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Parametric and power regression models : New approach to long range forecasting of monsoon rainfall in India

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सार — मानसून एक जटिल प्रणाली है। अतएव मानसून वर्षा के दीर्घ कालीन पूर्वानुमान के लिए एक निश्चयात्मक निदर्श (मॉडल) को विकसित करना अभी संभव नहीं है। भारतीय ग्रीष्म मानसून वर्षा से सम्बन्धित माने जाने वाले 15 प्राचलों से संकेतों का उपयोग करक मानसून वर्षा के पूर्वानुमान के लिए एक प्राचलिक तथा एक शक्ति समाश्रयण निदर्श (मॉडल) को विकसित करने का प्रयास किया गया है। कुछ प्राचल सार्वभौमिक हैं और कुछ अन्य का स्वरूप क्षेत्रीय हैं। इन प्राचलों का भारत के ग्रीष्म कालीन मानसून से भी भौतिक संबंध है। इनमें से कुछ प्राचल एक दूसरे से संबंधित हैं। इस प्राचलिक निदर्श (मॉडल) के अन्तर्गत पिछले 37 वर्षों (1951–87) से संबंधित आँकड़ों पर 15 प्राचलों के परिप्रेक्ष्य में किए गए मानसून वर्षा के विश्लेषण उत्साहजनक परिणाम देते हैं। यह देखा गया है कि जब भी 70 प्रतिशत से अधिक प्राचलों ने अनुकूल संकेत दर्शाए तब भारत में मानसून वर्षा न केवल सामान्य हुई (सामान्य से वर्षा का प्रतिशत प्रत्यंतर $\pm$10 प्रतिशत) बल्कि वह सामान्य से अधिक की ओर रही। 1988 में प्राचल काफी संख्या में (87 प्रतिशत) अनुकूल थे। इस विश्लेषण के आधार पर मानसून 1988 के लिए दीर्घ कालीन पूर्वानुमान में वर्षा का रुख सामान्य से अधिक की ओर आकलित किया गया था और वास्तव में 1988 में मानसूनी र्षा सामान्य (सामान्य से +19 प्रतिशत) से अधिक हुई।

यह प्राचलिक निदर्श, वास्तव में एक गुणात्मक निर्णायक यंत्र है जहां पर सभी 15 प्राचलों को समान महत्व दिया गया है। तथापि, अलग–अलग प्राग्वक्ताओं के साथ मानसून वर्षा का संबंध एक अरैखिक सम्बंध दर्शाता है। इस अरैखिकता को ध्यान में रखने के लिए विभिन्न डिग्रियों के समीकरणों को आसंजितकर एक वक्ररेखी संबंध निर्धारित किया गया है। सभी 15 प्राचलों के साथ संबंध की आसंजित उत्तम उपयुक्त डिग्री को सम्मिलित किया गया है और एक शक्ति समाश्रयण निदर्श विकसित किया गया है। प्रतिदर्श अवधि (1958–1980) जिस पर निदर्श विकसित किया गया है और स्वतंत्र परीक्षण अवधि (1981–88) के दौरान, दोनों में ही इस शक्ति समाश्रयण मॉडल स किए गए पूर्वानुमान, प्रोत्साहक पाये गये हैं। शक्ति समाश्रण निदर्श ने प्रतिदर्श और स्वतंत्र परीक्षण अवधि के दौरान सूखे और अधिक मात्रा में वर्षा की सही प्रागुक्ति की है।

शक्ति समाश्रयग मॉडल के कार्य निष्पादन की तुलना उस बहुरेखिक समाश्रयण मॉडल के कार्य निष्पादन के साथ की गई है, जिसका निर्माण बिल्कुल उसी आंकड़ा समुच्चय को उपयोग में लाकर किया गया है जिसका प्रयोग शक्ति मॉडल का निर्माण करने के लिए किया गया था। दोनों मॉडलों की तुलना से यह पता चलता है कि शक्ति समाश्रयण निदर्श (मॉडल) का कार्य निष्पादन बहुसमाश्रयण निर्देश (मॉडल) से बेहतर है।

