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Seasonal forecast of southwest monsoon rainfall – District level

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ABSTRACT

An empirical model has been proposed for district level seasonal forecast of rainfall during southwest monsoon season. Results relating to meteorological subdivision of Tamilnadu and Pondicherry are discussed. Cloud and rainfall data for a period of 36 years (1972-2008 except 1978) have been used in the study. It has been shown that different features of cloudiness over near equatorial regions of Indian Ocean during pre-monsoon months of April and May contain signals indicating likely performance of subsequent southwest monsoon. These features have been quantified by assigning an index called South Indian Convergence Zone (SICZ) Activity Index (SAI). SAI varies from 1 to 20. Verification of the forecasts has shown that the proposed model is capable of producing **'Useful'** forecasts of seasonal rainfall for meteorological sub-division of Tamilnadu and Pondicherry and its districts.

INTRODUCTION

Southwest monsoon rainfall shows large inter-annual variability. Therefore, seasonal forecast of southwest monsoon rainfall has remained an important aspect of weather forecasting in India. Seasonal forecast of monsoon rainfall at district level, if made available, could get integrated with other inputs, like seeds, fertilizers etc and prove to be a boon in planning for agricultural operations and a number of other activities.

The first operational Long Range Forecast (LRF) of seasonal rainfall for Southwest Monsoon (SWM) season for country as a whole was issued by India Meteorological Department (IMD) on June 4, 1886 (Blandford, 1884). Since then the LRF of SWM seasonal rainfall is issued every year. Since 1989, the operational LRF is issued using parametric and power regression model (Gowariker, Thapliyal, Sarker, Mandal, and Sikka, 1989). The model utilized signals from 16 regional and global atmospheric and ocean parameters. In an effort to improve the forecast, after the failure of SWM rains in the year 2002, a revised model using 10 parameters is being used since 2003. Forecast is given for four broad homogeneous regions and the country as a whole.

An important development in seasonal forecasting of SWM rainfall was reported by Gupta and Prasad (1992,1993). They proposed a model for forecasting SWM seasonal rainfall at spatial resolutions of (i) India as a whole, (ii) meteorological sub-divisions (35 and 36 since the year 2002), (iii) temporal resolutions of two months periods of June-July, July-August and August-September and (iv) for each month of the season. The model made use of two important results relating to intra-seasonal changes in SWM circulation obtained using satellite observed cloud data from the Indian Ocean (IO) region: (i) recognition of South Indian Convergence Zone (SICZ) as an important element of SWM circulation and its, in general, inverse relationship with the activity of SWM over India (Prasad,1981,1982; Prasad, Mishra and Jain, 1983; Prasad, Rama Sastry, Hasnda and De, 1988; De, Prasad and Vaidya,1995): Intense convection in the zone of SICZ (Equator-10°S and 40°E-100° E) causes considerable reduction in the cross-equatorial flow of southeast trades in to North Indian Ocean (NIO) leading to weak monsoon conditions over India. On the contrary, when SICZ is weak and close to equator, allowing large cross equatorial flow of southeast trades into NIO, the SWM is active. The inverse relationship is seen in composite OLR patterns, for 'break' in rainfall and active rainfall spells over Indian monsoon zone as reported by several workers (De and Mukhopadhyay (2001), Gadgil and Joseph (2003), etc). The inverse relationship was found to exist between the intensity of SICZ during the pre-monsoon months of April and May (Gupta and Prasad,1991) also. (ii) A slowly northward propagating mode with a period of around 40 days (Sikka and Gadgil, 1980; Yasunari,1981). This 40-50 day oscillation in the zonal wind in tropical Pacific had been first detected by Madden and Jullien (1971). This oscillation is often referred to as Madden-Jullien oscillation.

Relationship between features of cloudiness developing over Equatorial Indian Ocean (EIO) during pre-monsoon months of April and May, and performance of SWM over India forms the basis of this new approach to seasonal forecasting of rainfall over India. Different features of cloudiness over equatorial Indian Ocean are considered to be a manifestation of the activity of SICZ . Quantifying the activity of SICZ is the most important aspect of this approach. SICZ Activity Index (SAI) and SWM seasonal rainfall in meteorological sub-divisions for a period of 16 years (1972-1989 except 1978) had been used to work out Correlation Coefficient (CCs) and regression constants (straight line) (Gupta and Prasad, 1992). It was found that the CCs were significant at 95% level in a large number of subdivisions of northwest and Peninsular India, where the rainfall variability is large. Using the regression equations, LRF of seasonal rainfall during SWM season for India as a whole and for individual sub-divisions is being prepared since 1990. The results of verification for the years 1990-1992 and 1990-1998 had been reported by Prasad (1993, 2000). Verification of the forecast for Tamilnadu and Pondicherry is given in Table 1. Grouping of the years in 'Excess', 'Normal' and 'Deficient' in Table 1 is based on the Standard Deviation (S.D.) of seasonal rainfall in the subdivision which is about 24% for the period of study. S.D. criteria has been followed in discussions of rainfall in other sections also. It may be noted from Table 1 that model was unable to forecast deficient rainfall. Forecast was good in the remaining years except that it underestimated rainfall in the excess monsoon years. Thus for the sub-division of Tamilnadu and Pondicherry forecast

Figure 1. Cluster of districts in Meteorological sub-division of Tamilnadu and Pondicherry.

Table 1. Seasonal forecast of rainfall during southwest monsoon for meteorological sub-division of Tamilnadu and Pondicherry (Regression constants : a= -1.7, b= 131.0 (after Gupta and Prasad,1992)).

Criteria of 'Useful' forecast: (i) Forecast as well as realized rainfall are in the same broad departure category of 'Excess/Normal' or 'Deficient/Scanty', (ii) criterion (i) is not satisfied but the difference between the forecast and realized rainfall is within ±15%.

		Realised		
		Excess	**Normal**	**Deficient**
Forecast	**Excess**			
	Normal	**1996**(16/51)	**1990**(19/ -16), **1991**(7/13), **1992**(4/5), **1993**(16/ -5), **1994**(17/-23), **1995**(4/6), **1997**(16/-9), **1998**(19/12) **2000**(7/2), **2001**(21/-16), **2003**(21/8), **2004**(4/-10), **2005**(4/-7), **2006**(19/-21), **2007**(21/5), **2008**(19/5)	**1999** (22/-36), **2002** (9/-46)
	Deficient			

Note: Figures in brackets refer to forecast rainfall/realised rainfall.

overestimates (underestimates) rainfall in deficient (excess) monsoon years. It may be concluded here that SAI for rainfall forecast for India as a whole, could not provide good forecast in the sub-division of Tamilnadu and Pondicherry. The aim of the present study is to improve upon the methodology so as to forecast (i) 'Deficient' and 'Excess' monsoon in meteorological sub-divisions of India and to (ii) examine the possibility of preparing similar forecasts for a cluster of districts/ districts. Tamilandu and Pondicherry has been chosen as a test case as it witnesses large variability of rainfall at district level.

2. DATA USED AND METHOD OF ANALYSIS

2.1 Rainfall

Clustering of districts, having similar rainfall characteristics was found very helpful in recent studies related to a demonstration of possibility of issuing short/medium range quantitative forecast of rainfall at a spatial resolution of a district (Lal, Singh, Prasad, Roy Bhowmik, Kalsi, and Subramanian, 2006a; Lal, Singh and Prasad, 2006b; Singh, Lal and Prasad, 2007). Attempts had been made in the past also to group the districts of Tamilnadu on the basis of mean monsoon rainfall (Krishna Rao,1953). Clustering of districts could be made on the basis of rainfall peaks occurring in different seasons. For example, rainfall is very similar, with peaks occurring in August, in the districts of Chennai, Kancheepuram and Tiruvallur. These districts have been grouped into one cluster. 29 districts of Tamilnadu and Pondicherry, an Union Territory, have been grouped into 10 clusters of districts (Fig.1). Cluster-wise seasonal rainfall during SWM season has been worked out for the period 1972-2004 and used in this study.

2.2 Satellite observed cloudiness

Satellite observed cloud data for the years 1972-1983 (except 1978 when cloud data was not available) have been obtained from satellite pictures published by U.S. Department of Commerce under 'Key to Meteorological Documentation No.14.2'. The cloud data from 1984 onwards have been obtained from satellite pictures of INSAT series of geostationary satellites. Cloud data for pre-monsoon months of April and May for a period of 36 years (1972-2008 except 1978) and for SWM season (June-September) for 24 years (1982-2004) have been used in the study. The data series have been prepared using daily 0600 UTC Visible cloud imagery. Daily cloud amounts estimates have been obtained in every 5° lat. x 5° long. boxes over the region 20°S- 20°N, 40°E-100°E. Weekly Mean Cloudiness (WMC) (% area of the box covered by clouds) has been prepared for each box. Zonal Weekly Mean Cloudiness (ZWMC) has been prepared by adding cloudiness in each box (12 such boxes from 40° E to 100° E) in each 5° lat. belt. Week No.1 starts from January 1 and week No. 52 refers to the last week of the year. The data for pre-monsoon months pertain to Week Nos. 14-22 and that for SWM for the week Nos. 23-39. Eye estimate of cloud data is not supposed to cause any serious limitations in arriving at useful conclusions as we are using the data to identify synoptic scale systems like equatorial troughs and features related to them.

