A Predictive Monsoon Signal in the Surface Level Thermal Field over India

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ABSTRACT

This is primarily a statistical study based on linear correlation analysis. The mean monthly surface thermal field over India based on a fairly well-distributed network of 119 stations has been examined for March–May during the period 1901–75 for the relationship with rainfall during the following monsoon season. The study brings out three areas (the first and the third from the central portion of western India, the second from southern peninsular India) for which the relationships between area average of mean monthly minimum temperature for April (for the first and the second areas) or for May (for the third area), and Indian monsoon rainfall are stable and consistently significant for 20 to 30-yr periods after 1940. The best of these relationships is that with the May minimum temperature over the third area, significant at the 0.1% level. The relationships with mean April minimum temperature over the first and the second areas are just significant at the 5% level. The mean May minimum temperature over the third area is significantly related to the 500 mb April ridge, tendency in Southern Oscillation Index (SOI), and the tendency in eastern equatorial Pacific sea surface temperature (SST). In combination with the ridge, the mean minimum May temperature gives forecasts of Indian monsoon rainfall which are as good as those given by tendency in SOI in combination with the ridge. The parameters SOI tendency and the May minimum temperature are found to be equally useful.

1. Introduction

Having realized the need for an advance estimate of the monsoon rainfall over India for the purpose of planning, the search for suitable predictor parameters for forecasting Indian monsoon rainfall was initiated by Blanford (1884). His studies indicated that excessive winter and spring snowfall in the Himalayas is prejudicial to the subsequent monsoon rainfall. Later, Walker (1910, 1915, 1922, 1924a) made an extensive search for meteorological parameters related to Indian monsoon rainfall and obtained a number of important predictor parameters from different parts of the world. On the basis of these parameters Walker (1924b) developed regression equations for forecasting monsoon seasonal rainfall over northwest India and over the Indian peninsula. As mentioned by Jagannathan (1960) in his review of seasonal forecasting in India, a number of extra-Indian parameters and local predictor parameters have been used for forecasting the monsoon rainfall, and on the basis of inconsistent or unstable performance of the parameters, some of these had to be dropped. Some of the local parameters that have been used are local variation of the pressure from the mean (used by Eliot for forecasting monsoon rainfall over India and Burma during the period 1888–97); Indian pressure/pressure gradient in July, first introduced by Walker for forecasting August–September rainfall over peninsula/northwest India, but omitted after a short period; and Punjab temperature range (April–May), first introduced in 1949 for forecasting rainfall over northwest India during August–September. According to Jagannathan (1960), the parameter Punjab temperature range did not have a stable and consistent relationship with August–September rainfall over northwest India and was therefore omitted after some time. Thapliyal (1981) has mentioned that mean minimum March temperature of Jaisalmer, Jaipur and Calcutta which is significantly related to peninsular monsoon rainfall (correlation coefficient + 0.66 for the period 1944–73) is being currently used as one of the predictor parameters for forecasting peninsular monsoon rainfall. Jagannathan and Khandekar (1962) examined premonsoon upper-air contour height fields and thermal fields for obtaining predictor parameters for peninsular monsoon rainfall.

Studies of Ananthakrishnan (1977), Sikka and Gadgil (1980), Saha and Saha (1980), and Ananthakrishnan (1983) suggest spatial coherence of the thermal conditions over India and the Arabian Sea in premonsoon months. Anjaneyulu (1980) examined SST data over the Arabian Sea and the Bay of Bengal for the 7-yr period 1961–67 and observed that positive anomalies of SST during May, though small, are associated with subsequent good monsoon and vice versa.

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However, the small values of the SST anomaly and the small data sample do not permit any definitive conclusion to be drawn. Shukla (1987) found a significant negative bias before 1940 and a positive bias after this year in the SST anomaly data covering ships' tracks over the Arabian Sea and southern Bay of Bengal. He removed the bias from the SST data for the period 1900–74 and composited the SST anomaly over the area covered by the ships' tracks for years of heavy/deficient monsoon rainfall for the premonsoon months (April and May) and for the monsoon months. These composites for April and May show that for heavy as well as deficient monsoon rainfall years, the mean SST anomaly was negative (generally $\geqslant -0.3°C$) and that the mean SST anomaly in heavy rainfall years is about 0.2°C higher than that in deficient rainfall years. The small difference between the two composites for April–May is within the range of observational error. In view of this finding, the present study does not cover any examination of the SST anomaly over the Arabian Sea and the Bay of Bengal in the premonsoon months (March, April and May) in relation to the Indian monsoon rainfall. In this study, the thermal field over India during the premonsoon months March, April and May, based on mean monthly temperature/minimum temperature/maximum temperature at 119 fairly well-distributed stations for the period 1901–75, has been examined with the objective of locating significant predictor parameters for forecasting Indian monsoon rainfall.

