Premonsoon Ridge Location over India and Its Relation to Monsoon Rainfall

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ABSTRACT

The location of the 500-hPa ridge axis during April over India is one of the most important long-range predictors for the summer monsoon rainfall. This paper presents a comprehensive analysis on its space-time variability during the premonsoon season and its relation with the monsoon rainfall. Data on the daily latitudinal locations of the 500-hPa ridge axis along three longitudes during March, April, and May, as well as all-India rainfall and subdivisional monsoon rainfall for the period 1967–90, have been used.

The analysis involves correlations between the running means of the premonsoon ridge locations over windows of 15, 21, and 31 days, and the subsequent monsoon rainfall. The ridge location in March shows negative correlation with the all-India summer monsoon rainfall, while that in April shows positive correlation. The anticorrelation of the March ridge was more dominant with the monsoon rainfall of the peninsular India, while the positive correlation of the April ridge was more dominant with the monsoon rainfall of northern India. Regression equations for the prediction of the monsoon rainfall have also been developed.

1. Introduction

Among the various predictors used for long-range forecasting of Indian summer monsoon rainfall, the monthly mean latitudinal location along 75°E of the axis of 500-hPa ridge during April (hereafter called "ridge location") has been one of the most significant and reliable parameters. This was first suggested by Banerjee et al. (1978), and later used by Thapliyal (1982) as a leading indicator in developing a stochastic dynamic model for long-range prediction of the monsoon rainfall. The ridge location is an important parameter in the latest operational long-range forecasting models of the Indian summer monsoon rainfall (Gowariker et al. 1989; Thapliyal 1990).

Mooley et al. (1986), from a detailed analysis of the data during 1939–84, found that the relationship between the ridge location and the Indian summer monsoon rainfall is statistically highly significant and stable. Singh et al. (1986) found that the ridge location over the Indian region shows better relation with the monsoon rainfall than that over the Pacific region.

The 500-hPa ridge in April, being a transition zone between the westerly subtropical regime of the upper troposphere to its north and the easterly tropical regime of the lower troposphere to its south (Banerjee et al. 1978), is a measure of the influence exerted by the troughs in the westerlies on the upper-tropospheric thermal conditions over north and central India. A more southward ridge location from its normal location suggests a colder troposphere in April that may continue up to June, adversely affecting the monsoon. The average 500-hPa temperature over India (based on 10 well-spread stations) shows a high degree of persistence from April to June, with correlation coefficients (CCs) of 0.69 between April and May, and 0.81 between May and June (both significant at 0.1% level), during the period 1950–85 (for details of data, see Rupa Kumar et al. 1987). Even individual stations show high CCs among these three months. A more northward location of the ridge would indicate a combination of stronger influence exerted by the tropical easterly circulation and a weaker influence of the westerly circulation (Mooley et al. 1986). The ridge location is generally believed to be an indicator of the seasonal evolution of the midtropospheric circulation over India, as a feature of the slowly varying planetary circulation. However, the causes of abnormalities in this evolution are not well understood. Shukla and Mooley (1987) conjecture that a delayed northward displacement of the 500-hPa ridge is a good indicator of the subsequent planetary-scale circulation producing large-scale anomalous descending motion over the Indian region.

All the aforementioned studies are based on the monthly mean ridge location in April. However, on a shorter time scale, the ridge location could have different patterns of variations for the same monthly mean, which has important implications for the predictability. Therefore, in the present study, the mean daily variation of the ridge location during the premonsoon season has been examined to identify the specific subperiod mainly responsible for the correla-

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tion with the monsoon rainfall and its spatial manifestations. An attempt is also made to use the results to develop prediction equations for the monsoon rainfall.

2. Data

a. Monsoon rainfall

Area-weighted mean monsoon (June–September) rainfall data based on 306 stations for India as a whole, as well as for each of the 29 meteorological subdivisions, excluding some hilly subdivisions in the north, have been used in the present study for the period 1967–90. More details about this dataset are given by Mooley and Parthasarathy (1984) and Parthasarathy et al. (1987).

