Long range forecast of rainfall during southwest monsoon in the states of Maharashtra and Goa

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ABSTRACT

The close relationship known between the activity of South Indian Ocean Convergence Zone and southwest monsoon rainfall for India as a whole also exists for all the four meteorological subdivisions of the states of Maharashtra and Goa (viz., Konkan & Goa, Madhya Maharashtra, Marathwada and Vidarbha). The present study has shown that long range forecast of rainfall for southwest monsoon season as a whole (June-September), bi-monthly periods of August+ September and for the month of September could be prepared for all the four subdivisions. Forecast for seasonal rainfall, at the district level, could be prepared for all districts of the region except the 4 districts of Madhya Maharashtra, namely, Nasik, Pune, Satara and Sangli. For the months of July and September forecast could be prepared for the majority of the districts. For August rainfall forecasting could be possible for the districts of the subdivision of Marathwada only. Forecast for rainfall in the month of June could not be prepared for any of the subdivisions/districts.

Key Words: Long Range Forecast, South Indian Ocean convergence zone, Southwest monsoon and Maharashtra and Goa.

INTRODUCTION

Maharashtra and Goa are two contiguous western states of India with 36 and 2 districts respectively (Figure 1 and 2). Based on rainfall characteristics, the districts of Maharashtra and Goa have been clubbed together to form four meteorological subdivisions, namely, Konkan & Goa, Madhya Maharashtra, Marathwada and Vidarbha (Figure 1 & Table 1). All the four subdivisions receive rainfall during Southwest Monsoon (SWM) (June-September) and also during Northeast Monsoon (NEM) (October-December).The contribution of SWM (NEM) rainfall to the annual total is 94% (5%) in Konkan and Goa, 83% (12%) in Madhya Maharashtra, 84% (11%) in Marathwada and 88% (7%) in Vidarbha. Goa's annual rainfall is 3040.5 mm. Most of the annual rainfall (91%) is received during southwest monsoon season alone. As these two states receive rainfall mainly during southwest monsoon, a reliable advance information on it is a necessity for sustenance and development of the two states. It is in this context that the possibility of issuing long range forecast of southwest monsoon rainfall, in the states at district level, has been attempted by the authors and the results are discussed in the following.

Data Used and Method of Analysis

Subdivision and district level rainfall during Southwest monsoon and South Indian Ocean Convergence Zone (SIOCZ) Activity Index (SAI) values for a period of 43 years (1972-2015, except for 1978 when cloud data were not available) have been used in the study. Rainfall data were not available for the recently created district of Palghar. Also the data for the district of Mumbai Suburban were available for a limited period (1972-1989) only. Regression equations have been developed between SAI and rainfall using the data for a period of 32 years (1972-2004 except 1978) and data for the remaining 11 years (2005-2015) have been used for forecast verification.

RAINFALL

Long Period Average (LPA) of monthly, seasonal and annual rainfall for the subdivisions and their districts are given in Table1. The Coefficient of Variation (C.V.) is highest in Marathwada for monthly as well as for the seasonal rainfall. The frequency of occurrence of deficient rainfall is lowest in the subdivision of Konkan & Goa. The rainfall of the subdivision was deficient in 7 years only during the period of 66 years (1950-2015). The number of deficient rainfall years during the said period in the subdivisions of Madhya Maharashtra, Marathwada and Vidarbha are 17, 21 and 13 respectively. Long range forecast of rainfall for the subdivision of Marathwada and its districts assumes a special significance because of high variability in monthly and seasonal rainfall and high frequency of occurrence of deficient rainfall.
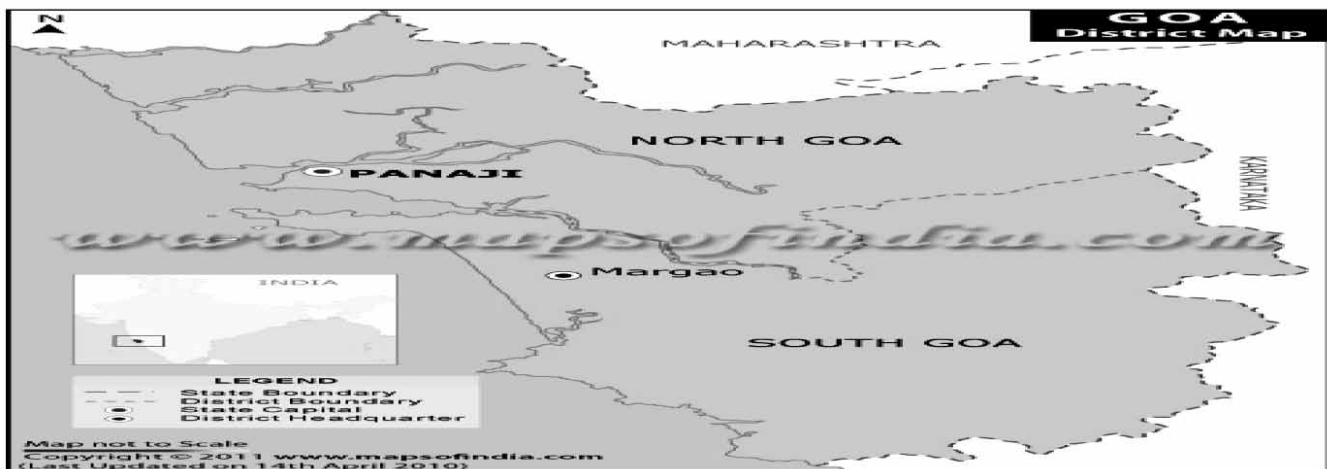
Figure 1. Districts of Maharashtra.

