

2016 Southwest Monsoon and Its Long Range Forecast

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ABSTRACT

With 3% below normal rainfall for India as a whole, 2016 southwest monsoon has gone in records as a normal monsoon. However, as per the data of daily, monthly and seasonal rainfall, 2016 monsoon was a weak monsoon: On daily basis, the rainfall, for India as a whole, was on the lower side of normal on 70(57%) days out of 122 days of the season (Jun:19, Jul:14, Aug:21 and Sep:16). The number of days with rainfall on the lower side of normal in four broad regions were: NW India, 75(61%) days (June:17, Jul:18, Aug:14 and Sep:26); NE India, 77(63%) days (June:24, July:15, Aug:25 and Sep:13); Central India, 66(54%) days (Jun:21, Jul:15, Aug:17 & Sep:13) and South Peninsula, 73(60%) days (Jun:11, Jul:20, Aug:26 and Sep:16). Except for the month of July when rainfall, for the country as a whole, was 7% above normal, rainfall was below normal by 11%, 9% and 3% in June, August and September respectively. Severe drought like conditions prevailed over North and Peninsular India in August and over Northwest India and south Peninsula in September. For the season as a whole, rainfall was 6% above normal over Central India, but it was below normal in NW India, NE India and South Peninsula by 5%, 8% and 11%, respectively.

Above normal rainfall had been forecast for 2016 monsoon by India Meteorological Department (IMD) and also by 'Skymet Weather'- a private forecaster. In contrast to these forecasts, 2016 monsoon had been foreshadowed as a weak monsoon by SIOCZ model. SIOCZ model forecast for country as a whole, was in 'Useful' category in June and September, bi-monthly periods of Jul+ Aug and Aug+ Sep and for season as a whole. At subdivision level, except for the month of July, the forecast was in 'Useful' category in the remaining three months, bimonthly periods as well as for the season as a whole. At district level, seasonal forecast was in 'Useful' category in the states of Andhra Pradesh, Telangana, Himachal Pradesh, Maharashtra and Goa. However, it was slightly below the 'Useful' category mark in the state of Tamilnadu. Development of different phases of 2016 SWM, performance of SIOCZ model forecast and updates are discussed.

Key words: Southwest monsoon, long range forecast, South Indian Ocean Convergence Zone model, intra-seasonal changes, forecast updates.

INTRODUCTION

Long Range Forecast (LRF) of rainfall during Southwest Monsoon (SWM), based on South Indian Ocean Convergence Zone (SIOCZ) model, is being issued since 1990. During the past 26 years period (1990-2015), large intra-seasonal changes in the activity of SIOCZ and also in rainfall over Indian subcontinent had taken place in 1992, 1999, 2001, 2005, 2010, 2012 and 2013. Here, an intra-seasonal change refers to a situation where the features, which had appeared in the activity of SIOCZ during November of the previous year till May of the current year, and which had formed the basis for formulating the LRF of rainfall based on SIOCZ model, did not continue till the end of the season. In other words, new features appeared in the activity of SIOCZ during the season. The intra-seasonal changes in the years mentioned above have been studied in detail and documented by the authors (Prasad and Singh, 2013; Prasad, Singh and Prasad, 2014 & 2016a). These studies had shown that foreshadowing the changes in rainfall scenario, due to intra-seasonal changes, could

be attempted by issuing forecast update/updates. However, for doing that, gaining sufficient experience in identifying the intra-seasonal changes in the activity of SIOCZ, their likely impact on the distribution of rainfall in days to come, assigning a new value of SIOCZ Activity Index (SAI), computing quantitative forecast for the remaining period of the season and above all the availability of forecast SST anomaly over South Indian Ocean (SIO), at least one month in advance, are needed. The forecast SST anomaly, one month in advance, are not available in public domain from any of the lead centres. Forecast updates are being issued by the authors of SIOCZ model since 2013. No update had been issued during 2014 & 2015. The results on the utility of the updates in capturing rainfall scenario during 2013 monsoon had been documented by Prasad, Singh and Prasad (2016a). The results were found encouraging. Intra-seasonal changes had taken place during 2016 SWM also: severe drought like conditions prevailed in a number of subdivisions and rainfall was deficient by 11% for India as whole, in June. Except for the month of July when rainfall for the country as a whole was 7% above

normal, severe drought like conditions prevailed in some parts of India in August and September. Rainfall, for the country as a whole, in these two months was 9% and 3% below normal, respectively. SIOCZ model forecasts, intra-seasonal changes, forecast updates, verification of forecasts and updates, and how far the updates were able to capture the subsequent rainfall scenario have been discussed in this paper. In addition, the forecasts from IMD's operational models as well as other models, which had appeared in media, have also been mentioned in brief. This has been done to enable the reader to make out as to how the various LRF models had performed in foreshadowing rainfall during 2016 monsoon.