b. 500-hPa ridge

Daily latitudinal location of the 500-hPa ridge along three longitudes, 70°, 75°, and 80°E, both at 0530 IST (0000 UTC) and 1730 IST (1200 UTC), during 1 March through 31 May for the period 1967–90 have been determined from the daily weather charts of the India Meteorological Department (IMD), Pune. The ridge location has been determined from wind observations and not from geopotential height. On a day-to-day basis, the ridge location can be determined with reasonable accuracy, as the ridge is generally well defined and east–west oriented, in the midtropospheric levels over the Indian region (Fig. 1a). However, it is not possible to locate the ridge over the Indian region on some typical weather situations like those mentioned in the following. There are days when monotonous westerlies prevail all over India (Fig. 1b) or a midlatitude westerly trough extends into the Indian region (Fig. 1c), thereby displacing the east–west ridge toward the equator much beyond the Indian peninsula. On some other occasions, the westerly trough moves eastward but still covers the central and eastern parts of the Indian region. In such a situation (Fig. 1d), the

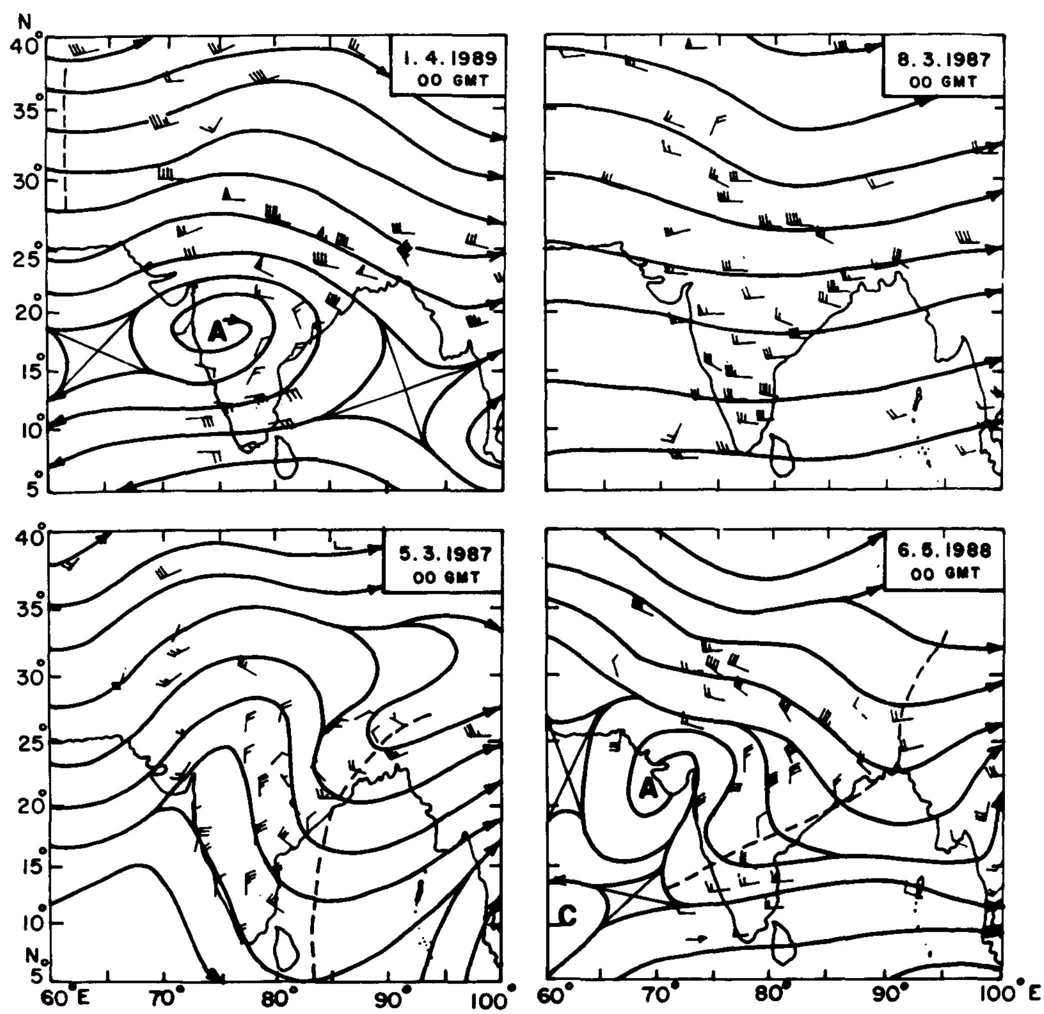

FIG. 1. Some typical streamline charts at 500-hPa level during the premonsoon season. (a) 1.4.1989; (b) 8.3.1987; (c) 5.3.1987; and (d) 6.5.1988.

ridge is seen on the upper left part of the westerly trough, which is dynamically a ridge in the midlatitude westerly system. As such, it cannot be considered as the east–west ridge. In the present study, the ridge on such days is treated as missing and the statistical analysis is based only on the days when the ridge is present. Altogether, such missing values amounted to 11%, 8%, and 17% of the total possible number of data points in March, April, and May, respectively. Relatively larger numbers of missing data are encountered at the end of May, due to less well-defined ridge locations.