ABSTRACT. Monsoon is a complex system. As such it is not yet possible to develop a deterministic model for long range forecasting of monsoon rainfall. An attempt has been made here to develop a parametric and a power regression model to predict monsoon rainfall by utilising signals from 15 parameters known to be related with the Indian summer monsoon rainfall. Some of the parameters are global and others are regional in nature. These parameters also have physical links with the Indian summer monsoon. Some of these parameters are inter-related. The parametric model, which analyses the monsoon rainfall *vis-a-vis* the 15 parameters for the last 37 years (1951–1987), shows encouraging results. It is observed that whenever more than 70% parameters showed favourable signals, the monsoon rainfall in India was not only normal (percentage departure of rainfall $\pm$10% of normal), but it was towards the positive side of the normal. In 1988, a large number (87%) of parameters were favourable. Based on this analysis the long range forecast for monsoon 1988 was estimated towards the positive side of the normal and actually the monsoon rainfall in 1988 was above normal (+19% of the normal)

This parametric model is purely a qualitative decision making tool where equal weightage has been given to all the 15 parameters. However, the relationship of monsoon rainfall with individual predictors exhibits a non-linear relationship. To take care of this non-linearity, a curvilinear relationship has been determined by fitting the equation of different degrees. The best fit degree of relationship with all the 15 parameters has been combined and a power regression model has been developed. The forecasts from this power regression model have been found encouraging both during the sample period (1958–1980) on which the model is developed, as well as during the independent test period (1981–1988). The power regression model has correctly predicted the drought and large excess rainfall during the sample and independent test periods.

The performance of the power regression model has been compared with that of the multiple linear regression model, formed by utilising exactly the same set of data which was used for formulating the power model. Comparison of two models shows that the performance of power regression model is better than that of the multiple regression model.

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1. Introduction

Year to year variation of Indian summer monsoon (June-September) rainfall (hereafter referred to as monsoon rainfall) generates profound socio-economic impact on many spheres of national activities. Several attempts have, therefore, been made in the past to develop long range forecast models for estimating, in advance, the total quantum of rainfall during the monsoon season over India. These efforts have mainly been concentrated in developing empirical models. This is because the monsoon is a complex atmospheric system and difficult to be represented by deterministic models. Based on the Himalayan snow-cover analysis, the first long range forecast of monsoon rainfall over India and Burma was issued in 1886 (Blanford 1884). In the beginning of this century, Walker (1923) introduced an objective technique of correlation for long range forecast and identified a few predictors from different parts of the world. Subsequently, several antecedent meteorological parameters were identified and used for prediction. A review of these attempts was made by Jagannathan (1960) and Thapliyal (1987). In all these attempts a limited number of parameters were used, utilising multiple linear regression technique. The accuracy of such models is not always very satisfactory. Recently, a dynamic stochastic transfer model has been developed by Thapliyal (1982) with some improvements noticed in forecast accuracy. Though two types of models are available in India Meteorological Department for long range operational forecasting, the need for a better model is felt, which may provide the forecasts as early as possible, before the monsoon season.

An attempt has now been made to develop a parametric and a power regression models which use signals from a large number of parameters that appear to be physically linked with monsoon circulation, for prediction of monsoon rainfall over India. The parametric model gives a qualitative forecast whereas the power regression model gives a quantitative forecast of monsoon rainfall over India. Although the parametric model gives qualitative forecast, it appears to be very useful as a decision making tool, sufficiently in advance, whenever the factors are favourable/unfavourable beyond a certain percentage.

2. Parameters

For long range forecasting of monsoon rainfall, the parametric qualitative model utilises signals from 15 regional and global meteorological and oceanic parameters. All the parameters along with their relationships with the monsoon rainfall are listed in Table 1. In the table, the parameters are divided into 4 main groups related to temperature, pressure, wind and snow-cover. Long period (1951-1987) data have been used to examine the relationships between the monsoon rainfall *vis-a-vis* each one of the parameters. Direct and inverse relationships are respectively indicated by positive and negative signs shown at the top of the table. These parameters have been selected on the basis of their possible physical linkages with the monsoon rainfall over the country. Some of the parameters are interrelated.

3. Physical linkages

The physical linkages of the various parameters with the monsoon rainfall are elucidated in the following discussion :

3.1. It may be seen from Table 1 that temperatures over east coast of India, central India and northern India (Thapliyal 1982) as well as of northern hemisphere (Verma *et al.* 1985) indicate direct relationship with monsoon rainfall. This shows that the warmer temperatures are conducive to good monsoon rainfall over the country. This supports the physically tenable relationship that the strength of monsoon is directly related to the differential heating between the land and ocean.

