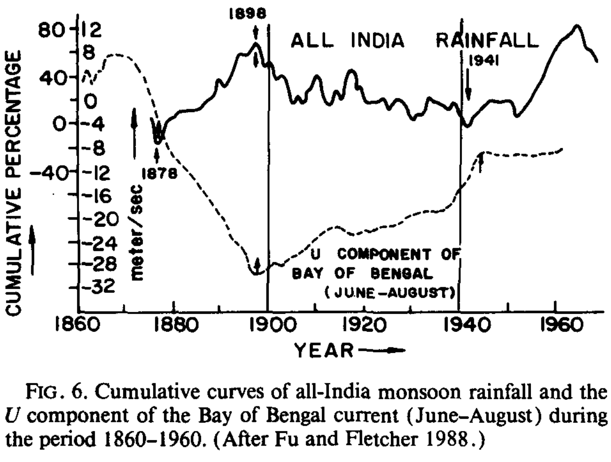

FIG. 6. Cumulative curves of all-India monsoon rainfall and the *U* component of the Bay of Bengal current (June–August) during the period 1860–1960. (After Fu and Fletcher 1988.)

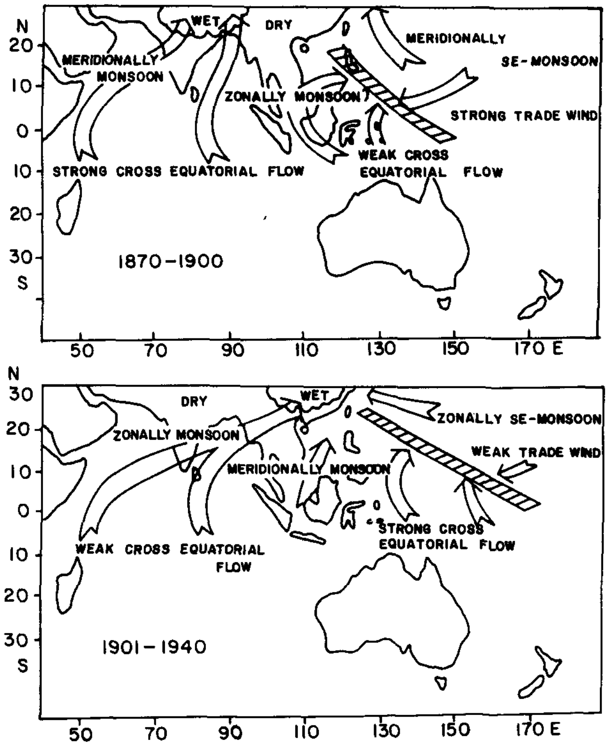

FIG. 7. Schematic maps of two flow patterns of Asian monsoon current (winds) during 1870–1900 and 1901–1940. (Adapted from Fu and Fletcher 1988.)

The activity of the Indian summer monsoon is also strongly linked to the surface air and sea surface temperatures over the Pacific Ocean and associated ENSO parameters (Sikka 1980; Mooley and Parthasarathy 1983; Rasmusson and Carpenter 1982, 1983; and Parthasarathy and Sontakke 1988). Secular variations in the ENSO cycle are known to exist in both amplitude and positions of the centers of action (Trenberth and Shea 1987). Therefore, it is important to determine whether there is a link between the secular changes in the monsoon–pressure relationships over India seen above and those in the ENSO cycle.

Schove and Berlage (1965) and Berlage (1966) constructed Southern Oscillation (SO) indices by simple half-yearly averaging of surface pressure anomalies at some stations in the Indian Ocean area, using data for the period 1841–1960. Using these data for the April–September SO index (mean of pressure anomalies at Bombay, Madras, Djakarta, Darwin, Mauritius, and Perth), we computed its correlations with the all-India (A) monsoon rainfall for different periods. A highly positive SO index of Berlage represents a strong ENSO event. The CCs obtained, along with their significance levels given in parentheses, are: −0.46 (0.1% level) for the whole period 1847–1960; −0.08 (not significant) for the zonal monsoon period 1847–1870; −0.75 (0.1% level) for the meridional monsoon period 1871–1900; −0.36 (5% level) for the zonal monsoon period 1901–40; and −0.68 (0.1% level) for the meridional monsoon period 1941–60. This indicates that the influence of the SO component in the Indian Ocean sector on the Indian monsoon rainfall, though very strong in general, becomes rather weak during the zonal monsoon periods. In this connection, it is also important to see the secular changes in the ENSO variance in Bombay pressure in comparison with the changes in its relationship with the Indian monsoon rainfall. For this purpose, the sliding correlation analysis of $P_{\mathrm{MAM-DJF}}$ at Darwin was performed with $P_{\mathrm{MAM-DJF}}$ at Bombay, as well as with all-India monsoon rainfall, during the period 1882–1990 (Fig. 8). Darwin $P_{\mathrm{MAM-DJF}}$ shows consistently negative CCs with the Indian monsoon rainfall, but they are significant only after 1950 (Fig. 8b). During the period 1901–1940, the CCs between Bombay and Darwin $P_{\mathrm{MAM-DJF}}$ are indifferent, with relatively higher positive CCs before 1900 and after 1940 (Fig. 8c). The CCs after 1940 are highly significant. It can be clearly seen that Bombay and Darwin $P_{\mathrm{MAM-DJF}}$ both show highly significant negative CCs with the Indian monsoon rainfall only when they are highly interrelated. Therefore, it can be concluded that the relationship between Bombay pressure and Indian monsoon rainfall becomes dominant when the ENSO variance in Bombay pressure is high and falls apart when the ENSO variance is small. Thus, it can be stated that the changes in the correlations observed in the present study reflect large-scale changes in the climatic regimes over a wide area.

