

District level long range forecast of rainfall during southwest monsoon in Andhra Pradesh

Onkari Prasad^{1*}, O.P. Singh² and K. Prasad³

¹43, Ritu Apartments, A-4 Paschim Vihar, New Delhi-110063

²B44, First Floor, Parshvnath Paradise, Mohan Nagar, Ghaziabad-201007 (U.P.)

³D-104, Seema Apartments, Sector 11, Dwarka, New Delhi-110075

*Corresponding Author: prasadonkari123@yahoo.in

ABSTRACT

Long range forecast of rainfall during southwest monsoon season, at spatial resolution of a district, could serve as an important input to the farming community. However, such forecasts are not yet available. It has been shown that making use of South Indian Ocean Convergence Zone (SIOCZ) model, long range forecast of seasonal rainfall and rainfall for bi-monthly periods of July+ August and August+ September could be prepared for all the districts of Andhra Pradesh. Long range forecasts could also be prepared for monthly rainfall in July, August and September for a limited number of districts. Verification results for the real time forecasts the past 2 years (2014-2015), have shown that the performance of the model in Andhra Pradesh is comparable to that in Himachal Pradesh.

Key words: Southwest monsoon, South Indian Ocean Convergence Zone, Activity index, District level long range forecast, Coastal Andhra Pradesh, Rayalaseema.

INTRODUCTION

Situated in southeastern coast, Andhra Pradesh (A.P.) is one of the southern states of India. The state has 13 districts and two meteorological subdivisions, namely, Coastal Andhra Pradesh (CAP) and Rayalaseema. CAP comprises of 9 coastal districts. Rayalaseema has 4 southern interior districts Figure 1. Because of being one of the highest producers of rice, A.P. is also known as the Rice Bowl of India. Water, therefore, is most important natural resource for the state. A. P. receives rain during Southwest Monsoon (SWM) (June-September) as well as during Northeast Monsoon (NEM) (October-December). Contribution of southwest monsoon rainfall to annual total is about 60% in CAP and 56% in Rayalaseema. Six districts of CAP and one district of Rayalaseema receive more than 60% of the annual rainfall during SWM season alone. Contribution of NEM rainfall to annual total is about 34% in CAP and about 32% in Rayalaseema.

Information on likely performance of SWM could prove to be a boon in agricultural planning and operations and water management, if the same could be made available to end users at spatial resolution of a district. Such a forecast could be readily used by farmers as an input, like seeds and fertilizers etc. However, because of limitations in issuing LRF of rainfall even for India as a whole, particularly for the extreme seasons (droughts/floods), LRF of SWM rainfall at sub-division/district level had, therefore, remained a challenging task. As at present, operational LRF of SWM rainfall are issued by India Meteorological Department (IMD) for country as a whole and for four broad regions of

India. Each broad region comprises of 7-10 meteorological subdivisions, out of a total of 36. Operational LRF of SWM rainfall are not yet available to users at spatial resolution of a meteorological subdivision/cluster of districts/district.

Using a new approach, LRF of SWM rainfall for individual subdivisions are being issued since 1990 (Gupta and Prasad,1992;Prasad,1993).The South Indian Ocean Convergence Zone (SIOCZ) model, based on this new approach, has succeeded in producing reasonably good forecasts for a number of subdivisions for the past 26 years, besides forecast for country as a whole. This model alone could foreshadow the droughts of 2002, 2004 and 2009. Encouraged from the success of this new approach, Prasad and Singh (2008) examined the possibility of preparing LRF of seasonal SWM rainfall at district level in the state of Himachal Pradesh (H.P.) using district level rainfall and satellite observed cloud data for a period of 25 years (1983-2007). Regression equations were developed between SIOCZ Activity Index (SAI) and SWM seasonal rainfall in the districts of the state using data for the period 1983-2002. The data for the remaining period (2003-2007) were used for forecast verification. At spatial resolution of a subdivision, a forecast had been termed as 'Useful' if (i) both the forecast as well as the realized rainfall were in the same broad category of 'Excess/Normal' or 'Deficient/Scanty' and (ii) criterion (i) was not satisfied but the difference between the forecast and realized rainfall was within $\pm 15\%$. These criteria were also used for verification of forecasts at district level. Verification results showed that the % of 'Useful' forecast ranged from 100% in the districts of Chamba, Hamirpur and Sirmur to 60% in the