3. FEATURES OF EQUATORIAL CLOUDINESS

In the technique described here, seasonal forecast of rainfall is based on recognition of certain patterns in the development of cloudiness during SWM season and their relationship with cloud patterns developing in the pre-monsoon months of April and May over EIO. The reason behind searching for the relationship is that the features of equatorial troughs (ETs) displayed during summer monsoon is believed to be a part of an oscillation in IO which may be present in pre-monsoon months of April and May also. The connecting link in the development of this oscillation, which originates in the zone of SICZ (Equ-10° S, 40°E-100° E), is believed to be Sea Surface Temperature (SST) distribution over IO (Gadgil, Rajeevan and Francis, 2007). Development of patterns in equatorial cloudiness have been studied with the help of mean and anomaly charts by clubbing 24 years(1982-2005) cloud data during SWM season and 33 years (1972-2005 excluding 1978) data for pre-monsoon months of April and May. Year-wise % departure of seasonal rainfall during SWM for the period of study (1972-2008 except 1978) is given in Table 2. Coefficient of Variation (C.V.) of rainfall in Tamilnadu is about 15% and Standard Deviation (S.D.) for the period under study is about 24%. The years have been clubbed into 3 groups, namely, 'Normal', 'Excess' and 'Deficient' based on 3 criteria of categorization of rainfall: (i) Standard Deviation (S.D.) ('Normal'- rainfall within (+/-) 1 S.D.) (ii) IMD (' Normal'- rainfall within (+/-) 19%) and (iii) Coefficient of Variation (C.V.) ('Normal', rainfall within (+/-) 15%). The number of years under 3 criteria for 3 categories of monsoon during 24 years of SWM seasons are: 'Excess'/ 'Active'(4,5,5); 'Normal'(18,16,12); and 'Deficient'/ 'Weak'(2,3,7) respectively. The terms 'Active' and 'Weak' refer to C.V. criteria. Differences, if any, between cloud features pertaining to S.D. criteria and those seen in the charts pertaining to IMD and C.V. criteria are summarized at the end of Sections 3.1.2, 3.1.3., 4.1.2 and 4.1.3.

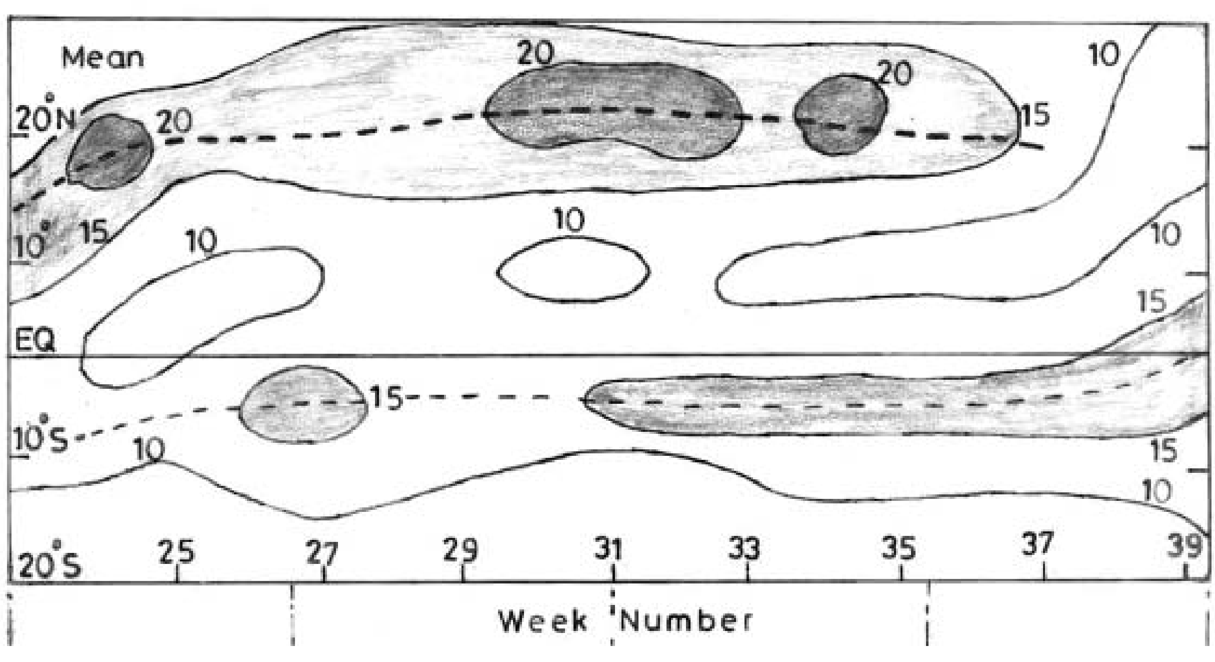

Figure 2. Mean cloudiness during southwest monsoon season.

Table 2. % departure of southwest monsoon seasonal rainfall in Tamilnadu and Pondicherry during the period of study (1972-2008 except 1978).

Category of monsoon (Range of % departure of rainfall)	Year (% departure of rainfall)
Excess Monsoon (> 1 S.D.)	1996(51), 1985(46), 1975(43), 1981(41), 1988(40), 1983(32)
Normal Monsoon (1 S.D. to -1 S.D.)	1984(24), 1979(18), 1973 (17), 1976(17), 1977(17), 1974(15), 1991(13), 1989(12), 1998 (12), 1972(10), 2003 (8), 1992(5), 2007(5), 1995(5), 2008(5), 2000(2), 1993(- 5), 2005(-7),1997(-9), 2004(-10), 1987(-14), 1982(-16), 1990(-16), 2001(-16), 1986(-19), 2006(-21),1994(-23)
Deficient Monsoon (< -1 S.D.)	1980(-30), 1999(-36), 2002(-46)

3.1. Mean Cloudiness during Southwest monsoon

In the chart of 24 years' mean cloudiness (Fig.2), a weak MCZ lies close to but south of equator. This MCZ corresponds to the presence of a weak SICZ. During June, the month of onset and establishment of summer monsoon over India, SICZ remains weak. The MCZ associated with the ET to the north of equator progressively moves northward and reaches the latitude belt of 20°N-25°N by the second half of July. Climatologically, SWM covers entire country by 15th July. Once established there, it becomes a quasi-permanent feature of SWM circulation system. This trough is more commonly known as 'Monsoon Trough (MT)' by Indian meteorologists. It is also referred to as Continental Tropical Convergence Zone (CTCZ). It remains active in this belt till the end of August. There are 3 Spells of Increased Cloudiness (SICs) (with weekly cloudiness 20% or more) in the MCZ of MT: (i) in June (for 1 week), (ii) in July-August for 3 weeks (last week of July- first week of August) and (iii) third week of August. Cloudiness in this trough zone decreases from the last week of August. Cloudiness is generally less in the belt, 5° N-10° N, which includes south Tamilnadu.

3.1.2 Mean cloudiness during 'Normal', 'Excess' and 'Deficient' southwest monsoon years

All the 3 groups of years have distinct patterns of development of equatorial cloudiness over EIO. The figures are not reproduced. The cloud features are briefly summarized here. Mean Cloud features during 'Normal' monsoon years are similar to the mean of all years (Fig. 2). There are only 2 SICs compared to 3 SICs in the mean of all years: In the years of 'Excess' SWM the zonal character of MT extending from June till the end of August is not seen. Instead there are 3 spells when MT is active. There is considerable reduction in cloudiness in MT zone , more particularly during July. South of equator, SICZ is well marked during July and August for 3 weeks in continuation. Another feature in this case is progressive northward movement of 3 MCZs from the zone of SICZ to 30°N lat.. Four important features are seen in the mean cloud chart pertaining to 'Deficient' SWM years : (i) the MCZ, associated with onset and establishment of SWM in June, develops in the zone of SIOCZ and moves to 30°N lat. in 3 weeks time which is rather fast as it takes about 6 weeks time for normal onset. (ii) SICZ is more prominent than MT for 4 weeks in continuation beginning from the last week of June, (iii) MT is weak till the end of July. Thereafter there are 2 spells of strengthening of MT for 2 weeks each. (iv) Considerable strengthening of SICZ from the second half of August till the end of the season. Cloud features were practically the same as described above in IMD as well as in C.V. criteria for all the 3 groups of years.

3.1.3 Mean cloud anomalies during 'Normal', 'Excess' and 'Deficient' southwest monsoon years

In order to gain further insight into the development of SICs and their movement during these three groups of years, yet another set of charts, obtained by subtracting mean cloudiness for 24 years' period (Fig.2) from mean cloudiness for 'Normal', 'Excess' and 'Deficient' groups of years have been prepared (Fig.3a-c). Movement of alternate Spells of Positive Cloud anomalies (SPCAs) and Spells of Negative Cloud Anomalies (SNCAs) is seen in all the four months of 'Normal' SWM years (Fig.3(a)). SNCAs are weak and short lived as compared to SPCAs during first two months. Areas to the south of equator are mainly covered by Positive Cloud anomalies (PCAs). Movement of alternate SPCAs and SNCAs is also seen in 'Excess' ' monsoon years (Fig. 3(b)). Unlike the quick northward movement of both anomalies in 'Normal' monsoon years, here the SPCAs have remained stagnated in the areas to the south of 15° N lat. for 2-4 weeks . Absolute values of Negative Cloud Anomalies (NCAs) are more than PCAs. SNCAs have moved from the zone of SICZ to 30°N lat. Development of alternate SPCAs and SNCAs is seen in 'Deficient' SWM years also (Fig. 3(c)). However, the anomalies in these years give an altogether different picture. First SPCAs quickly moves from the zone of SICZ to 30°N. Thereafter there is complete absence of northwards movement of PCAs for about 8 weeks and NCAs occupy almost the whole area of the chart. During the Second half of the season (August-September) there is a quick movement of 2 weak SPCAs. PCAs, moved both to the south and north of equator, dominate the chart during the second half of the season. Thus all the 3 groups of years have distinct patterns of development of equatorial cloudiness. The patterns remain the same under all the 3 criteria of grouping of years except that the SPCAs and SNCAs are more packed in C.V. criteria.