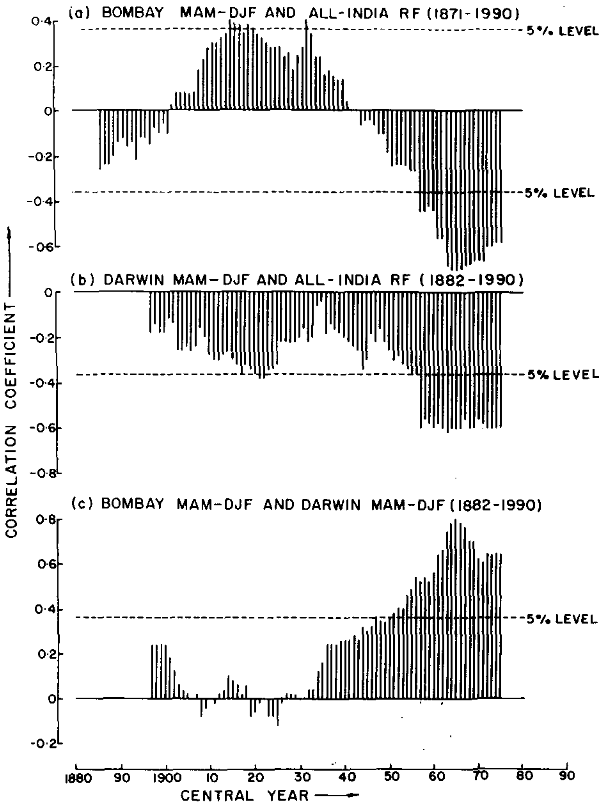

FIG. 8. Variation of the correlation coefficient over a 31-year sliding window width between all-India monsoon rainfall and $P_{\mathrm{MAM-DJF}}$ at (a) Bombay and (b) Darwin and (c) for $P_{\mathrm{MAM-DJF}}$ between Bombay and Darwin.

In view of the importance of the Bombay pressure record for studying multidecadal climate variability as demonstrated above, a listing of the mean monthly MSL pressure at Bombay along with all-India summer monsoon rainfall for the period 1847–1990 is presented in the Appendix.

6. Summary and conclusions

A detailed study of the relationship between the mean sea level pressure at Bombay (19°N, 73°E) and the Indian summer monsoon rainfall has been made. Secular changes in this relationship using long-period data during 1847–1990 were examined to identify the decadal-scale variations in the climatic regime over the area. An attempt was made to relate these changes to similar patterns in the global-scale circulation features. The important conclusions are:

(i) The CCs between all-India monsoon rainfall and Bombay pressure for different seasons up to one lag on either side of the monsoon season, for the period 1951–80, are significantly negative, suggesting that the large-scale circulation over India undergoes a low-frequency transition.

(ii) During this period, $P_{\mathrm{MAM-DJF}}$ at Bombay shows a significant CC of -0.70 with the subsequent all-India monsoon rainfall and composite values of $+0.5$ mb for deficient monsoons and -0.6 mb for excess monsoons, suggesting that during this period active monsoon conditions over the country are preceded by below-normal pressure and a steeper-than-normal seasonal pressure drop before the monsoon season and vice versa.

(iii) Sliding correlation analysis between all-India monsoon rainfall and $P_{\mathrm{MAM-DJF}}$ at Bombay for the period 1847–1990 showed systematic turning points in the CC values around the years 1870, 1900, and 1940. These turning points are temporally coherent with the changes in tropical circulation features observed by Fu and Fletcher (1988) and Elliott and Angell (1987, 1988).

(iv) The positive CC period before 1870 and during 1900–40 can be identified as a "zonal monsoonal circulation period." The negative CC periods during 1870–1900 and 1940 to present can be taken as a meridional monsoonal circulation period.

(v) The relationship between Bombay pressure and Indian monsoon rainfall, which has recently prevailed, is dominant only when the ENSO variance in Bombay pressure is high.

(vi) The most recent data shows a trend toward a more zonal monsoonal period.

