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RELATIONSHIP BETWEEN 500 hPa RIDGE AXIS POSITIONS OVER THE INDIAN AND THE WEST PACIFIC REGIONS AND THE INDIAN SUMMER MONSOON RAINFALL

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ABSTRACT

500 hPa ridge positions over the Indian and the West Pacific regions during April are related with the summer monsoon rainfall over India. The ridge position over the Indian region shows better relation with monsoon rainfall than that shown by the ridge over the Pacific region. The multiple correlation of these ridge positions with monsoon rainfall exceeds 0.7. These predictive relationships are better than those shown by other parameters, viz. (1) Northern Hemispheric surface temperature; (2) East-Pacific sea surface temperature; (3) El-Nino events and (4) Tahiti-Darwin pressure difference, and index of southern oscillation, over the 30-year samples analysed.

I. INTRODUCTION

Because of the large inter-annual variability of the Indian summer monsoon rainfall and its great impact on the Indian economy, numerous attempts have been made during the last 100 years to foreshadow the total quantity of rainfall received during the summer monsoon season, from the antecedent regional or global parameters. A large number of predictors have been explored. During the recent years the predictors such as Himalayan snow cover, Arabian sea surface temperature, Equatorial Pacific sea surface temperature, several indices of southern oscillation, position of 500 hPa ridge over India during April, upper tropospheric thickness, contour height and meridional wind over north-west India, upper air parameters over the Indian and Australian region, Northern Hemispheric surface temperature, longitudinal extent of the trough line on global 50 hPa charts, position and intensity of Aleutian and Icelandic low, Pacific and Atlantic subtropical high, etc., have been related with monsoon rainfall. The length and the period of data of these parameters have been varying widely. If a period of thirty years can be assumed to provide a stable relationship, then out of all the parameters explored, the latitudinal position of 500 hPa ridge over India during April shows the best predictive correlation for the samples of this size. The monsoon rainfall also shows significant correlation with concurrent and lagged parameters of southern oscillation[1], but these correlations are considerably less than those shown by 500 hPa ridge. The performance of the monsoon is related with the strength of the equatorial zonal east-west circulation commonly known as Walker Circulation[2]. The position and the intensity of the north-south Hadley Circulation and hence the position and intensity of the ridge in West Pacific are related with the Walker Circulation. It is thus likely that the position and intensity of the subtropical ridge in the West Pacific region during the premonsoon season may provide some useful predictive information about the Indian monsoon. The position of the subtropical ridge over the West Pacific region may be the important factor deciding the strength of the easterlies on the northern flanks of the monsoon trough. The effectiveness of these easterlies on the southern flanks of the Pacific ridge as the steering current, steering the pressure systems from the South China Sea and further east towards India, may also depend on the position of the ridge. The relationship between the subtropical ridge over the West Pacific and the Indian summr monsoon rainfall is thus worth exploring. In this paper the relationship of the 500 hPa subtropical ridge over the Indian and the West Pacific regions during the premonsoon and the monsoon season with the monsoon rainfall over India is studied. The main techniques employed for studying these relationships are those of correlation and regression.

II. DATA

Four indices of the position and intensity of the West Pacific subtropical ridge at 500 hPa level for the months from April to September for 33 years (1951—1983) were obtained from Prof. Zhang Yan of the Weather and Climate Research Institute, Beijing, China. These indices are: (1) Areal Index (AI)—The area enclosed within the 5880 geopotential meter (gpm) contour line in the north-west Pacific (north of 10°N latitude and between 110°—180°E longitudes, (2) Height Index (HI)—The sum of the contour heights over the same grid points as used in the AI, (3) Position Index (PI)—The average latitudinal position of the ridge line between longitudes 110°—150°E sampled at 10° longitude interval, and (4) Western-most Extent Index (WEI)—The western longitude of intersection between the ridge line and the 5880 gpm contour line.

These four indices were prepared by Prof. Zhang from the Chinese historical weather maps and for preparing these indices, rather a course mesh of 5° Lat./10° Long. was considered. (For further details see Ref. [3]). The rainfall data of all India for the corresponding years were kindly supplied by Dr. B. Parthasarathy of the Indian Institute of Tropical Meteorology and the seasonal rainfall anomalies for a 31 meteorological subdivisions for the period (1951—1981) are taken from Ref. [4]. The ridge axis positions over the Indian region were provided by Shri A. K. Banerjee of the Meteorological Office, Poona.