The presence of the *El Nino* (appearance of abnormal warm water off Peru coast) creates an adverse physical condition for the normal development of monsoon circulation (Sikka 1980). This is because *El Nino* creates a low pressure system over equatorial south Pacific and disturbs the normal low pressure system over the Indonesian-Indian monsoon area.

3.2. The second group in Table 1 consists of four pressure related parameters which are connected with the Southern Oscillation Index (SOI), discovered by Walker (1924). Southern Oscillation is a sea-saw of pressures between the equatorial central Pacific and the equatorial southeast Asia (Monsoon area). SOI is defined as the difference of normalised pressure anomaly between Tahiti (south central Pacific) and Darwin (Australia). It may be mentioned that monsoon circulation is depicted as a vast low pressure area and the lower the pressure in the monsoon circulation, the better it is for good rainfall over the Indian subcontinent. Thus, the SOI is one of the measures to monitor inter-annual fluctuation of pressure over the monsoon area. If the SOI is positive, it is conducive for good monsoon rainfall. The reverse is true when the SOI is negative.

3.3. All the wind parameters given in Table 1 would appear to be physically connected with monsoon through various dynamical processes of the atmosphere. The location of 500 hPa sub-tropical ridge over India, which shows a direct relationship (Banerjee *et al.* 1978) with the monsoon rainfall, is indicative of the transition of atmospheric circulation from winter type to summer type. This is also a parameter to judge the lag period of the progress of the season. If the position of sub-tropical ridge at 500 hPa is to the south of its normal position, it is an indication that setting-in of the summer conditions over the Indian subcontinent is slow and build-up of the ensuing monsoon conditions may lag behind. This is also an indicator of the development of adverse conditions in the flow patterns, immediately north of Indian subcontinent, during the monsoon season. The other two wind parameters, namely, 50 hPa ridge-trough extent over northern hemisphere (Thapliyal 1984) and westerly wind at 10 hPa (Bhalme *et al.* 1987) are connected with the easterly and westerly phases of Quasi-Biennial Oscillation (QBO) in the lower stratosphere. For good monsoon, the easterly QBO phase in the lower levels of stratosphere generates favourable dynamical forcings while the westerly QBO phase generates unfavourable dynamical forcings.

