Long-Range Forecasting of the Indian Summer Monsoon Onset and Rainfall with Upper Air Parameters and Sea Surface Temperature^{1,2}

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Abstract

Meteorological variables which likely are associated with the initiation and maintenance of the Indian summer monsoon are examined in a regression analysis. Consequently, a long-range forecasting scheme for the monsoon onset date in southwestern India and the total seasonal rainfall in central India is formulated. The regression forecasting scheme involves five predictors for the onset date and six predictors for the rainfall. These predictors include upper air parameters at 100, 200 and 700 mb over India and Australia and the sea surface temperature in the Indian region. The forecast experiments for the period 1958-77 show the predicted onset dates and seasonal rainfall to be very close to the recorded dates and rainfall. Various aspects of the forecasting scheme are discussed.

1. Introduction

Before the eventual goal of the long-range forecasting capability of the mathematical-dynamical models is attained through advanced knowledge of the geophysical fluid system, the development of empirical regional forecasting schemes at the seasonal range is desirable. Simultaneously, the knowledge acquired in the empirical effort also contributes to the physical understanding of the behavior of the atmospheric circulation.

In our preceding paper (Kung and Sharif, 1980) it was demonstrated that the recorded onset dates of the summer monsoon in southwestern India could be closely related functionally to the antecedent upper air conditions and that the multi-regression scheme developed on the basis of such a relationship could be utilized in an objective forecast of the onset date. The April mean values of the daily upper-air parameters at 100 and 700 mb over the forecast point were utilized as predictors because the hot weather season from March to May in India is associated with a distinct transition in values of various meteorological parameters, recognized as the prelude to the onset of the southwest India

monsoon. However, this sole dependency on the local upper air parameters led to the problem of multi-collinearity among predictors. The forecast experiment also demonstrated some notable cases of prediction failure, indicating insufficient information content given by predictors. Thus a further refinement of the forecasting scheme, through incorporation of predictors for additional information, appeared desirable.

The characteristic large-scale fields in association with the Indian summer monsoon have been studied extensively. A partial list of significant contributions includes, but is not limited to, those of Ananthakrishnan (1977), Findlater (1969), Flohn (1968), Krishnamurti and Bhalme (1976), Manabe *et al.* (1974), Murakami (1976), Ramage (1971), Ramage and Raman (1970), Ramaswamy and Pareek (1978), Shukla (1975), Sikka (1977), Singh *et al.* (1978), Walker (1923), Weare (1979), Winston and Krueger (1977), Yeh and Chang (1974), and Yoshino (1971). These studies collectively indicate that among the many large-scale features associated with the monsoon, three categories may stand out for their basic importance in initiating and sustaining the monsoon circulation system: 1) the large warm-core anticyclone formed in the upper troposphere and

lower stratosphere in response to heating in the area of the Tibetan Plateau, 2) the intense cross-equatorial southwesterly flow over the Indian Ocean, and 3) the pronounced temperature contrast between the land and sea.

In view of these physical features associated with the monsoon, four groups of meteorological variables were examined in the present study with respect to the monsoon onset and rainfall. These four groups include upper air parameters over India, upper air parameters over Australia, the Indian sea surface temperature and Eurasian snow cover. The resulting regression forecasting scheme for the onset date in southwestern India has shown a marked improvement over that utilized in our preceding study. The scheme for the seasonal monsoon rainfall in central India also yields a very close agreement between the forecasted and recorded amounts of rainfall. The regression schemes developed in the present study include upper air parameters over India and Australia and the Indian sea surface temperature as predictors. The number of predictors is five in the case of onset date forecasting and six in rainfall forecasting, a significant reduction from the previous eight in our preceding study when only upper air parameters over the forecast point were involved. In this paper the formulation of regression schemes is described and then the forecast experiments of the monsoon onset date and seasonal rainfall are presented.

2. Data and Meteorological Variables

Table 1 lists the record of monsoon onset dates observed on the Kerala coast in southwestern India and the total seasonal rainfall over central India from 1 June to 31 October during the years 1958 to 1977. The onset record was obtained from the India Meteorological Department and is expressed numerically in this study in terms of the number of days from 1 April. As discussed in Kung and Sharif (1980) the onset was recorded according to the India Meteorological Department's criteria by Ananthakrishnan *et al.* (see Subbaramayya and Kumar, 1978), according to which "beginning from 10 May if at least five out of seven stations report 24 hourly rainfall 1 mm or more for two consecutive days, the forecaster should declare on the second day that the monsoon has advanced over Kerala." The uncertainty associated with such recorded dates is considered to be at most one or two days by field meteorologists. The rainfall in cen-

Table 1. Monsoon onset on the Kerala coast and total rainfall from 1 June to 31 October over central India.

