

Association of some global/regional circulation parameters with subseasonal Indian summer monsoon rainfall

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Long-term (1962–1995) data of a number of global/regional circulation parameters have shown statistically significant correlations (at the five per cent level) with the subseasonal Indian monsoon rainfall. Utilising some of these circulation parameters, we have developed a few regression models to forecast the subseasonal monsoon rainfall. The performances of these models, assessed by cross-validation, are seen to be fairly good as the root mean square errors (RSME) of the forecasts for the entire period of study are significantly smaller than the standard deviations of corresponding rainfall series. The correlations between the actual and forecast series are also significant.

Introduction

The broadscale circulation features of several Indian summer monsoons may appear to be similar but the onset mechanism and timing, further progress of the monsoon and temporal distributions of rainfall are, however, quite different from one season to another. The factors responsible for the large intraseasonal variability are not yet clearly identified.

To meet the requirements of advance planning from national level to district level, reliable forecasts of rainfall on different scales of time and space are essential. In the years of delayed onset of monsoon over northern parts of India, as in 1987, 1991, 1992 and even in 1995, prior information on expected monsoon performance for the rest of the season is indeed crucial. Many statistical models are available at present to predict Indian monsoon seasonal (June to September) rainfall; the power regression model (Gowariker et al. 1989, 1991), based on 16 parameters used by the India Meteorological Department, is well known. But only a few studies (Parthasarathy et al. 1991a; Singh et al. 1993; Dhanna Singh et al. 1996) have attempted to associate Indian monsoon rainfall on subregional scale with circulation parameters.

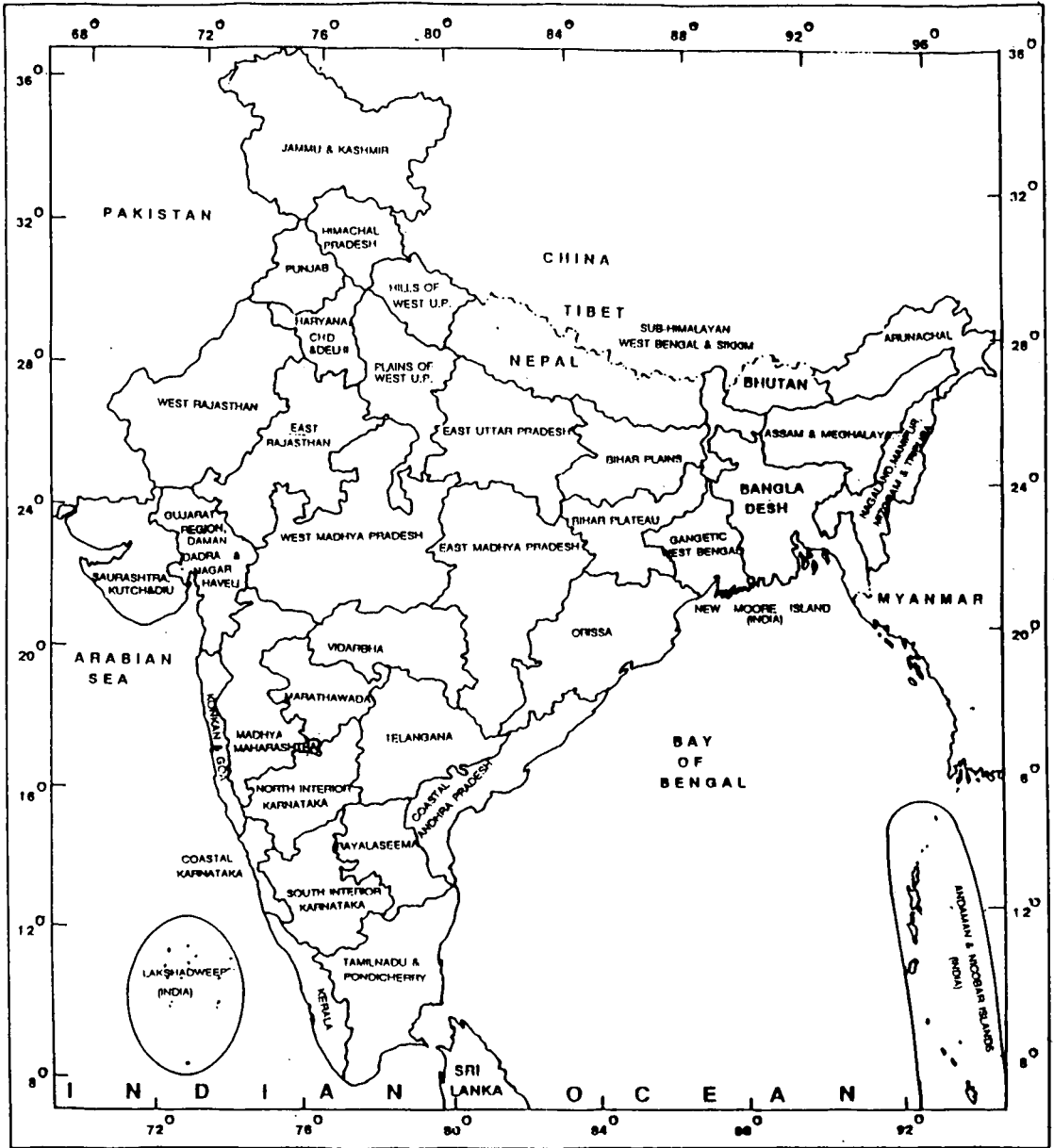
Earlier, the authors (Dhanna Singh et al. 1996) developed some regressions for seasonal forecast at regional and subdivisional level for northwest India. In the current paper, we have attempted to associate the long-range forecasting parameters with monthly, bi-monthly and tri-monthly subseasonal Indian monsoon rainfall. Also, we have developed a few regression models to forecast the subseasonal rainfall.

