Surface Pressure and Summer Monsoon Rainfall over India

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Received August 17, 1991; revised October 19, 1991

ABSTRACT

The relationship between the all–India summer monsoon rainfall and surface pressure over the Indian region has been examined to obtain a useful predictor for the monsoon rainfall. The data series of all–India monsoon rainfall and the mean pressures of three seasons before and after the monsoon season as well as the winter–to–spring pressure tendency (MAM–DJF) at 100 stations for the period 1951–1980 have been used in the analysis.

The all–India monsoon rainfall is negatively correlated with the pressure of the spring (MAM) season preceding the monsoon and winter–to–spring seasonal difference as pressure tendency (MAM–DJF), at almost all the stations in India, and significantly with the pressures over central and northwestern regions. The average mean sea level pressure of six stations (Jodhpur, Ahmedabed, Bombay, Indore, Sagar and Akola) in the Western Central Indian (WCI) region showed highly significant (at 1% level) and consistent CCs of −0.63 for MAM and −0.56 for MAM–DJF for the period 1951–1980. Thus, the pre–monsoon seasonal pressure anomalies over WCI could provide a useful parameter for the long–range forecasting scheme of the Indian monsoon rainfall.

I. INTRODUCTION

Monsoons are associated with large–scale seasonal reversals of pressure, temperature and winds. The Asiatic continent, with its unique geographical location having the Indian Ocean to the south, the Pacific Ocean to the east and a vast land mass extending from the tropics to the Arctic, witnesses one of the most prominent monsoon systems in the world in terms of a large–scale land and sea breeze phenomenon with yearly periodicity. The southwest (summer) monsoon of India results from this land–ocean configuration. The region of high temperature and low atmospheric pressure which gradually develops over the Indian sub–continent during the pre–monsoon months (March, April and May, MAM) leads to large–scale influx of maritime air from the south Indian Ocean into India. This is the summer monsoon wind which brings moisture, clouding and widespread rainfall over most parts of India. The summer monsoon (during June through September) is a regular phenomenon only in the sense that it comes every year, but its onset, rainfall amount and variability during the season and its withdrawal are subject to large variations. Forecasting the seasonal monsoon rainfall of India has been attempted since the last century on the basis of various regional and global predictors. The direct solar heating of the desert over northwest India and the latent heat released from the pre–monsoon thunderstorms of the Indian sub–continent play a predominant role in the development of monsoon circulation. Therefore, local events may be as crucial for monsoon rains, if not more than distant factors.

Recently Parthasarathy et al. (1988a) and Gowariker et al. (1989, 1991) made a comprehensive study of many parameters related to the Indian monsoon rainfall. However, the search for new parameters continues, as no forecasting scheme is as yet consistently successful over a period of time. In the 16–parameter model developed by Gowariker et al. (1991), the pressure over the Indian region has not been considered. Sundar (1990) found that pressure anomaly over the area between 20°N and 35°N and west of 80°E was linked to the monsoon rainfall.

In view of the importance of surface pressure over India for the development of the monsoon, a detailed study of the relationship between all–India monsoon rainfall and the space–time variability of pressure over India has been made, using data at several stations during the period 1951–1980, to obtain a useful predictor for the monsoon rainfall.

I. DETAILS OF DATA

Earlier studies of Hastenrath (1987) and Parthasarathy et al. (1988a) on the relationships between Indian monsoon rainfall and regional / global circulation parameters indicated that a data length of about 20 to 30 years is necessary and sufficient to establish a stable correlation for prediction purposes. Also, a period of 30 years is generally considered adequate for establishing climatic normals. In the present study we have mainly considered the data period 1951–1980, for which excellent data sets on vaious parameters related to Indian monsoon are available.

1. *Summer Monsoon Rainfall of India*

All–India (the whole country taken as one unit) and the 29 different meteorological sub–divisional mean summer monsoon (June through September) rainfall data sets have been prepared by properly area–weighting the rainfall at 306 well distributed raingauges over plain regions. Parthasarathy et al. (1987, 1990a) provide a detailed discussion on these data sets and listings of the data from 1871 onwards.