Salient Features of 2016 SWM

2016 SWM set in over Kerala on 8th June, i.e., 7 days after its normal date of 1st June. With a brief hiatus during the last week of June, monsoon covered the entire country by 13th July against the normal date of 15th July. Two deep depressions, 2 depressions, 3 well marked low pressure areas and 7 low pressure areas had formed against an average of 6 depressions & 8 low pressure areas. One depression each had formed over the Bay of Bengal (BoB) and the Arabian Sea (AS) and remaining two over land. The frequency of monsoon depressions was subdued in BoB. In general, cyclo-genesis was weak during 2016 monsoon. Less number of depressions/low pressure areas developed during the first half of the season as compared to the second half (Jun: Deep Depression-nil, Depression- one, Well Marked Low Pressure Area- nil, Low Pressure Area- one; Jul: nil, one, nil, one; Aug: two, nil, two, three; Sep: nil, nil, one and two) (IMD, 2016). The withdrawal of 2016 monsoon had commenced from west Rajasthan on 15th September against its normal date of 1st September.

With 3% below normal Indian Summer Monsoon Rainfall (ISMR), 2016 monsoon has gone in records as a normal monsoon. But, its rainfall distribution within the season was similar to that for a weak monsoon: For the season as a whole, except for the Central India where seasonal rainfall was 6% above normal, rainfall was below normal in NW India, NE India and South Peninsula by 5%, 8% and 11% ,respectively (IMD, 2016). The seasonal rainfall was excess in 4 subdivisions, normal in 27 and deficient in 9 (Haryana, Chandigarh and Delhi, Punjab and Himachal Pradesh in Northwest India; Assam and Meghalaya in Northeast; Coastal Karnataka, South Interior Karnataka, Kerala and Lakshadweep in South Peninsula). Except for July when the rainfall, for the country as a whole, was 7% above normal, rainfall was on the lower side of normal by 11%, 9% and 3% in June, August and September, respectively. In the subdivisions of India, June rainfall was excess in 6 subdivisions, normal in 18, deficient in 10 and scanty in 2 (Figure 1). The figures were 10, 16, 10

and nil for July; 8,8,17 and 3 for August and 11,5,11 and 9 for September.

On an average the monthly rainfall was in 'Deficient/ Scanty' category in 15.5(43%) subdivisions out of 36. On daily basis, the rainfall was on the lower side of normal on 70(57%) days out of 122 days of the season for India as a whole (Jun:19, Jul:14, Aug:21 and Sep:16). The figures in four broad regions (Figure 1) were: NW India, 75(61%) days (June: 17, Jul:18, Aug:14 & Sept:26); NE India, 77(63%) days (June:24, July:15, Aug:25 and Sep:13); Central India, 66(54%) days (Jun:21, Jul:15, Aug:17 & Sep:13) South Peninsula, 73(%) days (Jun:11, Jul:20, Aug:26 & Sep:16) (IMD's website: imd.gov.in/pages/monsoon-main.php). Cumulative rainfall for country as a whole was on higher side of normal (but below +5%) on 38 (31%) days only and that too during one spell, i.e., between 5th July and 16th August and on the lower side of normal on the remaining 84(69%) days of the season. Rainfall was below normal beginning from 11th August till 12th Sep (33 days in continuation) except for 2 days, i.e., on 1st and 2nd Sep. Week by week progress of rainfall and cumulative rainfall, for India as a whole, is given in Figure 2 and Figure 3, respectively.

Developments in equatorial Pacific and Indian Oceans

The monthly Oceanic Nino Indices (ONI) for Nino 3.4 region of Pacific from January to December 2016 were: 2.60, 2.40, 1.68, 1.09, 0.30, -0.12, -0.49, -0.54, -0.61, -0.73, -0.55, -0.42°C. El Nino conditions of the previous year continued till April, ENSO-neutral conditions during May-July and La Nina conditions during August-November. A transition from ENSO neutral-to-La Nina, during the mid-season of monsoon, has been found to be generally associated with active monsoon conditions over India during the second half of the season (August-September). But this did not happen in 2016.