Circulation parameters and sources of data

The period of study is 34 years (1962–1995). Subdivisional monthly rainfall data and upper air data of Indian stations for the period 1962–1988 were obtained from the India Meteorological Department, Pune. Meteorologically, India comprises 35 subdivisions as shown in Fig 1. Subdivisional monthly mean rainfall data are the arithmetic means of monthly totals of well-distributed rain-gauges. By area-weighting these mean rainfall values for each of the subdivisions and averaging for total weight of 35 subdivisions, the all-India (country as a whole) monthly rainfall data have been prepared. These monthly Indian rainfall data for the monsoon season (June to

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Fig. 1 Meteorological subdivisions of India.



September) have been used in this study. Sub-seasonal rainfall amounts are simple totals of these weighted averages of the months which comprise that subseason.

The monthly zonal and meridional wind components were computed from the mean monthly wind data of radiosonde/rawin stations (New Delhi, Jodhpur, Calcutta, Nagpur, Bombay, Madras, Portblair and Trivandrum) for the months April, May and June, for all standard isobaric levels up to 100 hPa.

The details of the parameters and sources of other data used in this study are as follows.

- (a) Darwin seasonal pressure difference, March, April, May (MAM) minus December, January, February (DJF): denoted as DP (computed from monthly means).
- (b) Tahiti minus Darwin seasonal pressure difference (MAM minus DJF): TDP (computed from monthly means).
- (c) Lowest monthly average mean sea-level pressure in the heat low region (Pakistan and

- adjoining northwest India) for the month of May: HLP (Dhanna Singh et al. 1995).
- (d) Bombay pressure tendency (MAM minus DJF): BPT (Parthasarathy et al. 1991b).
 - (e) Latitudinal position of the April 500 hPa ridge along 75°E: L (Mooley et al. 1986).
 - (f) Delhi meridional wind at 500 hPa: DLH₅₀₀ (computed from monthly means).
 - (g) Delhi meridional wind at 300 hPa: DLH₃₀₀ (computed from monthly means).
 - (h) Tropospheric thickness (averaged for the stations New Delhi, Bombay and Calcutta) for the month of May, 850–300 hPa: TH1; 850–100 hPa: TH2 (computed from data from NOAA (Monthly Climatic Data for the World)).
 - (i) West-central Indian temperature (based on six stations) of March, April, May: WCI (Parthasarathy et al. 1990).

The data needed to compute the parameters (a) to (i), for the periods beyond those available in the literature mentioned were taken from operational datasets processed by the authors at the India Meteorological Department, New Delhi.

The parameters (a) to (i) were selected on the basis of their physical linkages with the Indian monsoon rainfall. They mainly represent changes associated with ENSO conditions over southern Asia and prevailing conditions over the Indian subcontinent during pre-monsoon months, as discussed in the following paragraphs.

The Tahiti minus Darwin seasonal pressure difference (TDP) is one of the parameters used to monitor interannual fluctuations of the see-saw pattern of pressure over the Pacific Ocean. Several authors have studied the relationship between Southern Oscillation Index and related parameters (such as TDP) and the Indian summer monsoon. If the TDP is positive, it is generally conducive for good monsoon rainfall. Physically the strength of the monsoon and TDP are linked through the Walker circulation.

The west-central Indian temperature (WCI) of pre-monsoon months and the lowest heat low pressure of May (HLP) are measures of differential heating of land mass as compared to the ocean. Warmer temperatures and accordingly lower pressures in the heat low region are favourable for good monsoon rainfall.

Variations in the tropospheric thickness anomalies over the north Indian region during pre-monsoon months were shown to have a bearing on the performance of succeeding Indian monsoon rainfall (Verma 1980, 1982).