III. RESULTS

1. *Correlations between Pacific Ridge and All India Rainfall*

The four indices of the ridge over the West Pacific region (PR) during April, May and the monsoon season (average of four monsoon months June-September) are correlated with monsoon rainfall over all the 31 meteorological subdivisions and over whole India. The correlation with all the India rainfall are shown in Table 1 below.

It is seen that the PI during April offers the maximum predictive value. Hence for further investigations only this parameter of the Pacific ridge was considered.

Banerjee et al.[5] found considerably higher correlation between the latitudinal position of the 500 hPa subtropical ridge across 75°E longitude (henceforth called as Indian region (IR)) during April and some index of summer monsoon rainfall. Hence it was thought appropriate to compare the relative importance of the 500 hPa ridge position in the two regions, viz. IR and PR in foreshadowing monsoon rainfall. The correlation between the

April ridge position over IR and Indian Summer Monsoon rainfall is found to be 0.68 by using the same period of rainfall data. Thus it is found that when single parameter is used the predictive value of the ridge position over IR is higher than that over PR. Still the ridge position of PR may supply additional predictive information when both parameters are used together. This possibility is explored subsequently.

Table 1. Correlations between the Four Indices of 500 hPa Ridge over PR during April, May, and Monsoon Season with All India Monsoon Rainfall

Index \ Months	April	May	Season
PI	0.48	0.22	0.48
WEI	−0.41	−0.47	−0.18
AI	0.13	0.16	0.07
HI	0.18	0.15	0.10

To examine visually the inter-relationships between the ridge positions over the IR, and the PR scatter plots are prepared between the ridge positions and rainfall. (Fig. 1, the regression lines as obtained by least square fit are also shown). An interesting feature of Fig. 1a is that there are two clusters of points, one cluster has ridge location below 14°N and the other above 14°N. The scatter of points is high when the ridge position over IR is equal to or more than 14°N latitude. A close examination of Fig. 1b revealed that 3 points corresponding to the years 1953, 1967, 1971 contribute to a large extent for the poor correlation

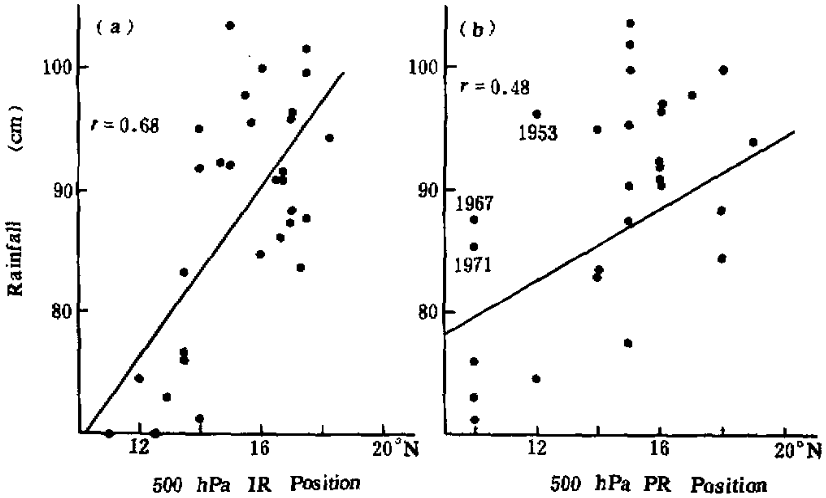

Fig. 1. Scatter plot between the Indian monsoon rainfall and the ridge position over the Indian region (a) and the Pacific region (b). The solid lines are the regression lines obtained by least square fit. The three years viz., 1953, 1967 and 1971 which show poor relationship in the case of Pacific region are also shown.

between the ridge position over PR and the monsoon rainfall and between the ridge positions over the two regions (Fig. 2). When these years and the year 1963 for which the position of the ridge over IR was not available were eliminated from the data the correlation between the two ridge locations became 0.61 and that between ridge position over PR and rainfall became 0.56. The correlation between the ridge location over IR and rainfall remained practically unchanged.

