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South Indian Convergence Zone Model: A new approach to seasonal forecasting of summer monsoon rainfall in India Part III: Forecast for meteorological subdivisions

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ABSTRACT
Long Range Forecast (LRF) of southwest monsoon rainfall for India as a whole is being issued by India Meteorological Department (IMD) since 1886. But issuing LRF of rainfall for smaller spatial and temporal resolutions has remained a challenging task till date. LRF of rainfall, if available at sub-division and district level, could get integrated in agricultural planning, water management strategies and a number of other activities. Issuing subdivision-wise forecasts of rainfall for monthly, bi-monthly periods of June+ July, July+ August, August+ September and for the season as a whole (June-September), and seasonal forecast in the cluster of districts/districts in the subdivision of Tamilnadu and Pondicherry are discussed in the present study. The study has shown that forecasts of southwest monsoon rainfall could be issued for a number of subdivisions with an accuracy of 80% to 100% for monthly forecasts, 70% to 100% for bi-monthly forecasts and 85% to 100% for seasonal forecasts respectively. The accuracy of seasonal forecast for cluster of districts/districts in Tamilnadu and Pondicherry ranges from 70% to 100%.

INTRODUCTION

For the purpose of monitoring rainfall and issuing forecasts, India has been divided into 36 homogeneous regions, referred to as meteorological sub-divisions. Beginning from the year 2003, these have been grouped into 4 broad homogeneous regions, namely, Northwest India, Central India, South Peninsular India and Northeast India (Fig.1). Operational LRF of southwest monsoon seasonal rainfall is issued for country as a whole. Since 2003, LRF is also being issued for 4 broad homogeneous regions. SICZ model of LRF (Prasad and Singh, 2012a) produces forecast for monthly, bimonthly and seasonal rainfall for country as a whole and in each meteorological sub-division. It has produced reasonably good forecasts of monsoon rainfall for individual subdivisions for the past 21 years, beginning from the year 1990 (Prasad, 1993, 2000, 2001; Prasad and Singh, 2012a). The model had been proposed using only 16 years' (1972-1989 except 1878 and 1981) satellite observed cloud data available till 1989 (Gupta and Prasad,1992,1993). Recently the model has been improved by making use of (i) cloud data for a longer period of time, i.e., 38 years and (ii) an improved method of assigning SICZ Activity Index (SAI) (Prasad. et al., 2010; Prasad, Singh and Prasad,2010; Prasad and Singh, 2012a). Improved method of assigning SAI has been discussed in Pt I. Forecast of rainfall for India as a whole has been discussed In Part II. An analysis of rainfall data for the past 61 years period (1950-2010), discussed in the following section, has shown that one forecast for broad homogeneous regions cannot indicate likely scenario of rainfall in a particular subdivision in any of the four broad homogeneous regions. Therefore, for LRF to become 'Useful' from users' point of view, it should be issued for individual subdivisions and possibly at cluster of districts/district level also. In this study we have discussed LRF of rainfall for individual meteorological subdivisions. Discussions on (i) how these forecasts could be further improved and (ii) preparation of LRF at cluster of districts/ district level have also been included.

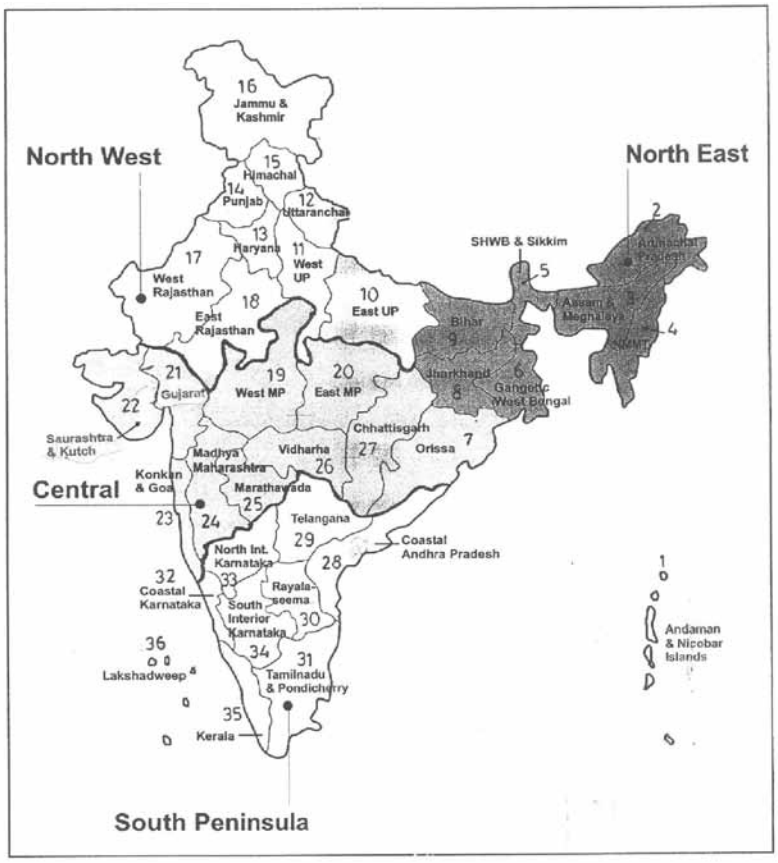

Figure 1. Meteorological subdivisions and broad homogeneous regions of India.

DATA USED AND METHOD OF ANALYSIS

Monthly and seasonal rainfall data in meteorological subdivisions of India during southwest monsoon season for 61 years period (1950-2010) and South Indian Convergence Zone (SICZ) Activity Index (SAI) for the period (1972-2010, except 1978) have been used in the study. Reader is referred to Part II of the paper (Prasad and Singh, 2012a) for assigning SAI in a year. Data for 25 years' period (1972-1997 except1978) have been used to work out Correlation Coefficients (CCs) between SAI and rainfall and to develop regression equations between them. Data for the remaining 13 years' period (1998-2010) have been used for forecast verification.