Figure 2. Districts of Goa.

South Indian Ocean Convergence Zone (SIOCZ) Activity Index (SAI)

The first set of 16 values of SAI, pertaining to the years 1972-1989, except 1978 and 1981 based on the features developing in the activity of SIOCZ during April-May, were assigned while proposing SIOCZ model (Gupta and Prasad, 1992). Beginning from the year 1990, SAI values are assigned on the real time basis and used for preparing forecasts (Prasad et al., 2010 a,b; Prasad and Singh, 2012; Prasad et al., 2014, 2016b,c). The values of SAI for the period 1972-2015 are reproduced here in Table 2.

Correlation between SAI and Rainafall

The Correlation Coefficients (CCs) between SAI and rainfall are given in Table 3. The value of CCs significant at 95% and 99% level, are 0.34 and 0.44 respectively. The CCs are small and not significant in the month of June in any of the subdivisions/districts of both the states. The CCs are significant in July for the subdivisions and 24 districts of the states. There is considerable reduction in CCs values during August. However, the CCs are significant for Marathwada subdivision and its 7 districts. The CCs are significant for all the four subdivisions and 32 districts of the states during September. The number of districts where CCs are significant increases from bimonthly period of Jun+ Jul to Aug+ Sep. For the seasonal rainfall, the CCs are significant in all the subdivisions and their districts, except in 4 districts of Madhya Maharashtra, namely, Nasik, Pune, Satara and Sangli. The regression coefficients in the subdivisions and districts where CCs are significant are included in Table 4.

Table 1. Long period average rainfall (mm) during southwest monsoon season in meteorological subdivisions and districts of the states of Maharashtra & Goa. [Period: 1901-2000, Source: India Meteorological Department]

Subdivision/ District	Jun	Jul	Aug	Sep	Jun-Sep	Annual	Jun-Sep rainfall as % of Annual
Konkan & Goa	678.5	1079.5	676.2	341.4	2775.6	2959.1	94
Thane	434.5	924.1	575.2	319.6	2253.4	2368.1	95
Mumbai City	496.2	695.1	421.1	297.9	1914.7	2024.8	95
Mumbai suburban	540.1	803.5	514.9	316.0	2152.5	2239.9	96
Raigarh	619.3	1200.4	805.3	400.6	3025.5	3183.6	95
Ratnagiri	821.8	1237.3	782.8	374.6	3216.5	3433.6	94
Sindhudurga	854.3	1014.8	593.2	290.7	2753.0	2984.6	92
North Goa	873.0	1050.9	610.3	290.9	2825.1	3099.8	91
South Goa	870.4	997.2	572.4	279.1	2726.6	3006.3	91
Madhya Maha.	144.2	249.9	178.3	154.8	727.3	874.3	83
Nandurbar	131.7	282.6	203.4	145.9	763.5	830.0	92
Dhule	116.2	165.4	116.0	113.2	510.9	592.1	86
Jalgaon	131.1	201.4	172.6	136.7	641.7	734.3	87
Nasik	149.7	309.0	227.6	174.0	860.4	979.4	88
Ahmednagar	108.1	100.6	80.3	149.2	438.2	571.8	77
Pune	165.8	333.2	224.5	166.6	890.1	1042.5	85
Satara	199.5	427.6	279.1	173.3	1079.5	1282.5	84
Sholapur	100.7	92.1	92.9	169.7	455.4	618.8	74
Sangli	102.1	143.8	97.8	124.2	467.9	680.1	69
Kolhapur	281.2	602.1	367.9	158.6	1409.8	1658.3	85
Marathwada	140.5	181.6	164.6	182.0	668.7	800.6	83
Aurangabad	131.6	167.1	138.9	161.7	597.6	719.8	83
Jalna	139.2	169.4	157.8	139.8	606.2	722.8	84
Beed	121.5	130.6	123.7	189.4	565.2	692.7	82
Parbhani	154.2	211.7	194.9	194.7	755.4	895.4	84
Hingoli	174.4	230.6	217.9	151.9	774.8	904.3	86
Osmanabad	139.0	158.5	146.1	198.5	638.8	778.4	82
Latur	142.7	195.1	196.5	173.5	707.9	855.4	83
Nanded	154.3	239.3	219.0	191.1	803.4	936.9	86
Vidarbha	172.2	332.2	284.8	176.7	968.5	1101.7	88
Buldhana	146.2	205.6	171.6	138.3	661.7	776.1	85
Akola	139.0	228.5	178.5	137.5	683.7	793.9	86
Wasim	159.8	246.1	209.1	161.2	776.5	893.2	87
Amraoti	148.1	272.3	232.1	159.0	811.5	933.2	87
Yeotmal	170.9	285.7	233.5	165.8	855.8	990.9	86
Wardha	173.5	307.1	247.7	175.0	903.2	1047.6	86
Nagpur	176.5	338.2	283.8	183.2	981.8	1132.8	87
Bhandara	186.9	425.7	395.8	203.5	1211.9	1361.8	89
Gondia	189.3	440.1	419.3	204.1	1253.9	1397.1	90
Chandrapur	189.9	403.6	355.4	201.5	1150.4	1299.2	89
Gadchiroli	200.3	466.0	402.2	208.7	1277.3	1427.1	89