2. Data utilized

The monthly rainfall data for the fixed network of 306 stations evenly distributed over India for the period 1871–1978 used earlier by Mooley et al. (1981) are available. From these data, a rainfall series for India for the summer monsoon season has been obtained for the period 1901–75. Maximum and minimum temperature data for the period 1901–75 for 119 stations fairly uniformly distributed over India (Fig. 1) were used by Bhalme and Mooley (1979) for computation of modified Palmer drought index for the meteorological subdivisions of India. These temperature data have been used in the present study. It may be mentioned that the mean minimum and maximum temperature data for May 1917 are missing.

3. Composites of thermal field for good and deficient monsoon seasons

Features of the surface level thermal field, characteristic of good and deficient performance of the monsoon, can be revealed by composites for these contrasting monsoon performances. In view of this, it was decided to prepare the composites of mean monthly temperature (mean of minimum and maximum) for March, April and May and examine these for characteristic features.

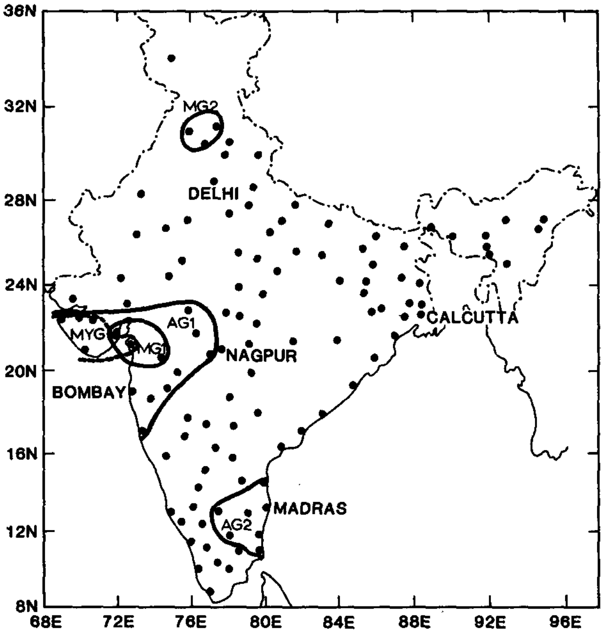

FIG. 1. Network of stations for which minimum and maximum temperature data are utilized for the period 1901–75. Groups of stations with good thermal contrast in deficient and good monsoon activity are delineated.

In this study, good/deficient monsoon performance or activity over India has been defined by the criterion, normalized anomaly (normalized by S.D.) of Indian monsoon rainfall (hereafter, IMR) $\geqslant 1.0/\leqslant -1.0$. On the basis of this criterion, the years of good monsoon activity during the period 1901–75 are 1916, 1917, 1933, 1942, 1947, 1956, 1959, 1961, 1970 and 1975 (in all, 10 years) and those of deficient monsoon are 1901, 1904, 1905, 1911, 1918, 1920, 1928, 1941, 1951, 1965, 1966, 1968, 1972 and 1974 (in all, 14 years). From the mean monthly minimum/maximum temperatures, mean monthly temperatures are computed for each of the stations, for each of the months March, April and May and for each of the years 1901–75 and from these, mean and standard deviations are obtained for each of these three months. Utilizing these means and standard deviations, composites of normalized anomaly of mean monthly temperature are prepared for March, April and May for the good/deficient monsoon activity years. These composites for March, April and May have been examined carefully to locate groups of contiguous stations for which the normalized thermal anomalies for good and deficient monsoon activity years showed good contrast and were of opposite signs. The limits on thermal anomalies should be numerically neither too high in which case no station can be located nor too low in which case several stations can be located. In the light of experience, it was found that the limits of normalized monthly temperature anomalies of ±0.3 would be adequate to delineate groups of stations with good thermal contrast in good and deficient monsoon activity. Limits of normalized anomalies of +0.3 and −0.3 are set to locate the groups of contiguous stations which satisfy jointly the criterion of normalized anomaly ≥ 0.3 in good monsoon years and ≤ -0.3 in bad monsoon years. Five groups, MG_1, MG_2, AG_1, AG_2 and MYG, have been located; these are shown in Fig. 1. Hereafter, these will be referred to as groups of stations with good thermal contrast.