RAINFALL IN METEOROLOGICAL SUBDIVISIONS

Southwest monsoon rainfall varies from one region of the country to another and often the differences are large: Though the rainfall for country as a whole may be normal, it could be 'Excess' in one region and 'Normal' or 'Deficient' in another region/ regions. Similarly rainfall may be 'Deficient' in some subdivisions even during a year of 'Excess' rainfall for India as a whole. Rainfall could be 'Excess' or 'Normal' in one region even during a drought. Some characteristics of rainfall distribution in the subdivisions of 4 broad homogeneous regions in relation to rainfall for country as a whole are given in Table 1. The average number of subdivisions receiving deficit rainfall in NE India increases to 2 during 'Deficit' years as compared to 1 during 'Excess'/'Normal' rainfall years for India as a whole. In South Peninsular India average number of subdivision receiving 'Deficient' rainfall varies from 1 in 'Excess' rainfall years to 2 during 'Normal' rainfall years and 3 during 'Deficit' rainfall years for India as a whole. The average number of subdivisions receiving 'Deficit' rainfall in Central and NW India jumps from 1 in the years of 'Excess'/'Normal' rainfall years to 5 and 6 respectively in the years of 'Deficit' rainfall for India as a whole. This shows that the subdivisions of Central and NW India are more prone to drought. The other important inference drawn from Table 1 is that one forecast for country as a whole or even for broad homogeneous regions cannot indicate likely scenario of rainfall in a particular subdivision in any of the 4 broad homogeneous regions. Thus issuing forecast for individual subdivisions appears to be the only solution if the forecast is to be termed as 'Useful' from the users' point of view.

While attempting to forecast rainfall at sub-divisional level, pin pointing the subdivisions likely to receive deficient rainfall becomes important. Frequency of occurrence of deficient rainfall in subdivisions during the past 61 years is shown in Table 2. Nineteen subdivisions received deficient rainfall once in 4/5 years. Subdivisions like Marathwada, Haryana, Chandigarh and Delhi and Gujarat Region experienced deficiency of rainfall once in 3-4 years. The frequency of occurrence of deficient rainfall is highest (on an average once in 3 years) in West Rajasthan, Saurashtra and Kutch, S.I.K. and Arunachal Pradesh. Some of the subdivisions have also suffered due to rainfall deficiency for several years in continuation.

Average Rainfall (A.R.) and Coefficient of Variability (C.V.) for each month, bimonthly periods and southwest monsoon season as a whole in meteorological subdivisions are given in Table 3. During the month of June, A.R. is high in Lakshadweep, in the subdivisions along the west coast and in NE India. Rainfall increases in all subdivisions of India during July except in 2 subdivisions of NE India, i.e, Assam and Meghalaya and Nagaland, Manipur, Mizoram and Tripura. During July C.V. is large (45% and more) in some subdivisions of Northwest India, Saurashtra & Kutch in Central India and 4 subdivisions of extreme South Peninsula. In August rainfall decreases in almost all subdivisions except in West M.P., East M.P., Rayalaseema and Tamilnadu and Pondicherry where there is slight increase. In August the highest C.V. occurs in Saurashtra and Kutch, followed by subdivisions of Arunachal Pradesh, West Rajasthan, J & K., Marathwada and Rayalaseema. There is a large decrease of rainfall from August to September except in some sub-divisions where there is marginal increase, e.g., in Haryana, Chandigarh and Delhi, West U.P., Madhya Maharashtra, Marathwada, Rayalaseema and Tamilnadu and Pondicherry. In September C.V. increases in general, in comparison to August, except over the subdivisions where rainfall has increased. C.V. for bimonthly periods have reduced considerably compared to those for individual months. For the season as a whole C.V. ranges from 13% in Assam and Meghalaya to 38% in West Rajasthan and 40% in Saurashtra and Kutch.

MONTHLY RAINFALL FORECAST

On an average, the accuracy of the forecasts of monthly rainfall varies from 80% to 90% during Model Development Period (MDP) and from 82% to 88% during Forecast Verification Period (FVP). The values of SAI are given in Pt II of the paper. Correlation Coefficients (CCs) between SAI and monthly rainfall are given in Figs.2-5. In the month of June, when monsoon establishes over different regions of India, CCs are significant at 95% level (CC $\geq$ .39) in 6 sub-divisions of Central and Northwest India only (Fig.2). During July, the peak month of monsoon activity, CCs are significant in 19 sub-divisions of Northwest and South Peninsular India (Fig.3). Situation changes in August when number of sub-divisions, where CCs are significant reduces to 9 only (Fig. 4). These sub-divisions are mainly located in South Peninsular India. Subdivisions lying in the monsoon core zone, i.e., East Rajasthan, West U.P., West M.P., East M.P., Chattisgarh, and Orissa have low correlation with SAI. These subdivisions get rainfall even during weak monsoon conditions, due to formation and movement of weak low pressure areas/ upper air cyclonic circulations, which develop during August, the month of in general weakening of monsoon circulation system over India. CCs between SAI and rainfall again increase during September when they become significant in 16 subdivisions (Fig. 5).

The linear regression coefficients relating SAI and monthly rainfall (% departure from normal) in respect of those subdivisions only where CCs are significant are included in Table 4. The Standard Deviation (S.D.) criteria has been used for verification of forecasts (Prasa. et al., 2010; Prasad and Singh, 2012a). For the purpose of verification, both realized and forecast rainfall have been grouped into 2 broad categories, namely, 'Excess/Normal' and 'Deficient/

Table 1. Seasonal rainfall in broad homogeneous regions and subdivisions in relation to rainfall for India as a whole [Period: 61 years (1950-2010)]

Rainfall for India as a whole	Rainfall in broad homogeneous regions and subdivisions				
Category of monsoon (No. of years)	Category of mon-soon	Average number and range of number of subdivisions in a year in different categories of monsoon			
		Northwest India (No. of subdiv.: 9)	Central India (No. of subdiv. :10)	South Peninsula (No. of subdiv.: 10)*	Northeast India (No. of subdiv.: 7)
Excess (11 including 1994)	Excess	4 2-8	5 2-8	3 1-6	1 1-3
	Normal	4 2-6	5 2-8	6 2-8	5 1-7
	Deficit	1 0-2	<1 0-1	1 0-5	1 1-3
Normal (37)	Excess	2 0-6	2 1-6	1 0-5	1 1-3
	Normal	6 2-9	7 4-9	7 3-9	5 2-7
	Deficit	1 0-5	1 0-5	2 0-7	1 1-3
Deficit (13)	Excess	< 1 0-1	<1 0-2	1 0-3	1 1-4
	Normal	3 0-5	5 1-8	6 1-6	4 3-6
	Deficit	6 3-9	5 2-8	3 1-8	2 1-4