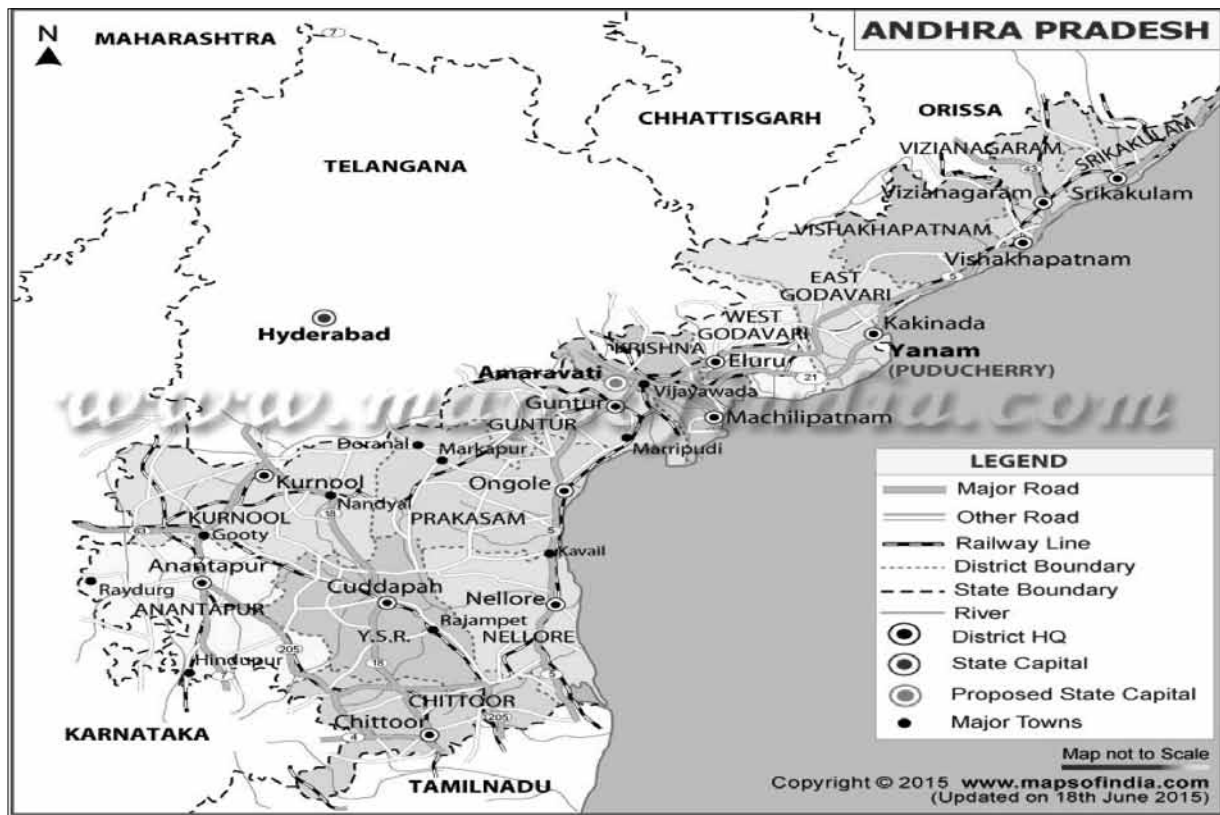


Figure 1. Districts of Andhra Pradesh.

district of Simla. The % of 'Useful' forecast was low in Kangra (40%), Solon (40%) and Kullu (20%). Thus the % of 'Useful' forecast had ranged from 100% to 60% in as many as 7 out of 11 districts. Forecast for the district of Lahol-Spiti was not available because of missing rainfall data in several years. These preliminary results hinted towards the possibility of preparing LRF of rainfall at district level also based on SIOCZ model.

Preparing LRF of seasonal rainfall for the districts of the subdivision of Tamilnadu and Pondicherry was taken up next (Prasad, Singh and Subramanian, 2010a). The subdivision was chosen as a test case because the variability in rainfall from one district to another is largest in this subdivision and also that the rainfall amounts in the districts are small during SWM season. The values of SAI, which had been used for forecasting rainfall in the subdivisions including H. P., was found not adequate to prepare forecasts in the districts of Tamilnadu and Pondicherry. The Correlation Coefficients (CCs) were small and not significant. Therefore, the complete exercise of assigning SAI, calibrated with the seasonal SWM rainfall for the subdivision of Tamilnadu and Pondicherry, was carried out. District level rainfall data were not available. 29 districts of Tamilnadu and Pondicherry were clubbed into 8 clusters of districts. Clubbing of the districts, to form a cluster of districts, was done on the basis of similar

characteristics of rainfall during SWM. The districts of Kanyakumari and Nilgiri Hills could not be clubbed with any other district. Seasonal rainfall data were worked out from station level data for 8 clusters of districts and the districts of Kanyakumari and Nilgiri Hills for the period 1972-2004. Regression equations were developed between SAI and rainfall in each cluster of districts/district using data for a period of 20 years (1972-1992 except 1978 when cloud data were not available). CCs between SAI and rainfall improved for the subdivision as well as for the cluster of districts/districts. Verification of the forecasts, for the period 1993-2004 and real time forecasts for the period 2005-2008, had shown that the forecasts were reasonably good.

Recently, IMD has made available rainfall data at district level for 100 year period, 1901-2000. With the availability of district level rainfall data, a new set of regression equations were developed between SAI and district level rainfall in the state of Tamilnadu. Substantial improvement was seen, as the CCs became significant at 95% level or more in all the districts except Kanyakumari. Verification of district level real time forecasts, available from the new set of equations for the past 7 years (2009-2015), has further confirmed that the forecasts are satisfactory and reasonably good. With the availability of satellite observed cloud data for a period of 43 years (1972-

Table 1. Long period average rainfall during southwest monsoon season in the districts of A.P. [Period: 1901-2000]

District	Rainfall (mm)						
	Jun	Jul	Aug	Sep	Jun-Sep	Annual	Southwest monsoon seasonal Rainfall as % of annual
Srikakulam	135.2	177.6	195.3	203.5	711.6	1113.5	64
Vizianagram	140.4	168.0	189.4	203.0	700.8	1120.4	62
Vishakhapatnam	118.1	149.1	153.2	190.3	610.7	1056.6	58
East Godavary	131.9	208.9	185.6	184.2	710.6	1142.4	62
West Godavary	132.7	227.4	206.7	174.3	741.1	1087.4	68
Krishna	112.9	195.6	179.5	163.0	651.0	978.9	66
Guntur	90.3	140.8	145.2	149.4	525.7	858.6	61
Prakasam	55.1	91.6	92.5	121.8	361.0	775.6	46
Nellore	44.8	78.9	83.2	104.8	311.7	1041.5	30
Kurnool	74.5	109.1	116.3	143.2	443.1	642.4	69
Anantpur	49.6	58.5	74.3	130.3	312.7	542.7	58
Cuddapah	61.5	93.9	103.5	126.7	385.6	703.5	55
Chittoor	59.2	90.3	104.1	130.0	383.6	877.3	44

Source: India Meteorological Department

2015 except 1978), district level rainfall data, the forecast technique already developed and the results tested on the real time basis for the past several years in Tamilnadu and H.P., it has now become possible to examine the possibility of preparing district level LRF of rainfall during SWM in other states also. To begin with, we have discussed the results related to the state of A. P., in this paper.