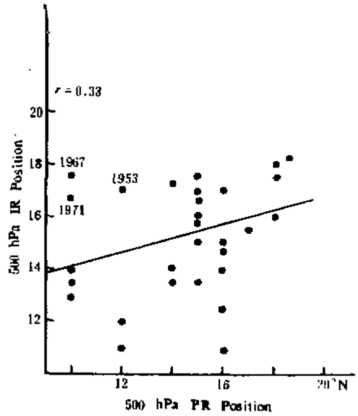

Fig. 2. The scatter plot between the ridge axis locations over the Indian and the Pacific regions. The solid line is the regression line obtained by least square fit. The three apparent outliers, viz., 1953, 1967, and 1971 are shown.

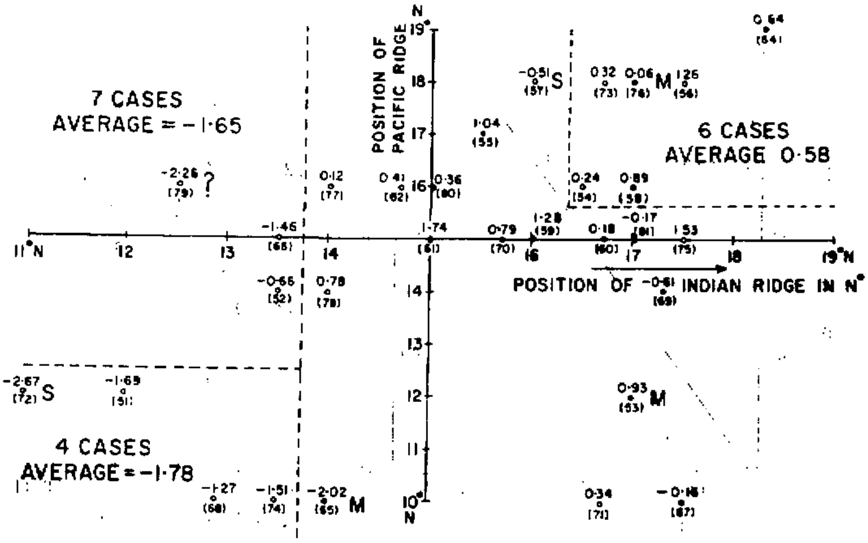

Fig. 3. Standardised monsoon rainfall in relation to the ridge axis positions. The standardised value of rainfall is shown above and the year (in paranthesis) below the open circle representing the ridge axis location combination. The severe and moderate El-Nino years are represented by letters S & M respectively. A question mark (?) is put for the year 1979.

To examine the combined influence of the two ridge axes on monsoon reinfall, values of standardised rainfall and the corresponding year were plotted on the graph which has the abscissa as the ridge position over IR and the ordinate as the ridge position over PR (Fig. 3). The mean and standard deviation needed for standardisation were computed from 81 years (1901—81) of data. All the 7 years when the position of the ridge over the IR is less than 14°N show below normal rainfall (Average Standardised Departure (ASD)$=-1.65$) and the average ASD of the four years when the position of the PR ridge $\leqslant 12°$N and that of IR ridge is$<14°$N, is -1.78. When the position of the ridge over IR is more than 16°N, 10 out of the 13 years (77 % of the cases) show above normal (ASD$=+0.42$) rainfall. When we consider the combined influence of the ridge locations over the two regions, we find that when the location of the ridge over the IR is more than 16°N and that over the PR is equal to or more than 16°N, all the 6 years show above normal rainfall (ASD$=+0.58$).