* Includes Bay Islands and Lakshadweep Islands also

Table 2. Number of years in which different subdivisions suffered from 20% or more deficiency in southwest monsoon seasonal rainfall during 61 years' period (1950-2010)

< 6 years	6-10 years	11-15 years	16-20 years	21-25 years
Assam and Meghalaya (2) Coastal Karnataka (4) Orissa (5) East M.P. (5)	Chhattis-garh(6) Konkn and Goa (6) Bay Islands(7)	Jharkhand (8) S.H.W.B. (8) Uttarakhand (9) TamilNadu & Pondicherry (10) N.I.K.(10) West M.P.(11) NMMT(12) GWB (12) Bihar (12) West U.P(12) Kerala (12) Lakshadweep(12) Vidarbha (13) East Raj.(13) H.P.(13) East U.P.(14) Coastal A.P.(14) Rayalaseema(14) Madhya Maha.(15)	Punjab(17) Telangana(17) Marathwada(18) Haryana, Chandi-grh and Delhi (19) Gujarat Region(20)	Jammu and Kashmir (21) West Rajasthan(21) South Interior Karnataka (21) Arunachal Pradesh (22) Saurashtra and Kutch(23)

Table 3. Average Rainfall (A.R) in Cm and Coefficient of Variability (C.V.) of rainfall in meteorological subdivisions during 61 years period (1950-2010)

S. No. & Name of Subdivision	Period [Month ,Bimonthly Period and Season]											
	Jun		Jul		Aug		Sep		Jun+ Jul	Jul+ Aug	Aug+ Sep	Jun- Sep
	A.R..	C.V..	A.R..	C.V..	A.R..	C.V..	A.R..	C.V..	C.V	C.V	C.V	C.V
1. Bay Isls.	30	30	37	33	36	28	39	22	22	21	18	13
2. Aruna. Pr.	64	38	85	45	58	70	47	43	33	41	47	30
3. Assam, Meghalaya	44	24	44	21	36	25	27	32	15	17	18	13
4. NMMT	39	33	36	37	33	39	24	30	28	34	27	25
5.SHWB & Sikkim	52	29	68	27	52	43	42	33	20	27	30	20
6. GWB	25	42	34	30	31	28	27	42	25	24	26	19
7. Orissa	21	36	32	27	35	28	25	35	22	19	21	16
8. Jharkhand	21	47	33	29	32	26	24	34	29	21	20	18
9. Bihar	18	45	32	33	28	33	21	40	26	24	28	20
10. East U.P.	11	58	29	36	28	28	20	42	34	24	25	21
11. West UP	8	70	26	35	27	34	15	52	34	23	29	21
12. Uttarkhand	19	51	47	26	46	24	24	50	28	19	25	20
13. Har,Ch., Delhi	7	64	18	50	20	48	9	72	42	35	39	31
14. Punjab	6	83	20	46	18	42	10	103	38	29	49	35
15. H.P.	12	58	36	36	35	37	17	59	29	32	38	29
16. J & K	6	62	16	52	16	57	8	86	44	45	53	42
17.West Raj.	3	84	11	55	9	64	4	95	47	40	59	38
18. East Raj.	6	62	22	36	22	35	10	69	32	22	34	24
19.West M.P.	10	51	28	33	30	30	16	67	25	20	30	20
20. East M.P.	14	57	36	28	37	28	19	51	27	20	25	18
21. Guj Reg	13	75	34	44	27	49	15	85	39	34	49	36
22. Saur. & Kutch	9	75	21	60	14	83	8	88	46	47	68	40
23. Kon.Goa	68	28	103	25	69	39	35	51	16	21	33	17
24. Madhya Maharashtra	15	36	23	41	18	38	15	44	28	32	31	23
25. Marathwada	14	46	21	47	20	57	17	54	31	37	41	28
26. Vidarbha	16	41	30	27	29	29	16	53	20	19	27	19
27. Chhattisgarh	19	45	37	22	36	23	21	41	22	17	20	17
28. C'stl AP	11	46	16	39	16	34	17	40	32	29	25	22
29. Telangna	13	39	24	40	24	39	17	47	30	30	28	24
30. Rayala.	8	70	10	49	11	58	13	44	38	39	35	30
31. T'nadu Pondy.	5	53	7	46	9	38	11	36	33	29	24	22
32. C'stl Kar	93	27	111	29	72	32	32	59	16	20	29	15
33. NIK	11	36	15	34	13	38	14	48	25	25	31	21
34. SIK	13	51	22	61	16	42	14	38	52	48	31	37
35. Kerala	57	31	58	38	36	32	24	53	25	27	30	21
36. Laksha.	32	32	29	41	21	44	16	52	27	28	33	21

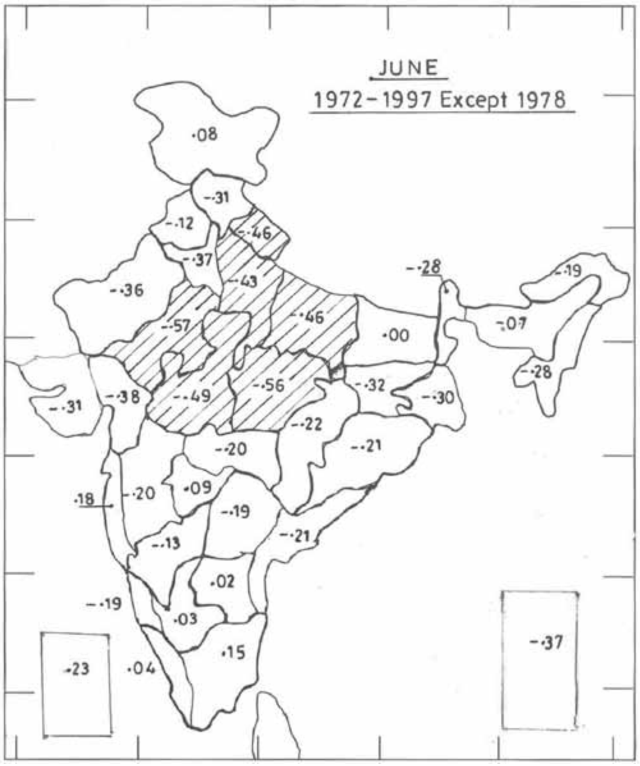

Figure 2. Correlation coefficients between SAI and rainfall for the month of June.