Table 2. South Indian Ocean Convergence Zone Activity Index (SAI). [Period: 1972-2015] *Cloud data were not available in 1978 after 16 March.

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	2014	2015
SAI	16	7	6	7	15	8	9	18	7	14	15

Table 3. Correlation coefficients between SAI and rainfall (mm) in the subdivisions and districts of Maharashtra and Goa. The CCs significant at 95% level or more are shown in bold italics. [Period: 32 years (1972-2004 except 1978)]

Subdivision/District	Jun	Jul	Aug	Sep	Jun+ Jul	Jul+ Aug	Aug+ Sep	Jun-Sep
Konkan & Goa	-.06	*-.40*	-.10	*-.67*	*-.43*	*-.41*	*-.43*	*-.63*
Thane	-.06	*-.41*	.12	*-.63*	*-.42*	-.25	-.31	*-.51*
Mumbai City	.07	-.11	-.08	*-.63*	-.04	-.15	*-.48*	*-.42*
Raigadh	-.20	*-.38*	-.07	*-.61*	-.41	*-.36*	-.35	*-.56*
Ratnagiri	.07	-.27	-.16	*-.64*	-.20	-.32	*-.44*	*-.46*
Sindhudurga	-.02	*-.38*	-.26	*-.54*	-.30	*-.43*	*-.46*	*-.50*
North Goa	.00	*-.43*	-.17	*-.51*	-.33	*-.42*	*-.38*	*-.45*
South Goa	-.08	-.22	-.24	*-.58*	-.22	-.31	*-.46*	*-.45*
Madhya Maha.	-.07	*-.52*	-.01	*-.49*	*-.40*	*-.39*	-.35	*-.55*
Nandurbar	-.18	*-.53*	-.03	*-.42*	*-.48*	*-.34*	-.29	*-.45*
Dhule	-.17	-.30	-.01	*-.52*	*-.35*	-.22	*-.37*	*-.48*
Jalgaon	.04	*-.34*	-.16	*-.57*	-.23	*-.36*	*-.45*	*-.49*
Nasik	-.03	*-.41*	.27	*-.58*	-.27	-.07	-.15	-.29
Ahmednagar	.10	*-.45*	-.24	*-.40*	-.20	*-.46*	*-.49*	*-.50*
Pune	-.05	-.28	.04	*-.40*	-.23	-.15	-.16	-.25
Satara	-.04	*-.41*	.09	-.31	-.28	-.23	-.09	-.29
Sholapur	.00	-.31	*-.35*	-.33	-.26	*-.45*	*-.44*	*-.46*
Sangli	-.02	*-.39*	-.16	-.06	-.23	*-.38*	-.11	-.26
Kolhapur	-.24	-.31	.06	-.30	*-.42*	-.25	-.08	*-.37*
Marathwada	.08	*-.49*	*-.55*	*-.53*	*-.34*	*-.68*	*-.69*	*-.67*
Aurangabad	.15	*-.37*	-.32	*-.48*	-.10	*-.50*	*-.55*	*-.52*
Jalna	.04	-.28	*-.34*	*-.47*	-.23	*-.45*	*-.56*	*-.54*
Beed	.09	*-.38*	*-.56*	*-.46*	-.26	*-.62*	*-.66*	*-.58*
Parbhani	.05	*-.45*	*-.51*	*-.57*	-.31	*-.62*	*-.73*	*-.69*
Hingoli	.30	*-.47*	*-.34*	*-.58*	-.16	*-.58*	*-.55*	*-.59*
Osmanabad	-.08	-.28	*-.43*	*-.42*	-.29	*-.47*	*-.57*	*-.56*
Latur	.07	*-.38*	*-.58*	*-.52*	-.29	*-.63*	*-.59*	*-.63*
Nanded	-.02	*-.56*	*-.59*	*-.54*	*-.48*	*-.72*	*-.71*	*-.73*
Vidarbha	-.15	*-.44*	-.10	*-.68*	*-.46*	*-.40*	*-.54*	*-.61*
Buldhana	.03	*-.44*	-.18	*-.50*	-.32	*-.52*	*-.40*	*-.50*
Akola	-.03	*-.45*	-.05	*-.55*	*-.38*	*-.36*	*-.38*	*-.48*
Wasim	.14	*-.39*	-.22	*-.46*	-.19	*-.45*	*-.45*	*-.46*
Amraoti	-.22	*-.38*	.11	*-.63*	*-.53*	-.15	-.30	*-.51*
Yeotmal	-.03	*-.52*	*-.35*	*-.62*	*-.50*	*-.61*	*-.63*	*-.72*
Wardha	.03	*-.41*	.11	*-.52*	-.33	-.18	-.26	*-.34*
Nagpur	-.20	-.21	-.16	*-.69*	-.27	-.27	*-.60*	*-.54*
Bhandara	-.18	-.30	-.02	*-.70*	*-.35*	-.27	*-.45*	*-.49*
Gondia	-.20	*-.39*	.08	*-.65*	*-.43*	-.23	-.29	*-.46*
Chandrapur	-.17	*-.44*	-.07	*-.63*	*-.41*	-.31	*-.41*	*-.48*
Gadchiroli	-.21	-.31	-.06	*-.60*	*-.37*	-.25	*-.37*	*-.43*
No. of districts where CC is significant at 95% level or more (≥.34)	Nil	24	10	32	15	23	30	32