Data Used and Method of Analysis

District level rainfall during SWM season and SAI values for a period of 41 years (1972-2013 except 1978) have been used in the study. Regression equations have been developed between SAI and rainfall using data for the first 32 years (1972-2004 except 1978) and data for the remaining 9 years (2005-2013) have been used for forecast verification.

Rainfall

Long Period Average (LPA) of monthly, seasonal and annual rainfall for the districts of A. P. are given in Table 1. The districts have been listed in Table 1, as well as in other Tables also, beginning from north to south. As many as 7, out of 13 districts of A. P., receive more than 60% of the annual rainfall during SWM season alone. East Godavary district receives the maximum rainfall and rainfall is minimum in the southern most coastal district of Nellore and neighboring interior district of Chittoor. In general, seasonal rainfall decreases from north to south and the decrease is sharp in the districts south of Krishna. Rainfall

is maximum in the month of July in the districts of East Godavary, West Godavary and Krishna and it gradually decreases in August and September. The characteristic feature of monthly rainfall in other districts is that rainfall increases from June to September and it is maximum in September. This feature in rainfall occurrence gets reflected in rainfall during bi-monthly periods of Jun+ Jul, Jul+ Aug and Aug+ Sep also. The maximum contribution to SWM seasonal rainfall comes from the bi-monthly period of Aug+ Sep followed by Jul+ Aug and Jun+ Jul. An exception to this is that the districts of East Godavary, West Godavary and Krishna receive maximum rainfall during the bi-monthly period of Jul+ Aug.

Siocz Activity Index

The new approach to long range forecasting of rainfall during southwest monsoon season makes use of close relationship between the activity of SIOCZ and rainfall in India. Quantifying the activity of SIOCZ during the period January-May, in relation to Indian Summer Monsoon Rainfall (ISMR) by assigning an index (called SIOCZ Activity Index (SAI), which ranges from 1-20 and is inversely related to ISMR), is the most important aspect of the new approach. The first set of values of SAI for a period of 16 years (1972-1989 except 1978 and 1981) had been assigned at the time of proposing SIOCZ model (Gupta and Prasad, 1992). Assigning SAI in relation to rainfall in the subdivision of Tamilnadu and Pondicherry has been discussed by Prasad, Singh and Subramanian (2010a). The method of assigning SAI has been improved

Table 2. South Indian Ocean Convergence Zone Activity Index (SAI) [Period: 1972-2013]

Year	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
SAI	20	6	15	4	10	9	*	16	7	7	14
Year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
SAI	3	13	14	16	17	1	8	7	14	16	9
Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
SAI	8	10	9	9	7	5	14	6	16	6	16
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013		
SAI	16	7	6	7	15	8	9	18	7		

* Cloud data were not available in 1978 after 16 March.

Table 3. CCs between SAI and rainfall (mm) in the districts of A.P. [Period: 1972-2004 except 1978]

District	Jun	July	Aug	Sep	Jun+ Jul	Jul+ Aug	Aug+ Sep	Jun-Sep
Srikakulam	-.11	-.13	-.20	-.06	-.19	-.22	-.18	-.22
Vizianagram	-.04	-.07	-.40	-.19	-.09	-.33	-.40	-.40
Vishakhapatnam	-.01	-.31	-.19	-.26	-.23	-.32	-.33	-.34
East Godavary	-.03	-.45	-.28	-.32	-.39	-.49	-.44	-.52
West Godavary	-.08	-.54	-.17	-.31	-.46	-.43	-.30	-.50
Krishna	-.03	-.57	-.21	-.41	-.48	-.46	-.44	-.50
Guntur	-.01	-.48	-.32	-.34	-.41	-.52	-.53	-.57
Prakasam	.13	-.32	-.28	-.28	-.18	-.36	-.42	-.35
Nellore	.08	-.40	-.33	-.11	-.21	-.45	-.34	-.34
Kurnool	.20	-.24	-.41	-.35	-.06	-.52	-.49	-.44
Anantpur	.13	-.28	-.47	-.25	-.20	-.50	-.45	-.45
Cuddapah	.19	-.42	-.43	-.29	-.21	-.51	-.48	-.48
Chittoor	.16	-.42	-.49	-.26	-.22	-.59	-.52	-.44

CCs $\geq .34$, significant at 95% level or more, have been shown in bold italics.

by making use of cloud amounts and cloud anomaly data for a longer period of time (Prasad, Singh and Prasad (2010b) and Prasad and Singh (2012)). The value of SAI is being assigned on real time basis since 1990. Using the value of SAI, real time long range forecasts of rainfall are being issued regularly from 1990. The values of SAI for the period 1972-2013 have been reproduced in Table 2.

Correlation between Sai and Rainfall

Correlation Coefficients (CCs) between SAI and rainfall (monthly, bi-monthly and seasonal) for a period of 32 years (1972-2004 except 1978) are given in Table 3. The value of CCs significant at 95% and 99% level are .34 and .44 respectively. CCs are small and not significant in the month of June in any of the districts. They become significant in 7 districts in July, 5 districts in August and 3 districts in September respectively. CCs are significant in as many as 10 districts for bi-monthly periods of Jul+ Aug and in Aug+ Sep. CCs are significant in 12 districts for seasonal rainfall. Srikakulam district is the exception where CCs are not significant in any of the months, bi-monthly

periods as well as for the season. The regression constants, for those districts only where the CCs are significant, are given in Table 4. Forecasts prepared using the regression equations have been discussed in the forecast verification section. How to improve the forecasts in the districts where CCs are not significant has also been discussed.

