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A scheme for advance prediction of northeast monsoon rainfall of Tamil Nadu

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सार — अप्रैल, जून, जुलाई, अगस्त और सितम्बर के महीनों में भारत के दस सुवितरित उपरितन वायु स्टेशनों के सात मानक समदाब (आइसोबारिक) स्तरों की वायु, सम्मोच रेखा ऊँचाई और तापमान के मासिक माध्यों की जाँच सहसंबंध विश्लेषण से की गई है। इसका उद्देश्य तमिलनाडु में उत्तरपूर्वी मानसून वर्षा के पहले से ही पूर्वानुमान करने के लिए प्रागुक्त मानों वाले प्राचलों का पता लगाना है। 1965 से 1987 तक विकासात्मक अवधि तथा1988-94 तक की अवधि को परीक्षण अवधि के रूप में माना गया है। छः पूर्वसूचकों मे से तीन एकदम नए पूर्वसूचकों का पता लगाया गया है। पुरानी तकनीक से भिन्न स्क्रीनिंग तकनीक के द्वारा छः पूर्वसूचकों पर आधारित प्रत्येक पूर्वानुमान के मान्य औसत के रूप में वर्षा का अन्तिम पूर्वानुमान प्राप्त किया गया था। इस प्रणाली से परीक्षण अवधि के दौरान प्रागुक्ति की 13 प्रतिशत से 18 प्रतिशत के बीच मानक त्रुटि सहित 65 प्रतिशत से 77 प्रतिशत के बीच विभिन्नता का पता चला है, तथा इससे जाँच के दौरान यथोचित पूर्वानुमान प्राप्त हुआ है। भारत में आए उपोष्णकटिबंधीय प्रतिचक्रवात की तीव्रता पर आधारित पूर्वसूचकों के भौतिक महत्व को समझाया गया है। दक्षिणी दोलन सूचकांक (इंडेक्स) तथा भारत के उत्तर पूर्वी मानसून काल के बीच जाँचे गए नकारात्मक और महत्वपूर्ण संबंध के संदर्भ में भूमंडलीय प्राचलों सहित अध्ययन को बढ़ाने की संभावना की चर्चा की गई है। इस विषय पर शोध के कार्यक्षेत्र को यहां और अधिक बढ़ाने के बारे में बताया गया है।

ABSTRACT. Monthly means of winds, contour height and temperature of seven standard isobaric levels of ten well distributed Indian upper air stations for the months of April, June, July, August and September were subjected to correlation analysis to detect parameters that have predictive value to forecast in advance the northeast monsoon rainfall of Tamil Nadu. The period 1965-87 was taken as developmental period and 1988-94 as test period. Six predictors, out of which three were completely new, were identified. The final forecast of rainfall was obtained as the weighted average of the individual forecasts based on the six predictors by employing a screening technique different from the conventional ones. The system explained between 65-77% variation of the predictand with standard error of 13-18% and provided reasonably correct forecasts during the test period. The physical significance of the predictors has been explained based on the intensity of the subtropical anticyclone over India. The possibility of extending the study to include global parameters in the context of proven negative and significant relationship between Southern Oscillation Index (SOI) and the Indian northeast monsoon has been discussed. Scope for further studies on the topic has been spelt out.

Key words — Tamil Nadu, North east monsoon, Advance prediction, Correlation, Screening.

1. Introduction

In recent years considerable progress has been achieved by the scientific community in advance prediction of southwest monsoon rainfall of India (SMRI) as seen from the large number of research papers that have been published, *e.g.*, Banerjee *et al.* (1978), Joseph (1978), Mooley *et al.* (1986), Hasternath (1987), Gowariker *et al.* (1989 and 1991). Parthasarthy and Pant (1985), Parthasarthy *et al.* (1990), Bhalme *et al.* (1990), Verma (1990 and 1993), Thapliyal (1990), Thapliyal and Kulshrestha (1992) and Srivastava and Singh (1993) etc. In msot of these works SMRI has been predicted based on antecedent meteorological parameters.