4. Relationship between IMR and mean monthly temperature at stations in each group

After locating the groups of stations with good thermal contrast, the next step is to examine the relationship between IMR and temperature at these stations. It is noticed that the stations in groups MG_1 and MYG are contained in group AG_1. In the case of stations in group MG_2, the composites for April and May show that though normalized anomaly is numerically not 0.3 or more it is positive for good monsoon and negative for deficient monsoon in April and May, suggesting some relationship of April and May mean temperature with IMR. For stations in group AG_2, the anomaly is generally negative (> -0.3) in good as well as deficient monsoon years both in March and May, clearly suggesting no relationship between rainfall and mean monthly temperature for March and May. In view of this situation, correlation coefficients (CCs) between rainfall and mean monthly temperature/mean monthly minimum temperature/mean monthly maximum temperature have been computed for March, April and May for the stations in groups MG_2 and AG_1, and for April only for the stations in group AG_2.

The thermal conditions may be influenced by air mass changes or by cloud cover or both. If these are influenced only by air mass changes, then whether we use mean monthly temperature, mean monthly minimum temperature, or mean monthly maximum temperature for computation of CC, CC would differ little. But, if clouds affect the thermal conditions on a large number of days in a month, then the relationship is expressed better by CC between rainfall and mean monthly minimum/maximum temperature. This is due to the fact that the mean temperature of the day under cloudy conditions differs little from the mean temperature under clear sky conditions, the effect of clouds being a lowering of maximum temperature and a raising of minimum temperature. But the minimum and maximum temperature differ appreciably on clear and cloudy days. Hence, it would be advisable to consider only the CCs with mean monthly minimum/maximum temperature to identify the relation between thermal conditions at the surface and IMR. An examination of these CCs suggest that areas of India can be delineated for which the relationship of March maximum temperature/April minimum temperature/May minimum temperature with Indian monsoon rainfall is significant at 5% level or is close to this level. Table 1 gives these areas, named A_1 to A_5, the stations contained in them, and the concerned parameters. These areas are shown in Fig. 2.

5. Relationship of IMR with areal mean monthly minimum/maximum temperature

Series of area averages of mean March maximum temperature for areas A_1 and A_2, of mean April minimum temperature for areas A_3 and A_4, and of mean May minimum temperature for area A_5 are computed from the station data for the period 1901–75. The temperature parameters for the five areas will hereafter be referred to as $TXMA_1$, $TXMA_2$, $TNAA_3$, $TNAA_4$, and $TNMYA_5$, with the first letter denoting temperature, the second, maximum (X) or minimum (N), the third and/or fourth, the month (M for March, A for April, and MY for May) and the last, the area. CCs between IMR and these temperature parameters are calculated. The relationships between IMR and $TXMA_1$/$TXMA_2$/$TNAA_3$/$TNAA_4$ are significant at the 5% level, but that between IMR and $TNMYA_5$ is significant at the 0.1% level. These results show that these five temperature

TABLE 1. Areas covering stations for which the relation between monthly mean minimum/maximum temperature and Indian monsoon rainfall is significant or nearly significant.

Area	Locations	Stations within the area	Parameter
A_1	Portions of Punjab and of Haryana	Ambala, Ludhiana, Simla	Mean March maximum temperature ($TXMA_1$)
A_2	South Gujarat, northwest Maharashtra and adjoining parts of southwest Madhya Pradesh	Veraval, Bhaunagar, Surat, Malegaon, Indore, Khandwa, Akola, Aurangabad, Pune, Bombay	Mean March maximum temperature ($TXMA_2$)
A_3	Nearly same as A_2	Jamnagar, Rajkot, Bhaunagar, Surat, Malegaon, Indore, Khandwa, Akola, Aurangabad	Mean April minimum temperature ($TNAA_3$)
A_4	North Tamilnadu and adjoining parts of Andhra Pradesh and Karnataka	Madras, Cuddalore, Nagapattinam, Salem, Bangalore, Vellore, Nellore	Mean April minimum temperature ($TNAA_4$)
A_5	South Gujarat and adjoining southwest Madhya Pradesh	Jamnagar, Rajkot, Surat, Indore, Khandwa	Mean May minimum temperature ($TNMYA_5$)