2. *Suface Pressure Data*

The mean monthly station level surface pressure of 100 well distributed observatories in India, for the period 1951–1980, is used in the present study. For some selected stations, the mean monthly sea level (msl) pressure data during the period 1891–1990 have been used for detailed analysis. These data series were obtained from the records of the India Meteorological Department, Pune.

III. METHODOLOGY

To study the association between the Indian summer monsoon rainfall and surface pressure over the Indian region, the following approach has been used: (i) simple correlation analysis, (ii) consistency of significant Correlation Coefficients (CCs) over a long period using sliding windows of different widths and (iii) composites of pressure anomalies during the excess and deficient years of all–India monsoon rainfall.

To understand the temporal characteristics of the relationship between pressures and the all–India monsoon (JJAS) rainfall, the CCs with seasonal pressures up to 3 lags on either side of the monsoon season have been calculated for the period 1951–1980. The mean pressures are obtained for the seasons lag–3 (SON), lag–2 (DJF), lag–1 (MAM), lag 0 (JJA), lag+1 (SON), lag+2 (DJF) and lag+3 (MAM). In addition, the seasonal tendency of pressure from the previous winter to the current spring (MAM minus DJF) has been considered for correlation analysis.

The consistency of significant CCs over a long period of time has been examined for some selected stations, by calculating the CCs over sliding windows (Bell, 1977) of widths 11, 21 and 31 years during the period 1891–1990.

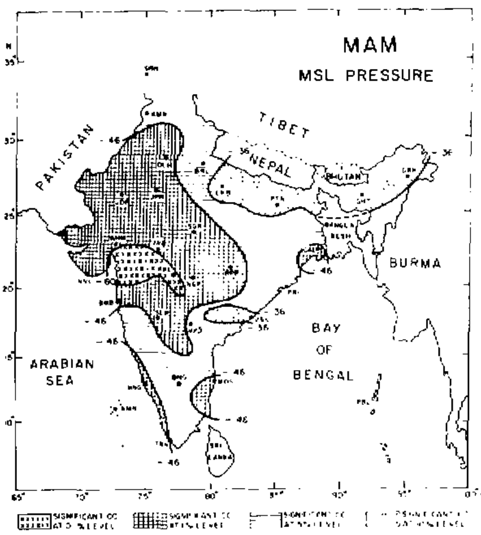

Fig.1. Correlation coefficients between all–India summer monsoon rainfall and surface pressure for spring season (MAM, lag–1) of different stations over India for the period 1951–1980).

To see the strength of the signal of extreme monsoon rainfall years in the pressure series of the region showing significant CCs, composite values of spatial average of surface pressure anomalies (from the 1951–1980 mean) for lag–3 to lag+3 seasons and MAM–DJF have been calculated for years of deficient ($<\bar{R}$–S) and excess ($\geqslant \bar{R}$+S) all–India summer monsoon rainfall ($\bar{R}$ is the mean and S is the standard deviation of all–India monsoon rainfall), during the period 1951–1980. There were seven deficient (1951, 1965, 1966, 1968, 1972, 1974 and 1979) and five excess (1956, 1959, 1961, 1970 and 1975) monsoon rainfall situations during this period (see Fig.3), which have also been found to have a definite impact on the production of food–grains over India (Parthasarathy et al., 1988b).

IV. RELATIONSHIPS BETWEEN SURFACE PRESSURE AND MONSOON RAINFALL OF INDIA

The CCs between all–India monsoon rainfall and different seasonal surface pressures (lag–3 to lag+3; MAM–DJF) of all the 100 stations during the period 1951–1980 have been computed. These CCs show a systematic change as the season advances from lag–3 to lag+3. The mean pressures of the spring season (MAM, lag–1) over India are negatively related with monsoon rainfall, with strong and spatially coherent CCs over the western perts of the country (Fig.1). Significant (at 1% level or above) negative CCs occur over the contiguous region between latitudes 17°–30°N and longitudes 70°–80°E, mainly consisting of the states Gujarat, Rajasthan, northern parts of Maharashtra, Punjab and Haryana. The level of significance of CCs over the remaining parts generally varies from 5% to 10% except for some isolated pockets of high significance.