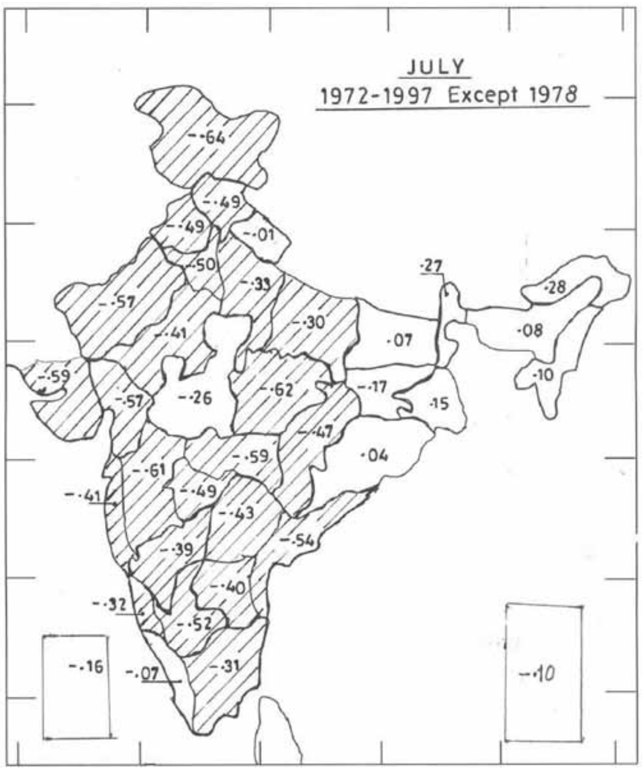

Figure 3. Correlation coefficients between SAI and rainfall for the month of July.

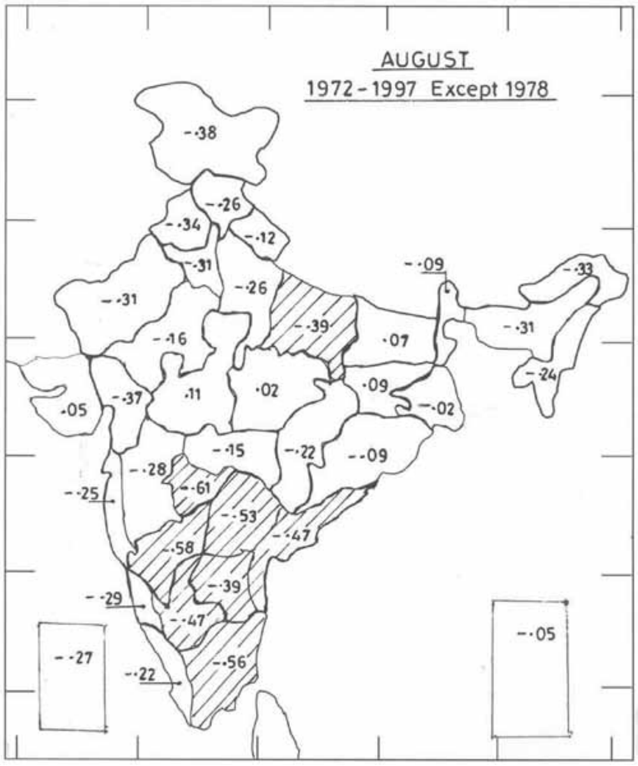

Figure 4. Correlation coefficients between SAI and rainfall for the month of August.

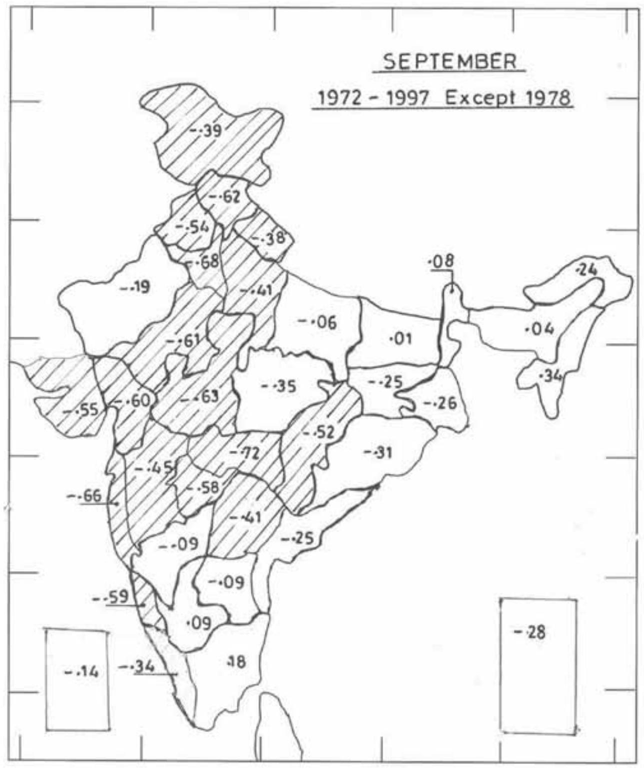

Figure 5. Correlation coefficients between SAI and rainfall for the month of September.

Scanty' where 'Normal' refers to rainfall within (+/-) 1 S.D.. The expected error in assigning SAI is ±2 (Prasad and Singh, 2012a). Accordingly the Model Error (M.E.) in forecast rainfall computed from regression equations becomes twice the value of regression constant 'a' (Table 4). The error varies from one sub-division to another. The values of S.D. of rainfall for the period of study (38 years) have been included in Table 5.