Subsequent to the retreat of southwest monsoon rains from India during September-October, lower levels winds reverse direction to blow from northeast and cause an increase in rain over parts of southern peninsula, which is taken as the onset of northeast monsoon rains (Rao 1963 and India Met. Deptt. 1973). For Tamil Nadu located in the southeast part of peninsular India, this is the rainiest season contributing 47% of the annual rainfall of 1005 mm which is more than the 34% contribution of the four month southwest monsoon period thus making it as the sole Indian state

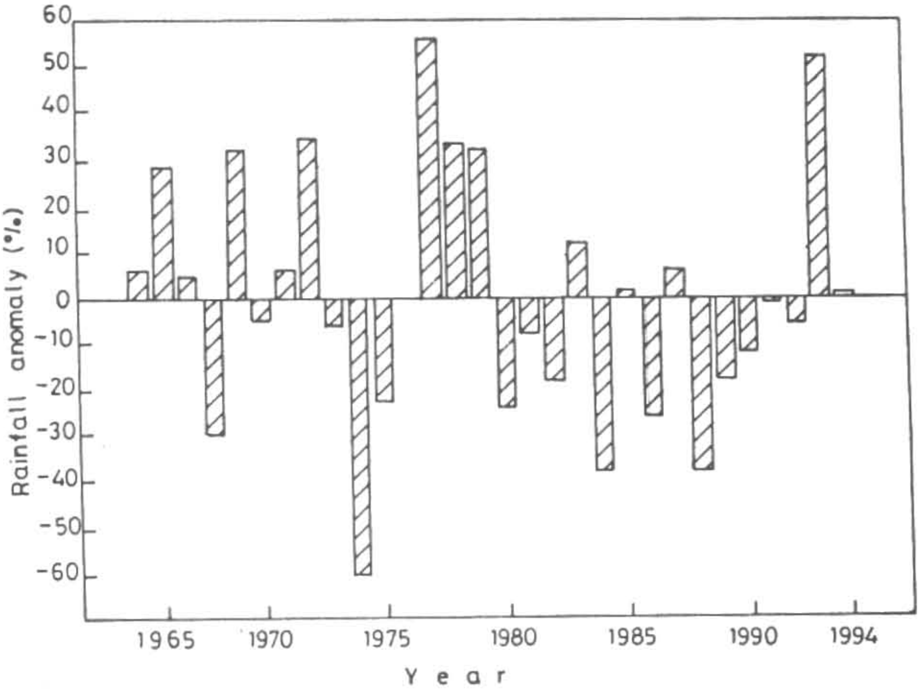


Fig.1. October-December rainfall of Tamil Nadu (as - percentage anomaly) for 1965-94

with such a seasonal rainfall pattern.The coefficients of variation of southwest and northeast monsoon rainfall are 20 and 27% respectively. (The above statistics are based on the subdivisional rainfall data supplied by India Met.Deptt., Pune). As Tamil Nadu depends substantially on the highly variable northeast monsoon rainfall for hydrological and agricultural sustenance advance prediction of northeast monsoon rainfall of Tamil Nadu (NMRT) holds importance. Besides, this is also a problem of scientific intrigue and interest.

The first study on the topic dates back to Doraiswami Iyer (1941). Subsequently in Raj (1989) and Raj *et al.* (1993), attempts were made to identify parameters with predictive value. In Raj (1989) several upper air and surface parameters of representative stations of India were screened and linear regression equations derived to predict rainfall of four subdivisions of southern peninsula including NMRT. In Raj *et al.* (1993) the upper winds of Chennai and Thiruvananthapuram were screened to develop a prediction system for the NMRT by adopting the technique of stepwise screening. A multiple regression equation with six predictors explaining 48.5% of the variation with a standard error of 18% was derived.

With the availability of increased volume of computerised data of monthly means of meteorological parameters over India carrying out a study which is much more broad based than Raj (1989) and Raj *et al.* (1993) appeared worthwhile and hence the present study. Herein the complete data pertaining to the developmental period is computerised thus ensuring error-free input data. In Raj (1989) and Raj *et al.* (1993) data of southwest monsoon season, *viz*., June - September alone were searched whereas in the present study data of April, a representative month for premonsoon circulation features, also have been included. In Raj (1989) upper air temperature and contour height were not included as possible predictors due to discontinuity in such data resulting from change of instrument design (Raj *et al.* 1987). Now, with the availability of data of more than two decades of homogeneous since 1971, inclusion of temperatures and contour heights was not deterred by a very short data series. When several predictors with significant correlation with the predictand are identified a crucial problem is the technique to be followed to obtain a final forecast. In this paper we have adopted a slightly different technique compared to the conventional ones.

The objective of the study is to arrive at an improved forecasting system for the NMRT based on the meteorological parameters of pre-monsoon and monsoon season of India.