It follows from the description of the anomaly charts that development of spells of Cross Equatorial Flow (CEF) (seen as northward movement of SPCAs)

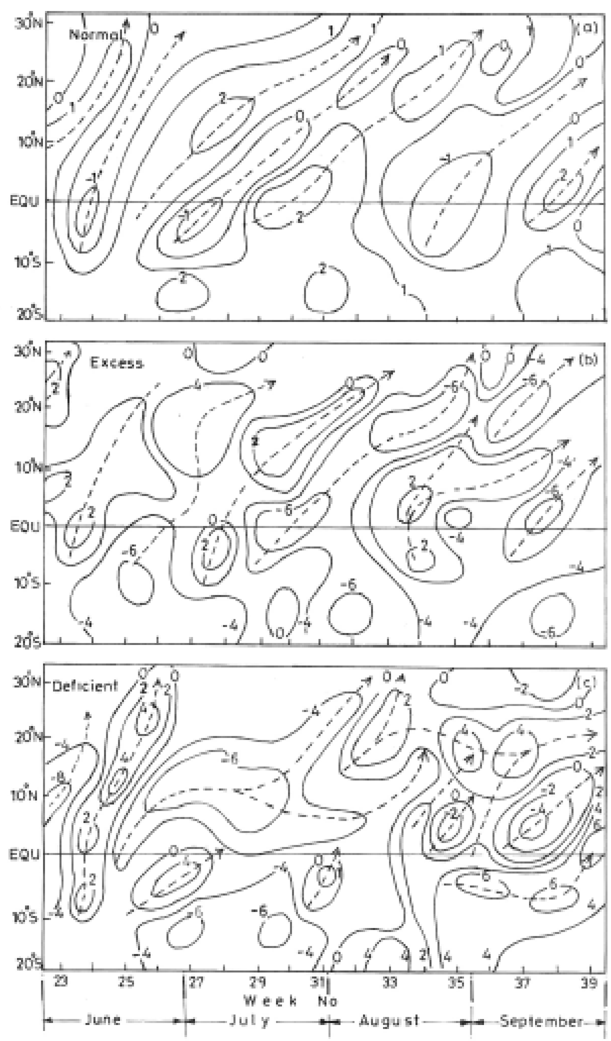

Figure 3a-c. Mean cloud anomalies during southwest monsoon, (a) 'Normal' , (b) 'Excess' and (c) 'Deficient'.

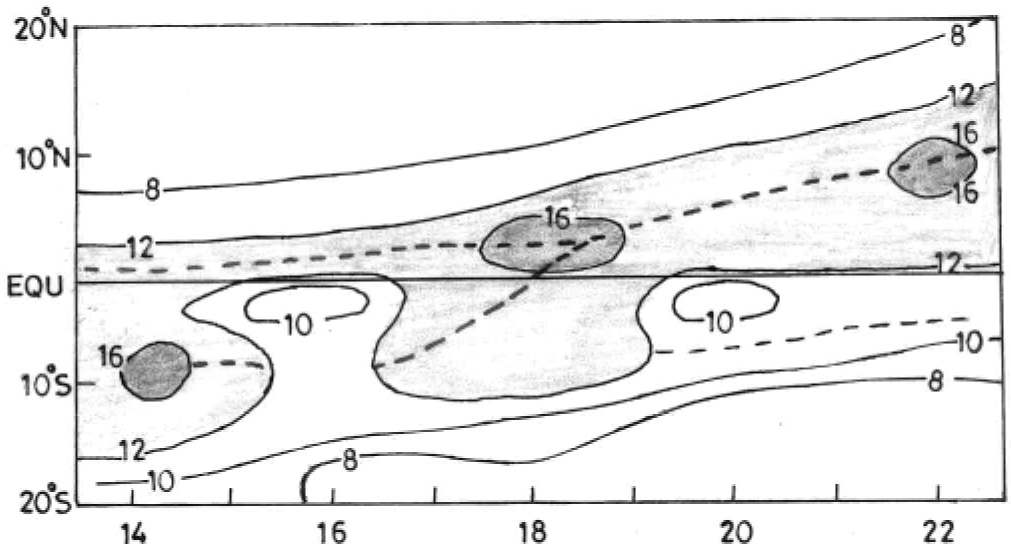

Figure 4. Mean cloudiness during pre-monsoon months of April and May.

are common to all the three groups of years. In 'Normal' monsoon years the spells are short lived and quickly move northward. In 'Excess' monsoon years they affect the areas south of 15° N lat., in which Tamilnadu and Pondicherry are located, for a longer duration. In contrast, there is a reduction in development and northward movement of CEF in the years of 'Deficient' SWM.

4. CLOUD FEATURES DURING PRE-MONSOON MONTHS OF APRIL AND MAY

As discussed above , mean cloudiness for 33 years(1972-2005 except 1978), mean cloudiness for three groups of years and anomalies obtained by subtracting 33 years' mean from the mean for 'Normal', 'Excess' and 'Deficient' monsoon years have been discussed below. The number of years in 3 criteria (S.D.,IMD and C.V.) under 3 categories of monsoon for pre-monsoon months of 33 years period are: 'Excess'/'Active'(6,7,11); 'Normal'(23,22,14); and 'Deficient'(4,4,8) respectively.

4.1 Mean cloudiness

In the mean cloudiness (Fig.4), a MCZ lies in the latitude belt, equator- 5° N, for the first 6 weeks. It starts moving northward and reaches the latitude belt 5° N -10° N by the end of May. In addition a MCZ also lies to the south of equator, in the lat. belt 5° S-10° S, during the first 4 weeks. It then moves northward and merges with the one to the north of equator during the 5th and 6th weeks. Thereafter only a trace of the MCZ to the south of equator is seen during the next 2 weeks. Thus both ETs are present in near EIO during pre-monsoon months and the one to the south weakens considerably during the last 3 weeks of May.

4.2 Mean cloudiness during pre-monsoon of 'Normal', 'Excess' and 'Deficient' southwest monsoon years

All the 3 groups of years have distinct pattern of development of cloudiness in the near EIO. The figures are not reproduced. The main feature of the mean cloudiness for 23 'Normal' monsoon years is the presence of a MCZ on either side of the equator. The one to the south of equator lies in the lat. belt 5° S-10°S from week No. 14 to 19 and weakens thereafter. The MCZ to the north of equator extends from week No.16 to 22. It moves from close to equator to the lat. belt 5°N-10°N by the end of May. In the mean cloudiness for 6 years of 'Excess' monsoons, there is only one MCZ to the north of equator between equator and 5° N lat. from week No. 14 to 19. It moves northward and reaches the lat. belt 10° N-15° N lat. by the end of May. In the mean cloudiness for 3 years of 'Deficient' monsoons, a MCZ is practically absent on either side of equator during the first 3 weeks. A MCZ develops to the south of equator in week No. 17, weakens in the subsequent week and develops again to the north of equator. It becomes prominent during the subsequent weeks and reaches the lat. belt 10° N – 15° N by the end of May. MCZ remaining close to equator for 4 weeks, in continuation, is a feature of pre-monsoon cloudiness during 'Deficient' monsoon years. Cloud features are practically the same as described above in IMD and C.V. criteria also.

Absence of a MCZ in the zone of SICZ during the pre-monsoon months of 'Excess' SWM would suggest that Cross Equatorial Flow (CEF) gets established in the near equatorial regions of NIO from the beginning of April and it is sustained during the entire pre-monsoon period. In the years of 'Deficient' monsoon, CEF is practically absent during April. CEF develops at the end of April/beginning of May. Its northward progress is sluggish and it remains confined to areas of NIO up to 10° N lat. only. In the years of 'Normal' monsoon, CEF develops from the second half of April. Though 3 spells of CEF develop till the end of May, the spells are weak, short lived and their northward movement is sluggish.