A forecast is termed 'Useful' if broad rainfall categories for both, the realized as well as forecast rainfall, are the same or they become same after M.E. in forecast rainfall is taken into account. Percentages of 'Useful' Forecast (POUF) during the Model Development Period (MDP) and Forecast Verification Period (FVP) have been included in Table 5. It follows from Table 5 that in the month of June, POUF has varied from 80% in West M. P. to 96% in East Rajasthan during MDP and from 77% in East M. P. to 100% in East Rajasthan and West M.P. during FVP. In the month of July, POUF has varied from 80% in Chhattisgarh to 96% in a number of subdivisions during the MDP and from 77% in a number of subdivisions to 100% in the subdivisions of Jammu and Kashmir and Gujarat Region during FVP. In the month of August, POUF varies from 70% in J & K to 96% in Telangana, Rayalaseema and Tamilnadu and Pondicherry during MDP and from 77% in J & K to 100% in Telangana and SIK during FVP. In the month of September, POUF varies from

Table 4. Linear regression coefficients relating SAI and monthly rainfall in meteorological subdivisions [Period: 25 years(1972-1997 except 1978)]

Sub-division	Jun		Jul		Aug		Sep	
S. No.	a	b	a	b	a	b	a	b
10	-5.6	162.3			-2.2	107.1		
11	-5.2	157.4					-4.3	129.8
12	-3.5	130.0					-3.7	124.0
13			-6.4	189.5			-8.9	167.1
14			-6.9	191.2			-7.9	155.9
15			-3.1	116.2			-6.2	143.5
16			-8.1	199.3	-8.4	212.7	-4.5	122.9
17			-7.6	202.2				
18	-9.0	211.6	-3.2	130.0			-18.4	299.5
19	-5.4	154.2					-7.6	158.1
20	-7.2	179.6	-3.1	116.5				
21			-5.4	145.9			-11.0	196.8
.22			-6.8	148.9			-8.1	165.5
23			-2.2	115.7			-9.0	187.0
24			-3.4	126.6			-5.6	159.2
25			-4.7	146.6	-8.6	204.9	-8.1	175.6
26			-3.3	122.0			-7.2	149.8
27			-2.2	112.3			-4.3	129.0
28			-4.5	144.4	-4.0	140.6		
29			-3.9	142.8	-4.9	154.5	-3.9	122.2
30			-5.3	160.3	-8.0	196.4		
31					-4.8	140.3		
33			-3.0	118.0	-4.7	155.7		
34			-3.5	122.9	-4.0	144.1		

Table 5. Standard Deviation (S.D.) of monthly rainfall, Model Error (M.E.) %, Percentage of 'Useful' Forecast (POUF) during Model Development Period (MDP) [25 years: 1972-1997 except 1978] and POUF during Forecast Verification Period (FVP) [13 years: 1998-2010] in meteorological subdivisions where CC was significant at 95 %.

Sub-division S. No.	Jun				Jul				Aug				Sep			
	S.D.	M.E (±)	POUF MDP	FVP	S.D.	M.E (±)	POUF MDP	FVP	S.D.	M.E (±)	POUF MDP	FVP	S.D.	M.E (±)	POUF MDP	FVP
10	58	11	88	85	32				23	4	76	85				
11	63	10	88	85	34	11			33				51	9	92	77
12	40	7	88	85	22				23				42	7		
13	80				56	13	88	75	53				56	8	84	100
14	97				55	14	96	85	48				57	16	84	92
15	45				27	6	84	77	24				41	12	84	92
16	66				48	16	92	100	81	16	70	77	44	9	84	85
17	113				57	15	96	77	59				97			
18	66	18	96	100	33	6	88	85	36				109	37	80	85
19	44	11	80	100	29				37				53	15	92	92
20	52	14	88	77	20	6	88	77	44							
21	86				41	11	92	100	50				76	22	88	100
22	97				54	14	96	85	97				83	16	80	100
23	25				23	4	88	77	36				56	11	92	100
24	45				27	7	96	77	37				50	16	96	100
25	40				44	9	96	77	56	17	96	92	53	14	88	96
26	41				26	7	96	85	30				42	14	96	92
27	42				21	4	80	85	20				34	8	88	100
28	55				33	9	96	92	36	8	84	85	39	16		
29	32				39	8	96	62	39	10	96	100	42	8	76	100
30	89				53	11	96	77	67	12	96	92	41			
31	51				47				40	10	96	92	41			
32	22				27	4	84		38				60		84	92
33	43				33	6	92	77	33	9	92	00	42			
34	40				30	7	88	92	36	8	89	100	39			
35	26				27				27				60			
Average			88	88			90	82			88	80			87	94

76% in Telangana to 96% in Madhya Maharashtra and Vidarbha, with intermediate values in other subdivisions, during the MDP and from 77% in West U.P and West M.P. to 100% in a number of subdivisions during FVP. Verification results have shown that the performance of the model during FVP was comparable to that during MDP.

BI-MONTHLY RAINFALL FORECAST

On an average, the accuracy of the forecasts for bimonthly periods varies from 90% to 93% during MDP and from 84% to 90% during FVP. CCs between SAI and bi-monthly rainfall in sub-divisions are given in Figs.6-8. During the bi-monthly period

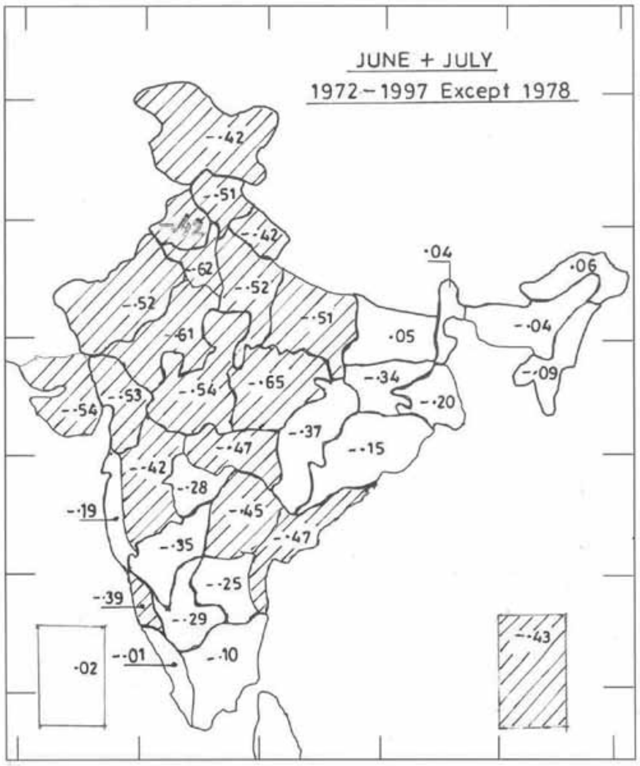

Figure 6. Correlation coefficients between SAI and rainfall for bimonthly period of June+ July.