3. Results and discussion

So far, the ridge location has been considered only along 75°E, based on the morning (0530 IST) observations. However, in view of the considerable east–west extent of the ridge, we examined the interrelationships of the ridge locations along 70°, 75°, and 80°E. The CCs between the daily ridge locations along the three longitudes, in each of the 21 years (1967–87) for the whole season March–April–May, are worked out. All the CCs are found to be very high (0.68 to 0.99) and significant much above the 0.1% level, indicating a uniform south–north propagation along all the three longitudes. The CCs between the ridge locations of morning and evening observations at all the three longitudinal locations are also significant at the 0.1% level. Therefore, the morning ridge location along 75°E is considered to be well representative and is used for further analysis.

a. General characteristics of the daily ridge location during the premonsoon season

The 21-year mean daily ridge locations clearly show the south-to-north progression of the ridge during March through May. This movement is found to be relatively more rapid from April to May than that from March to April. The monthly mean ridge locations of March, April, and May are 13.1°, 14.4°, and 17.4°N, respectively.

The CCs between the monthly mean ridge locations are −0.039 (March vs April), 0.35 (April vs May), and 0.18 (March vs May), which are not statistically significant.

IMD determines the mean monthly ridge location along 75°E during April by analyzing the mean monthly winds. These values are compared with the monthly means of daily ridge locations on all available days in April, during the period 1967–87. The mean and standard deviation of the IMD series are 14.9°N and 1.93°, respectively, and the corresponding values for the series obtained in the present study are 14.4°N and 1.24°. These two series are generally in good agreement with a CC of 0.74 (significant at 0.1% level), except for two years (1968 and 1969) when they differ by about 3°.

b. Relation between the premonsoon ridge location and all-India summer monsoon rainfall

In order to identify the exact period when the ridge location becomes critically important for the Indian monsoon, the following procedure is adopted. In each year, running means of the ridge location during the premonsoon season have been calculated over windows of lengths 15, 21, and 31 days. For all running windows, the mean is based only on the days when the ridge can be located. Then, the CCs have been worked out between each of the aforementioned means and the all-India monsoon rainfall. Differences were not statistically significant, so only representative results for 21-day running windows are presented.

The CCs between 21-day running means of the ridge location at 0530 IST and the all-India summer monsoon rainfall are plotted against the serial number of the corresponding running mean periods in Fig. 2. The CCs are negative throughout March and the early part of April and later change over to positive. The CCs reach a negative peak around the middle of March (−0.47 for the 21-day period centered on 22 March) and a positive peak around late April (+0.63 for the 21-day period centered on 27 April), and later gradually decrease and become insignificant during the later part of May.

The marked negative CCs between the ridge location in March and Indian monsoon rainfall have previously not been reported. This feature is of potential utility for the long-range forecast of monsoon rainfall of India because of greater lead time.

In view of the opposite signs of the CCs shown by the ridge locations of March and April, the relationship between the change of ridge location from March to April and the all-India monsoon rainfall is also examined. It is found that the difference between the ridge locations for the two 21-day periods with the highest opposed correlations (17 April–7 May minus 12 March–1 April) shows a very high CC of 0.73 (significant at 0.1% level) with the Indian monsoon rainfall. Thus, change in the mean ridge location from March to April may be a better predictor than the ridge location of April or March individually. The correlation suggests that the larger the latitudinal extent traversed by the ridge during March–April from south to north, the better the subsequent monsoon rainfall will be. The year-to-year variations of the mean ridge location during these individual periods as well as their differences are shown in Fig. 3 along with the monsoon rainfall. For the sake of comparison, the figure also includes the mean monthly ridge location of April as per the IMD analysis, which shows a CC of 0.66 with the all-India monsoon rainfall, during 1967–87. It can be seen clearly that the all-India monsoon rainfall curve more closely follows the curve of the ridge-location differences between April and March.