TABLE 1

Analysis of 15 parameters

Year	Monsoon condition	Temperature: *El Nino* in current year (—)	Temperature: *El Nino* in previous year (+)	Temperature: Northern India (March) (+)	Temperature: East coast of India (March) (+)	Temperature: Central India (May) (+)	Temperature: Northern hemisphere (Jan & Feb) (+)	Wind: 500 hPa ridge (April) (+)	Wind: 50 hPa ridge-trough extent (Jan & Feb) (—)	Wind: 10 hPa (30 km) westerly wind (Jan) (+)	Pressure anomaly (SOI): Tahiti-Darwin (Spring) (+)	Pressure anomaly (SOI): Darwin (Spring) (—)	Pressure anomaly (SOI): Scuth America, Argentina (Apr) (—)	Pressure anomaly (SOI): Indian Ocean Equatorial (Jan-May) (—)	Snow-cover: Himalayan (Jan-March) (—)	Snow-cover: Eurasian (Previous Dec) (—)	No. of parameters favourable/Total No. of parameters
1951	D	F	U	U	U	F	U	U			U	U	U	F	U		3/12
1952	N	F	U	U	U	F	F	U			F	U	U	U	F		5/12
1953	N	U	U	F	F	F	F	F			U	U	U	U	F		6/12
1954	N	F	F	F	F	F	U	F			F	F	U	F	U		9/12
1955	N	F	U	F	F	F	F	F			F	F	F	F	F		11/12
1956	N	F	U	F	U	F	U	F			F	F	F	F	F		9/12
1957	N	U	U	U	U	U	U	F			U	U	U	U	U		1/12
1958	N	F	F	F	F	F	F	F	U	U	U	U	F	U	F		9/14
1959	N	F	U	F	U	F	F	F	F	F	F	F	F	F	U		11/14
1960	N	F	U	U	U	U	F	F	U	U	F	F	F	F	F		8/14
1961	N	F	U	F	F	F	F	U	F	F	U	U	F	F	U		9/14
1962	N	F	U	U	U	U	F	U	F	U	F	U	U	F	F		6/14
1963	N	F	U	U	U	U	F	U	F	F	F	F	F	F	F		9/14
1964	N	F	U	F	F	U	U	F	F	F	F	F	U	F	F		10/14
1965	D	U	U	U	U	U	U	U	U	U	U	U	U	U	U		0/14
1966	D	F	F	U	F	U	F	U	F	F	U	U	F	U	F		8/14
1967	N	F	U	U	U	U	U	F	F	U	F	U	U	F	F	F	7/15
1968	D	F	U	U	U	U	U	U	U	U	F	U	U	F	U	U	3/15
1969	N	F	U	F	F	F	U	F	F	F	U	U	F	U	F	U	9/15
1970	N	F	U	F	F	F	F	F	F	U	U	U	F	U	F	F	10/15
1971	N	F	U	U	U	U	U	F	F	F	F	F	F	F	U	F	9/15
1972	D	U	U	U	U	F	U	U	U	U	U	U	F	F	U	U	3/15
1973	N	F	F	U	F	F	F	F	F	F	U	U	F	U	U	U	9/15
1974	D	F	U	F	F	U	U	U	U	U	F	F	U	F	U	U	6/15
1975	N	F	U	U	F	F	F	F	F	F	F	F	F	F	U	F	12/15
1976	N	U	U	F	F	U	F	F	F	F	F	U	U	F	F	U	9/15
1977	N	F	F	F	F	U	U	U	F	F	U	U	F	U	F	F	9/15
1978	N	F	U	U	U	F	F	U	U	F	F	U	U	U	F	U	6/15
1979	D	F	U	U	U	U	U	U	U	U	U	U	U	U	F	U	2/15
1980	N	F	U	F	F	F	F	U	F	F	U	U	F	U	U	F	9/15
1981	N	F	U	F	F	U	F	F	F	U	U	U	U	U	F	F	8/15
1982	D	U	U	U	F	U	U	U	U	F	U	U	U	U	F	U	3/15
1983	N	F	F	U	F	F	F	U	F	F	U	U	F	U	F	U	9/15
1984	N	F	U	U	U	F	F	U	F	U	U	U	U	U	F	F	6/15
1985	N	F	U	F	F	F	U	U	F	F	U	F	F	F	U	F	10/15
1986	D	F	U	F	F	U	F	U	U	U	U	U	F	F	U	U	6/15
1987	D	U	U	F	U	U	F	F	U	U	U	U	F	U	F	U	5/15
1988	N	F	F	F	F	F	F	U	F	F	F	F	U	F	F	F	13/15

NOTE : + ve and —ve signs indicate direct and inverse relationship of predictors with monsoon; N and D indicate normal and deficient monsoon rainfall; F and U indicate favourable and unfavourable signals from predictors for normal monsoon.

3.4. In Table 1 there are two snow-cover parameters Himalayan (Blanford 1884) and Eurasian (Hahn and Shukla 1976) which would appear to show inverse relationship with the monsoon rainfall. The extent of snow-cover determines the net solar radiative heating due to the albedo factor. The large extension of snow-cover may lead to less sensible heating on the continental scale which is considered detrimental to good monsoon.

4. Analysis of parameters for formulating parametric model

For the past 38 years (1951-1988), signals from all the 15 parameters are shown in Table 1. F and U in the table indicate favourable and unfavourable signals respectively for normal monsoon rainfall over India. Year to year behaviour of monsoon rainfall has been indicated by N and D, where N indicates normal monsoon rainfall (⩾ 90% of long term normal rainfall) and D stands for deficient rainfall (< 90% of the normal) for the country as a whole. The normal monsoon rainfall of the country, as a whole (including hilly regions), based on long period data of 1901-1970 is 88.1 cm.

In the first stage, signals from individual parameters have been studied. For example, during past 37 years (1951-1987), there were 7 moderate and severe *El Nino* years and on all these occasions, except in 1966, the monsoon was normal on subsequent years. Similarly, when period of analysis was extended to past 87 years (1901-1987), there were 7 severe *El Nino* years and monsoon was normal on all the subsequent years. For the same period, there were 8 occasions when moderate *El Nino* occurred and monsoon was normal on all subsequent years except in 1966. In 1987, moderate *El Nino* was observed. Based on this factor alone, the monsoon rainfall in 1988 would have been normal. Similar results are found when signals from other individual parameters are studied.