The MAM–DJF tendency parameter also shows highly significant negative CCs, which are more widespread than those for the spring season considered alone (Fig.2). The CCs are significant at more than 5% level or above over the whole country, except for a small portion over 0.6 (significant at 0.1% level) occur over Gujarat and some parts of Konkan coast. The

CCs are significant at 1% level or above over the contiguous region between latitudes 10°–30°N and 70°–85°E longitudes. This indicates a broad region covering the southern, central and northwestern parts of India where the pre–monsoon pressure tendency has an important bearing upon the subsequent all–India monsoon rainfall.

To make a detailed study of the surface pressure and to prepare a predictor candidate for the monsoon rainfall, six representative stations well spread over west central and northwestern India and showing highly significant CCs with the all–India monsoon rainfall, were selected. These six stations are, Jodhpur (JDP), Ahmedabed (AHM), Bombay (BMB), Indore (IND), Sagar (SGR) and Akola (AKL). The locations of these stations are indicated in Fig.1 and Fig.2. The arithmetic average of monthly mean sea level (msl) pressure of these six stations, called West Central Indian (WCI) region pressure hereafter, which effectively minimizes the noise component due to local variation at individual stations and amplifies the large–scale spatial signal, has been subjected to further analysis. Fig.3 shows all–India summer monsoon rainfall along with the msl pressures of WCI (MAM–DJF and MAM) during the period 1951–1990. It can be seen that the pressure parameters and the all–India monsoon rainfall are oppositely varying, which is more conspicuous in extreme rainfall years.

The CCs between all–India monsoon rainfall and the lag–3 to lag+3 and MAM–DJF msl pressure of WCI region are presented in Fig.4. A systematic change can be seen in the CCs, from near–zero values before the monsoon season (lag–3 and lag–2) to highly significant negative values during one season earlier and one season after monsoon (lag–1 to lag+1) and then to positive later. This variation of CCs suggests that the monsoon rainfall is highly sensitive to the seasonal transition of the pressure over the WCI region. The CC with the

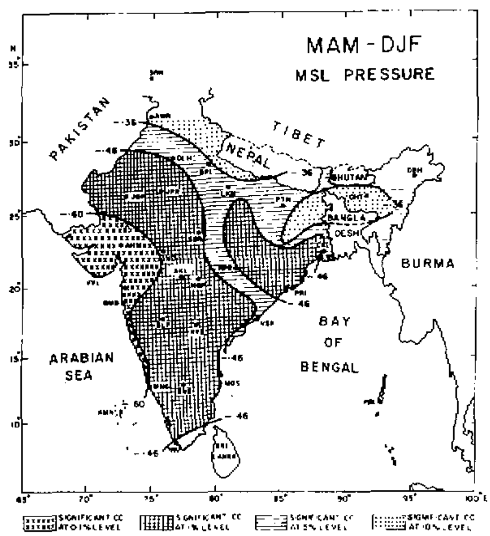

Fig.2. Correlation coefficients between all–India summer monsoon rainfall and surface pre–monsoon pressure tendency (MAM–DJF) of different stations over India for the period 1951–1980.

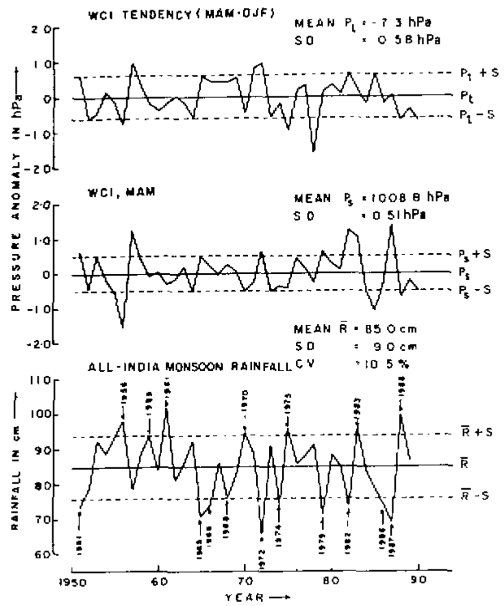

Fig.3. Year–to–year variation of all–India summer monsoon rainfall along with WCI (six stations average) msl pressure of pre–monsoon MAM and MAM–DJF for the period 1951–1990.