Forecast Verification

As mentioned earlier, assigning SIOCZ Activity Index (SAI) is the most important aspect of the new approach to long range forecasting of rainfall in India. It is desirable to achieve an accuracy of ± 1 in assigning SAI. However, as the satellite observed cloud/OLR data required for assigning SAI are available for a limited period of time (41 years) achieving this accuracy could not be possible in every year. Hence it is presumed that there could be an error of ± 2 in the assigned value of SAI in a year (Table 2). Accordingly the Model Error (M.E.) becomes twice the value of constant 'a' of the regression equations. The M.E., which is in mm, has been converted into % of Long Period Average (LPA) rainfall. The M.E. in the

Table 4. Constants of regression equations (straight line) in the districts of A. P. where CCs are significant at 95% level or more [Period: 1972-2004 except 1978].

District	Jun		July		Aug		Sep		Jun+ Jul		Jul+ Aug		Aug+ Sep		Jun-Sep	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Srikakulam																
Vizianagram					-4.7								-3.7		-8.4	
					229.0								218.8		748.3	
Vishakhapatnam															-10.2	
															768.2	
East Godavary			-8.0						-4.2		-6.9		-5.8		-20.0	
			288.2						213.6		283.2		254.5		936.1	
West Godavary			-10.5						-5.9		-7.2				-20.3	
			322.0						228.6		295.0				936.2	
Krishna			-10.3				-6.7		-5.3		-6.9		-5.2		-20.9	
			295.3				225.8		202.9		261.8		227.1		860.0	
Guntur			-6.7				-5.9		-3.4		-5.9		-5.5		-17.8	
			219.5				206.2		155.7		215.8		209.1		729.8	
Prakasam											-3.7		-4.1		-9.6	
											134.3		156.0		471.7	
Nellore			-4.3								-4.0		-2.6		-8.5	
			133.5								130.4		127.7		427.0	
Kurnool					-5.8		-5.0				-4.2		-5.4		-11.6	
					184.5		183.6				158.3		184.0		557.4	
Anantpur					-5.0						-4.0		-4.4		-11.1	
					123.9						107.3		146.8		427.6	
Cuddapah			-5.0		-6.0						-5.5		-5.2		-13.2	
			146.3		168.6						157.4		169.8		525.5	
Chittoor			-4.9		-5.9						-5.4		-4.6		-13.4	
			157.1		171.3						164.2		174.4		565.0	

districts, in the order as they have appeared in Tables 3-4, and where the CC is significant in the months of Jul, Aug and Sep are 8,9,11,10,11,11,11; 5,10,14,12,11, and 8,8,7 respectively. Similarly the M.E. for bimonthly periods of Jun+Jul, Jul+Aug and Aug+Sep are 5,7,7,6; 7,7,7,8,10,7,12,11,11 and 6,4,6,8,8,5,8,9,8,8 respectively. The M.E. for seasonal rainfall are 2,3,6,5,6,7,5,5,5,7,7,7 for the respective districts. We have used the categorization of rainfall based on % departure from normal as used in IMD ('Excess' (E), R/F >20%, 'Normal' (N) 19% to -19%, 'Deficient' (D) -20% to -59%, 'Scanty' (S) -60% to -99% and 'No Rain' (NR) -100%) for describing rainfall in districts. For ISMR, rainfall is more than 10% for 'Excess' category, between 10% and -10% for 'Normal' and less than -10% for 'Deficient' category. At the spatial resolution of a district, a forecast has been considered 'Useful' if both, the forecast as well as the realized rainfall, are in the same broad category of 'Excess/Normal' or 'Deficient/Scanty' or they become so when M.E. is taken into account. The results of verification for a period of 9 years (2005-2013) have been included in Tables 5 and 6. The forecasts in a given year have been considered to be reasonably good if

it were in 'Useful' category in at least 60% of the districts where CC was significant.

Forecast of monthly rainfall

District-wise % of 'Useful' forecast during the period 2005-2013 are given in Table 5. The CCs are not significant in any of the districts in the month of June. CCs are significant in 7 districts in July. The % of 'Useful' forecasts has varied from 67% in 5 districts to 91% in East Godavary district. The CCs are significant in 5 districts in August. The % of 'Useful' forecasts has varied from 78% to 89% except in Anantpur district where it is 45%. During September, the CCs are significant in 3 districts only. The % of 'Useful' forecasts was 67% in all the 3 districts. There was some deterioration in forecasts in the month of September as compared to July and August. The verification results on the performance of the model in the districts, where CCs are significant, in individual years have been included in Table 6. The forecasts were in 'Useful' category except for Aug-Sep 2005, Jul-Aug 2006, Sep 2008 & 2011 and Jul-Sep 2012,. It follows from the

Table 5. Forecast verification District-wise % of 'Useful' forecast [Period : 2005-2013]

District	Month/bi-monthly period/season									
	Jun	Jul	Aug	Sep	Jun+ Jul	Jul+ Aug	Aug+ Sep	Jun- Sep		
Srikakulam										
Vizianagram			78				90	90		
Visakhapatnam								90		
East Godavary		91			89	90	100	100		
WestGodavary		67			78	60		90		
Krishna		67		67	78	80	90	90		
Guntur		78		67	89	80	80	90		
Prakasam						80	90	90		
Nellore		67				100	80	90		
Kurnool			89	67		80	90	90		
Anantpur			45			60	80	80		
Cuddapah		67	78			60	100	80		
Chittor		67	89			90	100	100		

results of verifications of monthly forecasts that, at this stage, long range forecasts of southwest monsoon rainfall could be prepared for a limited number of districts only. As mentioned above, forecasts in a given year have been considered to be reasonably good if it were in 'Useful' category in at least 60% of the districts where CC was significant. The reasons for reduction in districts in 'Useful' category of forecasts below 60% in some of the years are discussed below.