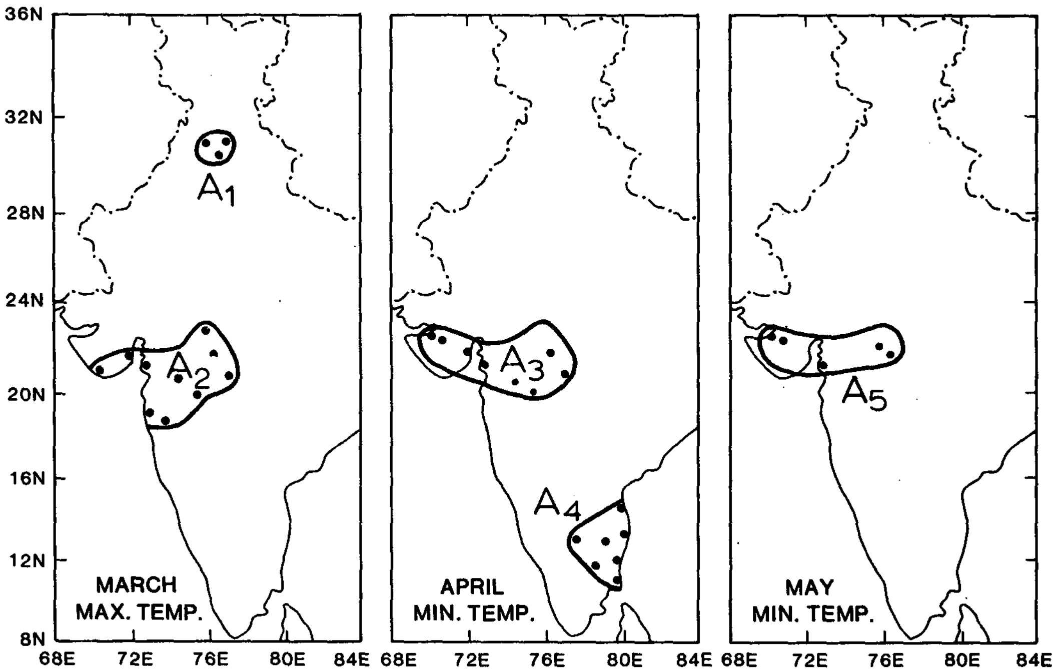

FIG. 2. Areas A_1, A_2, A_3, A_4 and A_5 for which mean monthly temperature as indicated is significantly related to Indian monsoon rainfall.

parameters could be useful as predictor parameters if their relationships with the IMR are stable and consistently significant.

6. Stability of the relationship of the temperature parameters with IMR

The stability and consistency in significance of the relationships have been examined by computing the CCs for sliding 20-, 25-, 30- and 35-yr periods (periods commencing with 1901 and sliding forward by one year at a time), and examining their behavior. The examination of these CCs shows that: 1) for area A_1, the CC though positive and significant to start with, gradually fell to near zero and then rose to near significance level (5%) for periods commencing in the 1930s or 1940s, and thereafter it fell and became nonsignificant towards the end; 2) for area A_2, the CC which was generally positive, but nonsignificant, became significant for periods commencing in the 1930s or 1940s, and later towards the end, fell and became nonsignificant; and 3) for areas A_3, A_4 and A_5, the CC though generally positive was nonsignificant up to about 1940, but became significant (5% level) for periods commencing after 1940, and generally remained so until the end.

After about 1940, the relationships of IMR with $TNAA_3$, $TNAA_4$, and $TNMYA_5$ only are stable and consistently significant (5% level for $TNAA_3$ and $TNAA_4$, and 1% for $TNMYA_5$) for 25- to 30-yr periods. The CC for sliding 25- and 30-yr periods for areas A_3, A_4 and A_5 is shown in Fig. 3.

The relationships between IMR and $TNAA_3$/$TNAA_4$ are positive. The mean April minimum temperature is thus indicative of favorable or unfavorable position in respect of heating of the lower atmosphere. If the lower atmosphere is relatively much warmer than average in April, then it is reasonable to assume that in view of the persistence in the thermal field from one month to the next, and the seasonal northward march of the sun, the lower atmosphere would be warmer than average in May and possibly in June also, leading to the development of a thermal field favorable to a good monsoon. The reverse can be expected if the lower atmosphere is relatively much colder than average in April. An examination of the values of $TNAA_3$ and $TNAA_4$ show that about 70% of the cases of deficient monsoon over India were preceded by the values of these parameters which were below the long-period average, and about 70% of the cases of good monsoon over India were preceded by values of the parameters which were above the long-period average.

Ananthakrishnan (1977), Sikka and Gadgil (1980), Saha and Saha (1980), and Ananthakrishnan (1983) have examined the meteorological conditions over Indian longitudes during premonsoon as well as monsoon months. These studies suggest spatial coherence of thermal anomalies over India and the Arabian Sea during premonsoon months (April and May). The positive relationship between IMR and $TNMYA_5$ is highly significant. It is possible that the anomalous thermal conditions over the area A_5 in May may be linked to anomalous thermal conditions over the Arabian Sea.