Table 4. Regression coefficients between SAI and rainfall for the subdivisions and their districts where CC is significant at 95% level or more. The CC is not significant in any subdivision/district during the month of June.

Subdivision/ District	Jul a	Jul b	Aug a	Aug b	Sep a	Sep b	Jun+ Jul a	Jun+ Jul b	Jul+ Aug a	Jul+ Aug b	Aug+ Sep a	Aug+ Sep b	Jun-Sep a	Jun-Sep b
Konkan Goa	-19.8	1219.1			-22.9	556.1	-11.0	964.0	-12.1	998.9	-13.7	667.4	-49.3	3262.7
Thane	-21.1	1061.5			-24.7	553.8	-11.8	755.9			-9.5	560.4	-42.9	2636.6
Mumbai City					-27.8	604.5					-15.9	578.8	-34.8	2402.0
Raigadh	-22.6	1375.4			-23.4	626.6	-15.8	1050.0	-13.3	1129.2	-13.8	754.8	-59.1	3609.6
Ratnagiri					-24.5	602.3					-16.7	760.5	-45.3	3593.6
Sindhudurga	-20.5	1206.3			-19.0	466.9			-16.1	1003.3	-15.3	633.6	-52.1	3352.3
North Goa	-25.4	1300.8			-16.5	417.5			-16.8	1043.0	-12.4	601.4	-50.1	3445.5
South Goa					-21.2	474.5					-17.0	642.0	-52.4	3356.4
MadhyaMaha.	-6.3	298.2			-7.2	224.9	-3.6	237.7	-3.3	249.4	-3.7	212.7	-14.6	900.8
Nandurbar	-12.1	400.9			-9.0	221.7	-8.1	306.2	-6.4	328.5			-25.5	1081.1
Dhule					-7.8	184.0	-3.2	181.3			-3.9	161.0	-14.3	684.6
Jalgaon	-4.5	232.4			-9.1	211.3			-3.6	230.1	-5.9	219.5	-15.6	799.1
Nasik	-7.6	359.2			-9.7	262.4								
Ahmednagar	-4.2	135.4			-7.6	220.9			-3.4	127.1	-5.1	169.9	-13.3	580.7
Pune					-22.9	556.1								
Satara	-9.2	480.0												
Sholapur			-4.8	151.0					-4.0	135.7	-6.9	201.1	-15.7	627.6
Sangli	-4.0	154.3							-2.6	129.8				
Kolhapur	-12.1	746.7					-9.5	595.5					-21.4	1841.5
Marathwada	-7.2	242.6	-10.0	286.1	-10.9	268.9	-3.1	180.7	-8.6	264.3	-10.4	277.5	-27.2	929.6
Aurangabad	-4.2	184.5			-9.2	239.2			-4.3	190.3	-6.8	217.7	-15.5	721.7
Jalna			-5.9	223.2	-9.1	231.8			-5.0	209.7	-7.5	227.5	-19.7	796.1
Beed	-6.0	186.4	-9.9	241.4	-10.5	276.1			-7.9	213.9	-10.2	258.8	-25.6	833.6
Parbhani	-9.1	287.9	-13.6	364.9	-12.8	287.4			-11.3	326.4	-13.2	326.1	-34.6	1094.0
Hingoli	-10.0	318.2	-9.9	328.3	-11.6	265.8			-10.0	323.2	-10.7	297.0	-28.7	1071.4
Osmanabad			-7.3	216.4	-9.0	266.5			-5.3	187.8	-12.6	305.6	-20.4	771.1
Latur	-6.3	233.1	-13.0	319.5	-12.2	291.8			-9.7	276.3	-8.1	241.4	-30.9	967.6
Nanded	-13.7	82.8	-15.8	419.0	-13.5	294.2	-7.0	271.1	-14.7	400.9	-14.6	356.6	-43.3	1255.6
Vidarbha	-8.7	388.1			-11.4	259.7	-5.4	294.4	-5.2	356.3	-6.6	292.1	-24.1	1173.1
Buldhana	-5.7	244.5			-7.9	195.0			-4.3	238.1	-5.4	213.3	-16.2	814.7
Akola	-8.2	291.6			-9.0	205.6	-4.4	225.1	-4.6	259.9	-5.0	216.9	-18.9	884.3
Wasim	-7.0	303.4			-10.2	255.5			-5.9	291.7	-7.5	267.8	-19.2	981.2
Amraoti	-7.3	317.7			-11.1	243.8	-5.1	249.0			-4.1	244.7	-18.4	987.9
Yeotmal	-10.6	364.3	-7.6	342.8	-12.4	256.9	-5.5	271.7	-9.1	353.6	-10.0	299.8	-31.2	1143.1
Wardha	-9.3	354.0			-10.6	247.8					-3.9	242.6	-16.5	1003.9
Nagpur					-13.9	295.0					-8.3	307.2	-25.6	1195.4
Bhandara					-13.3	302.1	-6.5	337.4			-6.8	341.4	-26.6	1357.5
Gondia	-11.9	519.5			-13.1	308.3	-8.6	387.0			-5.4	347.7	-28.0	1469.5
Chandrapur	-10.8	456.1			-11.6	270.9	-7.2	341.7			-6.7	325.0	-27.8	1333.3
Gadchiroli	-10.8	541.3			-11.0	281.2	-7.7	409.5			-6.4	364.8	-28.7	1550.6