Year	Onset date (day/month)	Onset date (number of days from 1 April)	Rainfall (mm)
1958	14/6	75	1005
1959	31/5	61	1149
1960	14/5	44	765
1961	18/5	48	1064
1962	17/5	47	959
1963	31/5	61	919
1964	6/6	67	970
1965	26/5	56	709
1966	1/6	62	669
1967	6/6	67	987
1968	8/6	69	744
1969	25/5	55	855
1970	26/5	56	1071
1971	29/5	59	943
1972	18/6	79	631
1973	23/5	53	1034
1974	26/5	56	722
1975	31/5	61	1124
1976	1/6	62	794
1977	29/5	59	824
Mean		60	897
Standard deviation		8.8	158

tral India is defined by the precipitation record at stations 1 through 15 given in Fig. 1. The monthly precipitation amounts obtained from *Monthly Climatic Data for the World* by the National Oceanic and Atmospheric Administration (NOAA) were averaged for these stations; the amounts were summed from June through October to yield the total seasonal rainfall.

Meteorological variables, including those of upper air parameters over India and Australia, the Indian sea surface temperature and the Eurasian snow cover, were examined in this study as possible predictors. The daily 1200 GMT geopotential height and temperature at 100 and 700 mb over the Indian region during April were obtained from the National Meteorological Center's (NMC) octagonal grid data archives, as shown in Fig. 2 (see Kung and Sharif, 1980). The eastward and northward components of winds at these levels were approximated with the geostrophic wind components, and the kinetic energy per unit mass was obtained with the approximated wind components. The daily values of these upper air parameters were averaged for the April mean values. A 5-point average of the April mean values is then taken to represent

Fig. 1 Climatological stations for the precipitation record, regions for the sea surface temperature record, and Australian upper air stations.

Fig. 2 NMC octagonal grids over India and regions over which upper air parameters are selected for regression analysis.

a diamond grid region. As shown in Fig. 2, seven such grid regions are involved in the final regression analysis following the initial selection process for predictors (see Table 2). The April mean temperature at 200 mb at New Delhi obtained from the NOAA *Monthly Climatic Data for the*

Table 2. Monthly mean meteorological variables selected after correlation analyses for further regression analyses with respect to monsoon onset and rainfall. z is the geopotential height, k the kinetic energy, u the eastward wind, v the northward wind, and T the temperature.

Notation	Variable	Region	Month
Upper Air Parameters Over Indian Grid Region			
Z100	z at 100 mb	3	Apr
Z10A	z at 100 mb	1	Apr
Z700	z at 700 mb	4	Apr
Z70A	z at 700 mb	6	Apr
K100	k at 100 mb	2	Apr
K700	k at 700 mb	2	Apr
U100	u at 100 mb	7	Apr
U700	u at 700 mb	7	Apr
V100	v at 100 mb	2	Apr
V700	v at 700 mb	7	Apr
T200	T at 200 mb	New Delhi	Apr
T700	T at 700 mb	5	Apr
Indian Region Sea Surface Temperatures (SST)			
T13J	SST	13	Jan
T18J	SST	18	Jan
T02F	SST	2	Feb
T16F	SST	16	Feb
T02M	SST	2	Mar
T11M	SST	11	Mar
T09A	SST	9	Apr
T14A	SST	14	Apr
Upper Air Parameters Over Australia			
UA2J	u at 200 mb	6 stations	Jan
VA7J	v at 700 mb	6 stations	Jan
TA7M	T at 700 mb	3 stations*	Mar
ZA2A	z at 200 mb	6 stations	Apr
TA7A	T at 700 mb	6 stations	Apr
Snow Cover Over Eurasia			
PPTD	Precipitation	Eurasia	Dec
PPTS	Precipitation	Eurasia	Dec to Mar

* 3 stations: Alice Springs, Giles and Port Hedland.

World was substituted for the 100 mb temperature of the corresponding grid region due to the incomplete data of the region in the time series.

The daily geopotential height, temperature and wind observations at 200 and 700 mb at six Australian stations from 1 January to 30 April, shown in Fig. 1, were obtained from the upper air data archives at the National Center for Atmospheric Research (NCAR) and used to compute the monthly means of these upper air parameters over the area.