The cyclone season in South Indian Ocean (SIO) is 15 November-30April. Slightly below average number of tropical cyclones formed in SIO. Out of them, only 3 could reach the tropical storm intensity stage (Meteo-France, RSMC Tropical Cyclones- La Reunion). April 2016, the last month of the cyclone season of 2015-16, witnessed development of a very intense tropical cyclone "Fantala" during 11th to 23rd. It developed to the south of Diago Garcia, moved westward for several days gaining strength aided by warm waters. Thereafter, moving northwest wards it dissipated on 24th. The other system, a severe tropical storm, "Abela", developed to the south of Diago Garcia on 15th July. It was the first cyclone that developed before the commencement of 2016-17 cyclone season for SIO. It tracked westward and dissipated near the coast of Madagascar on 20th July. Tropical storms rarely develop in

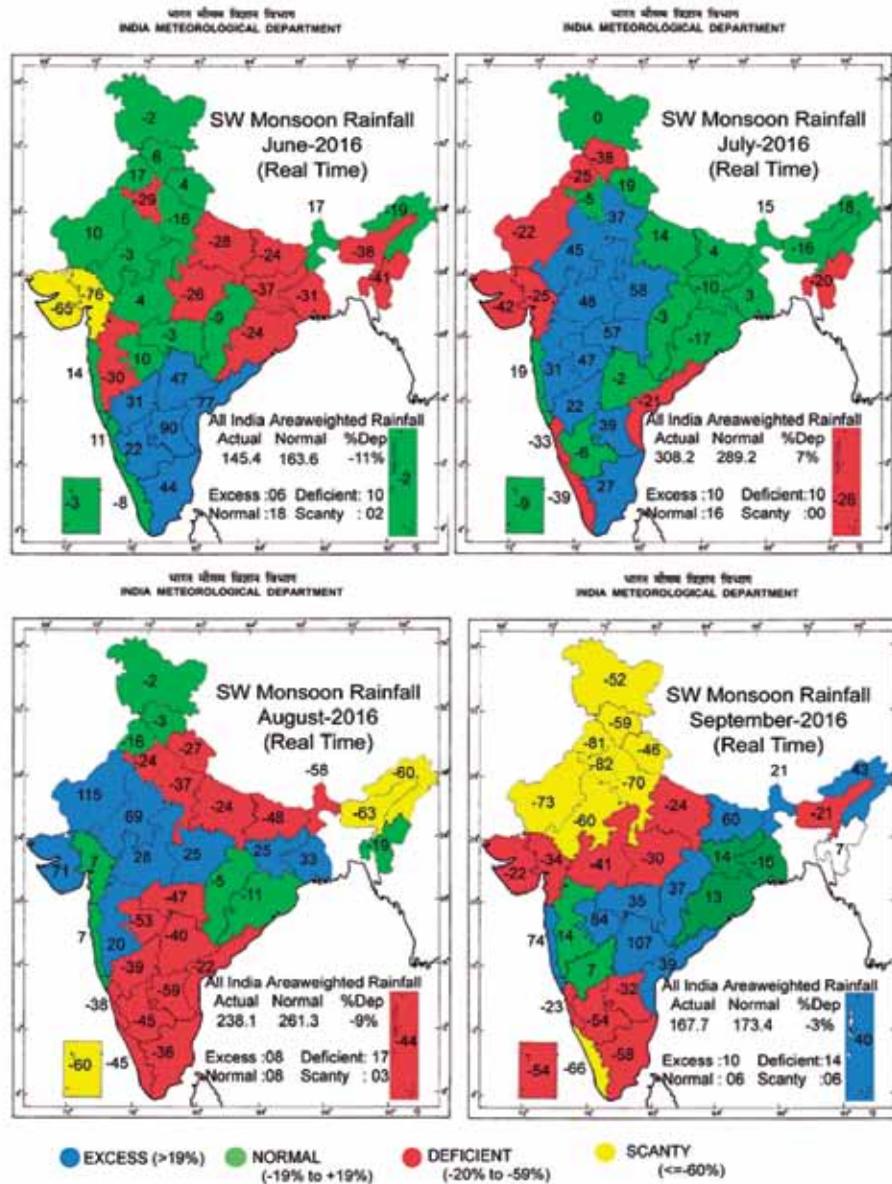


Figure 1. Subdivision-wise monthly rainfall distribution during 2016 southwest monsoon.

SIO basin in the month of July. “Abela” marked only the 4th occurrence of a tropical storm in the SIO during the month of July. The other storms on record were a moderate tropical storm in 1971, a tropical depression in 1997 and a tropical storm in 2007. Both April and July tropical storms remained active to the north of 15°S.