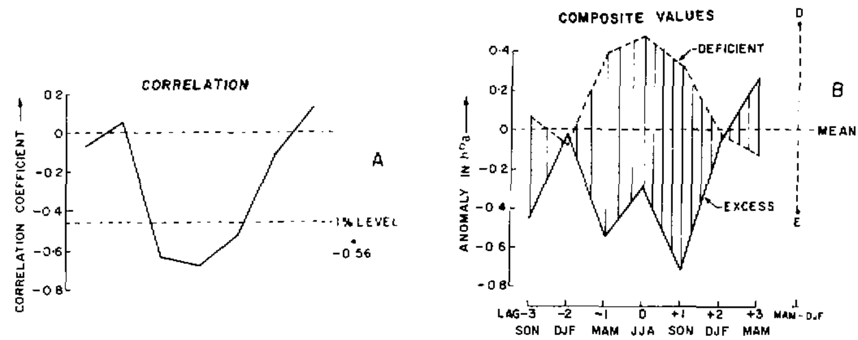

Fig.4. (a) Correlation coefficient between WCI seasonal msl pressure and all–India summer monsoon rainfall. (b) Composite values of WCI seasonal pressure anomalies during years of excess (5 years) and deficient (7 years) all–India monsoon rainfall for the period 1951–1980.

MAM (lag–1) pressure is –0.63 and that with MAM–DJF pressure tendency is –0.56, both significant at 1% level. Therefore, MAM pressure over WCL would be a better parameter for monsoon rainfall prediction purposes. The composite values of seasonal pressure anomalies for lag–3 to lag+3 and MAM–DJF of WCI regions (Fig.4) for the extreme years of deficient and excess all–India monsoon rainfall show strong opposite signs from lag–1 to lag+1 and a gradual transition in magnitude with the season.

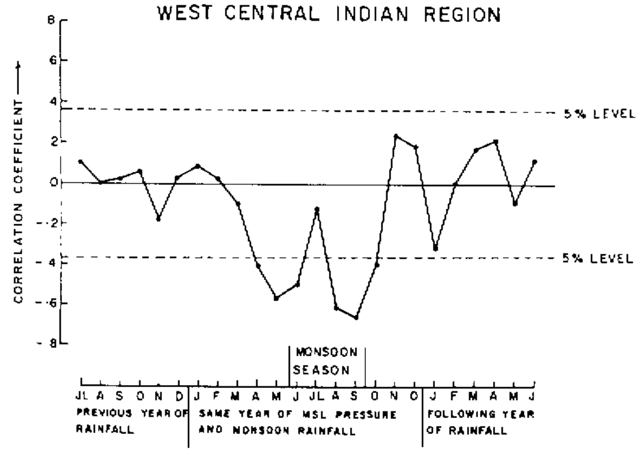

Fig.5. Correlation coefficients between all–India summer monsoon rainfall and WCI monthly msl pressure for the period 1951–1980.

The monthly data of WCI pressures are also subjected to correlation analysis with all–India monsoon rainfall to understand the monthly transition of the relationship. Thus, the all–India summer monsoon rainfall is correlated with 24 monthly pressures, consisting of 6 months in the previous year (July to December), all the 12 months of the current year and 6 months in the following year (January to June). The corresponding CCs are presented in Fig.5. The CCs of monsoon rainfall with monthly pressures of the previous July through current March are not significant and many of them are positive. The CCs are negative and significant at 5% level during the months April to June and August to October of the current monsoon year. The CCs from current November through June of next year are again not significant and generally positive. Thus, there is a clearly defined signal of pre–monsoon pressures affecting the monsoon performance. The CCs for the months April through October of the current year are negative and significant at 5% level, except for July in which the CC is negative but not significant. As July and August are in the middle of the monsoon season, the cause and effect mechanisms behind the CCs for these two months are mixed up and no clear explanation can be given for the lack of significance in July. Similar feature has been noticed by Parthasarathy et al. (1990b) for the month of August, while correlating the monthly surface temperature with the monsoon rainfall. Since the monthly CCs are more noisy, the seasonal values are preferable for a better representation of the signal.