Acknowledgments. The authors are thankful to Mr. D. R. Sikka, Director, Indian Institute of Tropical Meteorology (IITM), for the interest and facilities and to the Additional Director General of Meteorology (Research), India Meteorological Department, Pune, for the supply of meteorological data. They are also grateful to Prof. R. Ananthakrishnan and Dr. G. B. Pant, Head, Climatology and Hydrometeorology Division of IITM, and the reviewers, Drs. S. Hastenrath and E. M. Rasmusson, and the Editor Dr. R. E. Livezey, for critically going through the manuscript and offering valuable suggestions. Thanks are also due to Mrs. J. V. Revadekar for typing the manuscript.

APPENDIX

All-India summer monsoon rainfall and monthly MSL pressure at Bombay (1847–1990)

Year	RF1	RF2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1847	840		14.5	14.0	13.3	10.2	7.7	3.7	4.6	6.7	8.4	11.4	13.9	14.0	1847
1848	761		14.9	14.4	11.8	9.5	8.3	4.6	4.7	6.7	10.6	11.5	14.4	14.9	1848
1849	879		15.5	14.1	13.2	9.8	7.4	3.8	5.3	6.4	7.7	12.0	13.8	14.5	1849
1850	828		13.2	14.8	13.7	11.1	9.1	4.3	4.3	7.7	9.7	10.1	13.8	15.8	1850
1851	786		15.9	13.9	12.7	9.8	8.3	4.0	2.8	6.3	9.6	11.5	12.0	15.7	1851
1852	945		14.9	14.0	11.8	10.3	8.5	4.0	4.9	7.5	8.7	12.5	14.3	14.9	1852
1853	824		15.3	13.0	12.8	10.4	9.5	4.5	5.3	7.9	10.0	12.4	12.9	16.0	1853
1854	903		15.2	14.6	13.7	10.3	9.0	5.5	3.5	6.9	7.3	10.1	14.9	15.3	1854
1855	715		15.2	15.0	12.6	11.2	9.9	5.1	4.8	7.9	9.8	11.5	15.5	15.6	1855
1856	744		16.8	14.6	12.0	10.1	7.6	4.7	3.2	6.7	10.2	11.7	14.0	15.2	1856
1857	767		15.0	12.8	11.9	10.2	8.1	4.3	4.5	5.8	10.6	12.5	14.7	16.9	1857
1858	738		14.7	15.2	12.6	10.5	6.1	6.3	5.2	7.1	9.5	11.3	15.0	15.6	1858
1859	901		15.1	14.5	13.5	10.1	10.0	5.1	3.8	7.5	9.5	12.4	12.5	15.2	1859
1860	837		15.8	13.1	12.3	11.5	9.1	4.7	3.9	7.3	8.0	10.9	14.7	14.8	1860
1861	936		14.2	13.8	12.7	9.3	7.4	5.2	4.2	6.1	9.3	12.5	13.0	15.2	1861
1862	888		14.6	12.9	12.9	10.6	9.9	4.1	3.7	6.1	6.6	9.9	12.5	13.7	1862
1863	937		15.3	13.3	12.1	8.7	8.1	3.2	4.1	6.3	9.1	11.0	14.0	15.7	1863
1864	763		15.5	14.7	13.8	11.3	10.9	5.5	4.9	7.9	10.0	12.8	14.8	15.2	1864
1865	777		16.4	14.2	13.3	10.5	8.3	5.3	4.8	5.3	9.8	12.2	13.8	14.7	1865
1866	884		16.0	14.1	13.1	11.1	9.5	5.5	4.9	6.7	10.0	10.9	15.0	16.5	1866
1867	853		16.2	14.4	13.5	11.2	8.1	5.4	5.1	6.2	8.5	11.5	16.9	16.9	1867
1868	707		15.2	14.6	13.6	11.6	10.2	5.4	6.2	7.9	10.8	12.5	14.8	16.3	1868
1869	855		16.2	15.1	13.5	11.3	9.4	5.0	5.2	6.6	7.8	11.4	14.4	14.3	1869
1870	879		13.3	13.1	12.0	10.4	9.1	4.7	4.1	7.3	8.6	10.8	14.1	15.4	1870
1871	867	846	13.8	13.6	12.9	10.3	9.3	4.3	5.3	7.6	9.5	11.3	13.1	15.2	1871
1872	954	910	15.0	14.1	12.5	9.7	9.2	4.3	4.8	5.7	8.9	11.3	13.0	13.9	1872
1873	740	755	14.8	13.7	12.8	10.6	8.1	4.5	4.2	7.9	9.8	11.4	15.3	15.6	1873
1874	934	971	16.5	14.7	12.7	11.4	7.6	3.9	4.7	7.1	8.2	10.6	14.8	15.9	1874
1875	884	929	14.7	14.1	12.5	9.9	9.4	4.7	4.8	7.3	8.6	11.8	14.8	15.4	1875
1876	721	776	14.7	14.1	13.1	9.2	9.2	5.7	3.9	7.4	10.3	13.2	14.0	16.0	1876
1877	577	604	16.5	15.2	13.7	11.4	10.0	6.7	7.9	8.6	10.4	12.7	14.8	14.7	1877
1878	873	974	15.8	15.3	14.3	11.1	9.8	5.7	4.6	5.1	6.3	9.8	12.0	13.6	1878
1879	871	894	14.8	13.8	12.8	10.4	6.1	5.6	5.5	5.9	10.1	11.8	13.9	14.1	1879
1880	865	817	14.5	14.2	12.2	10.2	8.5	5.3	5.8	8.3	9.4	12.2	14.5	16.7	1880
1881	888	860	16.2	15.4	14.0	11.2	8.9	6.4	6.1	6.3	9.4	11.7	12.9	14.6	1881
1882	883	901	16.2	14.5	13.3	9.8	9.2	4.7	3.9	7.5	9.2	10.6	13.1	15.4	1882
1883	748	849	15.0	13.9	13.6	10.3	8.3	4.2	5.3	7.1	9.8	12.1	13.1	17.2	1883
1884	953	929	17.2	15.2	12.7	11.4	9.6	6.4	4.6	6.2	8.8	13.2	14.1	15.9	1884
1885	838	842	16.9	14.0	13.4	11.2	10.4	4.7	5.1	6.3	10.3	12.1	15.0	15.0	1885
1886	923	870	15.4	14.7	13.0	10.8	7.7	4.8	4.7	7.1	9.9	10.2	13.9	15.7	1886
1887	843	897	13.9	15.1	12.6	10.5	9.7	5.1	5.8	7.4	10.3	11.9	14.2	15.0	1887
1888	806	810	16.5	15.6	13.8	11.0	9.0	5.2	5.7	7.1	11.3	12.8	13.6	16.2	1888
1889	958	927	16.2	15.6	14.8	10.8	9.5	5.0	4.3	6.1	8.3	10.4	13.3	15.0	1889
1890	892	904	14.1	13.8	12.0	10.2	8.7	3.9	4.9	8.1	9.4	12.4	14.3	15.5	1890