4.3 Mean cloud anomalies during pre-monsoon of 'Normal', 'Excess' and 'Deficient' southwest monsoon years

All the 3 groups of years have distinct patterns of development of cloudiness in the near EIO during the pre-monsoon months also as was the case during southwest monsoon. Fig. 5(a) shows mean cloud anomalies during 'Normal' monsoon years. There are 2 SNCAs with a very weak SPCAs in between. Another weak SPCAs is seen close to equator and mainly to the south of it during the last 2 weeks of May. First SPCAs develops in the last week of April and moves up to the lat. belt 5°N-10°N during the next 3 weeks. It shows weakening in the second week. Areas to the south of equator are covered by a weak SPCAs from the third week of April onwards. Mean cloud anomalies for 'Excess' monsoon years

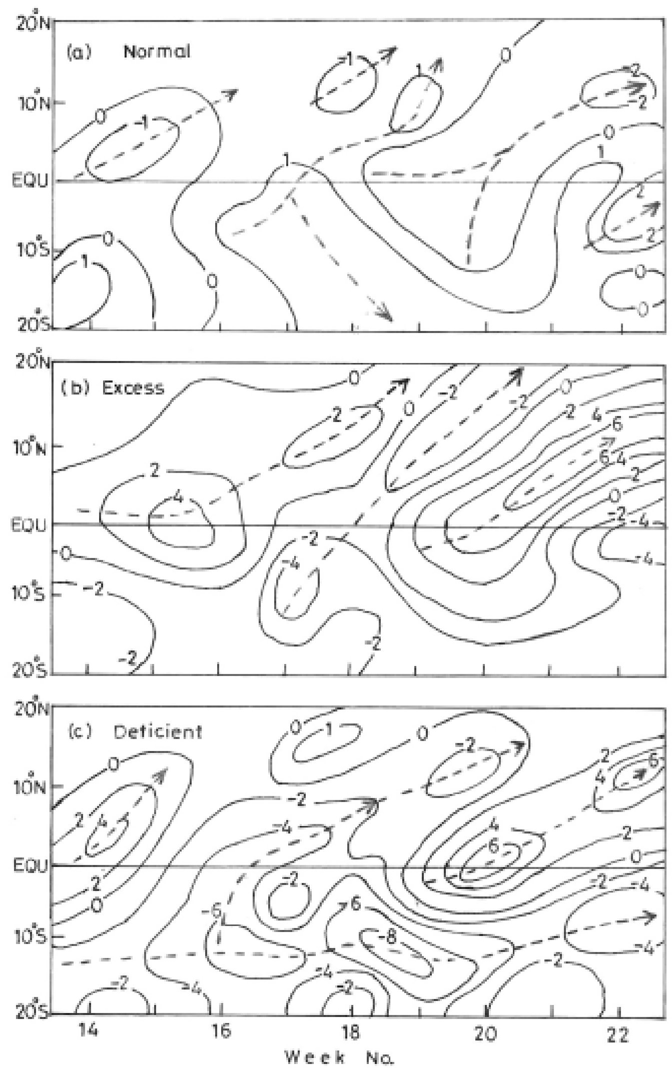

Figure 5a-c. Same as Fig. 3 but for pre-monsoon months of April and May.

are given in Fig. 5(b). There are two prominent SPCAs with a short lived SNCAs in between them. Both type of anomalies move up to 20° N. First SPCAs shows slight weakening in the third week of April. In the years of 'Deficient' SWM (Fig.5(c)) also there are 2 SPCAs and 1 SNCAs. However, the SNCAs is very prominent and dominates the anomaly chart. First SPCAs is short lived (for 2 weeks only) and confined to areas below 10° N. Second SPCAs develops in the zone of SICZ in the first week of May, moves northward and reaches up to the lat. belt 10° N- 15° N. by the end of May. Cloud features are practically the same as described above in IMD and C.V. criteria also except that SPCAs to the south of equator are more marked in C.V. criteria compared to that in S.D. and IMD criteria.

It follows from the discussions above that pre-monsoon cloudiness over the near EIO displays distinct patterns of development during 3 different groups of years of SWM: (i) development of strong CEF during April and May of 'Excess' monsoon years, which reaches up to 20° N. In addition these spells affect areas to the south of 15° N lat. for longer durations. (ii) development of weak CEF which could reach up to 10° N only till the second half of May in the years of 'Deficient' monsoons. In addition, active SICZ is present for 3-4 weeks, in continuation, in these years. (iii) Weak CEF which could quickly move up to the lat. belt 10° N- 15° N lat. in the years of 'Normal' monsoons.

Discussions under Sections 3 & 4 have shown that the cloud features seen during 3 groups of years, namely, ' 'Excess', 'Normal' and 'Deficient' during SWM season were also present in near equatorial regions of EIO during pre-monsoon months of April and May. In other words, one may say that the annual oscillation of ETs which brings SWM over Indian sub-continent starts developing in pre-monsoon months in the near EIO. Thus, the pre-monsoon features of equatorial cloudiness contain signals about likely performance of SWM. How these signals have been used to develop a model for seasonal forecast of rainfall for meteorological sub-division of Tamilnadu and Pondicherry, its cluster of districts/districts is discussed in the following sections.

It may be mentioned here that the purpose of grouping of years in 'Excess'/'Active', 'Normal' and 'Deficient'/'Weak' under 3 different criteria, i.e., S.D., IMD and C.V. in discussions above was to demonstrate, using a reasonably long period of data, that the patterns of development of cloudiness in one group of years is different from the other two groups in all the 3 criteria. It may be noted that the features of 'Excess' and 'Deficient' monsoon were brought out more clearly in the charts pertaining to S.D. criterion as compared to IMD and C.V. criteria. S.D. criterion alone has been followed in discussions below.

5. SOUTH INDIAN CONVERGENCE ZONE (SICZ) ACTIVITY INDEX (SAI)

Had the cloud data been available for a large number of years, say 100 years or so, then there was every likelihood of a previous anomaly chart being available which could be used as an analogue and the rainfall of that year as the forecast for the given year. Since the cloud data are limited in temporal extent, there is a necessity to quantify them (by assigning an Index) so that correlations and regression constants between the index and the seasonal rainfall could be worked out. Looking into the important role played by SICZ in the development of summer monsoon and its different phases, the index has been named as SICZ Activity Index (SAI). During the period of study, the highest value of rainfall (51% above normal) was recorded in the year 1996 and the lowest rainfall (46 % below normal) in the year 2002. Thus the

Table 3. SAI Nos., corresponding range of % departure of rainfall and numbers of years (in bracket), for which pre-monsoon anomaly chart was available during the period 1972-2008 except 1978.

SAI	1	2	3	4	5	6	7	8	9	10
Range of rainfall	⩾ 50– 46 (2)	45– 41 (2)	40– 36 (1)	35– 31 (1)	30– 26 (-)	25 – 21 (1)	20 – 16 (4)	15 – 11 (4)	10– 6 (2)	5– 1 (5)
SAI	11	12	13	14	15	16	17	18	19	20
Range of rainfall	0– -4 (-)	-5 – -9 (3)	-10– -14 (2)	-15– -19 (4)	-20– -24 (1)	-25– -29 (-)	-30– -34 (1)	-35– -39 (2)	-40– - 44 (-)	-45-- ⩽-49 (1)

period of study covers a fairly large range of rainfall departures. SAI values have been also ranked in a graded way in 20 ranges considered appropriate to accommodate important features of equatorial cloudiness for the range of rainfall departure (from 50 % above normal to 50% below normal). Difference of one SAI number, therefore, represents a difference of 5 % of rainfall departure. SAI number with respective range of % departure of rainfall and number of years for which anomaly charts were available for each range, during 36 years period(1972- 2008 except 1978) for which pre-monsoon cloud data are available, are included in Table 3. Salient cloud features of 'Excess', 'Normal' and 'Deficient' groups of years, helpful in arriving at SAI index, are summarized below.

5.1 'Excess' southwest monsoon (SAI: 1-6)

The following salient cloud features have been found to occur during pre-monsoon months of 'Excess' monsoon years:

(i) Development of 2-3 spells of PCAs and NCAs which originate close to equator and move northward up to 10° N-20° N lat..

(ii) The absolute value of PCAs are smaller than NCAs.

(iii) SPCAs affect areas south of lat 15° N lat. for longer duration compared to that in 'Normal' monsoon years.

(iii) SNCAs are more prominent than SPCAs.

(iv) Development of SICZ for a period of 3-4 weeks in continuation either in the latitude belt equ-10°S or further south not showing any movement. Appearance of this feature, which generally occurs in addition to the above mentioned features, shows intensification of SICZ. This feature repeats during the SW monsoon season also and thereby weakens SWM circulation and results in reduction in rainfall. As per the inverse relationship between SAI and rainfall, this features is accounted for by suitably increasing SAI number.

In the year 1975 (rainfall 43% above normal) there were 3 prominent SPCAs and 2 weak SNCAs. Last 2 SPCAs reached up to 20° N lat. (Fig.6(a)). SPCAs developed either in the zone of SICZ or to the north of it. The last SPCAs showed a tendency to stay for a longer duration in the lat. belt 10°N-15°N, as it has already stayed there for 2 week till the end of May and was still moving northward. The second lowest value of SAI index ,i. e., 2 was assigned to the cloud features in this year. In the year 1983 (rainfall 32% above normal) there were 3 SPCAs/ SNCAs (Fig.6(b)). Second SNCAs was very weak. April SPCAs moved to the north as well as south of equator. Presence of PCAs and NCAs for 3-4 weeks, in continuation, was also seen. A value of 4 was assigned to SAI index in this year.

5.2 'Normal' southwest monsoon (SAI: 7-15)

The following salient cloud features have been found to occur during pre-monsoon months of 'Normal' monsoon years:

(i) Development of 2 SPCAs. First spell is more prominent. The first spell generally develops from second half of April and continues up to the first half of May.

(ii) The MCZ associated with the first SPCAs progressively moves northward and reaches the latitude belt of 15° N-20° N. The MCZ associated with the second SPCAs reaches the latitude belt 10° N-15° N by the end of May.

(iii) Development of 2 SNCAs. In some years there is only one SNCAs. The MCZ associated with them also move northward and reaches up to 20°N lat.. In some years the northward movement is sluggish.