This stratification between the above normal and below normal rainfall is better than what can be achieved by the El-Nino (or non El-Nino) events which are the most significant manifestations of short-term climatic variability of the ocean. It may be noted that considerable evidence has been gathered during the recent years that the El-Nino events are accompanied by the deficient monsoon rainfall[6,7]. According to Mooley and Parthasarathy[7], moderate (severe) El-Nino events are followed by deficient rainfall on 66% (90%) of the occassions. If the intensity of El-Nino is ignored then on 77% of the occassions the El-Nino is associated with below normal rainfall. In the period of present study, i. e. 1951—1981 there were 5 El-Nino years viz. 1953 (Moderate (M)), 1957 (Severe (S)), 1965 (M), 1972 (S) and 1976 (M)[8]. There is conflicting evidence about 1979 being an El-Nino year[9]. Out of the 5 El-Nino years during the period of study 3, i. e. 60% are associated with below normal rainfall (ASD$=-1.73$). This association, in terms of frequency of deficient rainfall years, is poorer than that obtainable with the location of ridge over IR. It may be noted that the events with the ridge position over the IR$<14°$N, viz. 1951, 1952, 1956, 1968, 1972, 1974 and 1979, are more frequent than the El-Nino events (7 as compared to the 5 El-Nino events) and all these years are associated with deficient rainfall as against 77% of the El-Nino years associated with the deficient rainfall. Hence the ridge position can be used to foreshadow the deficient monsoon rainfall more frequently and with higher confidence.

We notice from the results presented above some asymmetry in the relationship between the ridge axis location and rainfall. When the ridge position is below normal the absolute value of ASD of rainfall is more than that when the ridge position is above normal. To investigate this asymmetry quantitatively, we tested the significance of the difference between the average values of the ridge position from the overall mean value (for successively increasing number of cases from 1 to 10) for the ridge positions corresponding to the rainfall ordered from the lowest to the highest or vice versa. The Students t-values were found to be nearly double for the low rainfall cases as compared to those for high rainfall cases. Similar asymmetry is also noted for other factors like El-Nino events. While a large percentage of El-Nino years are followed by deficient rainfall, a smaller percentage of years receive above normal rainfall for non El-Nino years or even cold Pacific events. The reverse El-Nino events (cold east-Pacific SST) are not too well defined. Similar asymmetry is noted for the relation between the stratospheric winds and rainfall. When the stratospheric wind is westerly (easterly) the absolute value of the probability of deficient (excess) years is more (less). These results suggest that the prediction of large-scale deficient drought years should be more successful than that of excess years.

2. *Partial and Multiple Correlations and Their Stability*

To examine the relationship of each ridge position with rainfall, after eliminating the influence of the other ridge position, the partial correlation coefficients (PCC), and to examine the combined influence of the two ridge positions on rainfall, the multiple correlation coefficients (MCC) have been computed. If rainfall, ridge positions over IR and over PR are designated as variable number 1, 2 and 3 respectively, then in standard terminology the PCC and MCC computed by using the 30 years of data(excluding the year 1963) are:

$$r_{12,3}=0.63; \qquad r_{13,2}=0.30; \qquad R_{1,23}=0.72;$$

and when the years 1953, 1967 and 1971 are removed (see Section III. 1) we get

$$r_{12,3}=0.52; \qquad r_{13,2}=0.24; \qquad R_{1,23}=0.70.$$

Thus we see that after elimination of 3 bad years (bad in the sense of relationship between PR position and rainfall) the MCC actually declines slightly as the correlation r_{23} rises from 0.38 to 0.61.

Due to the sampling fluctuation, the correlation coefficient between any two parameters can exhibit large fluctuation in their magnitude and sometimes even show change of sign. Such instances have been noted in meteorology. It is thus advisable to check the stability of the fluctuation[10]. We use a 15-year sliding window to examine the stability of the simple, partial and the multiple correlations (see Table 2).

Table 2. Simple, Partial and Multiple Correlations Computed by Using 15-Year Sliding Window (the Year 1963 Excluded)

Period of Data	Simple Correlation Coefficients		Partial Correlation Coefficients		Multiple Correlation Coefficients
	IR	*PR*	$r_{13,2}$	$r_{12,3}$	$R_{12,3}$
1951—1966	0.69	0.52	0.19	0.56	0.71
1952—1967	0.54	0.43	0.35	0.49	0.62
1953—1968	0.59	0.51	0.36	0.48	0.66
1954—1969	0.51	0.59	0.47	0.33	0.65
1955—1970	0.49	0.58	0.47	0.32	0.64
1956—1971	0.50	0.56	0.46	0.38	0.64
1957—1972	0.64	0.52	0.40	0.57	0.71
1958—1973	0.65	0.59	0.49	0.57	0.75
1959—1974	0.66	0.61	0.50	0.57	0.76
1960—1975	0.70	0.61	0.48	0.62	0.78
1961—1976	0.69	0.57	0.41	0.60	0.75
1962—1977	0.74	0.60	0.49	0.69	0.81
1964—1978	0.70	0.57	0.43	0.62	0.76
1965—1979	0.71	0.39	0.37	0.71	0.76
1966—1980	0.71	0.34	0.34	0.70	0.74
1967—1981	0.68	0.38	0.35	0.67	0.73