Table 5a. Summary of verification of forecasts of monthly rainfall. The CCs is not significant in any of the subdivisions/ districts in the month of June.

Subdivision & No. of Districts in it	Subdivison & No. of districts where CCs is significant	% of 'Useful' forecast in the subdivision & mean % of 'Useful' forecast in the districts		Subdivison & No. of districts where CCs was significant	% of 'Useful' forecast in the subdivision & mean % of 'Useful' forecast in the districts		Subdivison & No. of districts where CCs was significant	% of 'Useful' forecasts in the subdivision & mean % of 'Useful' forecasts in the districts	
		July			August			September	
		1972-2004	2005-2015		1972-2004	2005-2015		1972-2004	2005-2015
Konkan& Goa 7	Yes 4	87	73	No Nil	-	-	Yes 7	84	73
		80	80		-	-		78	71
Madhya Maha. 10	Yes 7	94	91	No 1	-	-	Yes 6	66	82
		76	68		78	82		71	65
Marathwada 8	Yes 6	72	55	Yes 7	81	100	Yes 8	62	64
		75	61		80	86		65	69
Vidarbha 11	Yes 11	78	73	No 1	-	-	Yes 11	78	55
		81	65		84	82		78	55

Forecast Verification

For the purpose of verification of forecasts at subdivision as well as district level, only two broad categories of rainfall, namely, 'Excess/Normal' and 'Deficient/Scanty' are used. A forecast has been termed 'Useful' if the realized as well as the forecast rainfall are in the same broad category or they become so if Model Error (M.E.) denoted in mm is taken into account. The forecasts in a year are considered reasonably good, if they are in 'Useful' category in 60% of the districts of a subdivision. As the satellite observed cloud/OLR data required for assigning SAI are available for a limited period of time, the desired accuracy of ±1 in assigning the value of SAI could not be achieved. 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 M.E. in forecast rainfall becomes twice the value of the coefficient 'a' of the regression equations. In order to compare forecast rainfall with the realized rainfall, which is available in %, the M.E. was converted into % of Long Period Average (LPA) rainfall. For describing rainfall 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%. The results of verification for a period of 11 years (2005-2015) have been included in Tables 5 & 6.