(iv) Feature No. (iv) as seen in some 'Excess' monsoon years, is seen in some of the 'Normal' monsoon years also.

Cloud anomaly chart for the year 1973 (rainfall 17% above normal) is given in Fig.6(c). There were 2 SPCAs and 2 SNCAs. First SPCAs was prominent. It developed in the second half of April and MCZ associated with it moved up to 20° N. lat.. Second SPCAs developed in the second half of May and was confined to areas below 10° N lat. by the end of May. Out of 2 SNCAs, May anomaly was prominent and this also moved up to 20° N lat.. SAI index assigned to these features is 7. Rainfall was 17% above normal in 1976 and 1977 also. Cloud anomaly charts in these 2 years were very similar to that in 1973. This points towards possibility of preparing a model/mean anomaly chart for each SAI No., as and when sufficient data become available. This may greatly facilitate assigning SAI index. In the year 1992 (rainfall 5% above normal) (Fig.6(d)), there were 3 prominent SNCAs which moved from close to but north of equator to 20° N lat.. There was practically only one SPCAs in May as the SPCAs in April was very weak. In addition, areas to the south of equator were dominated by PCAs in which a period of 3-4 week could also be seen. A value of 9 was assigned to SAI index. in this year. In the anomaly chart for the year 1986 (rainfall 19% below normal) (Fig. 6(e)) there was only one spell of both PCAs and NCAs. Appearance of a period of 3-4 weeks in

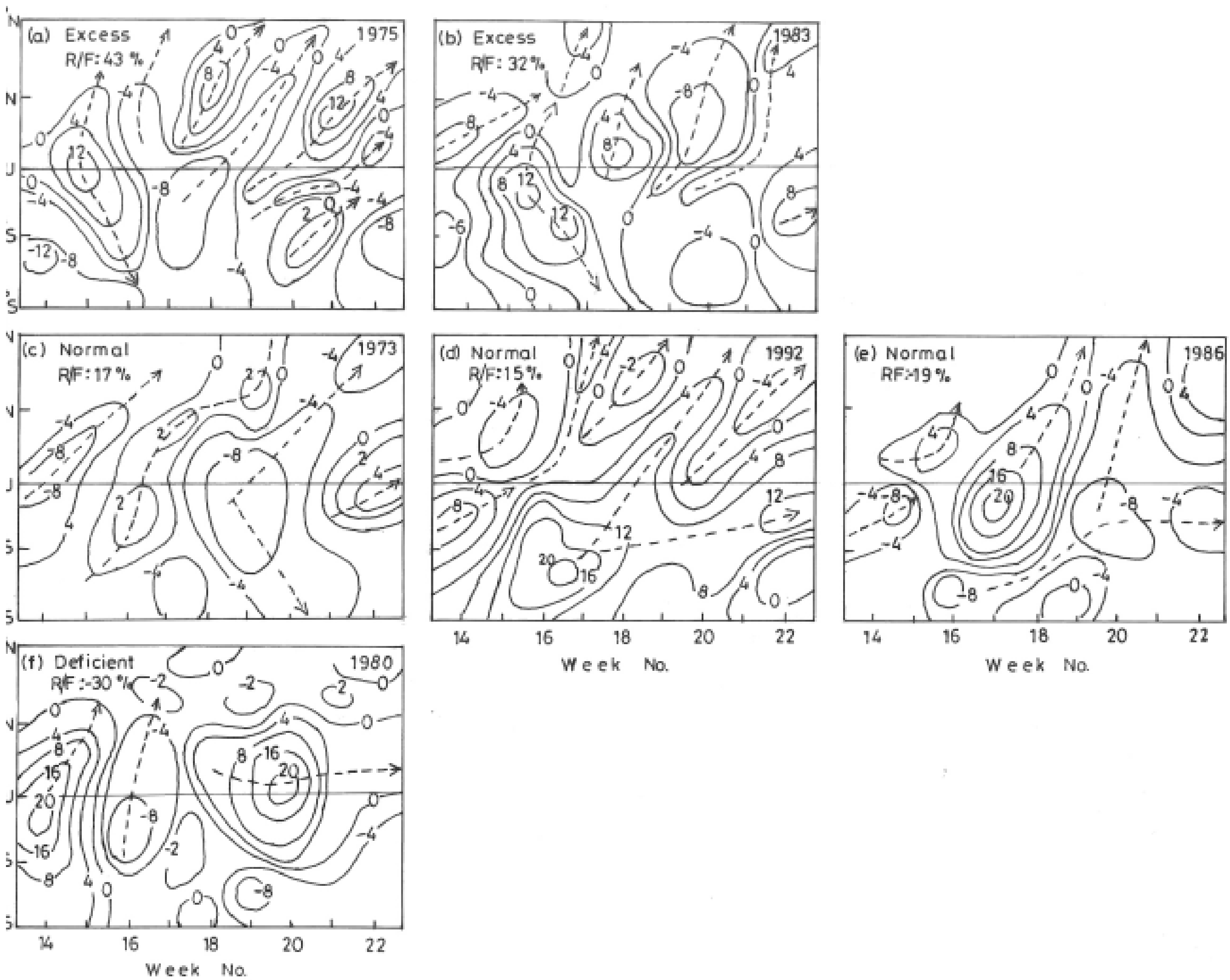

Figure 6a-f. Cloud anomalies during pre-monsoon months of "Excess' monsoons (a) 1975 and (b) 1983; 'Normal' monsoons (c) 1973, (d) 1992 and (e) 1986; and 'Deficient' monsoon (f) 1980.

continuation, was seen in both anomalies. However both anomalies showed movement to the north up to 20° N lat.. A value of 14 was assigned to SAI index in this year.

5.3 'Deficient' southwest monsoon (SAI: 16-20)

The following salient cloud features have been found to occur during pre-monsoon months of 'Deficient' monsoon years:

(i) Development of 2 -3 Spells of PCAs and NCAs. The MCZ associated with SPCAs moves northwards. In some years the PCAs move from the zone of SICZ in both hemispheres simultaneously.

(ii) In some years northward/southward movement of MCZ associated with SPCAs is absent. Instead MCZ stagnates in the equatorial regions for 2 to 4 weeks, in continuation. This is common in several 'Deficient' monsoon years.

(iii) Development of 2 SNCAs. In some years there is only one. The minimum cloud zone associated with SNCAs moves northward and reaches up to 20° N lat. In some years the northward movement is sluggish.

(iv) Feature and (v) as noted in 'Normal' and 'Excess' monsoon years is generally present in 'Deficient' monsoon years.

Cloud anomaly chart for the year 1980 (rainfall 30% below normal) is given in Fig.6(f). There were 2 SPCAs: one in the beginning of April and another from the beginning till the end of May. The MCZ associated with the first spell moved from equator to 10° N lat. and up to 20° S lat. in the South Indian

Ocean. The second spell remained active between 10° S and 10° N for 4 consecutive weeks in May. The sluggish movement northward seen in April was suppressed in May. There was a SNCAs in between the two SPCAs. It also remained confined to areas between 10° N and 10° S. Both features, i.e., Sluggish northward movement of SPCAs and appearance of a period of 4 weeks in continuation in the activity of ETs were indicative of severe deficiency of rainfall. A value of 16 was assigned to SAI index in this year.

It could not be possible to include description of cloud features for every year of the period of development of the model. Initially assigned values of SAI index have been included in Table 4. How the most appropriate value of SAI index for a year has been arrived at, starting from the initially assigned values, is discussed below.

Table 4. Rainfall, SAI No., mean, S.D., correlation coefficients and regression constants.

Year	% departure of rainfall and category of monsoon (Table 3)		SAI values			
			Set 1	Set 2	Set 3	Set 4
1972	10	'N'	8	8	9	9
1973	17	'N'	7	7	7	7
1974	15	N	7	7	7	7
1975	43	'E'	2	2	2	2
1976	17	'N'	7	7	9	7
1977	17	'N'	8	8	8	8
1979	18	'N'	6	7	8	7
1980	-30	' D'	16	15	15	17
1981	41	'E'	3	4	4	3
1982	-16	'N'	18	16	15	14
1983	32	'E'	4	4	3	4
1984	24	'N'	5	6	6	6
1985	46	'E'	2	3	3	3
1986	-19	'N'	14	14	13	15
1987	-14	'N'	14	14	13	14
1988	40	'E'	2	3	3	3
1989	12	'N'	2	5	7	9
1990	-16	'N'	13	9	13	13
1991	13	'N'	13	8	8	8
1992	5	'N'	9	9	9	9

Mean and S.D. (rounded off to nearest whole number) of rainfall departures and SAI Nos.