2. Data

Table 1 gives complete details of the data collected for 10 stations, 7 isobaric levels and 5 months for the period 1965-87 taken as the developmental period. This data and that of some selected parameters for the test period 1988-94 and also rainfall data for Tamil Nadu for 1965-94 were obtained from India Met. Deptt., Pune. Fig.1 presents the time series of NMRT for 1965-94.

TABLE 1
Upper air data used in the study

Stations	AHM, BMB, CAL, DLH, HYD, MDS, MNC, PBL, TRV and VSK
Pressure levels	850,700, 500, 300, 200,150 and 100 hPa
Months	April, June, July, August and September
Parameters	Monthly means of wind, contour height and temperature
Time of observation	0000 and 1200 UTC
Period	1965-87 (Winds) 1971-87 (height and temperature)

AHM-Ahmedabad, BMB-Mumbai (Bombay), CAL-Calcutta, DLH-Delhi, HYD-Hyderabad, MDS-Chennai (Madras), MNC-Minicoy, PBL-Port Blair, TRV-Thiruvanthapuram, VSK-Visakhapatnam

3. Methodology

The monthly mean winds were resolved into their zonal and meridional components. For each station, pressure level and month there were four parameters, *viz.*, zonal and meridional winds, temperature and contour height. From this aggregate the June and July series were averaged to form a new series for June-July and similarly for August-September and June-September which is the entire southwest monsoon season. In the event of missing data inter-correlation analysis between two consecutive levels or adjacent stations was carefully employed to fill up odd gaps. On the whole, a total of 1960 series were available for further analysis.

Linear correlation coefficient (CC) between each of the above parameters and NMRT was computed based on the data of developmental period and the significance of the CC tested by the Student's t- test. The CCs thus obtained were subjected to critical evaluation and their genuineness assessed by giving due consideration to both horizontal and vertical continuity of the CCs. The noteworthy features thus identified, which showed significant antecedent relationship with NMRT, are discussed below.

The zonal 200 hPa winds of stations located south of 20° N were all positively correlated with the CCs varying between 0.4 and 0.6. The CCs were significant at 300 and 150 hPa also, though for a given station they reached the maximum at 200 hPa. After studying the inter CCs amongst the various pairs, five stations - Mumbai, earlier Bombay (BMB), Chennai, earlier Madras (MDS), Minicoy (MNC), Thiruvananthapuram, earlier Trivendrum, (TRV) and Hyderabad (HYD)- were chosen and an average series based on the five individual series was derived. This average series exhibited a CC of 0.61 with NMRT.

The April meridional winds at Ahmedabad (AHM) and Mumbai (BMB) at 150 hPa level were significantly correlated with NMRT. The average series of these two was taken as another predictor which manifested a CC of –0.50.

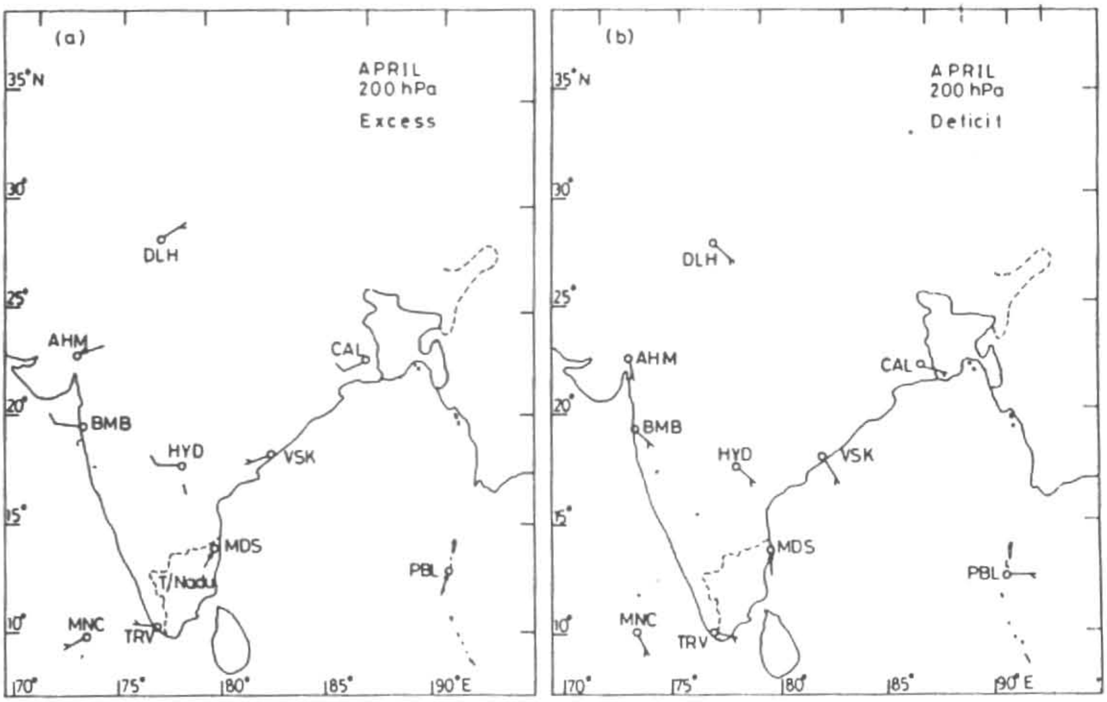
The June-September temperatures at upper tropospheric levels (between 300 and 100 hPa levels) at all the ten stations manifested good and consistent correlations. The distribution of the CCs, both horizontal and vertical, showed coherence The CCs attained maximum values at 150 hPa level of Hyderabad (HYD) and Port Blair (PBL) and so the series at that level for both stations were averaged to obtain a single series. Thus June- September HYD and PBL 150 hPa temperature was selected as another potential predictor. This parameter exhibited a CC of –0.80 with NMRT.