APPENDIX (*Continued*)

Year	RF1	RF2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1891	795	789	15.5	14.9	12.9	11.5	9.1	7.5	4.4	7.8	9.5	12.5	13.9	16.0	1891
1892	925	990	14.7	12.6	10.8	9.2	8.6	5.0	3.0	6.0	8.0	10.2	13.7	16.2	1892
1893	910	954	14.0	14.8	12.8	10.0	8.6	4.7	5.7	7.2	9.1	11.3	13.8	16.0	1893
1894	829	969	14.6	14.4	12.4	10.0	9.6	4.1	4.6	5.9	8.5	10.5	15.1	15.4	1894
1895	811	825	14.8	14.6	12.1	10.6	9.8	4.9	5.7	6.3	10.0	11.1	15.0	15.3	1895
1896	828	824	15.2	15.2	12.3	9.6	10.1	3.6	5.0	7.3	10.8	13.2	12.7	15.7	1896
1897	855	890	15.4	13.7	12.8	11.1	9.3	5.4	3.6	5.2	8.7	11.7	13.9	15.7	1897
1898	896	880	15.9	12.4	11.9	9.8	8.9	4.7	3.6	7.6	8.7	10.8	12.4	14.4	1898
1899	703	629	15.4	13.5	12.6	10.4	8.8	4.9	7.1	8.1	11.7	12.0	15.1	15.9	1899
1900	910	885	15.1	14.5	13.8	11.2	11.0	5.9	4.7	5.4	10.0	13.0	13.2	15.1	1900
1901	729	719	15.5	15.0	13.6	9.6	9.6	5.7	4.5	6.2	11.6	11.5	12.9	15.6	1901
1902	794	791	14.5	16.5	12.1	10.4	9.6	6.4	3.4	6.8	8.7	13.2	14.7	14.0	1902
1903	823	858	15.7	16.4	13.2	10.7	8.7	5.6	2.6	6.2	8.5	10.1	13.5	14.6	1903
1904	772	750	15.1	13.7	12.3	9.8	8.5	5.6	4.7	7.2	10.5	11.4	15.9	15.8	1904
1905	703	715	16.2	15.4	13.7	12.3	9.0	6.6	5.1	7.4	9.3	11.1	15.3	15.3	1905
1906	807	883	15.4	13.7	14.0	10.7	9.1	5.4	3.4	6.7	9.1	12.2	14.6	14.5	1906
1907	809	776	14.7	14.2	13.2	10.5	10.0	5.0	4.2	6.0	10.6	11.2	12.5	14.7	1907
1908	883	895	15.6	13.1	13.3	10.0	9.9	5.7	4.6	5.9	9.1	11.4	13.9	15.5	1908
1909	910	889	14.1	13.8	12.0	10.3	8.7	4.2	4.2	7.8	8.6	11.6	13.3	14.4	1909
1910	863	935	13.7	12.6	11.8	9.8	10.1	3.4	5.8	5.5	7.1	11.0	13.2	15.9	1910
1911	691	733	14.0	15.5	13.0	11.3	8.8	5.9	6.1	7.0	9.6	12.7	12.9	14.7	1911
1912	830	804	16.3	14.0	13.0	11.5	9.4	4.5	3.1	6.1	9.6	11.9	13.2	15.6	1912
1913	802	782	16.0	13.7	12.6	9.8	8.6	3.7	4.5	7.3	10.2	11.9	14.5	15.9	1913
1914	911	899	17.0	14.8	13.7	12.0	9.4	4.6	2.9	6.4	8.5	13.2	13.0	14.4	1914
1915	919	780	15.9	14.2	14.6	11.4	8.4	4.9	5.4	6.8	8.3	10.0	11.8	15.6	1915
1916	931	950	15.9	13.6	12.0	10.5	8.1	2.2	4.6	6.0	6.1	9.5	12.1	14.1	1916