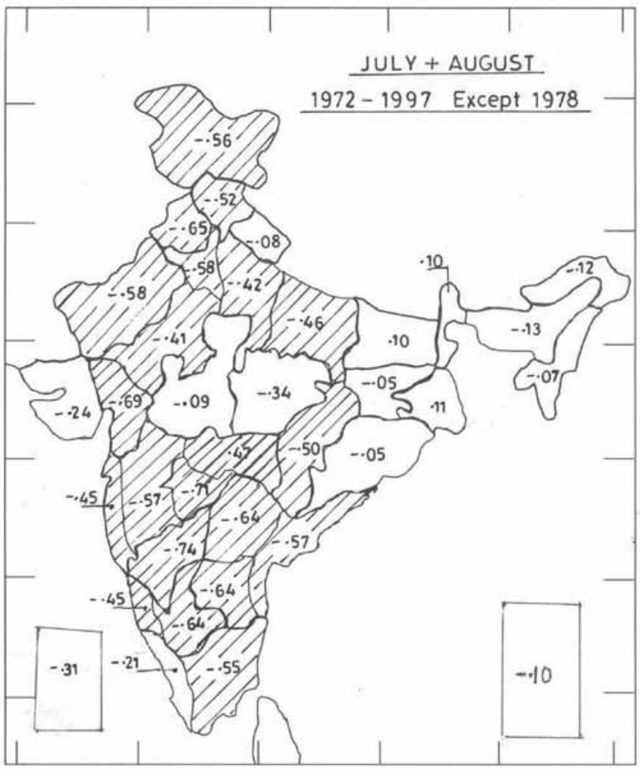

Figure 7. Correlation coefficients between SAI and rainfall for bimonthly period of July+ August.

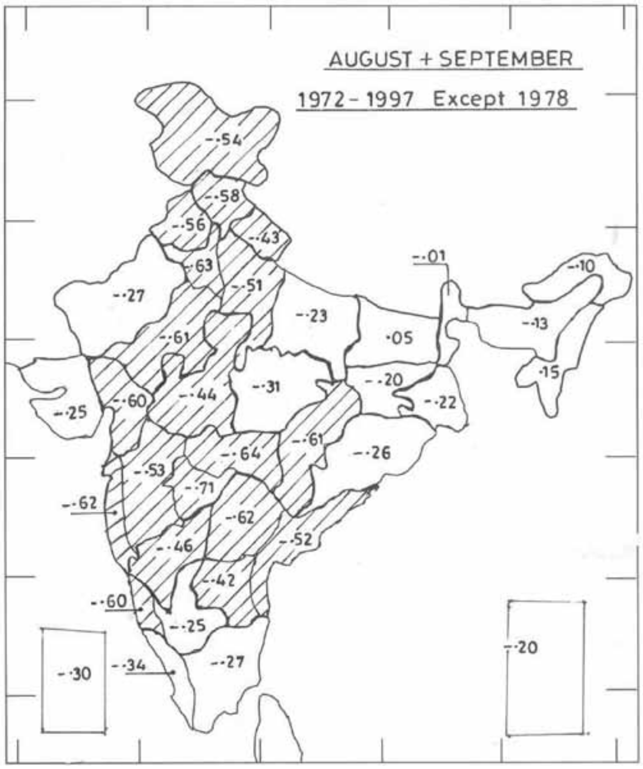

Figure 8. Correlation coefficients between SAI and rainfall for bimonthly period of August+ September.

of June + July and August + September CCs are either significant at 95% level or they are more than that in 18 and 19 sub-divisions of Northwest, Central and South Peninsular India respectively. The number of subdivisions, where CCs are significant, further increase to 21 during the bimonthly period of July+ August. These subdivisions cover almost entire country outside Northeast India, East India, and the subdivisions of Saurashtra and Kutch, Uttarakhand and Kerala. It was shown in Pt II of the study that a majority of the droughts in the past had occurred due to SICZ remaining active for 3-4 weeks in continuation. Such a situation is followed by a weak phase of SICZ (an active phase of summer monsoon) for 3-4 weeks in continuation. Under such a scenario, rainfall occurring during an active phase of monsoon compensates for the deficiency during the weak phase. Thus the deficiency gets moderated when rainfall is averaged for bi-monthly periods. Hence, before hand information on rainfall during bi-monthly periods of June+ July, July+ August and August+ September becomes important for those subdivisions where forecast is not available during June and August because of low correlation between SAI and rainfall, as discussed above.

The linear regression coefficients relating SAI and rainfall during bimonthly periods in those subdivisions where CCS are significant are included in Table 6. POUF during MDP and FVP have been included in Table 7. For bimonthly period of June+ July, POUF has varied from 84% in the subdivisions of Himachal Pradesh and Telangana to 96 % in a number of subdivisions during MDP and from 69 % in Telangana, to 100% in a number of subdivisions during FVP. For July+August, POUF has varied from 84% in Himachal Pradesh to 100% in a number of subdivisions during MDP and from 62% in West U.P. to 100% in Marathwada, Telangana and Rayalaseema during FVP. For bimonthly period of August+September, POUF has varied from 80% in the subdivision of Himachal Pradesh to 100% in West Rajasthan, Rayalaseema and Coastal Karnataka during MDP and from 77% in West U.P., Haryana, Chandigarh and Delhi and Himachal Pradesh to 100% in a number of subdivisions during FVP.

Table 6. Same as Table 5 but for bimonthly periods and season as a whole.

Subdivision	Jun+ Jul		Jul+ Aug		Aug+ Sep		Jun-Sep	
S. No.	a	b	a	b	a	b	a	b
1	-2.0	111..5					-1.6	109.9
8							-1.2	111.6
10	-4.0	142.3	-2.3	114.7			-2.2	119.4
11	-3.8	139.2	-2.2	119.2	-3.1	123.7	-2.6	121.8
12	-1.8	106.3			-2.1	105.1	-1.7	101.9
13	-6.4	198.4	-5.1	172.9	-6.4	161.7	-5.9	172.8
14			-5.5	174.6	-6.0	156.9	-5.8	171.0
15	-2.9	129.1	-2.3	107.6	-3.9	121.2	-3.0	117.0
16	-3.4	146.9	-8.2	206.0	-6.4	167.8	-5.6	165.7
17	-9.4	239.9	-6.0	173.6			-6.8	183.2
18	-6.1	170.8	-2.2	122.5	-9.8	207.3	-4.4	143.5
19	-3.6	130.4			-3.4	136.1	-2.7	127.3
20	-5.2	148.0					-2.6	121.2
21	-6.7	174.6	-4.8	156.1	-7. 6	181.6	-6.1	167.2
22	-7.4	184.2					-5.3	147.6
23			-2.2	126.2	-5.6	161.9	-1.9	119.6
24	-2.8	132.7	-2.9	129.9	-4.0	146.2	-3.3	136.6
25			-6.6	175.8	-8.3	109.2	-5.2	151.7
26	-2.5	117.2	-2.2	121.9	-4.2	135.8	-3.1	125.6
27			-1.6	108.4	-2.6	116.7	-2.2	113.3
28	-3.4	132.0	-4.2	145.2	-3.1	132.1	-3.7	135.5
29	-2.6	126.2	-4.4	148.6	-4.4	138.3	-3.6	134.3
30			-6.6	178.3			-3.6	145.6
31			-4.2	145.8	-1.6	125.0		
32	-1.5	115.4	-2.4	137.1	-5.3	165.0	-2.4	129.4
33			-3.8	136.9	-2.8	132.4	-2.1	122.6
34			-3.7	133.5				