We see from the Table 2 that the correlations are stable over the period of study and there is slight indication that the values of the correlations have increased in recent years, which could be due to the improvement in the quality of the data.

3. *Multiple Regression Equation*

A multiple regression equation was prepared by using the two ridge locations. 25-year data were used as dependent sample and 7 observations were reserved for verification. The equation obtained is

$$R(\text{in mm})=258.865+30.77IR+10.66PR.$$

The first variable, i. e. the position of the ridge over IR explained 52.5% variance and the second explained additional 6.42% of the variance. Hence the total variance explained on the dependent sample is 58.92% and the MCC is 0.77. Somewhat less variance (52.7%) of rainfall was explained by the 500 hPa contour heights over North-West India and over Australia during April as shown by Raj et al.(11) using the same length of development sample. Thus the ridge positions are slightly better predictors of monsoon rainfall than the contour heights. The average error in actual prediction of rainfall for 7 independent years (1977—1983) was 6.6%.

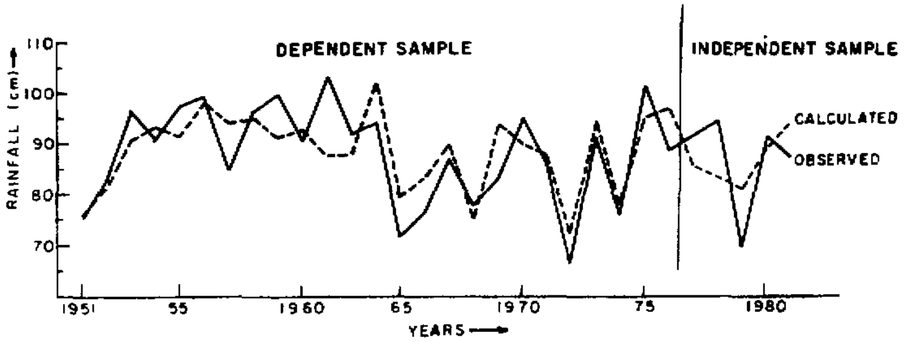

Fig. 4. The curves of observed (——) and predicted (– – –) rainfall.
The development and independent samples are separated by a solid vertical line.

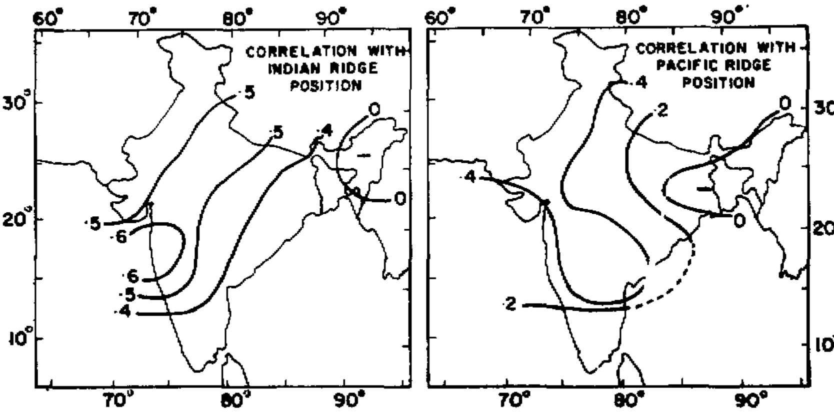

Fig. 5. The spatial distribution of the correlations between the ridge axis locations and the Indian monsoon rainfall of the meteorological subdivisions.