1917	997	1003	15.0	12.9	12.1	10.4	10.1	3.7	4.3	6.0	6.4	8.3	12.9	13.9	1917
1918	666	648	14.1	15.2	12.4	10.9	6.0	6.1	7.2	6.7	11.0	12.5	12.0	15.3	1918
1919	887	885	15.0	14.7	14.2	11.1	9.1	4.9	4.1	6.3	9.2	8.0	11.5	14.3	1919
1920	706	718	14.5	14.7	12.0	10.5	9.5	4.0	4.1	7.9	9.4	11.5	11.9	14.3	1920
1921	882	863	14.3	13.1	11.3	10.3	7.9	4.6	3.8	6.0	8.9	12.0	15.0	15.2	1921
1922	968	867	14.3	13.3	12.5	9.9	8.8	4.5	4.3	6.1	8.4	12.1	12.6	15.7	1922
1923	850	819	14.6	13.4	13.4	9.4	8.7	5.9	3.2	5.5	8.5	12.3	13.4	14.1	1923
1924	938	862	15.3	13.2	12.0	9.4	8.2	5.2	2.9	5.7	8.3	12.0	12.6	15.5	1924
1925	785	803	13.7	14.1	11.5	10.4	8.1	3.7	6.0	6.1	10.5	11.8	13.7	15.4	1925
1926	814	901	15.4	14.5	13.8	12.0	9.6	5.8	3.2	5.3	7.7	10.5	13.4	13.9	1926
1927	772	849	13.8	14.0	10.7	9.8	9.2	5.5	3.9	6.7	8.5	12.4	13.5	15.0	1927
1928	711	766	15.1	14.0	12.4	9.9	9.2	4.2	4.7	7.1	9.7	10.6	14.1	14.6	1928
1929	744	820	14.8	13.0	11.9	10.9	9.0	4.0	3.9	6.9	9.3	11.8	12.8	14.1	1929
1930	843	800	14.6	15.3	12.0	10.0	9.4	4.6	5.9	7.4	9.3	11.2	14.5	15.2	1930
1931	891	877	14.8	14.0	13.5	10.7	9.2	6.0	4.4	4.1	8.7	10.3	13.6	14.4	1931
1932	728	801	17.1	14.3	12.9	11.4	7.9	6.3	3.0	7.2	7.8	10.4	12.5	15.3	1932
1933	944	973	14.9	13.2	12.1	11.1	8.2	4.9	5.2	7.2	7.6	10.3	13.2	14.1	1933
1934	849	913	14.0	13.5	11.9	10.2	10.2	4.9	4.9	6.6	9.1	12.0	14.4	15.6	1934
1935	785	844	16.1	13.9	12.6	11.1	9.4	5.3	4.1	7.7	8.5	10.8	14.5	14.9	1935
1936	929	904	15.0	14.1	12.7	10.9	7.4	5.0	5.5	6.9	8.5	12.7	13.5	14.5	1936
1937	826	843	14.7	14.0	11.6	9.9	9.4	4.7	3.7	7.1	9.4	11.8	12.7	14.1	1937
1938	860	908	14.9	13.7	10.6	10.2	6.9	3.8	4.8	6.0	8.6	10.8	14.1	14.0	1938
1939	767	789	15.0	14.2	12.0	10.4	9.1	5.8	4.9	6.2	10.3	11.5	12.6	17.3	1939
1940	805	850	15.5	14.9	13.1	12.0	8.3	5.7	5.2	6.4	10.9	12.1	12.1	16.2	1940
1941	730	729	15.6	15.2	12.8	10.9	8.3	6.3	6.4	6.1	9.8	12.4	11.9	14.0	1941
1942	914	958	15.5	14.4	11.1	10.7	8.6	4.6	3.9	5.8	9.1	11.1	13.5	13.4	1942

APPENDIX (*Continued*)