August 150 hPa and September 300 hPa zonal winds of TRV were selected as predictors with CCs of 0.47 and 0.49 respectively. Both the zonal and meridional winds of TRV at 850 hPa for August- September were correlated, but on detailed scrutiny it was found that it was the speed of the wind that was related rather than the direction. Thereupon the wind speed which had a CC of 0.54 was taken as a predictor.

Figs.2(a&b) present the mean anomalous April 200 hPa flow pattern for the five years of developmental period (1965-87) with rainfall in excess of 20%, *viz.*, 1966, 1972, 1977, 1978 and 1979 and for the six years with rainfall in deficit of 20%, *viz.*, 1968, 1974, 1975, 1980, 1984 and 1986. During these two sets of years the NMRT had mean values of 37 and –33% respectively. Table 2 presents the mean temperature anomalies during the deficit and excess years of 1971-87. The westerly wind and negative temperature anomalies associated with the excess years and the easterly wind and positive temperature anomalies with the deficit years clearly demonstrate the established relationship.

Statistical analysis of all the above six predictors was carried out. The time series of all the predictors were found to be trend-free, homogeneous and stationary. Table 3 provides mean, standard deviation, sample size and the CCs in respect of each of the above six predictors.

The last three predictors listed above had been identified and used albeit in a slightly different form in Raj (1994) and Raj *et al.* (1993). The first three predictors identified, *viz.*, April zonal/meridional winds and June-September 150 hPa temperatures have not been reported in Raj (1989) and Raj *et al.* (1993) as neither April data nor temperatures were



Figs. 2 (a&b). Mean anomalous April 200 hPa flow for (a) deficit and (b) excess October-December rainfall of Tamil Nadu, 1965-87. (Also shown are the geographical locations of the stations considered and that of Tamil Nadu (TN)

TABLE 2

Mean temperature anomaly (°C) over India during June-September at 150 hPa during deficit and excess northeast monsoon years (1971-87)

S.No.	Station	E	D
1.	AHM	-0.9	0.8
2.	BMB	-0.4	1.2
3.	CAL	-1.0	0.7
4.	DLH	-1.1	1.3
5.	HYD	-1.9	0.4
6.	MDS	-1.6	1.1
7.	MNC	-2.0	0.6
8.	PBL	-1.9	1.0
9.	TRV	-0.5	0.3
10.	VSK	-0.8	0.8
11.	Years	1972, 1977, 1978, 1979	1974, 1975, 1980, 1984, 1986
12.	MRPA	39%	-34%

E - Excess, D- Deficit years, MRPA- Mean rainfall percentage anomaly

TABLE 3

Predictors identified for October-December rainfall of Tamil Nadu

S.No.	Predictor	Mean	SD	CC	n	VE	Wt
1.	April zonal wind 200 hPa BMB, MDS, MNC, TRV and HYD	9.2	3.2	0.61**	23	64.3	37.7
2.	April meridional wind 150 hPa BMB and AHM	2.7	3.9	-0.50*	23	65.5	24.9
3.	June-September Temperature 150 hPa PBL and HYD	-67.6	1.3	-0.80**	17	73.0	64.3
4.	August-September wind speed 850 hPa TRV	10.3	1.2	-0.54*	23	76.0	29.9
5.	August zonal wind 150 hPa TRV	-32.9	2.6	0.47*	23	77.0	21.8
6.	September zonal wind 300 hpa TRV	-7.8	1.8	0.49*	23	77.1	23.6