In the second stage, an attempt has been made to study signals from combinations of two parameters. Out of all possible combinations, it is observed that the combination of two wind parameters, *viz.*, 50 hPa ridge and 10 hPa zonal wind gives very good indication about the subsequent monsoon rainfall. During the past 30 years (1958-1987), for which data are available, there were 14 occasions when both the wind parameters were favourable for good monsoon and on 13 occasions monsoon rainfall was normal. Out of 9 occasions, when both the factors were unfavourable for good monsoon, rainfall was deficient on 7 occasions and normal on 2 occasions. In 1988, both the parameters were favourable. This suggests that in 1988 the monsoon was expected to be good (normal).

TABLE 2

Inferences based on signals from 15 parameters
(Period : 1951-1987)

Percentage of parameters favourable	No. of occasions	Subsequent monsoon condition	
		Normal	Deficient
⩾90 (11 out of 12)	1	1	0
⩾80	2	2	0
⩾70	6	6	0
⩾60	18	18	0
>50	21	20	1
⩽50	16	7	9
⩽40	12	3	9
⩽30	7	1	6
⩽20	6	1	5
10	2	1	1
0	1	0	1

Subsequently, all the 15 parameters have been tested in different combinations and results from these combinations have been analysed. It is found that the level of confidence on forecast for good monsoon increases as the number of favourable parameters increases.

5. Parametric model

For the first time, a detailed analysis of such a large number of parameters, all taken together, has been made. In the last column of Table 1, number of parameters favourable for good monsoon rainfall are indicated. Detailed analysis of the number of parameters and the behaviour of subsequent monsoon rainfall have been given in Table 2. In addition, the percentage number of parameters favourable in each year, since 1951 are shown in Fig. 1. It may be noted that during the past 37 years (1951-1987), whenever 60% or more factors were favourable, subsequent monsoon rainfall was normal on all the occasions. However, whenever less than 50% factors were favourable, the monsoon was not deficient on all occasions. During the past 37 years (1951-1987), there were 18 occasions when 60% or more parameters were favourable, and on all these occasions except two the monsoon rainfall was not only normal but was on the positive side of the normal. On the other hand, there were 7 occasions when 30% or less factors were favourable and the monsoon was normal on one occasion and deficient on the remaining 6 occasions.

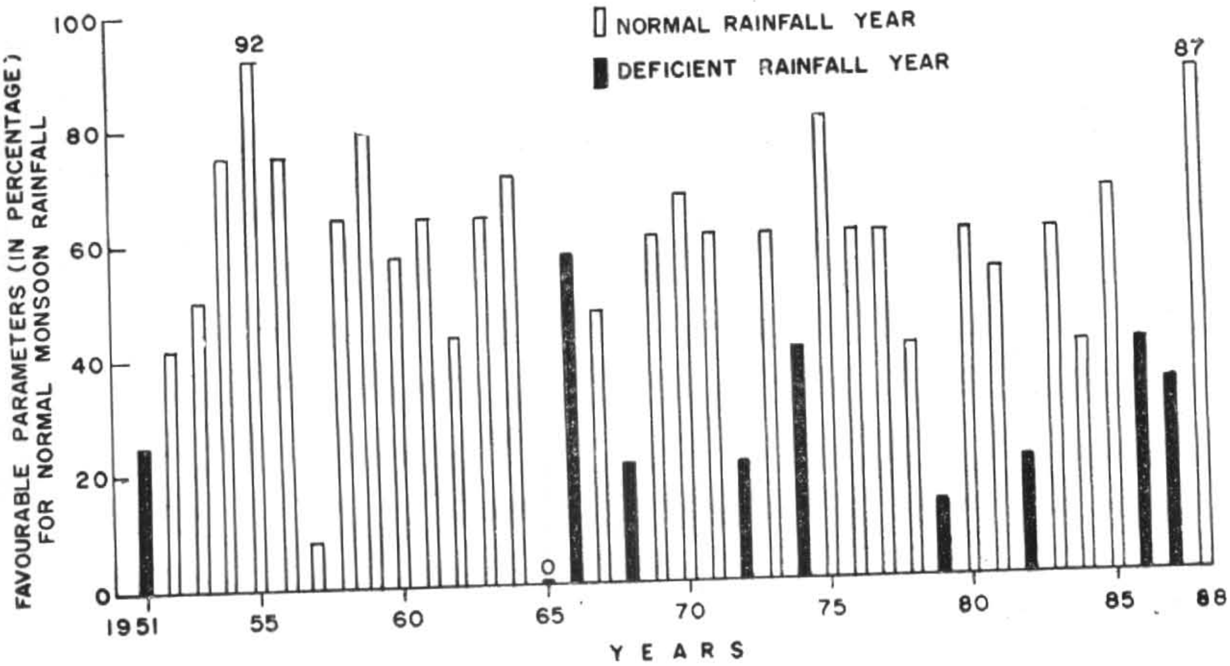

Fig. 1. Year to year variation in number of favourable parameters and monsoon rainfall over India