Year	RF1	RF2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1943	813	866	13.8	13.9	11.8	12.2	7.0	5.2	4.8	7.5	8.9	11.4	12.5	16.8	1943
1944	872	922	15.3	14.6	12.7	11.4	8.4	5.4	3.9	7.2	9.8	10.4	11.8	13.4	1944
1945	843	908	13.8	12.1	12.9	11.0	9.2	5.1	4.7	5.6	9.1	12.3	13.7	14.9	1945
1946	799	901	15.0	13.1	11.9	10.6	9.0	3.5	4.8	4.6	9.7	10.7	11.4	12.1	1946
1947	909	943	13.2	12.8	12.3	9.2	8.9	5.3	3.9	5.5	7.4	12.6	14.8	14.0	1947
1948	811	873	14.1	14.0	13.8	10.1	8.2	4.4	3.7	4.9	8.5	12.2	12.2	14.9	1948
1949	919	902	15.0	13.9	11.8	10.6	6.8	4.9	3.9	5.5	6.9	10.3	13.8	13.9	1949
1950	872	875	13.9	13.4	12.1	9.3	7.9	4.5	3.2	6.4	7.9	10.6	12.3	14.5	1950
1951	702	737	13.9	12.4	11.6	10.6	9.5	3.9	4.8	7.2	9.5	10.1	12.1	14.6	1951
1952	757	792	14.9	12.8	11.3	10.8	7.7	4.7	5.2	6.1	10.2	10.4	13.3	15.6	1952
1953	917	920	15.0	14.6	11.6	10.9	10.0	4.6	4.4	6.0	9.2	10.8	14.2	15.6	1953
1954	896	885	13.4	13.3	12.2	9.9	7.4	3.6	3.3	5.1	6.7	11.4	15.0	13.6	1954
1955	910	930	15.6	11.2	11.3	9.7	7.1	4.5	5.6	5.3	7.1	9.4	12.6	14.6	1955
1956	950	980	12.9	12.7	11.2	8.9	5.4	4.2	5.4	6.4	7.4	9.5	13.6	15.5	1956
1957	728	785	14.2	14.2	13.0	11.0	9.1	5.1	4.8	6.0	10.5	11.9	14.3	14.1	1957
1958	922	887	15.8	13.9	12.9	11.0	8.2	5.2	4.3	5.3	8.1	10.6	12.8	15.5	1958
1959	882	938	14.7	13.7	12.6	10.0	6.9	5.3	3.3	5.2	6.9	10.1	12.9	14.3	1959
1960	834	840	14.5	13.1	12.2	10.1	6.6	5.3	4.5	6.2	7.9	11.4	13.0	14.6	1960
1961	1019	1017	14.7	13.0	12.2	10.1	7.7	5.3	2.7	4.7	7.2	10.9	13.7	13.5	1961
1962	804	807	13.5	14.0	12.2	10.7	7.1	6.4	3.6	6.7	7.5	10.7	13.8	14.7	1962
1963	862	856	13.7	13.8	11.9	10.7	8.6	6.4	3.7	5.0	9.2	11.3	13.7	14.3	1963
1964	937	920	15.3	13.1	12.1	9.1	8.7	4.4	4.4	4.4	7.2	10.3	12.6	14.5	1964
1965	798	707	14.8	12.5	12.6	10.3	8.6	6.8	5.2	7.1	9.8	11.5	13.7	12.5	1965
1966	766	735	14.8	13.2	11.2	10.1	9.2	5.9	3.8	6.5	9.1	11.3	11.2	12.6	1966
1967	831	859	14.4	13.2	11.6	10.5	7.7	5.5	3.1	5.3	8.8	11.9	13.7	13.9	1967
1968	760	754	13.9	14.3	11.0	10.8	9.2	5.8	4.1	7.0	9.4	11.5	14.7	14.3	1968
1969	798	829	13.4	13.7	12.4	10.4	8.0	5.3	4.3	7.2	8.7	11.6	12.5	14.2	1969
1970	899	940	14.6	13.9	11.7	10.7	7.0	4.8	4.6	4.8	6.9	10.3	12.8	14.4	1970
1971	981	886	13.3	12.1	12.1	9.2	8.1	4.2	4.3	5.8	7.5	11.8	15.5	13.9	1971
1972	635	653	14.3	13.2	12.4	10.9	8.9	5.9	5.1	6.7	9.6	11.8	13.0	14.3	1972
1973	877	912	15.2	14.1	12.2	9.2	8.2	4.7	4.0	5.4	8.5	9.5	12.8	14.6	1973
1974	800	747	13.4	12.7	11.4	9.6	7.9	5.5	3.3	5.4	8.1	9.3	13.3	15.0	1974
1975	1084	960	15.1	13.6	12.1	9.1	8.2	3.4	5.2	3.8	7.1	8.6	12.8	14.5	1975
1976	849	855	15.1	13.5	11.4	11.5	9.6	5.2	4.1	5.8	9.8	11.5	10.6	13.7	1976
1977	941	881	14.2	13.5	12.6	9.9	8.4	4.3	3.0	6.6	9.0	12.3	11.9	15.3	1977
1978	946	908	15.4	14.8	12.5	10.6	7.2	4.1	4.4	5.5	9.4	11.4	13.3	15.0	1978
1979	672	708	14.7	13.5	12.6	10.2	9.4	5.6	5.9	6.2	9.2	13.1	11.1	15.0	1979
1980	937	883	14.2	13.4	12.4	10.0	8.8	3.9	4.5	6.3	9.9	11.1	12.7	13.7	1980
1981	896	853	15.3	13.8	12.6	10.3	8.3	4.9	4.4	5.5	8.2	11.1	12.5	15.4	1981
1982	778	735	14.6	13.7	12.4	10.9	9.7	5.9	4.7	5.9	10.3	12.0	12.1	14.6	1982
1983	928	956	15.6	14.6	13.3	10.9	9.2	5.3	4.5	5.1	7.1	10.5	15.0	13.9	1983
1984	940	836	12.7	11.5	11.3	9.1	7.6	3.8	4.5	6.1	9.5	11.2	14.3	12.8	1984
1985	949	787	13.8	10.0	11.3	9.3	7.1	5.8	6.0	6.0	9.0	10.1	13.3	13.9	1985
1986	740	747	13.8	13.2	11.2	9.3	8.7	4.4	6.3	7.1	10.2	11.9	13.0	15.2	1986
1987	784	688	15.1	15.2	12.3	11.6	10.6	5.7	6.5	6.0	10.0	10.9	11.9	14.7	1987
1988	1047	991	14.2	13.0	11.5	10.3	8.0	4.6	4.2	5.8	5.8	10.8	13.9	15.1	1988
1989	908	862	13.1	14.8	11.5	10.2	7.7	5.5	5.3	6.3	8.5	11.0	14.0	14.9	1989
1990	994	917	14.4	14.7	11.5	10.0	9.0	4.9	5.2	6.2	9.1	11.3	12.8	14.3	1990