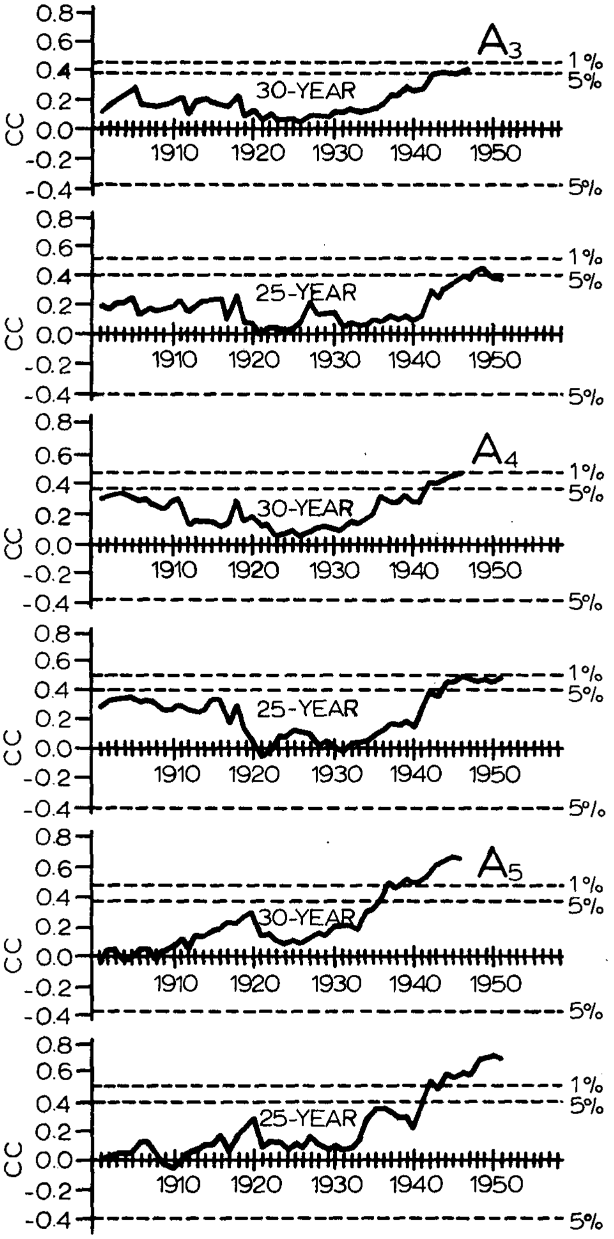

FIG. 3. Correlation coefficients between IMR and mean April minimum temperature over areas A_3 and A_4 and mean May minimum temperature over area A_5 for sliding 25 and 30-yr periods.

7. Interrelationship with other parameters related to IMR

Using Darwin mean sea level pressure as an index of the Southern Oscillation, Shukla and Paolino (1983) have shown that the relationship between the tendency in Southern Oscillation Index (SOI) from DJF to MAM season and Indian monsoon rain is highly significant. Shukla and Mooley (1987) found that by taking the tendency in SOI from January to April, the mid-months of the two seasons, the relationship between the tendency and rainfall continues to remain highly significant. Mooley and Parthasarathy (1984) have shown that the relationship between Indian monsoon rainfall and eastern equatorial Pacific sea surface temperature (SST) (Angell's series, 1981) in MAM season is significant.

Banerjee et al. (1978) have brought out the significant relationship between the number of Indian meteorological subdivisions with normal or above normal monsoon rainfall and the location of the 500-mb April ridge along 75°E.

Thapliyal (1981, 1982) has shown the utility of this ridge location in forecasting monsoon rainfall over Peninsular India by ARIMA (Autoregressive Moving Average) model.

Mooley et al. (1986) examined stability of the relationship between IMR and the location of this ridge, and have shown that the relationship is highly significant and stable.

Since the parameters $TNAA_3$, $TNAA_4$ and $TNMYA_5$ are significantly related to Indian monsoon rainfall, and since the stability in the relationships is generally attained after about 1940, it would be useful to examine the interrelationships between all these parameters for the period 1939–75. Data for the ridge location used are those from a study by Mooley et al. (1986). Data for monthly Darwin mean sea level pressure are obtained from NCAR and tendency from January to April (hereafter, SOIJA) has been considered instead of the tendency from DJF to MAM season. SST anomaly data for the eastern equatorial Pacific (0°–10°S; 90°W–180°W) were taken from Angell's series (1981) and SST tendency from DJF to MAM has been considered and referred to as SST tendency.