Forecast of monthly rainfall

The CCs are not significant in any of the subdivisions/ districts during June. The M.E. in the subdivisions and their districts, in the order they appear in Tables 4, and where the CCs are significant are: Jul (**4**,5,4,4,5; **5**,9,4,5,8,4,6,4; **8**,5,9,9,9,6,11; **5**,6,7,6,5,7,6,5,5,5), Aug (Sholapur-10;**12**,8,16,14,9,10,13,14; Yeotmal-7); Sep (**10**,10,13,8,11,12,10,14; **8**,11,10, 12,9,10,7**; 11,**11,12,10,11,14,9,13,12; **9**,10,11,10,9,12,9,10,9,8,9,7). The bold figure refers to the value of M.E. for the subdivision. Summary of verification is given in Table 5a. For the month of July, the % of 'Useful' forecast, during the period of development of the model equations, is 94% in Madhya Maharashtra and the least (72%) in Marathwada. With slightly reduced percentages, this trend is present during the forecast verification period also. The % of 'Useful' forecast has varied from 81% in Vidarbha to 75% in Marathwada. During the month of August, the CCs are significant in one district each in Madhya Maharashtra and Vidarbha, i.e., Sholapur and Yeotmal respectively. The % of 'Useful' forecasts in these 2 districts during the period of development of the model equations (forecast verification period) are 78% (82%) and 84% (82%) respectively. August rainfall in the districts of Marathwada is well correlated with SAI. With the exception of Aurangabad, the CCs are significant in all the remaining 7 districts of the subdivision. The % of 'Useful' forecast for the subdivision and the mean % of 'Useful' forecasts in the districts during the period of development of the model equations are 81% and 80% respectively. The respective figures for the period of verification are 100% and 86%. The situation improves remarkably during September, when the CCs become significant in the districts of the subdivisions of Konkan & Goa, Marathwada and Vidarbha. The % of 'Useful' forecast during the period of development of the

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Table 5b. Summary of verification of forecasts of bi-monthly rainfall.

Subdivision & No. of Districts in it	Subdivison & No. of districts where CCs is significant	% of 'Useful' forecast in the subdivision & mean % of 'Useful' forecast in the districts		Subdivision & No. of districts where CCs is significant	% of 'Useful' forecast in the subdivision & mean % of 'Useful' forecast in the districts		Subdivison & No. of districts where CCs is significant	% of 'Useful' forecast in the subdivision & mean % of 'Useful' forecast in the districts	
		Jun+ Jul			Jul+ Aug			Aug+ Sep	
		1972-2004	2005-2015		1972-2004	2005-2015		1972-2004	2005-2015
Konkan & Goa 7	Yes 2	87 81	100 91	Yes 3	87 86	100 88	Yes 7	84 84	91 91
Madhya Maha. 10	Yes 3	87 89	64 83	Yes 4	84 79	100 84	Yes 5	81 87	100 98
Marathwada 8	Yes 1	81 84	64 64	Yes 8	91 83	82 80	Yes 8	84 80	91 85
Vidarbha 11	Yes 6	84 84	82 79	Yes 4	91 84	82 79	Yes 11	87 81	100 87

model equations for the subdivisions' rainfall has varied from 84% for Konkan & Goa to 62% for Marathwada. The corresponding figures for the forecast in the districts have varied from 78% in Konkan & Goa and Vidarbha to 65% in Marathwada. The figures for the subdivisions for the period of verifications have varied from 82% in Konkan & Goa to 55% in Vidarbha. The corresponding figures for the forecasts in the district are 71% in Konkan & Goa to 55% in Vidarbha. There is some reduction in the % of 'Useful' forecast for the subdivision of Vidarbha for the month of September during the period of verification.

A comparison of % of 'Useful' forecasts in the districts of Maharashtra and Goa with those in the districts of A.P. and Telangana has shown that (i) during July, the forecasts % in Konkan & Goa is comparable to those in the districts of A.P. and higher than that in the districts of Telangana. The % of 'Useful' forecast is lower in the districts of other subdivisions as compared to A.P. and comparable to those in the districts of Telangana, (ii) during August, forecasts are not available for the districts of Konkan & Goa. The forecast % is higher than that in the districts of A.P. and comparable to that in the districts of Telangana, (iii) in September, the % of 'Useful' forecast in the districts of Vidarbha are lower than that in the districts of A. P. and Telangana. The forecast % in the remaining subdivisions is comparable to those in A.P. and Telangana.

Forecast of bi-monthly rainfall

The M.E. in the subdivisions and their districts, in the order as they have appeared in Tables 4, and where the CCs is significant are: Jun+ Jul (**2**,3,3; **4**,8,8; **4**,7; **4**,5,5,5,4,5,5,5), Jul+Aug (**3**,3,4,4; **3**,5,4,8,9,4; **10**,6,6,12,11,9,7,10,13; **3**,5,5,5,7), Aug+ Sep (**5**,4,9,5,6,7,5,8; **4**,7,8,7,10; **2**,9,10,13,14,12,9,14,14; **6**,7,6,8,4,10,4,7,5,3,5,5,4). The