During the period under study, there were two extremes – the year 1955 in which the maximum number of parameters (92%) were favourable and the monsoon was in excess (111% of normal); and the year 1965, in which none of the parameters was favourable and the monsoon rainfall was highly deficient (79% of the normal). The analysis, however, shows indifferent relationship for the year 1957 when only one parameter was favourable and the monsoon was normal. It may be inferred that one is talking here in terms of "sufficient condition" and not "necessary condition" and this is the main feature of the model.

The model was put to operational use in May 1988, when 87% of the parameters were observed to be favourable, as a qualitative decision making tool for the forecast of the 1988 monsoon season. This led to the conclusion, with good degree of confidence, that the monsoon rainfall in 1988 would be normal, in fact towards the positive side of the normal. The actual monsoon rainfall in 1988 was 119% of the normal, which validated the utility of the model as a decision making tool.

6. Power regression model

The parametric model, developed above, is purely qualitative and enables us for decision making, in advance, for foreshadowing the subsequent monsoon rainfall. The above model can further be improved either by including more predictors, like northern hemisphere pressure anomaly (Raman and Malickal 1985) etc or by making it quantitative. However, it may be mentioned that no single parameter exhibits one to one relationship with the monsoon. The analysis reported above, gives equal weightage to all the 15 parameters. It is known that the influence of parameters on monsoon varies from one parameter to the other, as can be noted from the fact that in 1957 the 500 hPa ridge was the only parameter out of 12 (available at that time) which was favourable and still, subsequent monsoon rainfall was normal. In view of this, the above study has been extended further. We have determined the magnitude of influence of each parameter and formulated a power regression model which has the equation of the type :

$$R = c_0 + \sum_{i=1}^{15} c_i \, X_i^{p_i} \quad (1)$$

where R is monsoon rainfall over India, $X_1, X_2 \ldots\ldots, X_{15}$ are different parameters and cs and ps are model constants.