Table 2 gives the correlation matrix of these parameters with Indian monsoon rainfall and the intercorrelation coefficients. It is seen from this table that (i) the CCs between IMR and the ridge/SOIJA/$TNMYA_5$ are all significant at the 0.1% level, and the CC with the ridge is highest but those with SOIJA and $TNMYA_5$ are almost equal. (ii) The ridge is significantly (5% level) related to $TNMYA_5$; however, the relationships of the ridge with $TNAA_3$ and $TNAA_4$ are close to significance at 5%. The CC between SOIJA and the ridge is seen to be significant at the 5% level. However, Shukla and Mooley (1987) who used data for 1939–84 found that 1) the CC was 0.25 which failed to attain significance at 5%, and 2) the contingency table between the two parameters (with three classes for each parameter) suggested quasi-independence. The CC, as obtained in this study for the period 1901–75, could be a case of sampling fluctuations. (iii) SOIJA is significantly related to the parameters $TNAA_3$, $TNAA_4$ and $TNMYA_5$. (iv) SST tendency is best related to $TNAA_4$ (significant at 0.1% level) and is significantly (5% level) related to $TNMYA_5$, but the relationship of SST tendency with $TNAA_3$ falls slightly short of significance at 5% level, and (v) The parameters $TNAA_3$, $TNAA_4$ and

TABLE 2. Correlation matrix of the relationship with Indian monsoon rainfall (IMR) and interrelationship amongst parameters (1939–75).

	IMR	April ridge	SOIJA	TNAA$_3$	TNAA$_4$	TNMYA$_5$	SST trend
IMR	1.00	0.75§	−0.58§	0.31	0.33*	0.60§	−0.22
April ridge	0.75§	1.00	−0.36*	0.31	0.31	0.39*	−0.14
SOIJA	−0.58§	−0.36*	1.00	−0.39*	−0.39*	−0.45†	0.23
TNAA$_3$	0.31	0.31	−0.39*	1.00	0.67§	0.61§	−0.28
TNAA$_4$	0.33*	0.31	−0.39*	0.67§	1.00	0.53§	−0.53§
TNMYA$_5$	0.60§	0.39*	−0.45†	0.61§	0.53§	1.00	−0.32*
SST trend	−0.22	−0.14	0.23	−0.28	−0.53§	−0.32*	1.00

* CCs significant at 5% level.
† CCs significant at 1% level.
§ CCs significant at 0.1% level.
SOIJA is the trend in Southern Oscillation Index from January to April (with Darwin pressure as measure of SOI).
SST trend is the trend in eastern equatorial Pacific sea surface temperature from DJF to MAM (Angell's SST series, 1981).

TNMYA$_5$ are strongly (0.1 percent level) interrelated and in view of this situation, it would be advisable to use only TNMYA$_5$ which is best related to rainfall as a parameter for forecasting IMR.

8. Utility of the parameter TNMYA$_5$

It is seen from the previous section that for the period 1939–75, while the relationships of IMR with TNAA$_3$/TNAA$_4$ are marginally significant at 5% level, that with TNMYA$_5$ is highly significant (0.1% level). In view of the high significance of the latter relationship, the parameter TNMYA$_5$ has been examined in some detail.

a. Discrimination between years of good/deficient monsoon

Figure 4 shows the normalized anomaly of the parameter TNMYA$_5$ during the period 1939–75. During the 21 year from 1939 to 1959, the parameter was mostly above normal and there were only two years (1941 and 1951) of deficient monsoon; but, during the 16 year from 1960–75, the parameter was below normal in many years, and there were five deficient monsoon years (1965, 1966, 1968, 1972 and 1974). Normalized Indian monsoon rainfall anomaly for each year is indicated in Fig. 4 to the first decimal place without giving the decimal point.

It is seen from Fig. 4 that the temperature anomaly is generally positive in good monsoon years and negative in deficient monsoon years. The variability of the temperature anomaly during good monsoon years is much smaller than that in deficient monsoon years. The mean normalized temperature anomaly for good monsoon years is +0.46 and that for deficient monsoon years is −1.29. The contrast between the two means is well marked. The difference between the mean nor-