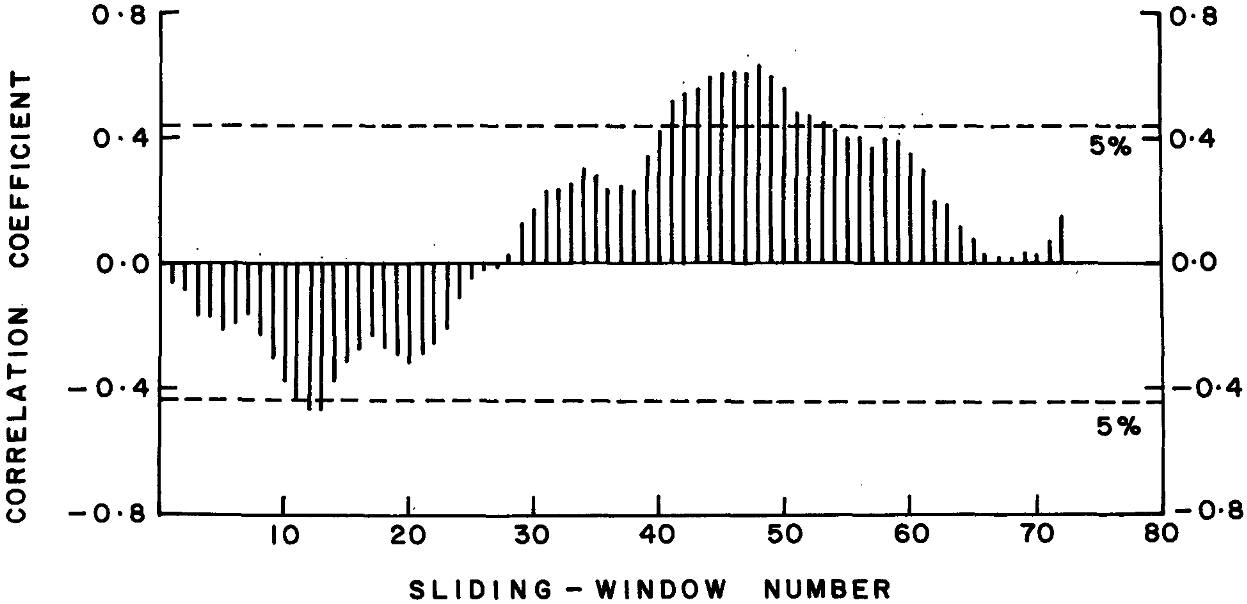

FIG. 2. CCs between all-India summer monsoon rainfall and running means of ridge location (0530 IST) over 21-day window.

To examine the consistency of the identified relationships, CCs between the ridge location parameters and all-India monsoon rainfall have been worked out over sliding windows of 10-year length, during the data period 1967–87. Figure 4 shows the variation of the sliding CCs between the all-India monsoon rainfall and the three ridge-location parameters of March (A), April (B), and their difference (B–A). The CCs of (B–A) parameter are significant throughout the study period, 1967–87, while the other two parameters show more inconsistency.

c. Relationships between the ridge location and subdivisional monsoon rainfall

The analyses in the previous sections have dealt with all-India monsoon rainfall. Though the prediction of monsoon rainfall of the country as one unit is of general interest, its practical utility is limited, because of the high spatial variability of rainfall over India. In view of this, the relationships between 21-day running means of the premonsoon ridge location and the summer monsoon rainfall of different subdivisions of India have been examined.

The peak CCs, both positive and negative, along with the corresponding 21-day running-window numbers given in parentheses, are presented in Figs. 5a and 5b. Positive CCs significant at the 5% level and above are mostly confined to the subdivisions lying west of 80°E and north of 18°N (Fig. 5a). The period of occurrence of peak positive CCs generally ranges between the running-period numbers 42 and 48 (centered on 21 and 27 April, respectively) for a majority of the subdivisions. The highest peak CCs are observed over the subdivisions of Punjab, Haryana, and east Rajasthan. Over most of the subdivisions in the peninsular India south of 18°N, the CCs are insignificant.