The monthly mean sea surface temperature (SST) in the Indian region was acquired from the NOAA Environmental Assessment Services. The SST data originally coded for $5^{\circ} \times 5^{\circ}$ and $1^{\circ} \times 1^{\circ}$ areas were modified to be recoded for the sea surface in the sixteen $10^{\circ} \times 10^{\circ}$ areas, as shown in Fig. 1. The monthly precipitation data from December to March at stations 16 through 37, shown in Fig. 1, were taken from the NOAA *Monthly Climatic Data for the World*.

The monthly precipitation data averaged over these Eurasian stations are used as snow cover data, and their seasonal total is taken to represent the seasonal accumulation of the snow cover.

All the data utilized in this study are for the period 1958 to 1977, since the SST data we used is not available after 1977. During the data period there was a recalibration of the Indian radiosonde around 1967, yielding somewhat lower geopotential height values thereafter. The processing and analysis of grid data by NMC models also has evolved during the 20-year period. No special attempt has been made to correct these possible sources of unhomogeneity of the NMC grid data. However, as discussed by Kung and Sharif (1980) and also as will be verified by the results reported here, both the data quality and the length of the data period seem adequate for the purpose of this study.

3. Regression Analysis

12 upper air parameters over India, 8 SST's, 5 upper air parameters over Australia and 2 snow cover parameters over Eurasia were selected for regression analysis following an extensive correlation analysis of all available monthly mean meteorological variables with respect to the onset date and seasonal rainfall. These parameters are listed in Table 2 with notations which will be used throughout this paper.

In the regression analysis eighteen regressors (Z100, Z700, K100, K700, U100, U700, V100, V700, T200, T700, T02F, T02M, T09A, T14A, VA7J, TA7M, PPTD and PPTS) are associated with the onset date, and nineteen regressors (Z10A, Z70A, K100, K700, U100, U700, V100, V700, T200, T700, T13J, T18J, T16F, T11M, UA2J, ZA2A, TA7A, PPTD and PPTS) are associated with the seasonal rainfall. The least-squares fittings with these meteorological variables as regressors are made to the general linear regression equation

$$y = b_0 + b_1x_1 + b_2x_2, \dots, + b_nx_n \quad (1)$$

where y is the monsoon onset date or total seasonal rainfall, b the regression coefficient, x the regressor and n the number of regressors employed in the functional expression of y . In computing the regression coefficients and statistical procedures the program package of the Statistical Analysis System (Barr *et al.*, 1976) was employed.

As up to 18 regressors are considered for the onset date and up to 19 regressors for the sea-

sonal rainfall, various combinations of regressors may be grouped according to the number of regressors, n . All regression equations are compared within each class and one equation is selected as the best combination of regressors to give the maximum R^2 and minimum MSE (see Neter and Wasserman, 1974). These are listed in Table 3 for a range of $n=1$ to 10. Since fitting of the onset date significantly improves until n reaches 5, with the subsequent increase of R^2 and the decrease of MSE becoming nearly asymptotic, $n=5$ appears to give the optimum fitting of the monsoon onset date with the regression equation

$$y = b_0 + b_1 \cdot Z100 + b_2 \cdot K700 + b_3 \cdot T09A + b_4 \cdot VA7J + b_5 \cdot TA7M \quad (2)$$

Likewise, the fitting of the total seasonal rainfall seems at its optimum for $n=6$ when the regression coefficients are obtained for the regression equation

$$y = b_0 + b_1 \cdot U100 + b_2 \cdot U700 + b_3 \cdot V100 + b_4 \cdot T200 + b_5 \cdot T16F + b_6 \cdot ZA2A \quad (3)$$

The stepwise regression selection procedure (see Barr *et al.*, 1976) is applied independently to the onset date and seasonal rainfall with eighteen and nineteen regressors; the same five variables for the onset date and the same six variables for the seasonal rainfall as given in Eqs. (2) and (3) are obtained, confirming the consistent results of regression analyses with different procedures.

The regression coefficients obtained with data

Table 3. Fitting of the monsoon onset date and rainfall with different number of variables for the period 1958-77.