Presented in Fig. 4 are the observed and the calculated (from the above regression equation) rainfall for all years. We notice that the major fluctuations in the rainfall are quite satisfactorily reproduced by the regression equations in both, the dependent (25) and the independent (7) sample. However, in 7 years the calculated rainfall appears to be more deviant from the observed rainfall than in the other 25 years. During two of these 7 years (1961, 1978) the calculated rainfall was less than observed and more than observed in 5 years (1957, 1964, 1965, 1969, 1979). The examination of individual years revealed that the calculated rainfall was less in 1978, mainly due to the below-normal (normal or the long-term average position being 15.4°N as determined from these 32 years of data) position of the ridge over the Indian region. The year 1961 was the one of severest flood during the present century. In two (1964 and 1969) of the above mentioned 5 years in which calculated rainfall was more, the Indian ridge position was too much above normal and the two years 1957 and 1965 were the El-Nino years. The remaining year 1979 was abnormal in several regional and global aspects. We realise that these two ridge position parameters cannot foreshadow the entire interannual variability of monsoon. Other factors like southern oscillation, winter snow cover, sea surface temperature are found to affect the monsoon rainfall in a significant way. It may, however, be noted that even all the relevant predictors combined together may not be able to foreshadow the entire interannual variability of the monsoon. There is a limit upto which this variability can be predicted (see discussion part below). However recently we have added some more parameters to the regression equations and have received slightly better results. These results when completed shall be reported elsewhere.

4. *Relationship of Ridge Axis with Subdivisional Rainfall*

India is a large country and contains wide range of geographical and rainfall regimes. It is known that almost on all time scales, the rainfall over the western and the central parts of the country exhibits see-saw with the rainfall over the north-eastern parts. It is thus thought appropriate to examine the spatial preferences in the relationship between the ridge axis and the monsoon rainfall of smaller regions (meteorological subdivisions). The correlations between the ridge axes positions and the subdivisional rainfall are presented in Fig. 5. It is seen that the correlations are higher for the subdivisions lying to the west of 80°E longitude and south of 20°N latitude and show opposite sign for the north-eastern parts of the country (also see Ref. [1]). The belt of high correlation for the IR axis is oriented in the south-west to north-east direction and that for the PR axis is oriented from south-east to north-west direction.

5. *Relationship of Rainfall with Other Parameters*

For comparison purpose, correlation of (1) Northern Hemispheric Surface Temperature (NHST) (Ref. [12]); (2) Tahiti-Darwin pressure difference during March-April-May (a Southern Oscillation, (S. O.) index—Ref. [13]); (3) Average of 500 hPa contour heights of Bombay, Karachi, Taskent, Jodhpur, Nagpur and Trivandrum during April (see Ref. [11]) were computed using the same rainfall data for 31, 31 and 27 years respectively. These correlations came out to be 0.54, 0.18, and 0.61 respectively. Mooley and Parthasarathy[14] have analysed the relationship between sea surface temperature over the equatorial Pacific (0°—10°S, 90°—180°W) and the monsoon rainfall. The correlations between the SST during the (1) preceeding December, January, and February, (2) preceeding March, April and May; (3) concurrent June, July and August, (4) succeeding September, October and November and (5) succeeding

December, January and February and the monsoon rainfall, when computed using 52 years (1925—1976) of data were found to be 0.13, −0.17, −0.52, −0.55 and −0.52 respectively. The correlations increased by some amount when 30-year data set was considered, but ramained generally less than that found with the ridge axis position. It may be noted that there is very little predictive value (correlation =0.13) in equatorial Pacific SST. All these results suggest the greater importance of the 500 hPa ridge over IR in foreshadowing monsoon rainfall. Data of other parameters like wind index and upper tropospheric thermal anomaly were not available for comparable period.