On the other hand, the distribution of the peak negative CCs (Fig. 5b) shows that the statistically significant CCs are mostly confined to the subdivisions lying between 12°N and 20°N latitude, with the CCs of highest magnitude (locally significant above 1% level) occurring over Andhra Pradesh and parts of Maharashtra and Karnataka. The period of occurrence of negative peak CCs generally ranges between running-period numbers 10 and 13 (centered on 20 and 23 March, respectively) for most of the subdivisions.

In view of the foregoing result, we studied the relationship of the ridge location during the premonsoon season with the average rainfall of these two broad regions separately. For this purpose, the rainfall of all the contiguous subdivisions showing significant or nearly significant CCs, along with a couple of subdivisions having similar climatological characteristics though showing indifferent CCs, are combined to form two groups. The first group (group I) consists of the subdivisions lying roughly north of 20°N latitude excluding northeast India and hills of extreme north India, and the second group (group II) consists of all the subdivisions in the peninsular India. Area-weighted average rainfall series of the two groups are obtained from the subdivisional rainfall data. The subdivisions of northeast India have been omitted as the rainfall there is poorly or negatively correlated with the rainfall of the other subdivisions (Mooley and Parthasarathy 1983; Parthasarathy 1984). The all-India monsoon rainfall shows a CC of 0.91 with the subdivisional group I rainfall and 0.77 with the group II rainfall. However,

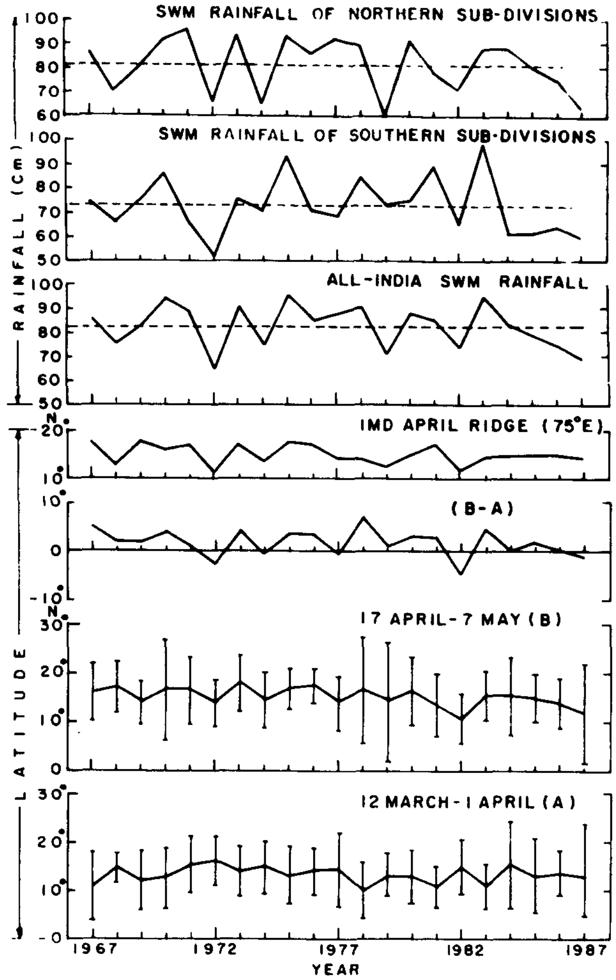

FIG. 3. Year-to-year variation of various ridge location parameters and the Indian summer monsoon rainfall. The vertical lines in the bottom two panels are error bars ($\pm 2\sigma$).

the rainfall series of group I and group II show a weaker CC of 0.45.

Correlation analysis has been done between the rainfall series of these two groups and 21-day running means of the ridge location. The peak values of negative and positive CC are −0.24 and 0.63 for north India and −0.72 and 0.39 for peninsular India. The periods of occurrence of these two peaks are the same as those observed with the all-India rainfall series. Thus, it appears that a preemptive northward displacement of the ridge in March itself is not favorable for good monsoon activity over the peninsular India, while this is not as crucial for north India.

d. Development of linear regression equations for the prediction of monsoon rainfall

Multiple linear regression equations are developed using a stepwise procedure based on the algorithm developed by Jennrich (1977). In this procedure, for a given dependent variable, starting from an equation with one independent variable showing the highest CC, further independent variables are added in a stepwise manner based on the F-value criterion. All-India monsoon rainfall (R) is the dependent variable, and the 21-day mean ridge locations during 12 March to 1 April (X_1) and 17 April to 7 May (X_2) are the independent variables.