The location of the 500 hPa subtropical ridge over India (L) is indicative of the degree of transition of atmospheric circulation from winter type to summer type. In other words, this location parametrises the progress of the season.

The meridional wind parametrises the changes in the upper air circulation which in turn affects the monsoon performance over India. Joseph (1978, 1981) showed that during the years of monsoon failure, southerly meridional winds occupy the whole of central and northwest India in June, and in good monsoon years northerlies occur all over India.

The above parameters are thus seen to be closely linked with the evolution of the monsoon circulation.

Methodology

Initially, statistical correlations were used to find the relationship between Indian subseasonal monsoon rainfall and the set of global/regional circulation parameters discussed in the preceding section. All the parameters whose linear correlation coefficients were statistically significant at least at the five per cent level were then subjected to regression analysis using a partial regression technique. In this method, the regression consists of a least squares fit. After computation of partial regression coefficients, a statistic representing the ratio of partial regression coefficient to the standard error was used as an indicator of significance for each of the parameters. By arranging the parameters in descending order of the above statistics, runs were made by dropping the least significant parameters one by one. Parameters were dropped up to a stage where absence of the last parameter decreased the total variance explained by more than one per cent. Out of the ten possible predictors, two to four finally figured in the the formulated regression equations for different subseasons. Multiple correlation coefficients (MCC) and Fisher (F) values also have been computed for statistical evaluation of the equations.

These regression equations were then tested by cross-validation over the entire (1962–1995) period, i.e. by removing each year in turn for verification while keeping the rest of the years to derive the model equation. Thus, all the 34 years actual rainfall has been tested individually against the corresponding forecast rainfall.

In order to assess the forecast skill in a quantitative way, we have computed four statistics, namely the correlation coefficient (COR) between the forecast (F) and actual (A) rainfall, root mean square error (RMSE), the absolute error (ABSE) and the bias (BIAS). The last three statistics are computed as follows:

$$\text{RMSE} = [\sum(F-A)^2/n]^{0.5} \quad \dots 1$$

$$\text{ABSE} = \sum|F-A|/n \quad \dots 2$$

$$\text{BIAS} = \sum(F-A)/n \quad \dots 3$$

where the summation extends over n forecast years. The variance explained, $\text{VAR} = \text{COR}^2$ in per cent is also computed.

Discussion of the results

Regressions were sought for the predictand of sub-seasonal Indian monsoonal rainfall (over the whole country), using the parameters (a) to (i) as potential predictors. The particular subseasons considered were July, August, September, July–August, August–September, and July–August–September. The climatological means, standard deviations, and coefficients of variability (C V) of the corresponding subseasonal rainfall series from 1962 to 1995 appear in Table 1.

Meridional components of upper winds for the month of May for some isobaric levels at several stations showed significant (at the five per cent level) correlations with subseasonal monsoon rainfall. However, Delhi meridional winds at the 500 and 300 hPa levels were found to be more promising with correlations between the 0.1% and 1.0% levels of significance. In addition, zonal and meridional components of winds at Bombay, Mangalore, Trivandrum, Delhi and Calcutta; tropospheric thickness for various layers for the month of June and rainfall series for June; and July were also tested for their suitability as predictors for the rainfall amounts of parts of the remaining season. But none of these showed significant association (at the five per cent level).

The parameters which finally figured in the regression equations were Darwin seasonal pressure difference (DP), Tahiti minus Darwin seasonal pressure difference (TDP), Delhi

meridional wind at 500 hPa (DLH₅₀₀), Delhi meridional wind at 300 hPa (DLH₃₀₀), tropospheric thickness for the month of May, 850–300 hPa (TH1) and west-central Indian temperature for March–April–May (WCI).

The details of multiple regression equations are given in Table 2. The multiple correlation coefficients (MCC) and the percentage of variance explained (var), shown in brackets below the MCC values, are for the entire period 1962–1995. The partial regression coefficients (PRC) of the concerned parameters are also given. The root mean square errors (RMSE) shown in Table 2 were computed for all the 34 forecasts based on 34 model equations based on 33 years of data, wherein the verification years were excluded in turn. The subseasonal forecast and actual rainfalls for July–August and August–September (models 2 and 3) from 1962 to 1995 are graphically depicted in Fig. 2. In general, there is a good agreement between forecast and actual rainfall values. The large differences seen in some of the years such as 1966, 1986 and 1994 could possibly be due to large internal variability of the monsoon in those years.