IV. DISCUSSION

We found above that 59% of the variance (MCC=0.77, sample size 25) of rainfall can be explained by only two variables related to the position of 500 hPa subtropical rigde over Indo–Pacific area. The test sample was not adequate to demonstrate the real utility of the regression equations. Banerjee et al.[5] found slightly higher correlation (0.82) between the 500 hPa ridge position and an index of rainfalll using 21 years (1950—70) of data. It appears that these correlations represent the upper limit as far as predictive correlations are concerned. An examination of the signal to noise ratio for the bi–monthly rainfall (July–August) revealed that the potential predictability of monsoon rainfall is slightly above 50%[15]. Assuming that the above estimate is conservative due to the limited data (data used in that study was only 19 years) or due to the methodology followed we may optimistically assume the potential predictability to be at most 80%. Further support to this limit of potential predictability is provided by examination of seasonal rainfall anomaly patterns. We may note that considering the complexity of the monsoon it may never be possible to explain the full (100%) variance of monsoon rainfall by any empirical (or other) method and in our opinion no method may be able to explain more than 80% of the variance and remain stable over various samples. Considering this limit of predictability, explanation of 59% of the variance by the ridge positions can be considered quite satisfactory. One basic problem with the ridge positions is that their time series are short as compared to NHST and some S. O. /El–Nino parameters. However, it has been indicated by Nicholls[14], Parthasarathy and Pant[1], and Mooley and Parthasarathy[14] that a sample of 30 can provide stable relationships suitable for long-range forecasting. We have seen in Section III.2 above that the relationship between the ridge positions and the monsoon rainfall is stable even over smaller (15 years) periods. The greater usefulness of the ridge position, a regional parameter, is thus undoubtedly established.

An important doubt may be raised as to why the April ridge position shows better correlation with monsoon rainfall than that obtained for the ridge positions in May which is closer to the monsoon season (see Table 1). A similar result was obtained by Raj et al[10]. From the forecasting point of view the use of parameters observed in April gives one month lead and hence is more useful than the use of parameters observed in May. But it is not understandable as to why the April parameters should show better relationship. If it is simple laggedness of the atmospheric evolution, then May should show a better result as this will provide the latest report on the atmospheric condition.

The ridge parameters can influence the total monsoon seasonal rainfall by affecting any of the three rainfall features, viz. (1) the total duration of the rainy season including the onset and the withdrawal dates; (2) the total number of rainy days; and (3) the intensity of rain on rainy days, or their combination. It is logical to think that these ridge parameters should show better relationship with the monsoon onset, the event which occurs earlier than to the total seasonal rainfall. The correlations between the two ridge axis locations and the dates of onset over Kerals and Bombay are given in Table 3. The data of onset are counted from 15 May onwards. These correlations are much less than those obtained for total rainfall although they are in the right sense. However, studies have indicated that the relationship between the onset dates and the subsequent monsoon rainfall is poor. So also is the relationship between the rainfall of successive months. Thus the relationship between various predictive parameters and total monsoon rainfall is too complex. In view of this it is worthwhile to study the relationship of these ridge (and other) parameters with the other three rainfall features mentioned above.

It is conjectured that the ridge axis over the Indian region may show some prediction relationship with Meiyu rainfall over central east China even though the ridge over the Pacific ridge may exercise more influence due to its physical proximity to China. The ridge position data over the IR are of quite good quality as those are obtained from manual analysis which uses a number of wind observations over Indian mainland. The accuracy of PR data may be slightly poor because of coarse resolution (5° Lat./10° Long.) used and sparse data over the oceanic area. Hence the relationship between the ridge position on the IR and the southern China rainfall is worth exploring.

Table 3. Correlation between the Onset Dates over Bombay and Kerala with the Position of the Ridge Axis

	Kerala	Bombay
PR	-0.26	0.18
IR	-0.25	-0.25

V. CONCLUSIONS AND FUTURE PLANS

From the above results the following conclusions are drawn:

(1) The position of the 500 hPa ridge during April over India is the better antecedent factor for foreshadowing the monsoon rainfall than the Northern Hemispheric Surface Temperature, Southern Oscillation Index. Equatorial Pacific SST and the El-Nino. When the position of the 500 hPa ridge during April over India is less than 14°N the monsoon rainfall is most likely to be deficient and when the ridge position is more than 16°N the probability of excess rainfall is 77%.

(2) The 500 hPa ridge positions over the Indian and the West-Pacific regions together explained 51% of the variance of the monsoon rainfall when 30 years of data were considered and 59% of the variance when 25 years of data were considered. The multiple regression equation developed from using 25 years predicted rainfall on an average up to 6.6% of the accuracy. It may be possible to improve the performance of the prediction by adding some more variables in the regression equations and by adopting robust regression methods or multivariate time series modelling. This is currently being attempted and the results are to be reported later elsewhere.

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