It may be mentioned here that the March ridge location and the April ridge location are not interrelated, having a nonsignificant CC of −0.121. Both the ridge parameters enter the regression equation as given in the following, showing a multiple CC of 0.74 (significant at 0.1% level, explaining about 55% of the variance):

$$R = 67.85 - \underset{(0.8116)}{2.0194X_1} + \underset{(0.7635)}{2.7782X_2}. \quad (1)$$

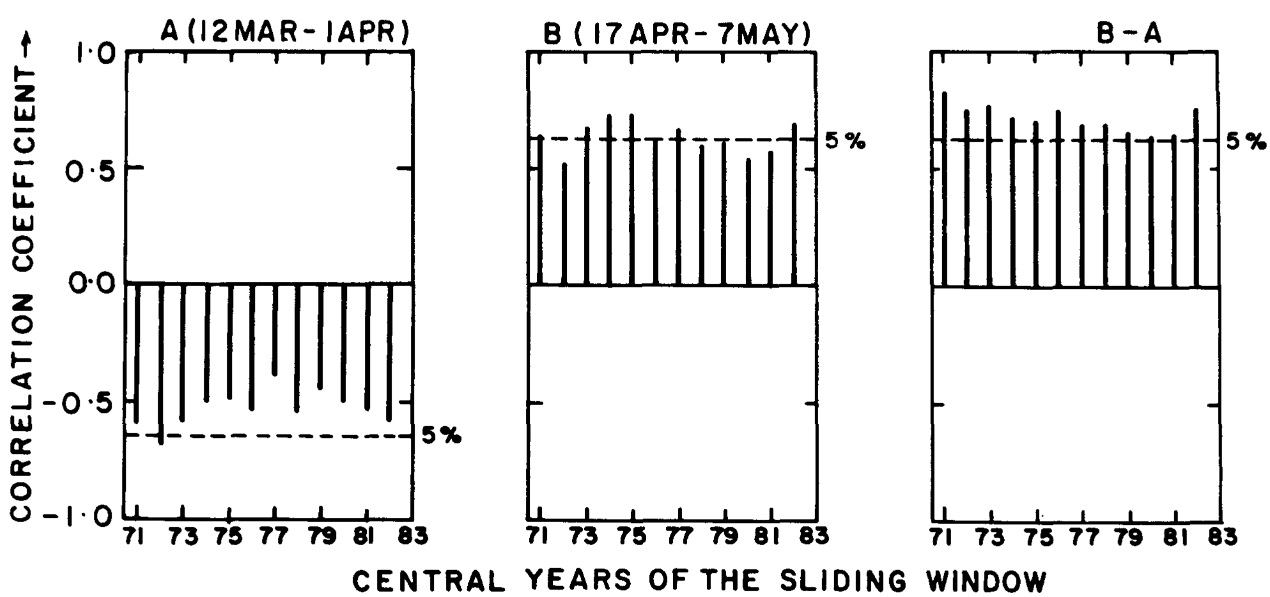

FIG. 4. 10-year sliding correlations between different ridge parameters and the all-India summer monsoon rainfall.