	'N'	'E'	'D'	'N'	'E'	'D'	'N'	'E'	'D'	'N'	'E'	'D'	'N'	'E'	'D'
Mean	6	40	-30*	9	3	16*	9	3	15*	10	3	15*	10	3	17*
S.D.	15	5	-	4	1	-	3	1	-	3	1	-	3	1	-

		Set 1	Set 2	Set 3	Set 4
Correlation Coefficient		-.91	-.93	-.97	-.99
Regression Constants	a=	-3.95	-5.06	-5.38	-5.04
	b=	144.26	152.26	156.93	154.38

* only one value

6. CORRELATION BETWEEN SAI AND SOUTHWEST MONSOON SEASONAL RAINFALL

Using the initially assigned values of SAI index, Set 1 . in Table 4, Correlation Coefficients (CCs) have been worked out between SAI and seasonal rainfall. CC was high (> .9). In order to find the best fit (straight line) between SAI and rainfall, 3 more sets of SAI index were tried . Differences between computed and realized rainfall for different sets of SAI index are given in Table 5. It may be noted that CCs are high (!CC! > .9) for all sets of SAI index. The best fit SAI index in Set 4 differ from the Set 1 index only in a few years. This shows that the initially assigned SAI index were in order. Since the same SAI index are to be used for computing forecast for the cluster of districts/districts also, it is necessary that they give good forecast for the sub-division's rainfall. Table 6 includes CCs for 10 clusters of districts obtained using the best fit SAI index (Set 4). CCs are significant at 99% level (!CC! > .56) in all other clusters except Cluster Nos. 6 and 10. Hereafter, values of SAI index referred to in the text are those given in Set 4 in Table 4.

7. REGRESSION EQUATIONS

Regression constants for the sub-division of Tamilnadu and Pondicherry are given in Table 4. Using these constants seasonal rainfall has been computed and the % departure of rainfall for 4 sets of SAI indexes reproduced in Table 5. Differences between computed and realized rainfall pertaining to

Table 5. Realized seasonal rainfall (% departure from normal) and their differences (computed -realized) for different sets of SAI for Tamilnadu and Pondicherry.

Year	Realized Rainfall	Differences (computed-realised) of rainfall for different sets of SAI values			
		Set1	Set2	Set3	Set4
1972	10	3	2	-2	-1
1973	17	0	0	2	2
1974	15	2	2	4	4
1975	43	-7	-1	3	1
1976	17	0	0	-9	2
1977	17	-4	-5	-3	-3
1979	18	2	-1	-4	1
1980	-30	11	6	6	-1
1981	41	-5	-9	-6	-2
1982	-16	-11	-13	-8	0
1983	32	-4	0	9	2
1984	24	0	-2	1	0
1985	46	-10	-9	-5	-7
1986	-19	8	0	6	-2
1987	-14	3	-5	1	-2
1988	40	-4	-3	1	-1
1989	12	24	15	-4	-3
1990	-16	9	23	3	5
1991	13	-20	-1	1	1
1992	5	4	2	3	4

Table 6. Correlation coefficients and regression constants (pertaining to the best fit SAI values of Set 4 (Table 4)) for clusters of districts/districts.

Cluster No.	Name of districts	Correlation coefficients	Regression Constants (Straight line)	
			a	b
1	Chennai, Kancheepuram,Tiruvallur	-.76	-4.69	136.01
2	Tiruvannamalai, Vellore, Villu puram	-.72	-4.25	136.98
3	Cuddalore, Nagapattinam, Tiruvarur, Pondicherry	-.84	-4.10	141.91
4	Salem, Namakkal, Dharmapuri	-.77	-4.00	131.82
5	Karur,Pudokottai,Perambalur,Tiruchirapalli, Tanjavur	-.81	-4.07	134.94
6	Coimbatoe, Erode	-.50	-8.82	342.36
7	Madurai,Theni,Virudhunagar,Dindigul,Sivganga	-.70	-3.15	138.75
8	Nilgiris	-.53	-3.49	141.40
9	Ramanathpuram, Tirunelveli, Tuticorin	-.57	-4.65	146.58
10	Kanyakumari	-.35	-3.54	138.24

Table 7. Difference between computed and realized rainfall in different clusters for best fit SAI Nos. (SAI Set 4 of Table 4).

Year	No. of clusters with computed - observed rainfall within ±					Percentage of 'Useful' forecast (Criteria (i)+(ii))
	10%	11 to 15%	15%	16 to 20%	>20% or <-20%	
1972	6	1	7	-	3 (2*)	90
1973	8	1	9	-	1 (1*)	100
1974	6	-	6	1(1*)	3(2*, 1**)	100
1975	7	1	8	-	2(1*, 1**)	100
1976	1	2	3	1(1**)	6(2*, 1**)	70
1977	4	2	6	1(1**)	3(1*)	80
1979	3	2	5	1(1*)	4(1*, 2**)	90
1980	4	2	6	2(2*)	2(2^^)	100
1981	3	3	6	-	4(4**)	100
1982	3	3	6	2	2(1*)	70
1983	3	2	5	1(1*)	4(3*, 1**)	100
1984	2	3	5	3(2*,1**)	2(2*)	100
1985	4	2	6	-	4(3*,1**)	100
1986	3	3	6	2	2(1**)	70
1987	3	4	7	2	1	70
1988	4	4	8	1(1*)	1(1**)	100
1989	5	-	5	1(1*)	4(4**)	100
1990	3	1	4	1	5(1*,1**)	60
1991	3	3	6	1(1*)	3(2**)	90
1992	2	1	3	-	7(5**)	80
Mean++	4	2	6	1	3	90

* Forecast and realized rainfall, both under category 'Excess/Normal' but difference is positive.
** Forecast and realized rainfall, both under category 'Excess/Normal' but difference is negative.
^ Forecast and realized rainfall, both under category 'Deficient' but difference is positive.
^ ^ Forecast and realized rainfall, both under category 'deficient' but difference is negative.
++ Rounded off to the nearest whole number

the best fit SAI indexes (Set 4) have been reduced considerably as compared to those obtained using SAI numbers worked out for forecasting rainfall for the country as a whole, and also used for Tamilnadu and Pondicherry (Table 1). Regression constants for different clusters of districts are given in Table 6. For examining the differences between computed and realized rainfall in the clusters of districts/districts, the differences have been grouped into 5 (Table 7). It follows from Table 7 that criterion (i) of 'Useful' forecast (Table 1) was satisfied in 6 (60%) or more clusters in 13 (65%) years. Criteria (i) and (ii) together were satisfied in 70% or more clusters in the remaining 7 years. Thus the computed rainfall was in the **'Useful'** category in 70% or more clusters in all the years of model development, except in 1990.

8. VERIFICATION OF FORECAST

The forecast technique has been verified using data for 16 years period (1993-2008) for the sub-division and 2 districts, namely, Nilgiri and Kanyakumari. Rainfall data available under District Rainfall Monitoring Scheme (DRMS) of IMD have been used for the years 2005-2008. 12 years (1993-2004) data have been used for verification in 8 clusters of districts, as cluster-wise data was available up to the year 2004 only.

8.1 SAI index during period of verification

Cloud anomaly chart for the year 1996 (rainfall 51% above normal) (Fig.7(a)) shows (i) development of 3 SPCAs (in March end/April beginning, April end/ May beginning and in the second half of May), (ii) 3 SPCAs were interspersed by 2 SNCAs (iii) while SPCAs originated close to equator/ north of it, the SNCAs originated in the zone of SIOCZ (iv) anomalies developing in March end/April beginning and April end took 2-3 weeks time to reach 20° N lat.. The third SPCAs reached up to 15°N lat. by May end. (v) the absolute values of PCAs were small (1 to 6) compared to NCAs (1 to 15). (vi) May SNCAs was more prominent than the spell in April (vii) First SNCAs reached up to 5° lat. and the second one reached up to 20° N. All cloud features mentioned here were indicative of an 'Excess' monsoon. The lowest value of SAI index (=1) was assigned to the cloud features in this year. In the year 2000 (rainfall 2% above normal) (Fig. 7(b)), there were 2 SPCAs in April and none in May. The first SPCAs was prominent. Both showed northward movement. Second spell was weak. Increased PCAs seen in the lat. belt 15° N -30° N were associated with a trough in zonal westerlies which affected north India in May. S-N oscillation was absent in May. The portion of the chart south of equator was dominated by PCAs in which development of a period of increased activity of SICZ for 4 weeks in continuation, was also seen. Features in April, indicative of 'Normal' monsoon, were masked by the developments in May. This indicated reduction in rainfall. Accordingly a value of 10 was assigned to SAI index in this year. Cloud anomaly chart for the year 2002 (rainfall 46% below normal) is given in Fig. 7(c). There were 2 Spell of PCAs and NCAs. The second SPCAs developed for 4 weeks in continuation, from April end in the zone of SICZ. PCAs showed movement to the south as well as to the north. South of equator it reached up to 20° S lat.. To the north of equator it was mainly confined in the areas between equator and 10° N lat.. It did move up to 20°N but as a very weak spell. First SNCAs developed for 3 consecutive weeks

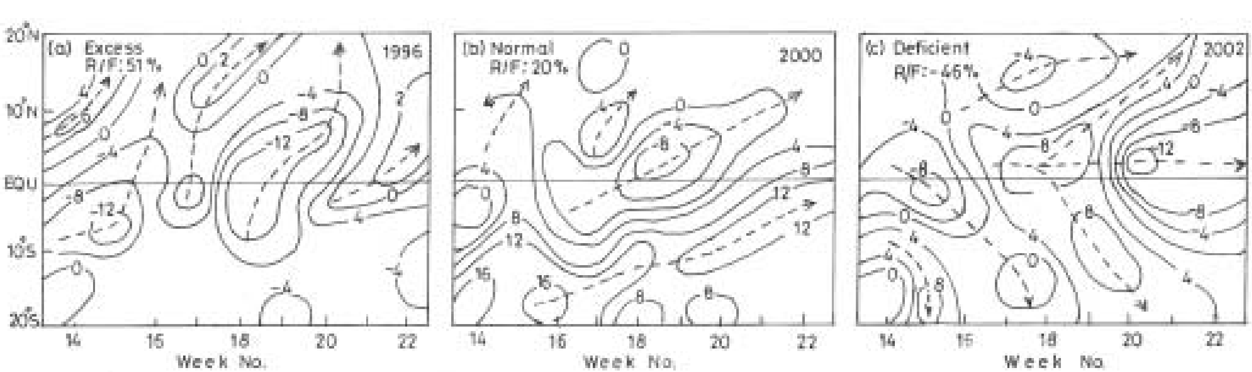

Figure 7a-c. Same as Fig. 6 but for 'Excess' monsoon (a) 1996; 'Normal' monsoon (b) 2000 and 'Deficient' monsoon (c) 2002.