V. CONSISTENCY OF THE RELATIONSHIPS

The WCI msl pressure for the spring season MAM (lag–1) and pre–monsoon pressure tendency (MAM–DJF), which have shown highly significant CCs of –0.63 and –0.56 with the subsequent monsoon rainfall, may be considered as predictors for the seasonal monsoon rainfall forecast. In this connection, it is important to examine the consistency of these relationships over a long period of time. Figs. 6 anf 7 show the variation of CCs of all–India monsoon rainfall with WCI, MAM pressure and MAM–DJF pressure tendency respectively over the period 1891–1990, over sliding windows of widths 11, 21 and 31 years; the CCs are plotted against the central years of the windows.

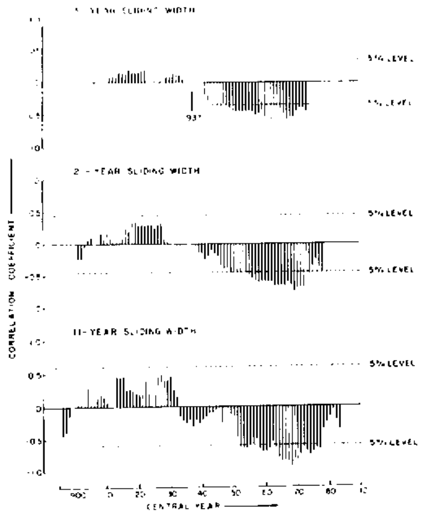

Fig. 6 : Variation of correlation coefficient over sliding window widths of 11,21 and 31 years, between all-India summer monsoon rainfall and WCI, MAM msl pressure during the period 1891-1989.

Fig.6. Variation of correlation coefficient over sliding window widths of 11, 21 and 31 years, between all–India summer monsoon rainfall and WCI, MAM msl pressure during the period 1891–1990.

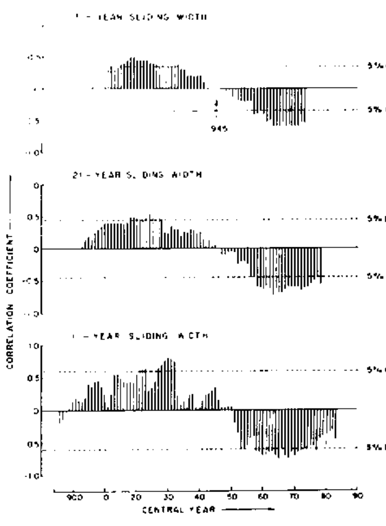

Fig.7. Variation of correlation coefficient over sliding window widths of 11, 21 and 31 years, between all–India summer monsoon rainfall and WCI, MAM–DJF pressure during the period 1891–1990.

It is seen from Figs.6 and 7 that the CCs fluctuating more rapidly for the window windths of 11 and 21 years than for those of 31 years. The variations of CCs for WCI MAM pressure over 31–year windows show that the values are continuously positive up to the year 1937 and negative afterwards; however, negative CCs are significant only after the year 1940, continuing to the present time (Fig.6). Similar variations may be seen in the case of MAM–DJF tendency also (Fig.7), but the change from positive to negative CCs occurs around the year 1945; however, the negative CCs are significant only from 1960 onwards. Another notable difference with the MAM–DJF tendency is that the positive CCs around 1920–1930 are significant. Similar changes in CCs around 1940 have been noticed earlier, while relating the Indian monsoon rainfall with regional / global circulations (Parthasarathy et al., 1990b; 1991b). Fu and Fletcher (1988) delineated the large–scale climatic variations in the Asian monsoon region, on the basis of surface winds over the Indian and west Pacific oceans. They identified distinct climatic regimes, with changes occurring in the years around 1875, 1900, 1940 and 1960; the period 1875–1900 is characterized as having "Meridional monsoon" and the period 1900–1940 as having " zonal monsoon" , which are also synchronous with the high and low epochs of the Indian monsoon rainfall. Thus, it may be reasoned that the changes over in the sign of CCs around 1940 in the present study could be a part of the large–scale changes in the climatic regimes over the area.