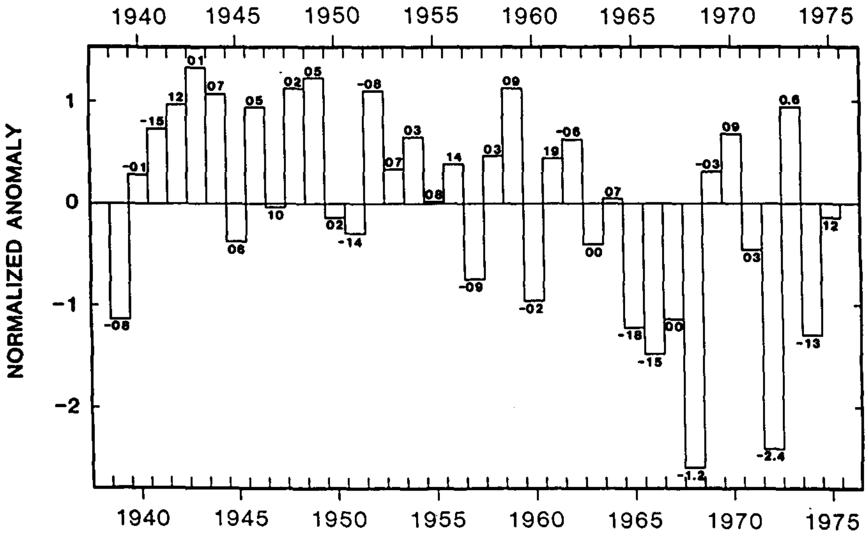

FIG. 4. Normalized anomaly of TNMYA$_5$ (1939–75). Mean: 25.8°C; standard deviation: 0.8°C. Figure against each year indicates the normalized Indian monsoon rainfall anomaly rounded to first decimal place without the decimal point.

malized temperature anomalies for the two sets of years as tested by Student's t-test is highly significant (0.5% level). Application of the Mann–Whitney *U*-test (Stoodley et al., 1980) to the two sets of anomalies also shows that the set for good monsoon years is significantly (near 0.5% level) higher than the set for deficient monsoon years. These results show that this parameter can discriminate well between good and deficient monsoon years.

Among the years when normalized anomaly of TNMYA$_5$ is close to or less than -1.0 are 1939 and 1967, which have not been classified as deficient monsoon years. For 1939, normalized anomaly of IMR is -0.85 and as such this year is fairly close to being a deficient monsoon year. For 1967, normalized IMR anomaly is 0.0 and it might be considered that large negative anomaly of TNMYA$_5$ did not influence IMR. It may be noted in this connection that other parameters, such as the 500 mb ridge and SOIJA, also influence IMR; of these, the ridge was located (at 17.5°N) north of the average location by more than one standard deviation, favoring much higher rainfall, and SOIJA being above average was unfavorable for above average rainfall. Perhaps the ridge location has strongly influenced IMR of 1967 which otherwise might have been below average. The year 1941 is a prominent drought year with positive anomaly of TNMYA$_5$; in this year, the ridge located at 11.2°N, almost the lowest possible location during April, has strongly and adversely influenced IMR; SOIJA being slightly below average had relatively little influence on IMR. It can be seen that a relatively large negative anomaly of TNMYA$_5$ is a good indicator of deficient monsoon season.

b. Performance of a single predictor for estimating Indian monsoon rainfall

Figure 5 shows the scatter diagram between the normalized Indian monsoon rainfall anomaly and the normalized anomaly of TNMYA$_5$ along with the regression line. The points are marked by the corresponding years, e.g., 1941 as 41. The points, in general, are uniformly distributed on both sides of the regression line and the linear fit to data is quite good.

Utilizing the data for 1939–75, sliding 25-yr period regression equations between normalized anomalies of IMR and TNMYA$_5$ are computed and these are used to obtain a forecast for the year immediately preceding/succeeding the period of the regression equation. A 25-yr period is used since the IMR–TNMYA$_5$ relationship stabilizes for this period. Forecasts of IMR are obtained for the independent 24 years, 1939–50 and 1964–75. The root-mean-square error (rmse) for these 24 forecasts is 69.2 mm (84% of S.D.), CC between forecast and observed IMR is 0.61 and the variance explained is 38%. The values of these overall measures of verification show that the performance of TNMYA$_5$ as a single predictor of IMR is not quite satisfactory.

c. Performance of a single predictor in conjunction with the April 500-mb ridge over India

The relationships of IMR with TNAA$_3$, TNAA$_4$ and TNMYA$_5$ stabilize for 25-yr periods. Considering the predictor pairs, ridge and TNAA$_3$, ridge and TNAA$_4$, ridge and TNMYA$_5$, regression equations for each predictor pair are computed for sliding 25-yr periods. From these regression equations forecasts of IMR for the independent 24 years, 1939–50 and 1964–75, are