Number of regressors (n)	Onset date		Rainfall	
	R^2	MSE (day ²)	R^2	MSE (mm ²)
1	0.373	51.16	0.432	14847.73
2	0.562	37.86	0.612	10744.00
3	0.769	21.21	0.694	9013.20
4	0.850	14.61	0.778	6972.54
5	0.886	11.98	0.824	5903.68
6	0.898	11.54	0.939	2195.15
7	0.909	11.15	0.947	2074.34
8	0.924	10.11	0.954	1962.28
9	0.939	8.96	0.967	1575.41
10	0.943	9.22	0.970	1394.81

Note: All regression fittings listed above are significant at the 1% level.

Table 4. Regression equations of monsoon onset and rainfall approximated with different data periods.

$$\text{Onset: } Y = b_0 + b_1 \cdot Z100 + b_2 \cdot K700 + b_3 \cdot T09A + b_4 \cdot VA7J + b_5 \cdot TA7M$$

$$\text{Rainfall: } Y = b_0 + b_1 \cdot U100 + b_2 \cdot U700 + b_3 \cdot V100 + b_4 \cdot T200 + b_5 \cdot T16F + b_6 \cdot ZA2A$$

Data Period	b_0	b_1	b_2	b_3	b_4	b_5	b_6
<u>Onset</u>							
1958-74	3432	- 0.1206	0.0511	-7.834	3.389	3.517	
1958-75	3130	- 0.1090	0.0742	-7.314	2.813	3.343	
1958-76	3170	- 0.1119	0.0678	-7.122	3.084	3.162	
1958-77	3157	- 0.1122	0.0666	-7.076	3.121	3.179	
<u>Rainfall</u>							
1958-74	-107233	-17.54	18.67	16.75	22.79	224.9	2.889
1958-75	-109627	-18.03	18.79	16.87	21.83	223.7	2.886
1958-76	-110766	-17.79	19.12	16.65	22.15	236.5	2.905
1958-77	-110682	-17.79	19.08	16.69	22.22	235.9	2.911

Table 5. Response of regression fitting to inclusion of Indian sea surface temperature (SST), Australian upper air parameter (AU), and Eurasian snow cover (SC) as regressors in addition to Indian upper air parameter (IU).

Regressor categories	Regressors	R ²	MSE
<u>Onset date</u>			
			(day ²)
IU, SST, AU	Z100, K700, T09A, VA7J, TA7M (Eq. 2)	0.886	11.98
IU	Z100, K700, U700, V100, T200	0.641	37.69
IU, SST	Z100, Z700, K100, K700, T09A	0.777	23.40
IU, AU	Z100, U100, U700, VA7J, TA7M	0.751	26.11
IU, SC	Z100, K700, U700, V100, PPTD	0.637	38.08
<u>Rainfall</u>			
			(mm ²)
IU, SST, AU	U100, U700, V100, T200, T16F, ZA2A (Eq. 3)	0.939	2195.15
IU	Z10A, Z70A, K100, U100, V100, V700	0.600	14477.08
IU, SST	Z70A, U100, V100, T700, T13J, T11M	0.779	8013.97
IU, AU	K100, K700, U100, V100, UA2J, ZA2A	0.795	7429.72
IU, SC	K100, U100, V100, T200, T700, PPTS	0.673	11851.80

for the complete period from 1958 to 1977 for Eqs. (2) and (3) are listed in Table 4, along with other sets of regression coefficients which are approximated for different data periods. The physical units of meteorological variables used in the regression fitting of Eqs. (2) and (3) are m for Z100 and ZA2A, ms^{-1} for U100, U700, V100 and VA7J, m^2s^{-2} for K700, and K for T09A, TA7A, T200 and T16F; y is given in days from 1 April in Eq. (2) and in mm in Eq. (3). All the regression fittings of the onset dates and seasonal rainfall with the equations, as listed in

Table 4, are significant at the 1% level.

Five and six regressors are involved in Eqs. (2) and (3), respectively. This is a significant reduction in the number of predictors, which was eight in Kung and Sharif's (1980) previous scheme involving only the April mean upper air parameters over the forecast point. The reduced number of predictors and the involvement of three categories of meteorological variables (i.e., upper air parameters over India and Australia and SST's) indicate that the problem of multi-collinearity among regressors should not exist in the present

scheme.