Forecast of bi-monthly rainfall

During the bi-monthly period of Jun+ Jul, CCs are significant in 4 central districts of CAP. The % of 'Useful' forecasts has varied from 78% to 89% (Table 5). The CCs are significant in as many as 10 districts during the bi-monthly periods of Jul+ Aug and Aug+ Sep. The % of 'Useful' forecasts has varied from 70% to 81% in Jul+ Aug and from 80% to 100% in Aug+ Sep. The verification results on the performance in individual years have been included in Table 6. The forecasts were in 'Useful' category in all other years except during 2006 and 2012,. During the bi-monthly period of Jul+ Aug, forecasts were in 'Useful' category in all other years except in 2006. There is further improvement in the forecasts during the bi-monthly period of Aug+ Sep. Forecasts were in 'Useful' category in all the years. Forecasts were in 'Useful' category in all the districts in 4 years and in as many as 7 to 9 districts (out of 10) in the remaining 5 years.

Forecast of seasonal rainfall

For seasonal rainfall the CCs were significant in 12 out of 13 districts. CC was not significant in the northern most

district of Srikakulam. The % of 'Useful' forecast was 80% in Anantpur and Cuddapah and 90% to 100% in the remaining districts. Year-wise verification (Table 6) showed that in 4 years, the forecasts were in 'Useful' category in all the district and in 9 to 11 districts during the remaining 5 years. Thus the forecasts for the seasonal rainfall could be termed as extremely good in all the districts. For the sake of illustration, the forecasts and the realized rainfall have been reproduced for a drought year (2009), a weak monsoon year (2012) and a normal monsoon year (2010) (Table 7). There was no excess monsoon year during the period of verification.

It follows from the results of the verifications of bimonthly and seasonal forecasts that they were in 'Useful' category in the majority of the districts during Jul+ Aug and Aug+ Sep and for the season as whole except for the bi-monthly period of Jun+ Jul. Thus preparing district level forecast could be attempted for all the districts of A. P. for bi-monthly periods of Jul+ Aug and Aug+ Sep and for the season as whole. The reasons for reduction in districts in 'Useful' category of forecast below 60% during some of the years have been discussed below.

Reduction in Number of Districts in 'Useful' Category Of Forecast In Some Of The Years

As mentioned above, there was a reduction in the number of districts falling in 'Useful' category of forecast below 60% in some of the years (Table 6). The months, bimonthly periods and the years when this happened were Aug-Sep 2005, July-Aug 2006, Jun+ Jul 2006, Jul+ Aug 2006, Sep 2008 & 2011, Jul-Sep and Jun+ Jul 2012. The reasons for the reduction in number of districts below 60% in 'Useful' category of forecast are briefly discussed below.

Table 6. Forecast verification Number of districts where the forecasts were in 'Useful' category [Period: 2005-2013]

Year	Jun	Jul	Aug	Sep	Jun+ Jul	Jul+ Aug	Aug+ Sep	Jun-Sep
	Number of districts where CC is significant							
	Nil	7	5	3	4	10	10	12
2005		6	1	1	4	9	9	12
2006		1	2	3	1	1	7	9
2007		5	4	3	3	10	10	12
2008		6	4	1	4	10	10	11
2009		6	4	3	3	10	10	12
2010		7	5	3	4	10	10	12
2011		6	5	0	4	10	7	10
2012		0	1	1	2	6	8	9
2013		7	3	3	4	8	9	9

Table 7. Forecast of seasonal rainfall

District	Model error	Drought (2009)		Weak monsoon (2012)		Normal monsoon (2010)	
		FR	RR	FR	RR	FR	RR
Srikakulam \$	2	97 N	88 N	94 N	114 N	104N	119 N
Vizianagram	2	89 N	102N	85 N/MD	107 N	97 N	136 E
Visakhapatnam	3	101N	102N	96 N	111 N	112 N	136 E
East Godavary	6	90 N	84 N	81 N/MD	134 E	109 N	173 E
West Godavary	5	85 N/MD	70 MD	77 D	141 E	104 N	153 E
Krishna	6	84 N/MD	70 MD	74 D*	142 E	106 N	172 E
Guntur	7	88 N	82 N	78 D	112 N	112 N	179 E
Prakasam	5	91 N	82 N	83 N/MD	106 N	109 N	170 E
Nellore	5	96 N	81 N	88 N	100 N	115 E/N	174 E
Kurnool	5	86 N	97 N	79 D	95 N	105 N	140 E
Anantpur	7	84 N/MD	117 N	73 D*	93 N	108 N	138 E
Cuddapah	7	85 N/MD	96 N	75 D	74 D	109 N	131 E
Chittoor	7	95 N	104N	84 N/MD	113 N	119 E/N	138 E
% of 'Useful' Forecasts		100%		85%		100%	

\$ CC is not significant Moderately Deficient (MD):Rainfall -20% to -30% FR: Forecast Rainfall

RR: Realized Rainfall

* The forecast is not in 'Useful' category.

Monsoon -2005

The value assigned to SAI in the year 2005 was 16 (Table 2). With SAI=16, the forecast rainfall in the districts of A.P. was normal in 7 districts in July, 8 districts in August and 6 districts in September and deficient in the remaining districts. The number of districts where forecast was in 'Useful' category was 1 out of 5 in Aug and 1 out of 3 in Sep 2005 respectively (Table 6). Large intra-seasonal changes took place during 2005 southwest monsoon and this resulted in forecast going out in some of the districts. In order to discuss the intra-seasonal changes, OLR anomaly field during June-October (pentad Nos. 31-60) has been reproduced in Figure 2. It may be seen that 2 weak monsoon surges, which developed to the south of

equator during the month of August (pentad Nos.43-48) could reach up to 15°N only. The result was that all the 4 districts of Rayalaseema received excess/normal rainfall and rainfall was deficient in the districts of CAP. This was just opposite to the forecasts in the districts of Rayalaseema during August. The weakening of the surges during August had resulted in deficient rainfall not only in CAP but also over 18 more subdivisions in central, northwest, north and east India. Country as a whole had received 28% below normal rainfall in August 2005 and the deficiency was 36% in CAP. This was the result of the intensification of weak monsoon conditions, as forecasted, during August 2005. Severe drought conditions prevailed over CAP during August 2005. Reader is referred to a recent paper by the authors (Prasad, Singh and Prasad (2014)) for more