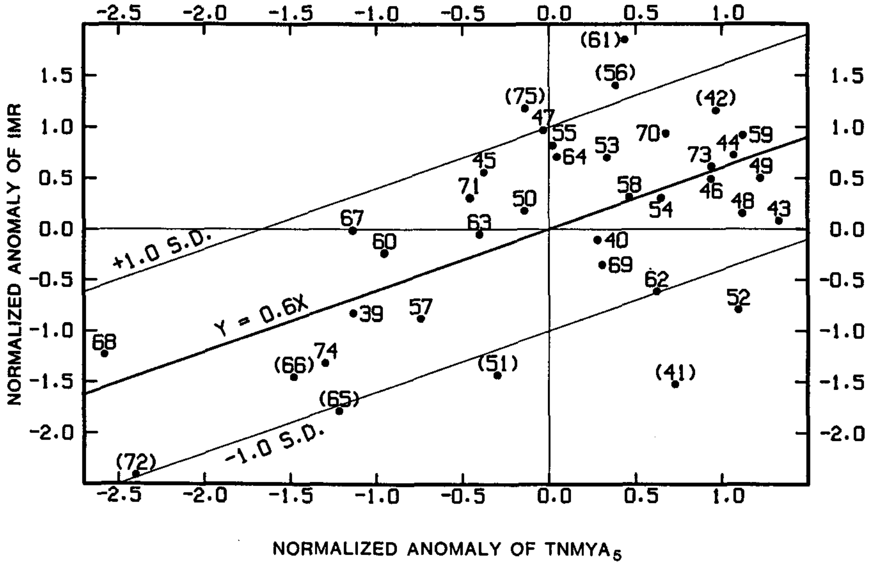

FIG. 5. Scatter diagram of normalized anomalies of IMR and TNMYA$_5$ along with regression equation. The two digits near the point indicate the year. Years within parentheses indicate large-scale flood/drought years.

TABLE 3a. Overall verification of 24 forecasts of IMR for the years 1939–1950 and 1964–75.

Predictors	RMSE (mm)	CC (Forecast and observed IMR)	Variance explained (%)
Ridge and $TNAA_3$	53.5 (65% of S.D.)	0.81	48.5
Ridge and $TNAA_4$	54.9 (67% of S.D.)	0.70	48.6
Ridge and $TNMYA_5$	41.7 (51% of S.D.)	0.88	85.0

TABLE 3b. Overall verification of 19 forecasts of IMR for the years 1939–50 and 1969–75.

Predictors	RMSE (mm)	CC (Forecast and observed IMR)	Variance explained (%)
Ridge $TNMYA_5$	38.5 (47% of S.D.)	0.88	73
Ridge SOI tendency	35.8 (44% of S.D.)	0.90	62

obtained for each of the three predictor pairs. Table 3a gives rmse in mm and also as percentage of S.D. for the total data period, i.e., 1939–75, CC between forecast and observed IMR, and the variance explained (ratio of variance of forecast IMR and variance of observed IMR expressed as percentage), for these 24 forecasts. It is seen from this table that the overall performance of $TNMYA_5$ in combination with the ridge is quite good, rmse being about 50% of S.D. For each of the remaining two predictor pairs in Table 3a, rmse is about 30% higher.

It would be interesting to compare the performance of the predictor pair ridge and $TNMYA_5$ with that of the predictor pair ridge and SOI tendency from January to April. Since IMR–SOI tendency relationship stabilizes for 30-yr periods, regression equations for the predictor pair, ridge and SOI tendency are computed for sliding 30-yr periods from the data for 1939–80 and these equations are used to obtain forecasts for the years 1939–50 and 1969–80. Darwin mean sea level pressure is used as a measure of SOI. Considering forecasts for the common 19 years, 1939–50 and 1969–75, rmse in mm and also as percentage of S.D., CC between forecast and observed IMR and variance explained are computed for these forecasts from the predictor pairs ridge–$TNMYA_5$, and ridge–SOI tendency. These overall measures of verification are given in Table 3b. On the whole, the difference in the overall performance of the two predictor pairs is small, and the two predictors $TNMYA_5$ and SOI tendency can be considered to be equally useful.

9. Conclusions

The following conclusions can be drawn from the study of the surface level mean monthly thermal field over India during the premonsoon months March, April and May.

(i) The parameters $TNAA_4$ (mean April minimum temperature over coastal Tamilnadu and neighborhood) and $TNMYA_5$ (mean May minimum temperature over South Gujarat State and adjoining southwest Madhya Pradesh) are stable and consistently significant in their relationship with Indian monsoon rainfall. The parameter $TNAA_3$ (mean April minimum temperature over South Gujarat State and adjoining parts of Maharashtra and Madhya Pradesh) also attains stability in significance. Of these, $TNMYA_5$ has the best relationship (CC = 0.60, significant at 0.1% level) with IMR.

(ii) Forecasts of IMR obtained from the predictor pair, April ridge and $TNMYA_5$ are as good as those from the predictor pair, April ridge and SOIJA, thus bringing out clearly that $TNMYA_5$ and SOI tendency are equally useful as predictors.

(iii) The study shows that the predictor $TNMYA_5$ has operational utility when used in conjunction with other parameters.

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