Development of the storm “Abela” was rare, as it developed outside the cyclone season for SIO. Development and westward movement of both the systems was aided by the availability of warm waters. This implies that the warming of equatorial SIO, which began in March 2016 had continued till July 2016. The real time weekly SST anomaly charts, not reproduced here, had shown that the

warming of equatorial SIO had continued during August-September also. Though the warming was not sufficient enough to create the necessary conditions for development of a tropical storm, yet it was sufficient enough to keep SIOCZ generally active during August - September

Long Range Forecast

In addition to forecast from IMD’s operational models and SIOCZ model, two more forecasts were available for 2016 monsoon: (i) Experimental forecast from Coupled Dynamical Model Forecasting System (Monsoon Mission Model), being developed by the Indian Institute of Tropical Meteorology

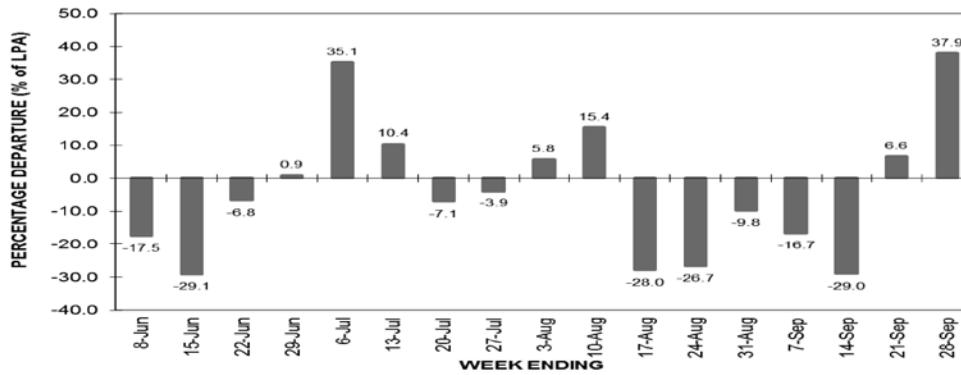


Figure 2. Week-by-week progress of rainfall during 2016 southwest monsoon for India as a whole.

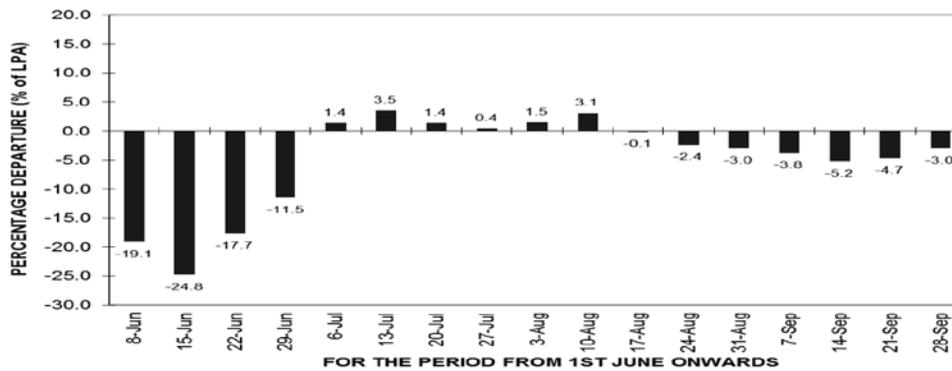


Figure 3. Week-by-week progress of cumulative rainfall for India as a whole.

Table 1. Long range forecast issued by IMD and realized rainfall.

Region	Period	Forecast (% of LPA)		Realized Rainfall (% of LPA)
		22 nd April	2 nd June (Update)	
All India	June to September	106 ± 5	106 ± 4	97
Northwest India	June to September		108 ± 8	95
Central India	June to September		113 ± 8	106
Northeast India	June to September		94 ± 8	89
South Peninsula	June to September		113 ± 8	92
All India	July		107 ± 9	107
All India	August		104 ± 9	91
All India	August to September (issued on 1st August)		107 ± 8	93

Source: 'End of season report' on 2016 southwest monsoon by IMD

(IITM) and the Ministry of Earth Sciences (MoES) and (ii) forecast from 'Skymet weather' - a private forecaster.

Operational forecast issued by IMD

The operational LRF of rainfall for 2016 monsoon was issued by IMD in 3 stages: (i) on 12th April for seasonal rainfall for India as a whole, (ii) on 2nd June. The 2nd

June forecast was an update on 12th April forecast and in addition, forecast for seasonal rainfall for four broad regions of India, namely, Northwest India, Central India, South Peninsula and Northeast India and rainfall for the country as a whole for the months of July and August were also included, (iii) on 1st August. It consisted of forecast for the rainfall during the second half of the season for India as a whole. These forecasts have been reproduced in Table 1.