summary of verification of forecasts in respect of bi-monthly rainfall are given in Table 5b. It may be noted that the number of districts where CCs are significant for the bi-monthly period of Jun+ Jul has reduced to 12 as compared to 24 for the month of July (Table 5a). This is due to the effect of rainfall in the month of June. In the subdivision of Vidarbha, where CCs are significant in the majority of the districts, the % of 'Useful' forecast has varied from 84% during the period of development of the equations to 82% during the period of verification. The corresponding figures for mean % of 'Useful' forecasts in the districts are 84% and 79%. Rainfall of Jul+ Aug is well correlated with SAI in all the districts of Marathwada. Also the mean % of 'Useful' forecasts in the districts, both during the period of model development and verification, are high: 91% and 82% respectively. There is a jump in the number of districts where CCs are significant for the rainfall during the bi-monthly period of Aug+ Sep and it is now in 31 districts (out of 36). The exceptions are: 5 districts of Madhya Maharashtra. The improvement is seen in the % of 'Useful' forecasts also. It is now between 81% to 87% for the subdivisions during the development of model equations and 91% to 100% during the period of verification. The corresponding figures for the mean % of 'Useful' forecasts in the districts are 80% to 87% and 85% to 98% respectively. In conclusion, there is a distinct possibility of issuing forecasts of rainfall for the bi-monthly period of Aug+ Sep. Forecast for the bi-monthly period of Jul+ Aug could also be issued for the districts of Marathwada. Similarly, Forecast for the bi-monthly period of Jun+ Jul could also be issued for the majority of the districts of Vidarbha.

A comparison of 'Useful' forecasts during the bi-monthly periods in the districts of Maharashtra & Goa with those in A.P. and Telangana has shown that (i) during

Table 5c. Summary of verification of forecasts of seasonal rainfall.

Subdivision & No. of districts in it	Subdivision & No. of districts where CCs is significant	% of 'Useful' forecast in the subdivision & mean % of 'Useful' forecasts in the districts	
		1972-2004	2005-2015
Konkan &Goa 7	Yes 7	94 88	100 90
Madhya Maha. 10	Yes 6	97 84	73 92
Marathwada 8	Yes 8	91 85	100 93
Vidarbha 11	Yes 11	84 87	100 91

Table 6. Subdivision-wise details of forecasts where it was in 'Useful' category in less than 60% of the districts where CCs was significant.

Month/ Period	Subdivision (No. of districts), No. of districts (figures in Italics) where CCs is significant and years with % of districts (in bracket) where forecast was in 'Useful' category . The figure, given at the bottom in the right hand corner of each block, refers to the % of forecasts which were not in 'Useful' category out of the number of total forecasts issued during the period (2005-2015).			
	Konkan & Goa (7)	Madhya Maha. (10)	Marathwada (8)	Vidarbha (11)
Jun	*Nil* -	*Nil* -	*Nil* -	*Nil* -
Jul	*4* 2006(50) 2007(25) 2008(25) 7%	*7* 2005(14) 2008(29) 2009(43) 4%	*6* 2005(0) 2006(0) 2007(50)2008(0) 2012(23) 8%	*8* 2005(0) 2008(12) 2011(50) 2012(12) 5%
Aug	*Nil* -	*1* Nil	*7* 2008(57) 2013(28) 3%	*1* Nil
Sep	*7* 2005(0) 2009(14) 2014(0) 4%	*6* 2005(0) 2011(33) 2012(50) 2014(33) 2015(16) 8%	*8* 2005(0) 2009(50) 2011(12) 3%	*11* 2005(0) 2008(54) 2012(0) 2013(45) 2014(36) 2015(27) 5%
Jun+ Jul	*2* Nil	*3* 2008(33) 8%	*1* 2006(0) 2007(0) 2008(0) 2011(0) 36%	*6* 2008(43) 2011(57) 2012(28) 5%
Jul+ Aug	*3* 2015(33) 3%	*4* 2005(50) 2008(50) 2015(50) 7%	*8* 2007(50) 2008(25) 2%	*4* 2008(25) 2%
Aug+ Sep	*7* 2015(57%) 1%	*5* Nil	*8* 2005(37) 1%	*11* 2012(45) <1%
Jun-Sep	*7* 2015(43%) 1%	*6* Nil	*8* Nil	*11* 2008(55) <1%

the period of Jun+ Jul, the % of 'Useful' forecasts was lower in Marathwada but nearly the same in the districts of other subdivisions as compared to the districts in A.P.. The % of 'Useful' forecasts in the districts of Marathwada was comparable and it was higher in the districts of other subdivisions of Maharashtra and Goa as compared to the districts of Telangana, (ii) during Jul+ Aug, the % of 'Useful' forecasts was higher in the districts of Konkan & Goa as compared to those in the districts of A.P. and Telangana. In other subdivisions it was comparable to those in the districts of A.P. and Telangana, (iii) during Aug+ Sep, the % of 'Useful' forecasts in the districts of Madhya Maharashtra is higher than that in the districts of A.P. and Telangna. In the remaining subdivisions, it is either higher or comparable to that in the districts of A.P. and higher than that in the districts of Telangana.