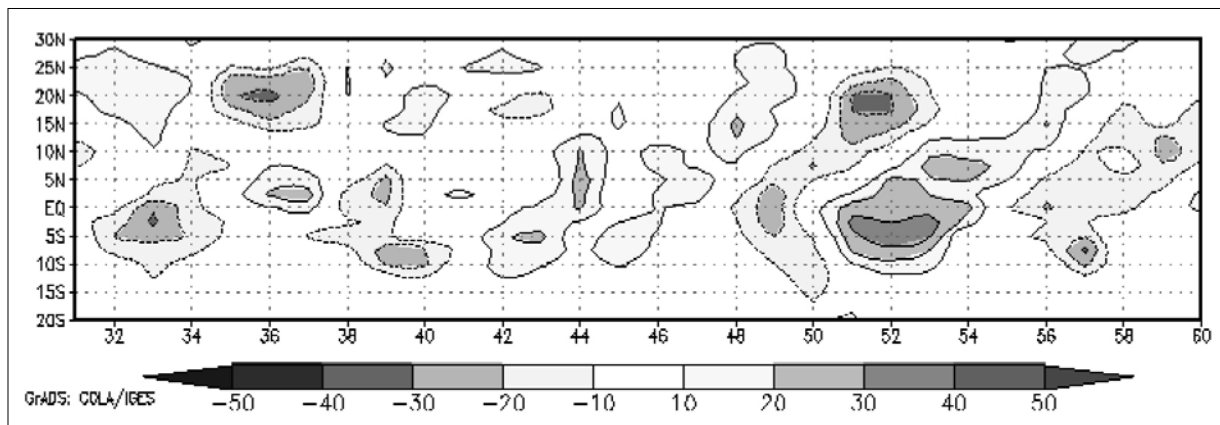


Figure 2. OLR anomaly during June-October 2005 (Pentad Nos. 31-60).

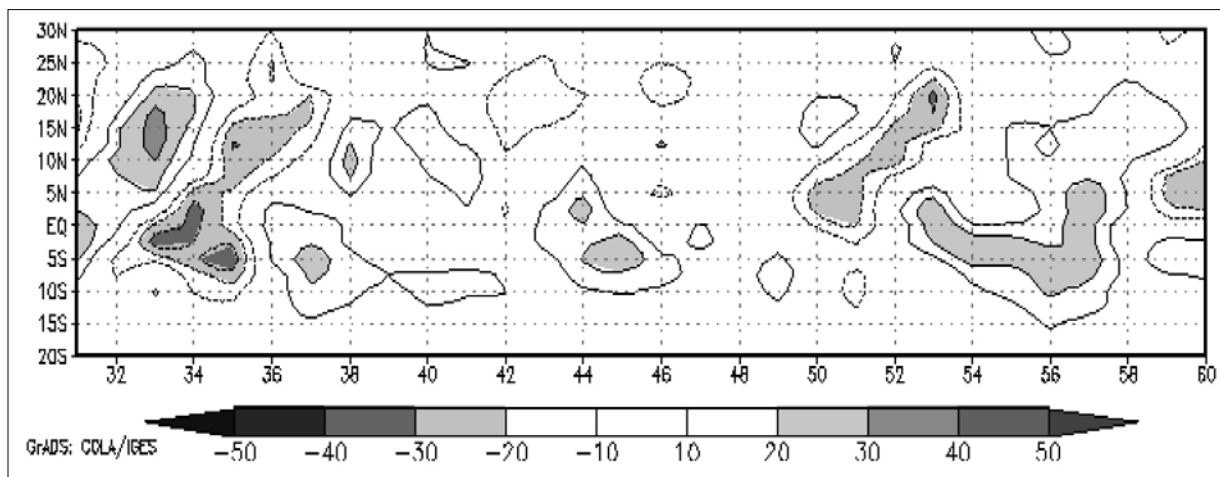


Figure 3. Same as Figure 2 but for the year 2006.

details on the intra-seasonal changes during southwest monsoon season in some of the years including that during Monsoon-2005.

Monsoon-2006

The value assigned to SAI in the year 2006 was 7 (Table 2). With SAI=7, the forecast rainfall in the districts of A.P. during all the four months of Monsoon-2006 was in 'Excess/Normal' category. The forecast was quite okay in June and September. However, there was a reduction in number of districts where forecasts were in 'Useful' category in July and August (Table 6). Summer monsoon circulation system weakened considerably during July and to some extent in August also. Figure 3 shows OLR anomaly field during June-October 2006. SIOCZ remained active during July (pentad Nos. 37-42) and during the first half of August (pentad Nos. 44-46) also. This was an intra-seasonal change in Monsoon-2006 which resulted in reduction in rainfall over CAP as well as over Rayalaseema. As many

as 9 districts received 'Deficient'/'Scanty' rainfall in July and 6 in August.

Monsoon-2008

The value assigned to SAI in the year 2008 was 7 (Table 2). With SAI=7, the forecast rainfall in the districts of A.P. during all the four months of Monsoon-2008 was in 'Excess/Normal' category. Forecast was okay during July-August. However, there was a reduction in the number of districts where forecast rainfall was in 'Useful' category in September (Table 6). The realized rainfall was deficient in 6 districts of CAP and in 'Excess/Normal' category in the remaining 7 districts. OLR anomaly Figure 4 shows that the surge which developed during September (pentad Nos. 49-54) remained confined to the areas south of 5°N during the first three pentads (Nos.50-52). It moved northward during the later half of the month (pentads 53-54), but still remained active to the south of 15°N only. This resulted in normal to excess rainfall in the districts of