Note: (i) RF1: All-India monsoon rainfall (1847–1990) in mm based on arithmetic average of 16 representative stations (for details see text). (ii) RF2: All-India monsoon rainfall (1871–1990) in mm based on weighted average of 306 stations. (iii) Monthly msl pressure values in mb may be obtained by adding 1000 to the values given above.

REFERENCES

Ananthakrishnan, R., and B. Parthasarathy, 1984: Indian rainfall in relation to the sunspot cycle, 1871–1978. *J. Climatol.*, **4**, 149–169.

Angell, J. K., 1981: Comparison of variations in atmospheric quantities with sea surface temperature variations in the equatorial Pacific. *Mon. Wea. Rev.*, **109**, 230–243.

Bell, G. T., 1977: Changes in the sign of the relationship between sunspots and pressure, rainfall and the monsoon. *Weather,* **32**, 26–32.

Berlage, H. P., 1966: The Southern Oscillation and World Weather, Royal Netherlands Meteorological Institute, *Meded. Verh.*, No. 88, 152 pp.

Cooper, N. C., K. D. B. Whysall and G. R. Bigg, 1989: Recent decadal climate variations in the tropical Pacific. *Int. J. Climatol.*, **9**, 221–242.

Elliott, W. P., and J. K. Angell, 1987: The relation between Indian monsoon rainfall, the Southern Oscillation, and hemispheric air and sea temperature 1884–1984. *J. Climate Appl. Meteor.*, **26**, 943–948.

——, and ——, 1988: Evidence for changes in Southern Oscillation relationships during the last 100 years. *J. Climate,* **1**, 729–737.

Fu, C., and J. Fletcher, 1988: Large signals of climatic variations over the ocean in the Asian monsoon region. *Adv. Atmos. Sci.*, **5**, 389–404.

Hastenrath, S., 1985: *Climate and Circulation of the Tropics.* D. Reidal, 455 pp.

——, 1986: On climate prediction in the tropics. *Bull. Amer. Meteor. Soc.*, **67**, 696–702.

——, 1987: On the prediction of Indian monsoon rainfall anomalies. *J. Climate App. Meteor.*, **26**, 847–857.

Mooley, D. A., and B. Parthasarathy, 1983: Indian summer monsoon and El Niño, *Pure Appl. Geophys.*, **121**, 339–352.

——, and ——, 1984a: Fluctuations in all-India summer monsoon rainfall during 1871–1978. *Clim. Change,* **6**, 287–301.

——, and ——, 1984b: Indian summer monsoon rainfall and the east equatorial Pacific sea surface temperature. *Atmos.–Ocean,* **22**, 23–35.

——, and J. Shukla, 1987: Variability and forecasting of the summer monsoon rainfall over India. *Monsoon Meteorology, Oxford Monogr. on Geol. and Geophys.* No. 7; C. P. Chang and T. N. Krishnamurti, Eds., Oxford University Press, 26–59.

Pant, G. B., K. Rupa Kumar, B. Parthasarathy and H. P. Borgaonkar, 1988: Long-term variability of the Indian summer monsoon and related parameters. *Adv. Atmos. Sci.*, **5**, 469–481.