SEASONAL RAINFALL FORECAST

The accuracy of the forecast for seasonal rainfall has varied from 84 % during MDP to 85% during FVP. CCs between SAI and seasonal rainfall in sub-divisions are given in Fig. 9. CCs are significant at 95 % level in as many as 25 subdivisions. CCs are low in the subdivisions of East India, Northeast India and three subdivisions of south peninsula. This shows that SAI, which has been assigned to cloud features in relation to seasonal rainfall for country as a whole, is intimately related with rainfall in the majority of the subdivisions also. POUF during MDP and FVP for seasonal rainfall has been included in Table 7. POUF ranges from 84% in the subdivision of Bay Islands and Uttarakhand to 100% in a few subdivision during MDP and from 54% in the subdivision of Bay Islands to 100% in a few subdivisions during FVP.

FURTHER IMPROVEMENT IN SUBDIVISIONAL LEVEL FORECAST AND FORECAST FOR CLUSTER OF DISTRICTS/DISTIRCTS

As mentioned above, SAI values assigned to cloud features to forecast rainfall for India as a whole had been used for producing forecasts of rainfall in the meteorological subdivisions also. CC between SAI and rainfall in subdivisions with 16, 25 and 38 years' data

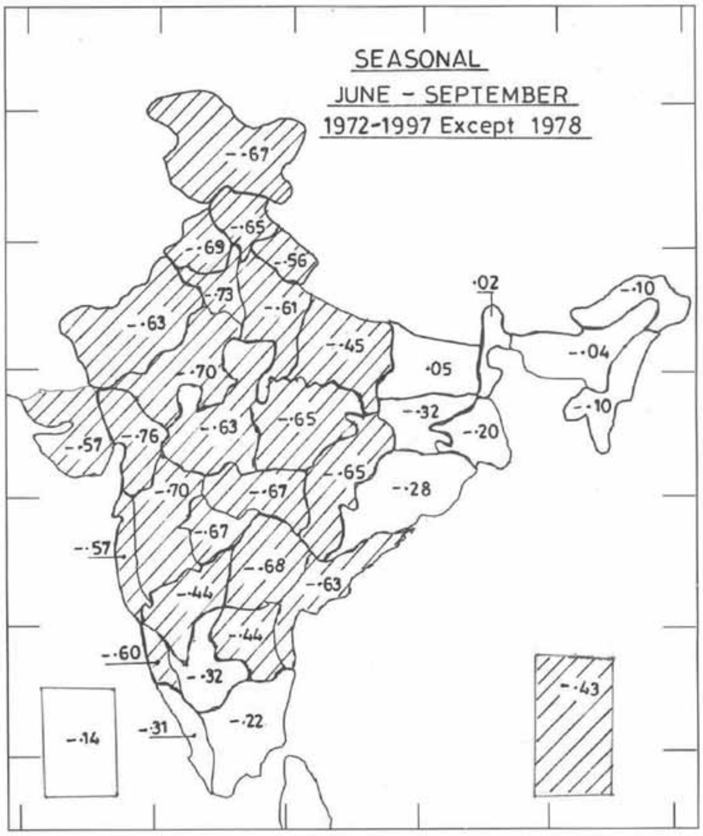

Figure 9. Correlation coefficients between SAI and rainfall during the southwest monsoon season (June - September)

are shown in Table 8. The relationship between the activity of SICZ and rainfall in different subdivisions is likely to remain the same in future also, as has been the case in the past, and CCs are likely to become significant in all most all subdivisions outside NE India when cloud data becomes available for 65 years or more.

Forecasts in those subdivisions where CCs are not yet significant could be improved with the available cloud data also, if SAI values are re-assigned in relation to rainfall in each subdivision separately. This has been demonstrated in a recent study relating to subdivision of Tamilnadu and Pondicherry (Prasad. et al., 2010). This has resulted into significant improvement in forecasts for Tamilnadu and Pondicherry. New set of SAI values were used to produce forecast at cluster of district/district level. Verification of cluster of districts/district level forecast for the period 1993-2008 had been discussed by Prasad, Singh and Subramanian (2010). Verification of real time forecasts for the years 2009 and 2010 are reproduced in Table 10. Except for the districts of Nilgiri and Kanyakumari, forecast rainfall in other districts refers to the forecast for the cluster of districts to which a district belongs to. Standard deviation criterion has been used for verification of forecasts. In both the years forecast rainfall was very close to or within the model error limit for the subdivision of Tamilandu and Pondicherry. At district level, POUF has varied from 70% in the year 2009 to 100% in the year 2010.It is believed that district level forecasts may further improve if regression equations could be developed for individual districts. Beginning from the year 2009, the improved version of SICZ model is being used to prepare long range forecast of seasonal rainfall during southwest monsoon in the subdivision of Tamilnadu and Pondicherry and its districts. Similar studies could be undertaken to develop the regression equations for other subdivisions and their districts also.

Table 7. Same as Table 6 but for bi-monthly periods and southwest monsoon season as a whole.