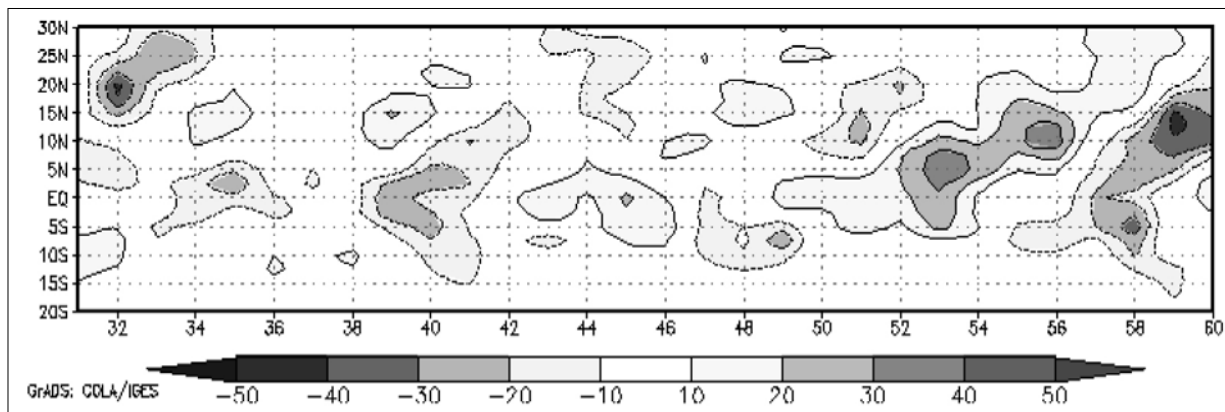


Figure 4. Same as Figure 2 but for the year 2008

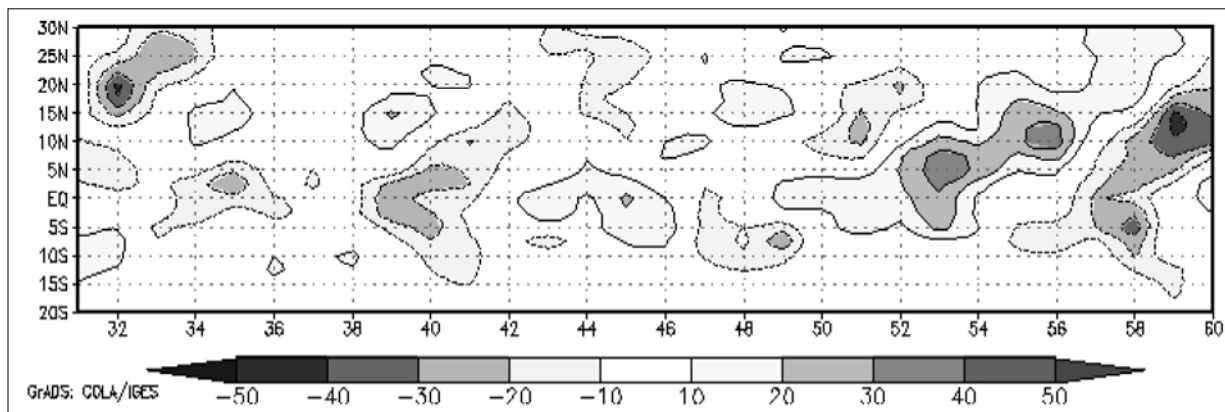


Figure 5. Same as Figure 2 but for the year 2011

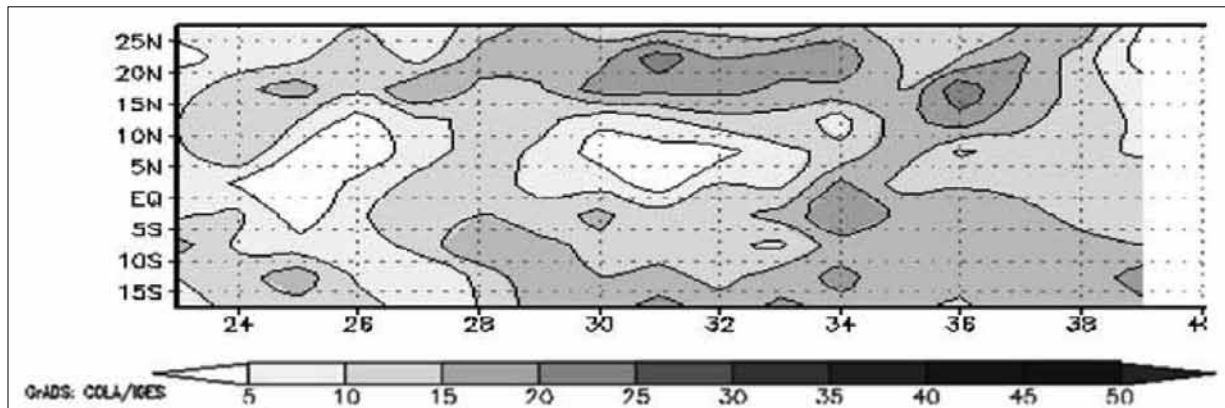


Figure 6. Zonal weekly mean cloudiness between 40°E -100°E during June-September 2012 (Week Nos. 23-39).

Rayalaseema and deficient rainfall in the majority of the districts of CAP.

Monsoon-2011

The value assigned to SAI in the year 2011 was 9 (Table 2). With SAI=9, the forecast rainfall in the districts of A.P. during all the four months of Monsoon-2011 was in 'Excess/Normal' category. Forecast was okay during July-August. However, there was a reduction in number

of districts in 'Useful' category of forecast rainfall during September. During September-2011, realized rainfall was scanty in 4 districts and deficient in 1 in CAP and scanty in 2 and deficient in 1 district of Rayalaseema. Rainfall was also deficient in Tamilnadu and Pondicherry, South Interior Karnatak, North Interior Karnatak, Telangana and Vidarbha during September 2011. This implies that the surge was very weak during September 2011. This is confirmed from the OLR anomaly field Figure 5 which shows that a weak surge which developed during pentad Nos. 49,

i.e., in the beginning of the month, moved northward and remained active in the areas north of 15°N during the next 3 pentads. The next surge which developed during pentad No.51, did not move northward and remained confined to the areas south of 10°N only. This surge weakened during the next pentad.