Table 8: Same as Table 1 but for forecast for the years 1993-2008 based on re-assigned values of SAI.

		Realised		
		Excess	Normal	Deficient
Forecast	Excess	**1996**(49/51)		
	Normal		**1993**(-6/ -5), **1995**(4/5), **1997**(-11/-9), **1998**(14/ 12), **2000**(4/2), **2001**(-11/-16), **2003**(9/5), **2004**(-6/-10),**2005**(-11/-7), **2006**(-21/-21), **2007**(9/7),**2008**(9/5)	
	Deficient			**1999** (-36/-36) **2002** (-47/-46)

Note: Figures in brackets refer to forecast rainfall/realised rainfall.

Table 9: Same as Table 7 but for forecast verification period of 1993-2004

Year	SAI	No. of clusters with difference (computed-observed) of rainfall lying within ±					% of 'Useful' Forecast
		10%	11% to 15%	15%	16% to 20%	>20% or <-20%	
1993	12	7	1	8	1	1(1*)	90
1994	16	2	1	3	2(1*, 1**)	5(1*,3**)	90
1995	10	5	1	6	-	4(1*, 3**)	100
1996	1	1	1	2	2(1*, 1**)	6(5*, 1**)	100
1997	13	7	1	8	-	2(1*,1**)	100
1998	8	4	-	4	-	6(6**)	100
1999	18	3	2	5	1(1^ ^)	4(1*, 1**)	80
2000	10	3	1	4	-	6(1*,5**)	100
2001	13	1	1	2	1(1*)	7(1*,3**)	70
2002	20	2	2	4	1(1**)	5(1**,1^,1^ ^)	80
2003	9	2	1	3	-	7(3**)	60
2004	12	-	3	3	1(1*)	6(1*, 4**)	90
Mean++		3	1	4	1	5	88

++ Rounded off to the nearest whole number

in the beginning of April in the zone of SICZ. NCAs remained confined to the areas 5° lat. either side of the equator. The second SNCAs developed for 3 consecutive weeks from the second week of May. This spell was prominent and remained confined to the areas within 10° lat. on either side of the equator. Development of spells of PCAs and NCAs for 3-4 weeks, in continuation, has been found to be a signal of severe drought. Added to that the anomalies had a tendency to move south of equator, a feature just opposite to the feature of movement of PCAs to the north of equator seen in 'Excess' and 'Normal' monsoon years. They were indicative of considerable reduction in CEF during SWM season. Accordingly the highest index of SAI, i. e., 20 was assigned to these cloud features. It is interesting to compare the cloud features for SAI index 1 , 10 and 20. Assigned SAI index for the period of verification have been given in Table 9. It could not be possible to include discussions on assigning SAI index in other years due to lack of space. It may be mentioned here that no serious difficulty was faced in assigning SAI indexes as development of cloud features were covered by the salient features discussed in Section 5.

8.2 Forecast for meteorological sub-division of Tamilnadu and Pondicherry

Realized and forecast rainfall for meteorological sub-division of Tamilnadu and Pondicherry are given in Table 8. There is a significant improvement in the forecasts as compared to those given in Table 1. This could be possible by arriving at a new set of SAI index as discussed above. This has further demonstrated that there could be a set of SAI index (1-20), appropriate for a given meteorological sub-division, and that the same could be arrived at by studying the cloud and rainfall data for a sufficiently long period of time.

8.3 Forecast for clusters of districts

Results of comparison of forecast rainfall computed using the regression equations for clusters of districts/ districts with realized rainfall is reproduced in Table 9. On an average forecast rainfall was within 15% of the realized rainfall in 4 (40%) clusters and in some years it was within this limit in as many as 8 (80%) clusters. If we consider the first criterion of 'Useful' forecast, i.e., ' forecast and the realized rainfall both should be in the broad category of 'Excess'/ 'Normal' or 'Deficient', then the forecast comes in the 'Useful' category in 88% clusters and it ranges from 6 (60%) to 10(100%) clusters in some of the years. Performance of the model in individual clusters of districts/districts is given in Table 10. Here the percentage of 'Useful' forecast has varied from 58% in the Cluster No. 9 to 100% in Cluster Nos. 2, 5 and 6. Forecast could be termed as very good in Cluster Nos. 1-7 where forecast was in 'Useful' category in 90% to 100% years. Forecast was fair in the remaining 3 clusters.

9. DISTRICT LEVEL FORECAST

Out of 10 clusters in Tamilnadu and Pondicherry, 2 clusters, namely, Nilgiri and Kanyakumari have only one district. Performance of the model in these 2 districts has been discussed in the following sub-sections. The purpose of inclusion of discussion in this section is to examine whether the technique could be extended to produce seasonal forecast of rainfall for the highest spatial resolution, i.e., a district. It may be mentioned here that rainfall monitoring is not yet done at Taluka level in India.

9.1 Forecast for Nilgiri district

Forecast and realized rainfall for Nilgiri district is reproduced in Table 11. Nilgiri district received 'Excess'/'Normal' rainfall in as many as 17 years out of 20 years period of model development and 'Deficient' rainfall in 3 years (1972,1987and 1990) only. Rainfall computed from the regression equations was 'Normal' in these 3 years also. Out of these 3 years, 2 years (1972 and 1987) were severe drought years for India as a whole. However, 1990 was a normal monsoon year. Fig. 8(a) shows monthly rainfall in Nilgiri district. Monthly rainfall continuously increases from January and peaks in

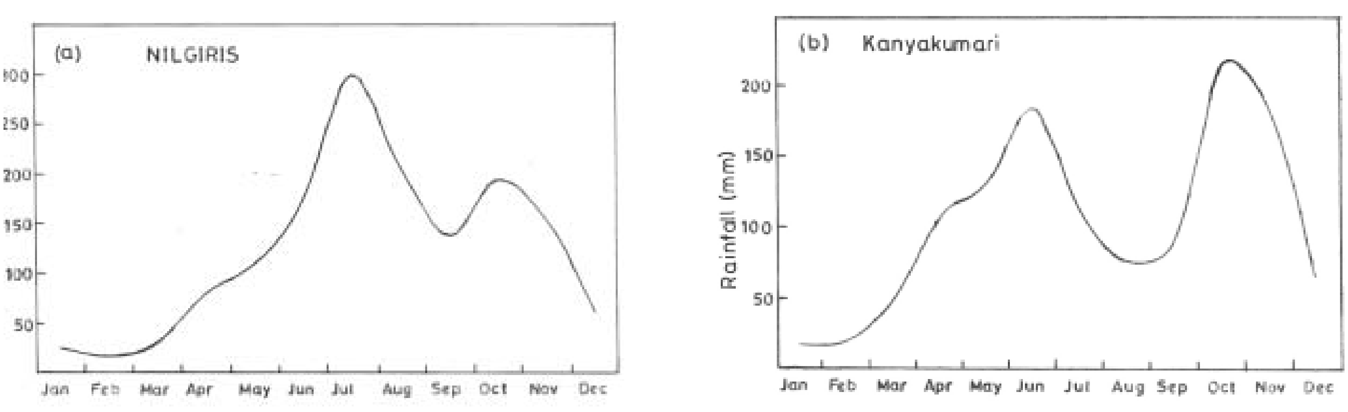

Figure 8(a-b). Monthly rainfall in the districts of (a) Nilgiri and (b) Kanyakumari.

July. Rainfall decreases thereafter. Thus rainfall in this district during southwest monsoon is similar to districts in central India. In the years of severe all India drought, this district also receives 'Deficient' rainfall. Thus SAI numbers used for computing rainfall for country as a whole when 'drought' is forecast should also be used for this district. This nudging of SAI number is necessary for improving forecast in the district. Deficient rainfall in the year 1990 in Nilgiri as well as other districts resulted due to lack of northward movement of SPCAs after the establishment of monsoon over entire country. Thereafter, MT remained anchored to the plains of north India. This was an intra-seasonal change in monsoon circulation which could not be forecast from the pre-monsoon cloud features. It follows from Table 11 that forecast rainfall was in **'Useful'** category in about 72% of the years during the verification period of 16 years (1993-2008). Forecast was not in the **'Useful'** category in the years 1999, 2003 and 2006. This was the case in some other clusters of districts also.

9.2 Forecast for Kanyakumari district

Kanyakumari district has an altogether different regime of rainfall distribution. Rainfall increases from February and peaks in June. Then there is a sharp decrease in rainfall and it is minimum in August and September (Fig. 8(b)). Forecast and realized rainfall are included in Table 11. Forecast was in 'Useful' category in 80% years during the model development period and 75% during the period of verification. Forecast was not in the **'Useful'** category in the years 1999, 2001, 2002 and 2003. Forecast rainfall was not in **'Useful'** category in 1999 and 2003 in some other clusters of districts also.