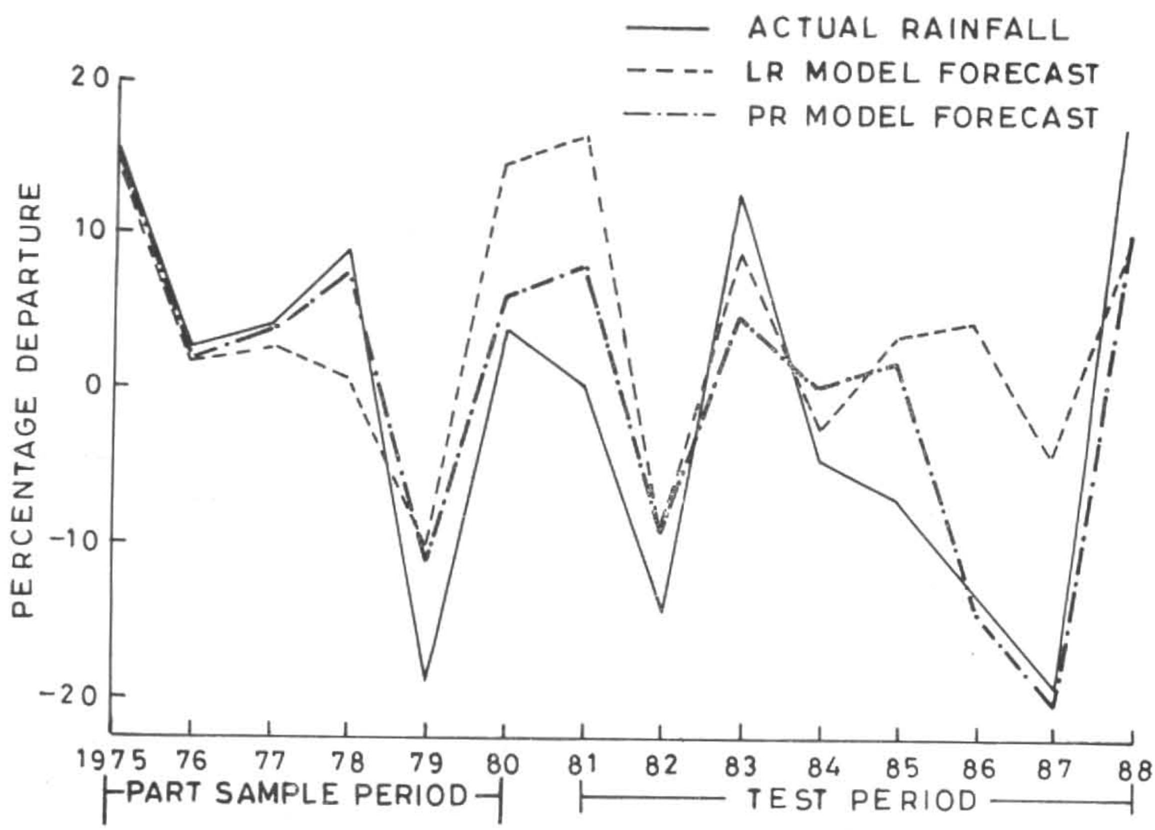

Fig. 2. Performance of linear regression (LR) and power regression (PR) models during part sample period (1975-1980) and test period (1981-1988)

For determining the model constants, 23 years (1958-1980) data have been used. The values of c s and p s have been determined by using step by step iteration together with the usual method of least square fitting. The iterations have been performed with an increment of 0.1 which has been found effective for determining the model constants. The resulting equation for the power model is given as :

$$R = 621.0 + \sum_{i=1}^{15} c_i X_i^{p_i} \tag{2}$$

where X s are defined in Table 1 and c s and p s are model constants.

The power regression model given in Eqn. (2) has been developed by arranging the parameters in order of their decreasing correlation coefficients with the monsoon rainfall over India. Similar exercise has been carried out by arranging the parameters in order of their availability. The parameter available earliest in a particular year, before monsoon, has been designated as X_1 in model. Similarly, all the other parameters have been arranged in order of their availability. Forecasts from both these models have been obtained and compared with the realised monsoon rainfall over India. The analysis shows that the performance of the power regression model using parameters in order of decreasing correlation is better. Therefore, the results obtained from the power regression model, using parameters in decreasing order of correlation, have been discussed below in detail.

Forecasts for a few years of the sample period (1975-1980) and for all the years of independent recent test period (1981-1988) have been obtained from the power regression model, expressed in Eqn. (2). For all these years, the forecast monsoon rainfall amounts, alongwith the corresponding realised rainfall amounts, are shown in Fig. 2. It is seen from the figure that during the dependent sample and the independent test periods, the forecast amounts are quite close to the realised rainfall amounts. During the independent test period, droughts have occurred in 1982, 1986 and 1987. On all these three occasions the power regression model has correctly predicted the drought. It is seen from the figure that the model predictions are quite close to the realised rainfall during both the excess and normal rainfall years. For independent test period (1981-1988), the root mean square error is 5.6 cm which is nearly 6% of the normal rainfall. Thus the performance of the model has been found encouraging during sample and test periods.

It may be interesting to compare the performance of power regression model with that of a multiple regression model. For this purpose, the same set of data which was used for developing the power regression model has been used for formulating the multiple regression model which has multiple correlation coefficient of 0.94. This suggests that the multiple regression model developed here accounts for higher percentage of variance as compared to other similar models reported in the literature. For the sake of comparison, the forecasts obtained from multiple regression and power regression models have been shown in Fig. 2. It may be seen from the figure that the power regression forecasts are closer to the actual, as compared to the multiple regression forecasts. In the recent two consecutive drought years 1986 and 1987 the forecasts obtained from the power regression model are found in close conformity with the actual while the forecasts obtained from the multiple regression model differ substantially from the actual.

The above discussion indicates that the performance of the power regression model is superior to that of multiple regression model. Since the power regression model utilises some kind of non-linearity, its performance is expected to be better as compared to that of the multiple regression model which utilises only the linear relationship. This analysis suggests that the power regression model is superior to multiple regression model not only on account of its better performance but also on account of its capacity to utilise some part of the non-linear relationship for prediction. The development of the power regression model, thus, provides one more technique to the operational forecaster. It may, however, be mentioned that like any other statistical technique, the power regression technique has also its inherent limitations. However, it is felt that the inherent limitations of this technique may, perhaps, be a little less as compared to other known operational techniques.