Forecast of seasonal rainfall

Except for 4 districts of the subdivision of Madhya Maharashtra, namely, Nasik, Pune, Satara and Sangli, the CCs are significant in all other districts (Table 3). The M.E. in the subdivisions and their districts are: **4**,4,4,4,4,3,4,4,4; **4**,7,6,5,6,7; **8**,5,6,9,9,7,6,9,11; **5**,5,6,5,5,7,4,5,4,4,5,4.The summary of verification of seasonal forecasts is given in Table 5c. The % of 'Useful' forecasts is high: 84% -100%, except for the subdivision of Madhya Maharashtra, where it is 73%. The mean % of 'Useful' forecasts in the districts has varied from 84% in Madhya Maharashtra to 88% in Konkan & Goa during the period of development of model equations. The figure for the period of verification is more than 90%. These results point towards the possibility of issuing operational long range forecasts of seasonal rainfall in the districts of Maharashtra and Goa. The % of 'Useful' forecasts in the districts of Maharashtra & Goa is comparable to that in the districts of A.P. and it is higher than that in the districts of Telangana.

Reduction in Number of Districts in 'USEFUL' Category of Forecast in Some Years

The % of forecasts which are not in 'Useful' category during the period of verification (2005-2015) for each month, bi-monthly periods and the whole SWM season have been worked out. For example, the number of districts where CCs are significant in the Konkan & Goa subdivision during the month of July are 4. During 11 year verification period, a total of 44 forecasts had been issued. 3 out of those, i.e., 7% forecasts were not in 'Useful' category. The details in respect of % of such not in 'Useful' forecasts category have been included in Table 6. It follows from Table 6 that, during the bi-monthly period of Jun+ Jul except for rainfall in just a lone district in Marathwada, i.e., Nanded, the % of forecasts which were not in 'Useful' category is <10%. This is an encouraging result. The corresponding figures for Aug+ Sep and seasonal rainfall, which are 1% or less, are still more encouraging. Intra-seasonal changes in the activity of SIOCZ are responsible for reduction in number of districts in 'Useful' category of forecasts, as it had been discussed in district level forecasts for the states of Andhra Pradesh (Prasad, et al., 2016b) and Telangana (Prasad, et al., 2016c). Due to lack of space, it could not be possible to include OLR/weekly mean cloudiness maps and discussions on intra-seasonal changes and their impact on forecasts in the districts of Maharashtra and Goa.

CONCLUSIONS

1. The close relationship between the activity of South Indian Ocean Convergence Zone and Indian Summer Monsoon Rainfall, also holds good for southwest monsoon rainfall in the states of Maharashtra and Goa.

2. Long range forecast of southwest monsoon seasonal rainfall could be issued for all the districts of the states of Maharashtra and Goa except for 4 districts of Madhya Maharshtra, namely, Nasik, Pune, Satara and Sangli. Forecasts could also be issued for a number of districts in July, August and September and bi-monthly periods of Jul+ August and August+ September.

3. Long range forecast of rainfall in the districts of Marathwada, the subdivision which is prone to occurrence of deficit rainfall, could be issued for the season as a whole, bi-monthly periods and also for monthly rainfall, except for the month of June.

4. The % of 'Useful' forecast varies from month to month and also from one subdivision to another. For the month of July, the best forecasts are available for the subdivision of Madhya Maharashtra, followed by Konkan & Goa, Vidarbha and Marathwada. In August the best forecasts are available for Marathwada. However, the forecasts are not available for this month in the remaining subdivisions. In September, the best forecast are available for Madhya Maharashtra followed by Konkan & Goa, Marathwada and Vidarbha.

5. A comparison of the % of 'Useful' forecasts in Mahrashtra & Goa with those in the state of Telangana has shown that July forecast for the former zone is slightly better than that in Telangana. August forecast is comparable to that in Telangana. September forecast % is lower in Vidarbha and in other subdivisions it is comparable to that in Telangana. During the bi-monthly period of Jun+ Jul, the % of 'Useful' forecast is lower in Marathwada and in the remaining subdivisions it is comparable to that in Telangana. During Jul+ Aug, the % of 'Useful' forecast is higher in Konkan & Goa. In the remaining subdivisions it is either comparable to or slightly higher than that in Telangana. During Aug+ Sep, the % of 'Useful' forecast is higher in Madhya Maharashtra. In other subdivisions it is either higher or comparable to those in Telangana. For the season as a whole, the % of 'Useful' forecasts in the districts of Maharashtra & Goa is better than that in Telangana.

6. The forecasts for the month of June are not available for any of the subdivisions/districts. In the remaining months, the forecast is not available for all the districts of the subdivisions. Similarly, seasonal forecast is not available for four districts of Madhya Maharashtra. SAI values used here for preparing forecast in Maharshtra and Goa, had been calibrated with Indian Summer Monsoon Rainfall (ISMR) data which represents June-September total rainfall for India as a whole. These SAI values are unable to take care of the characteristics of rainfall distribution in subdivisions and their districts. For improvement in results, a new set of SAI values calibrated with subdivision/district level rainfall data has to be worked out.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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