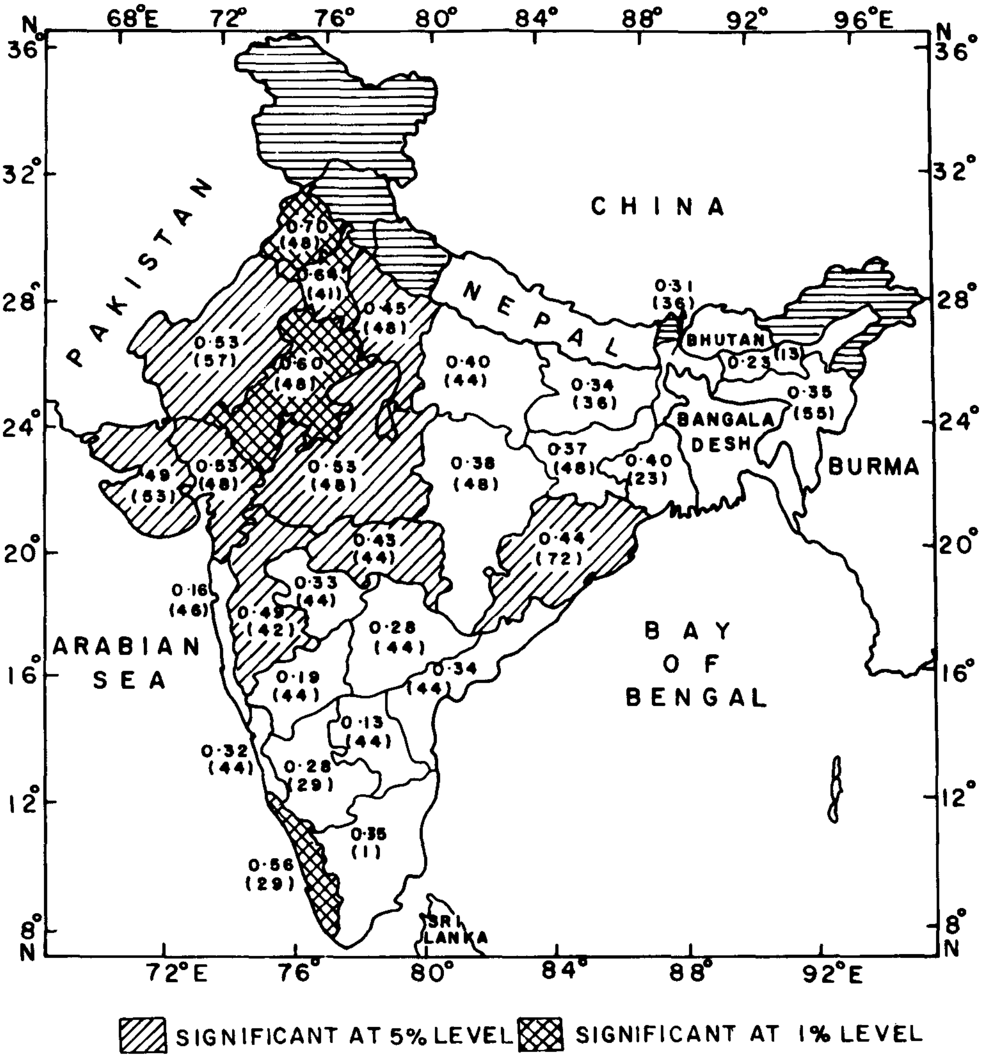

FIG. 5. Distribution of peak positive CCs between the subdivisional monsoon rainfall and the 21-day ridge locations. Numbers in parentheses indicate the corresponding 21-day running mean window numbers. (a) Positive CCs; (b) negative CCs. Areas indicated with horizontal striping are not considered in the present study.

The values in parentheses are the standard errors of the corresponding regression coefficients. The estimated values of all-India summer monsoon rainfall from this equation agree quite well with the observed values during the data period 1967–87.

To test the regression equation on an independent sample, we have obtained the mean ridge locations of the corresponding periods for three years, 1988–90, and estimated the all-India summer monsoon rainfall (Table 1). The very low estimate of 1988 is mainly due to the anomalous southward shifting of the ridge during the later part of April. Though the IMD ridge gave relatively better estimates for 1988 and 1989, this parameter also considerably underestimated the monsoon rainfall in 1988. When the correlations are recomputed for the period 1967–90, the multiple CC of Eq. (1) is found to have dropped to 0.55, resulting in a slight decrease in its relative advantage over the IMD ridge (CC = 0.57). Part of the loss in skill is no doubt the result of the effects of sampling error in the selection of a 21-day predictor data window.

4. Summary and conclusions

A comprehensive analysis has been done of the space–time variability of the daily latitudinal location of the ridge axis at the 500-hPa level over the Indian region during the premonsoon season and its influence on the subsequent monsoon rainfall during 1967–87. The following are the main conclusions from the study.

1) The ridge location along 75°E at 0530 IST is representative.