It follows from the discussions in this section that SAI index arrived at for forecast of rainfall in Tamilnadu and Pondicherry sub-division could also be used to prepare forecast for individual districts like Nilgiri and Kanyakumari. It will be worthwhile to examine the possibility of producing seasonal forecast of rainfall in other districts of the sub-division also.

Table 10: Performance of the model in individual clusters of districts/districts during the period 1993-2004 .

Cluster No.	Number of years when			Percentage of 'Useful' forecast
	Criterion (i) was satisfied	Criterion (ii) was satisfied	None of the Criteria was satisfied	
1	11	-	1	92
2	11	1	-	100
3	10	1	1	92
4	11	-	1	92
5	10	2	-	100
6	12	-	-	100
7	10	1	1	92
8	9	-	3	75
9	7	-	5	58
10	8	-	4	66
Mean++	10	1	1	87

++ Rounded off to the nearest whole number

Table 11. Forecast and realized rainfall in the districts of Nilgiri and Kanyakumari.

Year	Rainfall (% departure from normal)			
	Nilgiri		Kanyakumari	
	Model Development period (1972-1992 except 1978)			
	Forecast	Realized	Forecast	Realized
1972	10 'N'*	-26 'D'	6 'N'	3 'N'
1973	17 'N'	12 'N'	13 'N'	5 'N'
1974	17 'N'	19 'N'	13 'N'	41 'E'
1975	32 'E'	60 'E'	31 'E'	34 'E'
1976	17 'N'	2 'N'	13 'N'*	-52 'D'
1977	14 'N'	24 'N'	10 'N'*	-28 'D'
1979	17 'N'	20 'N'	13 'N'	22 'E'
1980	-15 'N'	19 'N'	-22 'N'	-13 'N'
1981	29 'E'	42 'E'	28 'E'	72 'E'
1982	-5 'N'	-5 'N'	-11 'N'	-1 'N'
1983	26 ' E'	23 'N'	24 'N'	-17 'N'
1984	20 'N'	33 'E'	17 'N'	-16 'N'
1985	29 'E'	3 'N'	28 'E'	-8 'N'
1986	-9 'N'	-1 'N'	-15 'N'*	-31 'D'
1987	-5 'N' *	-38 'D'	-11 'N'	-9 'N'
1988	29 'E'	13 'N'	28 'E'	42 'E'
1989	10 'N'	6 'N'	6 'N'	33 'E'
1990	-2 'N' *	-33 'D'	-8 'N' *	-55 'D'
1991	14 'N'	29 'E'	10 'N'	28 'E'
1992	10 'N'	53 'E'	6 'N'	32 'E'
	Model verification period 1993-2008			
1993	1 'N'	1 'N'	-4 'N'	2 'N'
1994	-12 'N'	35 'E'	-18 'N'	30 'E'
1995	7 'N'	11 'N'	3 'N'	-1 'N'
1996	36 'E'	14 'N'	35 'E'	20 'E'
1997	-2 'N'	-8 'N'	-8 'N'	64 'E'
1998	14 'N'	38 'E'	10 'N'	41 ' E'
1999	-18 'N'	67 'E'	-26 'D' *	31 'E'
2000	7 'N"	15 'N'	3 'N'	84 'E'
2001	-2 'N'*	-25 'D'	-8 'N' *	-36 'D'
2002	-24 'N'	-51 'D'	-33 'D'*	9 'N'
2003	10 'N' *	-60 'D'	6 'N' *	-73 'D'
2004	-1 'N'*	-30 'D'	-4 'N'	-20 'N'
2005	-1 'N'	-3 'N'	-4 'N'	19 'N'
2006	-11 'N' *	-38 'D'	-15 'N'	66 'E'
2007	1 'N'	8 'N'	7 'N'	69 'E'
2008	13 'N'	1 'N'	10 'N'	46 'E'

- Forecast rainfall did not meet any of the two criteria of 'Useful' forecast.

10. CONCLUSIONS

(i) Analysis of cloud data has shown a distinct pattern in the development and movement of equatorial troughs over Indian ocean during southwest monsoon season in 'Excess', 'Normal' and 'Deficient' monsoon years.

(ii) The pattern in development and movement of equatorial troughs as seen during monsoon months is also present, in the near equatorial regions of Indian Ocean, during pre-monsoon months of April and May.

(iii) Cloud features identified in anomaly charts have improved the method of assigning SAI numbers.

(iv) Re-assigned SAI numbers have improved the forecast for the sub-division and have enabled to prepare forecast for districts also.

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REFERENCES

Blandford, H. F.,1884, ' On the connection of the Himalayan snowfall and season of droughts in India', Proc. Royl. Soc., London, 37, 3-22.

De, U.S., Prasad, O. and Vaidya, D.V.,1995, 'The influence of Southern Hemispheric Equatorial Trough on rainfall during southwest monsoon', Theor. Appl. Climatol., 52, 177-181.

De, U. S. and Mukhopadhyay, R.K., 2002, Breaks in monsoon and related precursors, Mausam, 53, 309-318.

Gadgil, Sulochamna and Joseph, P.V.,2003, On 'break' of Indian summer monsoon, Proc. Indian Acad. Sci.(Earth and Planet. Sci.), 112, 529-558.

Gadgil, Sulochana, Rajeevan, M. and Francis, P. A., 2007, ' Monsoon Variability: Links to major oscillations over the equatorial Pacific and Indian Ocean, Current Science, 93, No. 2 pp 182-194

Gowariker, V., Thapliyal, V., Sarker, R. P., Mandal, G. S. and Sikka, D. R., 1989,' Parametric and power regression models: New approach to long range forecasting of monsoon rainfall in India, Mausam, 40, 115-122.

Gupta, G. R. and Prasad, O., 1991, 'Activity of south Indian Ocean convergence zone as seen in satellite cloud data during pre-monsoon months', MAUSAM,42,145-150.

Gupta, G .R. and Prasad, O., 1992, 'Role of southern hemispheric equatorial trough in long range forecasting', Jalvigyan Sameeksha- a publication of Indian National Committee on Hydrology, VII, 83-97.

Gupta, G. R. and Prasad, O., 1993, Southern hemispheric equatorial trough model of long range Forecast of monthly rainfall during southwest monsoon, J. of Indian Association of Hydrologists, XVI, 49-76.

Krishnarao, P. R. and Jagannathan, P. , 1953, 'A study of the north-east rainfall of Tamilnadu', I. J. Met. And Geophys,, 4, 22-44

Lal, B., Singh, O. P., Prasad, O., Roy Bhowmik, S. K., Kalsi, S. R. and Subramanian, S. K, 2006a, 'District level value-added dynamical synoptic forecast system for rainfall', MAUSAM, 57, 209-220.

Lal, B., Singh, O. P., Prasad, O., 2006b,' Value addition in district level dynamical forecast during intense rainfall spells over the west coast of India', MAUSAM, 57, 411-418

Madden, R. A. and Julian, P.R., 1971 , ' Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific', J. Atmos. Sci., 28 , 702-708.

Prasad, O.,1981, ' Vertical circulation during 'break' in monsoon', Herald Moscow State University, Ser.5, 74-77.

Prasad, O., 1982, ' Development of Indian summer monsoon and its different phases', Ph. D. Dissertation, Hydro-meteorological Centre USSR, Moscow, 118p. (In Russian)

Prasad, O., Mishra, D. K. and Jain, R. K., 1983, 'Satellite observed cloud distribution over Indian Ocean during southwest monsoon', MAUSAM, 34, 449-454.

Prasad, O., Rama Sastry, A. A., Hansda, A. K. and De, U. S.,1988,' 'Role of southern hemispheric equatorial trough in medium range forecasting', MAUSAM, 39, 167-178.

Prasad, O.,1993, 'Performance of southern hemispheric equatorial trough model of sub-division-wise long range forecast of rainfall during southwest and northeast monsoons',TROPMET-1993,159-166.

Prasad, O., 2000, 'Sub-division-wise long range forecast of rainfall during southwest monsoon', TROPMET-2000, 222-226.

Prasad, O., 2001, ' Sub-division-wise long range forecast of bi-monthly rainfall during southwest monsoon', TROPMET-2001, 252-257.

Sikka, D. R. and Gadgil, S., 1980, ' On the maximum cloud zone and the ITCZ over Indian longitudes during the southwest monsoon', MWR, 108, 1840-1853.

Singh, O. P., Lal, B. and Prasad, O., 2007, 'Value- addition in dynamical forecast of rainfall during cyclones and depressions ', MAUSAM, 58, 1-8.

Yasunari, T.,1980, ' A quasi -stationary appearance of 30 to 40 day period in the cloudiness fluctuations during the summer monsoon', J. Met. Soc. Japan, Ser. II, 58, 225-229.

Yasunari, T.,1981, ' Structure of an Indian summer monsoon system with around 40-day period', J. Met. Soc. Japan, Ser. II, 59, 336-354.

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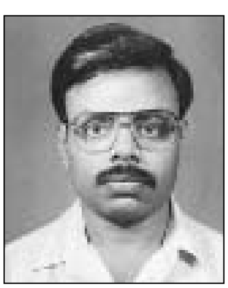

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