The response of regression fitting to inclusion of various categories of meteorological variables is summarized in Table 5 in terms of R^2 and MSE. The best fittings of the onset date and seasonal rainfall are obtained by Eqs. (2) and (3) when the upper air parameters over India and Australia and the SST's are all involved. The fittings significantly deteriorate when either Australian upper air parameters or SST's are eliminated and worsen further when only the upper air parameters over India are employed. The inclusion of the Eurasian snow cover does not materially improve the fitting. The adequacy of the station precipitation records in lieu of snow coverage in the area may be questioned. However, the heating effect of the Tibetan Plateau, which is regulated by the snow cover, is essentially represented by the 100 or 200 mb upper air parameters over India. Thus it is possible that the use of the upper air parameters has eliminated the necessity for snow cover information at the forecasting range treated in this study.

4. Forecasting of monsoon onset and rainfall

As pointed out earlier by Lorenz (1956), the standard methods of linear prediction may be used to good advantage with the data of the recent past to the extent that the information concerning the nonlinear processes is contained in the near past behavior of the atmosphere. Kung and Sharif's (1980) preliminary study and the regression analysis of this study seem to indicate that with the predictors utilized in this

scheme, a data period of less than 20 years is adequate for the regression forecast of the Indian summer monsoon at the seasonal range. It has been well recognized that the patterns of the general circulation undergo considerable variation in a period of a decade or two. This inter-annual transiency of the circulation patterns requires constant revision of the regression equations if they are to be used in operation. Thus, the continuous updating of the regression equation should be an integral part of the regression forecasting scheme. The predictors selected in Eqs. (2) and (3) are associated with physical mechanisms involved in the initiation and maintenance of the monsoon; for this reason it may not be necessary to repeat the entire set of selection procedures. However, the regression coefficients should reflect the prevailing operational mode of these mechanisms and thus will need to be revised continuously.

The results of forecast experiments for the monsoon onset date and total seasonal rainfall with Eqs. (2) and (3) are shown in Figs. 3 and 4 from 1958 to 1977. The forecasted onset date and rainfall in each individual year are obtained with separate regression equations whose coefficients were fitted without involving the data of the forecast year, thus making the forecast year independent of regression fitting. The forecasted values are compared with the recorded onset and rainfall.

As seen in Fig. 3, the forecast of the monsoon onset date in this study shows a marked improvement from our exploratory attempt (Kung and Sharif, 1980). The forecasted onset date

Fig. 3 The recorded and forecasted dates of monsoon onset on the Kerala coast from 1958 to 1977.

Fig. 4 The recorded and forecasted total seasonal rainfall in central India.

closely follows the recorded date. Previously observed gaps between the forecasted and recorded onset dates, such as those in 1966, 1969, 1972 and 1977, now seem to have been resolved in the present scheme. In the earlier scheme only the upper air data over the forecast point were considered to relate the pre-monsoon upper air condition to the onset date. In the present scheme the number of predictors has been reduced, but the pre-monsoon upper air pattern over India, the Southern Hemispheric circulation and the land-sea temperature contrast all are involved through inclusion of the upper air parameters over India and Australia and the SST. This apparently has resulted in a significant improvement of forecasting ability. If the accuracy of forecasting is measured in terms of the average absolute value of deviation from the recorded value, the deviation is 3.2 days. This is 5% of the average forecasted date of onset in terms of number of days from 1 April and also is approximately 1/3 of the standard deviation of the recorded onset date (Table 1). Likewise, the forecasted rainfall follows the recorded and fitted values of rainfall very closely, as shown in Fig. 4. The average absolute value of deviation from the record of forecasted rainfall is 53 mm, which is 6% of the average forecasted rainfall and again approximately 1/3 of the standard deviation of the recorded rainfall (Table 1).

As described in our preceding paper (Kung and Sharif, 1980), the onset and rainfall forecast also can be experimentally predicted by obtaining the values beyond the data period with which regression coefficients are approximated. Table 6 lists the results of such experiments with the

data periods 1958-67 through 1958-76. For the onset date, there is a clear improvement of the forecasting capability when the data period includes more than 10 years in approximating the regression equation; 16 to 19 years seems to lie within an optimum range. It also is readily observable that the data period of 17 to 19 years seems to lie within a similar optimum range for the rainfall forecast. However, for the case of the rainfall, data periods shorter than 17 years degenerate significantly the forecasting ability of the present scheme.