Monsoon-2012

The value assigned to SAI in the year 2012 was 18 (Table 2). With SAI=18, the forecast rainfall was in 'Deficient' category in 10, 7 and 9 districts during July, August and September respectively. However, the realized rainfall was 'Excess'/'Normal' in all the districts of A.P. during July and August. Rainfall was in 'Deficient' category in 5 districts in September. Thus there was a large reduction in the number of districts where the forecast rainfall was in 'Deficient/Scanty' category during July and August (Table 6). This resulted due to an intra-seasonal change, wherein very poor rainfall scenario during June changed to an improved one during July-September. As the plot of OLR anomaly field was not available, plot of zonal weekly mean cloudiness for the period June-September 2012 (Week Nos. 23-39) have been reproduced here Figure 6 to illustrate this intra-seasonal change. During the onset phase, a Maximum Cloud Zone (MCZ) moved from close to equator up to 25°N. However, the surge was weak as associated cloudiness cloud amounts were not high. Rainfall for country as a whole during June 2012 was -28% and as many as 27 subdivisions received 'Deficient'/'Scanty' rainfall. In A.P. June rainfall was 'Deficient'/'Scanty' in 7 districts and 'Excess'/'Normal' in 6. Rainfall improved significantly in July and August as a result of the strengthening of monsoon trough during this period. This could be seen in the presence of increased cloudiness as a Maximum Cloud Zone (MCZ) to the north of 15°N during July-August (Week Nos. 27-24). The MCZ weakened by the end of August. In the beginning of September, a weak surge moved from close to equator up to 30 °N. This surge resulted in the strengthening of MT and rainfall was 'Excess'/'Normal' in the districts of CAP. However, rainfall was deficient in all the districts of Rayalaseema.

Improvement in Forecasts

For seasonal rainfall, the CC is not significant in only one district, i.e., Srikakulam. There were 9 drought years during the period of study. However, the realized rainfall was deficient in Srikakulam only 2 years: 1974(78%) and 1987(50%). The chances of Srikakulam district receiving deficient rainfall during drought years is about 22% only. Thus a 'Normal/Moderately Deficit (MD)' category of rainfall could be forecast in a year when a deficit rainfall

has been forecasted for the country as a whole. With the use of this value addition tool for Srikakulam district, forecast of seasonal rainfall could be prepared for all the 13 districts of A.P. During the bi-monthly period of Jun+ Jul, the CCs were not significant in 9 districts. In these districts the forecast rainfall was in 'Useful' category in all the 9 districts in 5 years (2007,2010-2013), in 8 districts in 1 year (2005), in 6 districts in 2 years (2007,2008) and in 3 districts in 1 year (2009). Thus except for one year the forecast rainfall was in 'Useful' category in 6-9 districts out of 9 districts where the CCs were not significant. During the bi-monthly period of Jul+ Aug, CCs were not significant in 3 districts. The forecast rainfall was in 'Useful' category in all the 3 districts during 4 years (2006, 2010-2012), in 2 districts in 3 years (2008,2009), in 1 district in 1 year (2005) and in none of the 3 districts in 2 years (2007,2013). During the bi-monthly period of Aug+ Sep also, the CCs were not significant in 3 districts. The forecasts were in 'useful' category in all the 3 districts during 7 years (2005-2008, 2010-2012) and in 2 districts in 2 years (2009 and 2013). Thus the performance of the model in the districts where the CCs were not significant is nearly comparable to its performance in the districts where CCs were significant. The CCs worked out using 41 years (1972-2013 except 1978) data show that the CCs have become significant at 95% level or more in 3 more districts in August and 1 more district during the bi-monthly period of Jul+ Aug. This suggests that the CCs may become significant in some more districts when cloud data become available for some more years in future. It follows from the discussions, on the reasons for the reduction in number of districts in 'Useful' category of forecasts in some of the years, as discussed above, that the reduction resulted due to intra-seasonal changes in monsoon circulation system and that it had affected forecasts in the districts where CCs are significant as well as in those districts also where CCs are not significant. The verification results for bi-monthly periods, in the districts where CCs are not significant, suggest that forecasts could be prepared for those districts also where CCs are not significant. However, improvements are required so that forecasts could become 'Useful' in all most all districts in most of the years, as was the case for the forecasts for seasonal rainfall.

The forecasts could be further improved by studying the relationship between the activity of SIOFZ and rainfall in individual districts of A.P. The pattern found in the relationship between SAI and rainfall could be quantified by assigning a new set of SAI values pertaining to each district. It is believed that the regression equations developed with this new set of SAI values shall be able to improve the forecasts. This aspect did not form a part of the present study.

CONCLUSION

(i) The intimate relationship between the activity of SIO CZ during the period January-May and Indian Summer Monsoon Rainfall during June to September, which formed the basis for the new approach to long range forecasting of monsoon rainfall in India, also holds good for southwest monsoon rainfall in the districts of Andhra Pradesh.

(ii) Long range forecasts of seasonal rainfall as well as rainfall during bi-monthly periods of Jul+ Aug and Aug+ Sep could be prepared for all the districts of A.P and for 4 districts for rainfall during bi-monthly period of Jun+ Jul. Forecasts could also be prepared for monthly rainfall for 7 districts in July, 8 districts in August and for 3 districts in September.

(iii) In some of the years, there could be a reduction in the number of the districts in 'Useful' category of monthly/bi-monthly forecast. This happens in the years of large intra-seasonal changes in monsoon circulation system which could not be foreshadowed at the time of formulating the forecast at the end of May/beginning of June.

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Visible cloud imagery of EUMETSAT/IODC available on their web site on real time basis.

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