Wind in m/s, Temperature in °C, n - Sample size,.SD - Standard deviation, CC - Correlation Coefficient, *** - CC significant at 1%, 5% levels, VE-Variance explained in %, Wt - Weight

considered in the previous studies. Whenever temperatures exhibited high CCs, the corresponding contour heights also did but we preferred temperature which is a directly measured parameter. Besides those listed in Table 3 there were several other parameters which exhibited significant CCs but were not taken as predictors as they were either highly intercorrelated with one of the chosen predictors or appeared spurious.

4. Final forecast

Once various predictors are identified the next step is to arrive at a final forecast. The most popular methodology is the multiple regression technique described in Panofsky and Brier (1968), WMO (1966 and 1984) and Kendall and Stuart (1968). In this paper we have followed a slightly different screening technique, taking into consideration the requirement of having to use several predictors some of which may not be available for a particular year and also the smaller size of the developmental sample. The technique is described below:

Suppose $x_1, x_2, ..., x_n$ are the n predictors and u the predictand. In the conventional regression technique we minimise the errors of u from the regression equation,

$$u = \sum_{i=1}^{n} a_i x_i + a_o \quad (1)$$

and estimate a_i's by the method of least squares. In this paper we set the equation in the form,

$$u = \frac{\sum_{i=1}^{n} r_i^2 u_i^2}{\sum_{i=1}^{n} r_i^2} \quad (2)$$

where u_i is the theoretical value of u obtained from the univariate regression equation of u on x_i. Thus the final forecast is the weighted mean of individual forecasts of several parameters the weights being the squares of the respective CCs. The screening technique normally employed in multiple regression was used here also by selecting the first best predictor and then the second best and so on. This methodology ensured that only those predictors which contributed to significant additional variation got included. The choice of the square of the CC as the weighing factor was purely based on trial and error after trying with various powers. Maximum variance got explained when the power was close to 2. Further the square of r_i is the variance explained by the parameter x_i and so is open for easy interpretation.

The above method of screening was employed in selecting the predictors. The results of the screening based on the data of 1965-87 are presented in Table 3. The last predictor TRV SEP 300 hPa zonal wind did not contribute to additional variance being explained and so the first five predictors alone were selected. The total variance explained by the system was 77% equivalent to a CC of 0.88 and yielding a 13% standard error of forecast.

For the screening based on the 1965-87 data June-September 150 hPa temperatures of PBL and HYD was the leading predictor explaining 64.3% variation and April 200 hPa zonal wind explained an additional variance of 7.4%. Together all the three new predictors identified in this paper explained 74.7% variance out of a total of 77% variance explained by all the six. The remaining three predictors (No.4, 5, 6 of Table 3) if used solely in a forecasting scheme of NMRT were found to explain 40.9% of variance. These statistics together with the direct CCs given in Table 3 clearly bring out the relative importance of the new predictors identified *vis-a-vis* the old ones.

A slight modification of the above forecasting system was also considered by adopting varying developmental periods. For example, the forecast for 1989 could be obtained on the basis of screening done over 1965-88, that for

TABLE 4

Performance of the forecasting system during 1988-94

S.No.	Year	F I	F II	A
1.	1988	-22	-22	-38
2.	1989	-21	-23	-18
3.	1990	-33	-31	-12
4.	1991	-12	-10	-1
5.	1992	11	13	-6
6.	1993	0	-2	52
7.	1994	-8	-2	1
8.	Mean error of forecast	18	18	--

F I,II - Forecasts based on fixed, variable developmental samples
F, A - Forecast, actual rainfall of October-December rainfall of Tamil Nadu as percentage departure from normal

1990 based on 1965-89 and so on. The advantage of this approach is the increasing size of developmental period with each passing year and the resulting stability of the system. However, the weights and other parameters will have to be recomputed afresh every year based on the data upto the previous year. This methodology was also employed to obtain forecasts for the period 1988-94.