The values of predictors involved in Eqs. (2) and (3) in forecasting the onset and rainfall are plotted from 1958 to 1977 in Figs. 5 and 6. In comparing these values with the recorded onset dates and rainfall for the same period, given in Figs. 3 and 4, it is seen that none of the single predictors may be directly associated with the onset or rainfall through the entire period. Although the variation of some single parameter may be associated with early or late monsoon or with the amount of precipitation in some particular year or certain limited period, this does not always hold true in other years. It also may be noted here that all predictors involved undergo considerable interannual fluctuation. These factors illustrate not only the difficulty of long-range forecasting with a single predictor, but also the limitation of the multi-regression approach when the predictors are not properly selected.

The scheme presented in this study is to forecast the monsoon at the seasonal range with the predictors of the pre-monsoon season. The demonstrated closeness of the forecast to the recorded

Table 6. Difference between recorded and forecasted values (recorded-forecasted) in forecast experiments by regression equations approximated with different data periods. Numbers without parentheses indicate the onset date and those in parentheses indicate rainfall.

Forecast year	Data period to approximate regression equation									
	1958 -67	1958 -68	1958 -69	1958 -70	1958 -71	1958 -72	1958 -73	1958 -74	1958 -75	1958 -76
1968	-7 days (172) mm									
1969	2 (74)	1 (86)								
1970	-5 (7)	-2 (-37)	-2 (-17)							
1971	2 (13)	-2 (-21)	-2 (-22)	-2 (-23)						
1972	6 (-44)	6 (-99)	6 (-131)	6 (-128)	7 (-127)					
1973	19 (-60)	-4 (-70)	-5 (-62)	-8 (-58)	-3 (-57)	-5 (-42)				
1974	-1 (-142)	3 (-175)	3 (-186)	3 (-182)	3 (-172)	2 (-119)	1 (-119)			
1975	-15 (52)	-6 (-10)	-6 (-21)	-5 (-18)	-6 (-12)	-7 (11)	-7 (20)	-7 (30)		
1976	-6 (-137)	4 (-187)	4 (-191)	6 (-183)	4 (-175)	4 (-89)	2 (-81)	2 (-8)	2 (-12)	
1977	-15 (48)	0 (-39)	1 (-61)	3 (-60)	1 (-50)	3 (-22)	0 (-25)	0 (4)	1 (-3)	0 (-2)
A.D.	7.8 (74.9)	3.1 (80.4)	3.6 (86.4)	4.7 (93.1)	4.0 (98.8)	4.0 (56.6)	2.5 (61.3)	3.0 (14.0)	1.5 (7.5)	0 (2)

A.D.=average of absolute values of deviation.

Fig. 5 Interannual fluctuation of predictors for the onset date from 1958 to 1977.

onset date and rainfall in this study verifies the adequate inclusion of predictors in this scheme. The adequate selection of predictors is possible when initially the major categories of meteorological variables associated with the monsoon circulation system are properly identified. In an empirical forecasting study such as this one, an explicit analysis of the physical mechanisms involved in the development of the monsoon lies beyond the scope of the study. However, identification of the parameters related to the initiation and maintenance of the monsoon will be a valuable contribution to the study of these physical mechanisms.

5. Concluding remarks

The forecasted onset date and seasonal rainfall of the Indian summer monsoon in the present study are shown to be very close to the recorded date and rainfall. It may be concluded that the present multi-regression long-range forecasting scheme is capable of predicting the onset date and seasonal rainfall if regression coefficients are approximated with a data period of 16-19 years for the onset date and 17-19 years for the rainfall. Predictors include the upper air parameters at 100, 200 and 700 mb over India and Australia and the sea surface temperature in the Indian region. Examination of the regression analysis and forecast experiments shows that the

Fig. 6 Interannual fluctuation of predictors for seasonal rainfall from 1958 to 1977.

proper meteorological variables have been considered in formulating the present regression scheme. Continuous updating of the regression coefficients should be an integral part of the scheme due to the temporal variation of the patterns of the general circulation.

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高層気象要素と海面温度を用いたインド夏季モンスーンの 始まりと雨量の長期予報

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インド夏季モンスーンの始まりと維持に関係していると思われる気象要素を回帰解析により調べた。その結果、インド南西部のモンスーン入りの日と、インド中央部の全降水量の長期予報方式を求めた。この予報方式では、モンスーン入りの予報には5個の気象因子を、また、降水量の予報には6個の因子を用いている。これらの気象因子はインドおよびオーストラリアの100, 200, 700 mbでの気温と、インド領域の海水面温度である。1958-77年の期間について予報を行った結果、モンスーン入りと降水量の予報値は、観測値と非常によく一致した。この予報方式について、様々な角度から検討を行った。