Sub-division S. No.	Jun+ Jul				Jul+ Aug				Aug+ Sep				Jun-Sep			
	S.D.	M.E (±)	POUF MDP	FVP	S.D.	M.E (±)	POUF MDP	FVP	S.D.	M.E (±)	POUF MDP	FVP	S.D.	M.E (±)	POUF MDP	FVP
1	20	4	88	77	24				16				16	3	84	54
8	29	5	92	77	18				21				17	3	88	92
10	36	8	96	77	21	5	96	100	25				21	4	100	85
11	38	8	96	85	25	4	88	62	29	12	92	77	18	5	96	85
12	23	4	96	100	18				23	4	84	85	13	3	84	69
13	46	13	96	92	41	10	96	77	40	13	92	77	35	12	96	85
14	51	9	96	100	36	11	88	77	40	12	96	92	36	12	96	92
15	27	6	84	85	18	5	84	69	26	8	80	77	20	6	80	77
16	34	7	96	100	54	16	100	100	45	13	96	100	36	11	92	100
17	68	19	100	100	43	12	92	92	66				47	14	96	92
18	40	12	96	100	23	4	88	77	60	20	100	100	27	9	96	100
19	26	7	88	100	23				33	7	88	85	18	5	96	69
20	31	10	96	92	26				40	*	88	62	217	5	88	92
21	49	13	92	100	32	10	92	92	52	15	88	92	35	12	100	100
22	51	15	88	100	54				68				40	11	88	85
23	13				19	4	88	85	37	11	96	100	14	4	100	92
24	28	6	92	92	24	6	88	92	34	8	84	100	20	7	96	100
25	27				37	13	100	100	43	17	92	100	33	10	96	100
26	22	5	88	92	18	4	84	85	27	8	88	85	20	6	92	92
27	24	4	88	85	14	3	96	77	19	5	84	92	14	4	92	85
28	32		96	100	29	8	96	100	24	6	96	100	25	7	88	100
29	25	5	84	69	29	9	96	100	28	9	96	100	23	7	96	100
30	48				44	13	100	100	43	9	88	100	35	7	96	100
31	33				33	8	96	77	26				26			
32	16	3	100	77	22	5	100	92	37	11	100	100	17	5	100	85
33	26				23	8	96	85	28	6	84	92	21	4	88	85
34	23				26	7	96	92	29				29			
Average			92	90			93	87			90	90			93	84

Table 8. Number of subdivisions with CCs significant at 95% level for different period of data

Month/Period	No. of years	16	25	38	65
	CC	.49	.39	.32	.24
	No. of subdivisions				
June	3		6	8	19
July	12		19	20	25
August	7		9	12	17
September	16		16	16	22
June+ July	13		21	23	27
July+ August	16		19	20	24
August+ September	16		24	25	28
June-September	21		24	27	28

Table 9. Sub-divisional and district level real time forecast of monsoon seasonal rainfall (% departure from LPA (100%) and departure category (E/N/MD/D/S) for the years 2009-2010 for Tamilnadu and Pondicherry

Subdivision/ District	S.D. of rainfall	Model Error (±) %	Forecast rainfall	Realized rainfall	Forecast rainfall	Realized rainfall
			SW monsoon-2009		SW monsoon-2010	
Tamilnadu and Pondicherry	24	10	4	0 N	19 N/E	29 E
1. Ariyalur	21	8	-6 N	-40 D	7 N	-16 N
2. Chennai	26	9	-11 N/MD	-50 D	3 N	31 E
3. Coimbatore	75	18	-6 N	297 E	60 N/E	210 E
4. Cuddalore	21	8	1 N	-26 D	14 N	-2 N
5. Dharmapuri	21	8	-8 N	5 N	4 N	20 N
6. Dindigul	28	6	7 N	-16 N	18 N	16 N
7. Erode	75	18	-6 N	-2 N	60 N/E	24 N
8. Kanchipuram	26	9	-11 N/MD	-29 D	3 N	13 N
9. Kanyakumari	42	7	3 N	6 N	13 N	17 N
10.Karur	21	8	-6 N	-33 D	7 N	5 N
11. Krishnagiri	21	8	-8 N	13 N	4 N	-7 N
12. Madurai	28	6	7 N	-15 N	18 N	0 N
13.Nagapattinam	21	8	1 N	-42 D	14 N	41 E
14.Namakkal	21	8	-8 N	-21 N	4 N	-3 N
15.Nilgiri	25	7	7 N	19 N	16 N	15 N
16.Perabmalur	21	8	-6 N	-40 D	7 N	9 N
17.Puddukottai	21	8	-6 N	-41 D	7 N	5 N
18.Ramanathpuram	35	9	1 N	-19 N	15 N	91 E
19.Salem	21	8	-8 N	21 N	4 N	45 E
20.Sivaganga	28	6	7 N	15 N	18 N	73 E
21.Thanjavur	21	8	-6 N	-21 N	7 N	15 N
22.Theni	28	6	7 N	52 E	18 N	119 E
23.Tirunelveli	35	9	1 N	40 E	15 N	89 E
24.Thirupur	75	18	-6 N	-2 N	60 N/E	24 N
25.Tiruvallur	26	9	-11 N/MD	-26 N	3 N	83 E
26.Tiruvannamalai	24	8	-4 N	-16 N	6 N	10 N
27.Tiruvarur	21	8	1 N	-26 D	14 N	76 E
28.Trichy	21	8	-6 N	-14 N	7 N	8 N
29.Tuticorin	35	9	1 N	-37 D	15 N	6 N
30.Vellore	24	8	-4 N	-2 N	6 N	4 N
31.Villupuram	24	8	-4 N	-19 N	6 N	21 N
32.Virudhunagar	28	6	7 N	-57 D	18 N	16 N
33. Pondicherry	21	8	1 N	-45 D	14 N	76 E
% of 'Useful' forecast			70%		100%	

CONCLUSIONS

(1)The study has confirmed that the South Indian Convergence Zone (SICZ) Activity Index (SAI), assigned in relation to rainfall for India as a whole, could also be used to prepare reasonably good long range forecasts of monthly, bi-monthly and seasonal rainfall in a number of meteorological subdivisions of India.

(2)The forecasts in the sub-divisions could be further improved by studying the relationship between the activity of SICZ and rainfall in individual subdivisions.

(3) The new set of SAI values worked out for sub-divisional level forecast could also be used to prepare LRF of seasonal rainfall for cluster of districts/ districts.

(4) On an average the range of 'Useful forecast' varies from about 80% to 100 % for seasonal forecasts, 70% to 100% for bi-monthly forecasts, 82% to 100% for monthly forecasts and 70% to 100% for seasonal forecast at cluster of districts/district level.

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