The measures of the forecast skill as mentioned in the Methodology section have been computed for all the regression models for the 34-year period (1962–1995) and are presented in Table 3. The correlations between forecast and actual rainfall values are seen to be significant at the 0.1% level for all the subseasonal periods. These correlations can be compared with those reported by Hastenrath and Greischar (1993). Noting that they have studied all India seasonal (June to September) monsoon rainfall for a period of only 23 years, our results are more significant and are for subseasonal time-scales. Generally, predictability of monsoons decreases for smaller time and space-scales. The RMSE values for different subseasons are significantly less than the climatological standard deviations of corresponding rainfall series (Table 1). The bias between actual and forecast rainfall is marginally positive in all the models except for August where it is zero.

Amongst the different subseasonal periods studied, more promising results were obtained for the subseason August–September. In fact, August–September is the period for which the

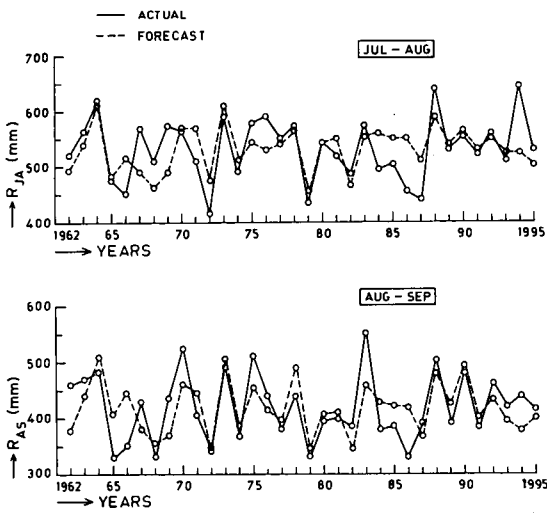
Table 1. Means (mm), standard deviations (mm) and coefficients of variability (%) for subseasonal Indian monsoon rainfall, based on the period 1962 to 1995.

	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Jul–Aug</i>	<i>Aug–Sep</i>	<i>Jul–Aug–Sep</i>
<i>Mean (mm)</i>	272.8	255.8	161.3	531.7	418.0	694.1
<i>Std dev (mm)</i>	34.8	36.2	34.2	56.0	59.8	79.4
<i>C V (%)</i>	12.8	14.1	21.2	10.5	14.3	11.4

Table 2. Regression models and their statistics 1962–1995 (see text for details).

Model no.	Rainfall period	MCC (var.)	F-value	Constant	RMSE* (mm)	Partial regression coefficients (PRC)					
						1	2	3	4	5	6
						DLH ₅₀₀	DLH ₃₀₀	DP	TDP	TH1	WCI
1	Jul–Aug–Sep	0.76 (57)	13.5	–3433.5	59.2		–0.99		18.43	0.51	
2	Jul–Aug	0.69 (48)	9.1	26.5	46.6	–1.11		–15.39			16.80
3	Aug–Sep	0.76 (57)	9.7	–1735.7	46.4	–0.95		–14.33	10.00	0.27	
4	Aug	0.69 (48)	14.6	275.2	28.6	–0.62		–16.09			
5	Sep	0.70 (50)	10.02	–1536.9	27.9		–0.28		10.64	0.21	

*RMSE of the 34 individual years forecasts (cross-validation) based on model equations of 33 years wherein the individual years are excluded in turn.

Fig. 2 Performance of the July–August and August–September models.

mid-season review of a long-range forecast is issued in India. It is interesting to note that this forecast model does not use any data beyond May. Therefore, this forecast for two months can be incorporated in the beginning of the season itself. Later, it can be utilised, in combination with actual rainfall for June–July, to issue a mid-season review of the seasonal forecast. It is also pertinent to note that data for the months of June and July for various regional parameters mentioned earlier have not shown significant association with rainfall amounts of the remaining season or parts thereof. This kind of behaviour of associations could possibly be due to the dominating nature of the monsoon circulation wherein the predictive signals are lost.

Table 3. Measures of forecast skill for Indian summer monsoon rainfall (see text for symbol definitions).

Regression model for subseason	RMSE (mm)	ABSE (mm)	BIAS (mm)	COR	VAR (%)
Jul–Aug–Sep	59.2	46.6	0.9	0.67	45
Jul–Aug	46.6	35.9	0.8	0.57	32
Aug–Sep	46.4	38.4	0.8	0.64	41
Aug	28.6	23.2	0.0	0.62	38
Sep	27.9	21.5	0.6	0.59	35

Conclusions

- Most of the global/regional parameters belonging to the pre-monsoon period used in the study have shown significant correlations (at the five per cent level) with the subseasonal (July–August–September, July–August, August–September, August and September) monsoon rainfall.
- The regression models developed here demonstrate the feasibility of issuing rainfall forecasts on the subseasonal scale.
- Regional circulation parameters for the months of June and July, analysed in this study, did not show potential for use in regression models for Indian monsoon subseasonal rainfall.

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