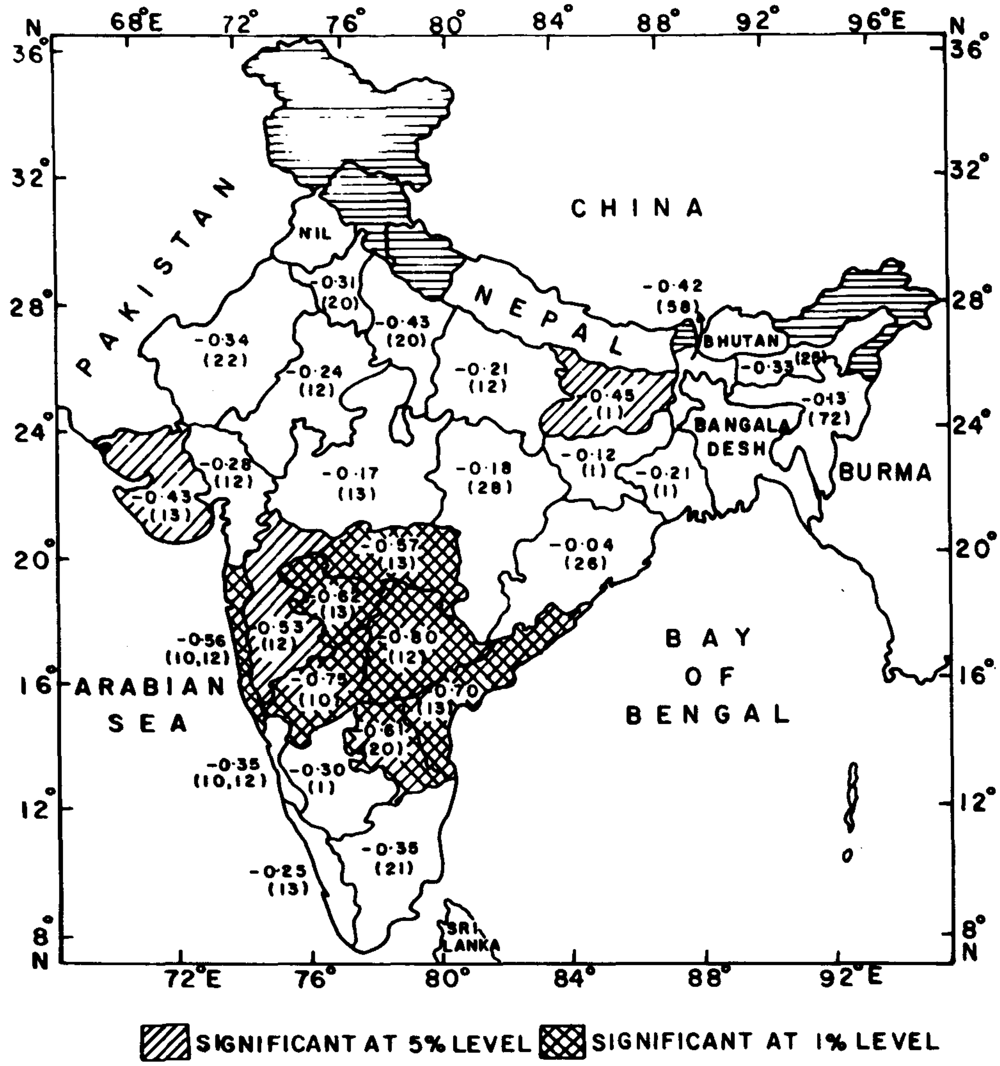

FIG. 5. (*Continued*)

2) The ridge location during March and early April is anticorrelated with the all-India monsoon rainfall, while that in the later part of the premonsoon season is positively correlated.

3) The negative peak CC (−0.47) is found between the mean ridge location of the period 12 March to 1 April and the all-India monsoon rainfall, while the positive peak CC (0.63) is found for the period 17 April to 7 May. The difference of ridge location between these two periods shows a significant and consistent CC of 0.73.

4) Significant positive peak CCs are confined to northwest India west of 80°E and north of 18°N, while the negative peak CCs are confined to the peninsular region between 12°N and 20°N.

5) The identification of negative relationship of the

TABLE 1. Performance of prediction equation for all-India monsoon rainfall during independent data period, 1988–90.

Year	Ridge location (°N) during: 12 Mar–1 Apr	Ridge location (°N) during: 17 Apr–7 May	All-India monsoon rainfall (cm): Estimated from Eq. (1)	All-India monsoon rainfall (cm): Observed	All-India monsoon rainfall (cm): Estimated from IMD ridge*
1988	13.9	11.7	72.4	99.1	83.0
1989	11.7	16.6	90.4	86.2	89.0
1990	13.1	15.8	85.3	93.2	83.0

* Using the linear equation given by Mooley et al. (1986).

March ridge location with the monsoon rainfall, which is a new finding from the present study, increases the lead time for long-range forecasting for peninsular India.

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