The predominantly significant CCs in the recent period is a useful result for the current efforts on monsoon prediction. However, the pressure parameters of MAM and MAM–DJF are hgihly interrelated, with a CC of 0.65 during 1951–1980. Therefore only one of them is needed for inclusion in the prediction scheme for monsoon rainfall. Further, the Indian summer monsoon rainfall cannot be fully determined from a single parameter, as it is a resultant of several regional and global teleconnections both at the surface and upper levels (Mooley et al., 1986, Parthasarathy et al., 1988a, 1991a). Therefore, a reliable forecast can be prepared only by considering the above–identified predictor along with other parameters.

VI. CONCLUSIONS

A study of relationships between Indian monsoon rainfall and surface pressure over the Indian region for the period 1951–1980 has brought out the following points:

(i) The surface pressure of the spring (MAM) season and its tendency from the preceeding winter (MAM–DJF) over India are negatively correlated with the subsequent monsoon rainfall, and significantly over the Western, Central and northwestern Indian regions.

(ii) The spatial averages of MAM and MAM–DJF msl pressures at six stations of West Central India (WCI) show a highly significant signal indicative of subsequent monsoon activity, which is more dominant in the recent 3 decades.

(iii) WCI MAM and MAM–DJF pressures have potential utility for the long–range prediction scheme of the Indian monsoon rainfall, along with other parameters.

The authors are thankful to Shri D. R. Sikka, Director, Indian Institute of Tropical Meteorology (IITM), Pune for the interest and facilities, to Additional Director General (Research), India Meteorological Department (IMD), Pune for the data and to Dr. G. B. Pant, Head, Climatology and Hydrometeorology Division of IITM for his valuable suggestions. Shri M. K. Soman has kindly gone through the manuscript and offered constructive comments. Thanks are also due to Mrs. J. V. Revadekar for typing the manuscript.

REFERENCES

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

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

Gowariker, V., Thapliyal, V., Sarker, R. P., Mandal, G. S. and Sikka, D. R. (1989), Parametric and power regression models: New approach to long range forecasting of monsoon rainfall in India, *Mausam*, **40:** 115–122.

Gowariker, V., Thapliyal, V., Kulahrestha, S. M., Mandal, G. S., Sen Roy, N. And Sikka, D. R. (1991), A power regression model for long range forecast of southwest monsoon rainfall over India, *Mausam* **42:** 125–130.

Hastenrath, S. (1987), On the prediction of Indian monsoon rainfall anomalies, *J. Climate Appl. Meteor.*, **26:** 847–857.

Mooley, D. A., Parthasarathy, B. and Pant, G. B. (1986), Relationship between Inian summer monsoon rainfall and location of the ridge at 500 mb level at 75°E. *J. Clim. Appl. Meteor.*, **25:** 633–640.

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

Parthasarathy, B., Sontakke, N. A., Munot, A. A. and Kothawale, D. R. (1987), Droughts / Floods in the summer monsoon season over different meteorological sub–divisions of India for the period 1871–1984, *J. Climatol.*, **7:** 57–70.

Parthasarathy, B., Diaz, H. F. and Eischeld, J. K. (1988a), Prediction of all–India summer monsoon rainfall with Regionaal and large–scale parameters. *J. Geophys. Res.*, **93:** D5, 5341–5350.

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

Parthasarathy, B., Sontakke, N. A., Mount, A. A. and Kothawale, D. R. (1990a), Vagaries of Indian monsoon rainfall and its relationships with regional / global circulations, *Mausam*, **41:** 301–308.

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

Parthasarathy, b. Rupa Kumar, K. and Deshpande, V. R. (1991a), Indian summer monsoon rainfall and 200 mbar meridional wind index: Application for long–range prediction. *Int. J. Climatol.*, **11:** 165–176.

Parthasarthy, B., Rupa Kumar, K. and Munot, A. A. (1991b), Evidence of secular variations in Indian monsoon rainfall–circulation relationships. *J. Climate*, **4:** (in press).

Sundar, R. S. (1990), Indian monsoon rainfall in relation to surface pressure anomalies. *Mausam* **41:** pp. 487–488.