Parthasarathy, B., 1984: Some aspects of large-scale fluctuations in summer monsoon rainfall over India during 1871–1978. Ph.D. Thesis, University of Poona, Pune, India, 370 pp.

——, and G. B. Pant, 1984: The spatial and temporal relationships between the Indian summer monsoon rainfall and the Southern Oscillation. *Tellus,* **36A**, 269–277.

——, and ——, 1985: Seasonal relationships between Indian summer monsoon rainfall and the Southern Oscillation. *J. Climatol.*, **5**, 369–378.

——, and N. A. Sontakke, 1988: El-Niño/SST of Puerto Chicama and Indian summer monsoon rainfall: Statistical relationships. *Geof. Int.*, **27**, 37–59.

——, H. F. Diaz and J. K. Eischeid, 1988a: Prediction of All-India summer monsoon rainfall with regional and large-scale parameters. *J. Geophys. Res.*, **93**(D5), 5341–5350.

——, A. A. Munot and D. R. Kothawale, 1988b: Regression model for estimation of Indian foodgrain production from summer monsoon rainfall. *Agric. Forest Meteorol.*, **42**, 167–182.

——, N. A. Sontakke, A. A. Munot and D. R. Kothawale, 1987: Droughts–floods in the summer monsoon season over different meteorological subdivisions of India for the period 1871–1984. *J. Climatol.*, **7**, 57–70.

——, K. Rupa Kumar and N. A. Sontakke, 1990a: Surface and upper air temperatures over India in relation to monsoon rainfall. *Theor. Appl. Climatol.*, **42**, 93–110.

——, N. A. Sontakke, A. A. Munot and D. R. Kothawale, 1990b: Vagaries of Indian monsoon rainfall and its relationships with regional-global circulation. *Mausam,* **41**, 301–308.

Quenouille, N. H., 1952: *Associated Measurements.* Butterworths Scientific, 242 pp.

Rasmusson, E. M., and T. H. Carpenter, 1982: Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation–El-Niño. *Mon. Wea. Rev.*, **110**, 354–384.

——, and ——, 1983: The relationship between eastern equatorial Pacific sea surface temperature and rainfall over India and Sri Lanka. *Mon. Wea. Rev.*, **111**, 517–528.

Savur, S. R., 1931: The seasonal forecasting formulae used in the India Meteorological Department, India Meteorological Department, New Delhi, *Scientific Notes,* no. 37, Vol. 4, 57–68.

Schove, D. J., and H. P. Berlage, 1965: Pressure anomalies in the Indian Ocean area, 1796–1960. *Pure Appl. Geophys.*, **61**(Part II), 219–231.

Shukla, J., 1987: Long-range forecasting of monsoons. *Monsoons,* J. S. Fein and P. L. Stephens, Eds., Wiley and Sons, New York. Chapters 14 and 16, 399–547.

——, and D. A. Paolino, Jr., 1983: The Southern Oscillation and long range forecasting of summer monsoon rainfall over India. *Mon. Wea. Rev.*, **115**, 695–703.

Sikka, D. R., 1980: Some aspects of the large-scale fluctuations of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters. *Proc. Ind. Acad. Sci. (Earth Planet. Sci.)*., **89**, 179–195.

Sontakke, N. A., 1990: Indian summer monsoon rainfall variability during the longest instrumental period 1813–1988. M.Sc. thesis, University of Poona, Pune, 146 pp.

Swed, F. S., and Eisenhart, E., 1943: Tables for testing randomness of grouping in a sequence of alternatives. *Ann. Math. Stat.*, **14**, 66–87.

Thapliyal, V., 1987: Prediction of Indian monsoon variability evaluation and prospects including development of a new model. *Climate of China and Global Climate,* D. Ye; C. Fu; J. Chano, and M. Yoshino, Eds., China Ocean Press, 397–416.

Thom, H. C. S., 1966: Some Methods of Climatological Analysis. WMO Tech. Note No. 81, WMO No. 199-TP-103, World Meteorological Organization, Geneva, 53 pp.

Trenberth, K. E., and D. J. Shea, 1987: On the evolution of the Southern Oscillation. *Mon. Wea. Rev.*, **115**, 3078–3096.

Verma, R. K., K. Subramaniam and S. S. Dugam, 1985: Interannual and long-term variability of the summer monsoon and its possible link with Northern Hemispheric surface air temperature. *Proc. Ind. Acad. Sci. (Earth Planet. Sci.)*, **94**, 187–198.

Walker, G. T., 1910: Correlation in seasonal variation of Weather. *Mem. Ind. Met. Dept.*, **21**, 1–21.

——, 1914: Correlation in seasonal variation of Weather III. *Mem. Ind. Met. Dept.*, **21**(Part 9), 12–15.

Wright, P. B., 1975: An index of the Southern Oscillation. Climate Research Unit Rep. No. CRUPR4. University of East Anglia, Norwich, UK, 20 pp.