7. Conclusions

Parametric and power regression models developed in this paper have been found very useful. The parametric model, which utilises signals from 15 different regional and global weather and oceanic parameters, provides qualitative forecasts. The set of the parameters used in the model appears to be physically linked with the summer monsoon. The forecasts obtained from the model are very useful for a decision maker as they provide the level of confidence to the forecasts. When more than 60% parameters were favourable during last 37 years, the monsoon rainfall was normal on all occasions. Based on this model the forecast for normal or above normal rainfall during June to September 1988 was made public. The realised rainfall during monsoon 1988 proved the utility of the model.

In parametric model all the parameters have been given equal weightage as linear relationship between different parameters and monsoon rainfall has been assumed. However, when relationships of all the 15 parameters with monsoon rainfall are analysed, different non-linear type of relationships have been found. For all the parameters the power of relationship varies from +4.0 to —4.0. This indicates the curvilinear or non-linear type of relationship of the individual parameters and rainfall exists. By using these different degrees of relationships, the power regression model has been developed. The performance of this model has been found encouraging during sample and independent test (1981-1988) periods. It appears that the performance of power regression model is particularly encouraging during drought years. This increases the utility of the model. On comparing the performance of power regression model with that of the multiple regression model, it has been found that the new model developed here is superior to that of multiple regression. The developments reported here are expected to provide two more tools in the hands of an operational forecaster. It may, however, be mentioned that like any other statistical technique, the parametric and power regression techniques also have inherent limitations. However, it is felt that these limitations of the new techniques reported in this paper may be less than those of the other techniques. By forming a set of larger number of parameters and also by using some portion of their non-linear relationship in the model, the accuracy of prediction is expected to increase. The model could be used as yet another operational tool for long range forecasting of monsoon rains.

References

Banerjee, A.K., Sen, P.N. and Raman, C.R.V., 1978, 'On foreshadowing southwest monsoon rainfall over India with mid-tropospheric circulation anomaly of April', *Indian J. Met. Hydrol. Geophys.*, 29, 425-431.

Bhalme, H.N., Rahalkar, S.S. and Sikdar, A.B., 1987, 'Tropical quasi-biennial oscillation of the 10 mb wind and Indian monsoon rainfall—Implications for forecasting, *J. Climatol.*, **7**, 345-553.

Blanford, H.F., 1884, 'On the connection of the Himalayan snow with dry winds and seasons of droughts in India', *Proc. Roy. Soc. London,* **37**, 3-22.

Hahn, D.G. and Shukla, J., 1976, 'An apparent relationship between Eurasian snow cover and Indian Monsoon rainfall' *J. atmos. Sci.*, **33**, 2461-2462.

Jagannathan, P., 1960, 'Seasonal forecasting in India—A Review', Meteorological Office, Poona (India), 67 pp.

man, C.R.V. and Malickal, J.A., 1985, 'A Northern Oscillation relating Northern Hemisphere Pressure anomalies and Indian Summer Monsoon', *Nature*, **314**, 430-432.

Sikka, D.R., 1980, 'Some aspects of the large-scale fluctuations of summer monsoon rainfall over India in relation to fluctuations in the planetary and regional scale circulation parameters', *Proc. Indian Acad. Sci.* (Earth and Planet. Sci.), **89**, 179-195.

Thapliyal, V., 1982, 'Stochastic dynamic model for long range prediction of monsoon rainfall in Peninsular India', *Mausam*, **33**, 399-404.

Thapliyal, V., 1984, 'Prediction of Indian droughts with lower stratospheric winds', *Mausam*, **35**, 367-374.

Thapliyal, V., 1987, 'Prediction of Indian monsoon variability : Evaluation and prospects including development of a new model', *Climate of China and Global Climate*, edited by D. Ye, C. Fu, J. Chao and J. Yoshino, China Ocean Press, Beijing.

Verma, R.K., Subramanian, K. and Dugam, S.S., 1985, 'Interannual and long term variability of the summer monsoon and its possible link with northern hemispheric surface air temperature', *Proc. Indian Acad. Sci.* (Earth and Planet. Sci.), **94**, 187-198.

Walker, G.T., 1923, 'Correlation in seasonal variation of weather VIII : A preliminary study of World Weather', *Mem. India Met. Dep.*, **24**, 75-131.

Walker, G.T., 1924, 'Correlation in seasonal variability of weather IX : A further study of World Weather', *Mem. India met. Dep.*, **24**, 275-332.