5. Performance of the forecasting equation during 1988-94

The forecast values of NMRT based both on fixed and flexible developmental periods were computed as detailed in Section 4. The results are tabulated in Table 4. It is seen that the performance of the system is good for 1988, 1989, 1991 and 1994 and satisfactory in 1990 and 1992. In 1992 a large defect is predicted, whereas the realised rainfall is deficient by only 12%. In 1993 near normal rainfall is predicted though the rainfall realised is in very large excess. During 1988-94 the system has predicted with a mean error of 18%.

6. Physical reasoning

In this section we advance a possible physical mechanism that could explain the relation between the predictors identified and NMRT established by statistical techniques.

During northeast monsoon season between 500-300 hPa the southern parts of India are warmer than the northern parts and aloft 200 hPa which is the level of strongest wind speeds the southern parts are colder than the northern parts. The subtropical anticyclone reaches its peak intensity between 300 and 200 hPa and aloft this level the anticyclone has a cold core as supported theoretically from the thermal wind concept (Byers 1959 and Holton 1979) and also from observational data (India Met. Deptt. 1972).

A west wind anomaly at 200 hPa in April would imply an equatorward extension of middle latitude westerly flow or weaker upper trophosphere easterly flow. This circulation anomaly in April goes with a relatively colder upper troposphere. It would appear that such an anomaly in the thermal structure, occurring sometimes and detected in the pre-monsoon month of April, persists in such years for reasons not yet clearly understood through the southwest monsoon months into the northeast monsoon period - the culmination is an increased activity of the northeast monsoon. On the other hand, anomalous easterly flow in April (Fig. 2) seems a pre-indicator of stronger upper tropospheric easterly flow, persistent warm upper layers leading to suppressed northeast monsoon activity.

Taking a holistic view, the study appears to tie in well with the role of the anomaly of 500 hPa ridge location in April, which, over the years, has been a crucial pre-indicator of southwest monsoon performance. In other words, the atmosphere over the sub-continent seems to get perturbed into one pattern of anmalous condition and then into another, perhaps in tune with large scale regional and global variations.

Despite non-availability of a larger series and apparent untenability in some years, the present study would point to a meaningful physical linkage between sub continental and regional- cum-global anomalies and hence deserves further intensive investigation.

7. Scope for further study

For Tamil Nadu, for which long range forecast of north-east monsoon rainfall has more relevance, the studies carried out in Raj (1989) and Raj *et al.* (1993) and the present one cover most of the directly measured parameters of surface and upper air over India. Sea surface temperature over Indian seas and radiation parameters over Indian region also appear to have the potential to become predictors for NMRT in the light of Sen *et al.* (1978) and Basu and Sastry (1984) who have established similar relationship with SMRI. The well known Southern Oscillation Index (SOI) is known to be positively correlated with SMRI (Bhalme and Jadhav 1984). The CC between SOI of August-October and NMRT based on data of 1901-80 was –0.41 significant at 0.1% level establishing the negative relationship which is also open to an easy physical interpretation.Thus SOI could be a potential global predictor for NMRT also.

As for the predictors already identified a watch has to be kept on their behaviour and the relations frequently updated. Studying the concurrent relationship between NMRT and the Indian upper air temperature and winds during October-December might provide firm answers to some of the postulates posed in section 6.

With the small area of the target region and the volatile and chaotic nature of northeast monsoon during which a single depression/cyclonic storm could be the difference between an excess and deficient monsoon, achieving a level of forecast accuracy similar to the forecasts issued for the very large Indian region for the well organised south-west monsoon might not be feasible. Still it should be possible to provide a reasonably accurate outlook and also a forecast on the quantum of rainfall with some skill at the beginning of the season.

8. Summary

The results of the study are summarized below:

(*i*) The wind, height and temperature of seven standard isobaric levels of ten well distributed Indian upper air stations for the months of April, June, July, August and September were subjected to correlation analysis to detect parameters with predictive value to forecast in advance the north-east monsoon rainfall of Tamil Nadu.

(*ii*) Six predictors out of which three were completely new were identified. A final forecast of rainfall was obtained as the weighted average of the individual forecasts based on the six predictors.

The forecasting system derived explained 65-77% of variation with standard errors of 13-18%.

(*iii*) The forecasting systems thus derived were tested in an independent sample based on data of 1988-94. By and large the results were satisfactory.

(*iv*) A possible physical mechanism to explain the relation between the predictors and predictand has been advanced.

(*v*) The plausibility of studying possible relationship between global parameters and the Indian north-east monsoon has been discussed. Scope for further studies in the same topic has been spelt out.

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