Forecast from Monsoon Mission Model

The experimental forecast from this model had been included in the press releases issued by IMD on 12th April and 2nd June. April forecast was for an excess monsoon (11% above Long Period Average (LPA) of 100%, for India as a whole). The forecast had been upgraded to 12% above normal on 2nd June.

Forecast from ‘Skymet Weather’

Forecast from ‘Skymet weather’ was issued in two stages, which appeared in the New Delhi Edition of ‘Times of India’ news paper: (i) The first forecast was issued on 11th April and it was for an above normal rainfall (105% of LPA), (ii) The forecast was upgraded to an above normal rainfall of 109% of LPA in the update issued on 25th May. It was also indicated that monsoon may have relatively poor start. Rainfall in June was predicted to be 13% below normal. The situation was forecasted to improve sharply, thereafter, with predicted rainfall being 8%, 13% and 23% above normal in July, August and September, respectively.

Good rainfall was predicted in central India, west coast including Madhya Maharashtra, Marathwada, Vidarbha, M.P. and East U.P. and not so good in Tamilnadu, South Interior Karnataka, Punjab, north Bihar and North Eastern states.

Forecast from SIO CZ model

SIO CZ model forecast for 2016 monsoon was issued in 2 stages: the first stage forecast on 30th March and the second stage forecast on 5th June. In addition, three updates had been issued on 22nd June, 11th July and 1st August. The first two updates were qualitative in nature and the third one was quantitative. The forecasts, updates and realised rainfall are briefly mentioned in Table 2.

Cloud data for the period Nov 2015- May 2016 had been used in preparing the forecast. Cloud data for the period Jan-May 2016 are reproduced in Figure 4. The figure shows zonal weekly mean cloudiness (in every 5° lat. belt) over the area bounded by 20°S-30°N and 40°E-100°E. Alternate spells of active and weak SIO CZ developed at an average interval of 3 weeks during the

Table 2. Forecasts and updates based on SIO CZ model.

Date of issue	Forecast/Update	Realised ISMR, rainfall in subdivisions and the districts of Tamilnadu, Andhra Pradesh, Telangana, Himachal Pradesh and Maharashtra & Goa
30th Mar	Forecast: “2016 southwest monsoon is expected to develop as a normal one with ISMR on the lower side of its long period average (100%)”	ISMR was 3% below normal.
5th Jun	Forecast: March forecast was downgraded to a “weak’ monsoon. Quantitative forecast for monthly, bi-monthly and seasonal rainfall was issued for India as a whole, 36 Subdivisions of India and the districts of the states of Tamilnadu, Andhra Pradesh, Telangana, Himachal Pradesh and Maharashtra & Goa.	The table containing monthly, bi-monthly and seasonal forecasts and realised rainfall in the subdivisions and for country as a whole could not be reproduce due to lack of space. Seasonal rainfall in the districts of the states of Tamilnadu, Andhra Pradesh, Telangana, Himachal Pradesh and Maharashtra & Goa have been given in Table 3. Forecast for India as a whole has been included in Table 4 and the summary of verification of forecasts has been included in Table 5.
26th Jun	Update No.1: “2016 Southwest monsoon, which was weak during the past 3 weeks, shall strengthen now and shall remain active for the next 3-4 weeks”.	Rainfall improved in July. July rainfall, for country as a whole, was 7% above normal. The summary of verification of forecasts in the subdivisions has been included in Table 5.
11th Jul	Update No. 2: The forecast was downgraded for rainfall after 14th July, more particularly over Central, North and Northwest India. Increase in rainfall was forecast over south peninsula and northeast India.	The rainfall for the country as a whole was 7% and 4% below normal on the week ending on 20th and 27th July respectively. Rainfall was below normal in East, NE and South Peninsula during the second half of July. Though rainfall decreased over central India also but it remained above normal during the second half of July.
1st Aug	Update No. 3: The forecast was upgraded for the months of Aug & Sep for the season as a whole, in the subdivisions and also for the country as a whole.	August rainfall was above normal in NW and central India and below normal in E, NE and South Peninsula. Verification results in the subdivisions and for India as a whole for the months of August & September, bi-monthly periods of Jul+ Aug and Aug+ Sep and for the season as a whole have been given in Tables 4 & 5.

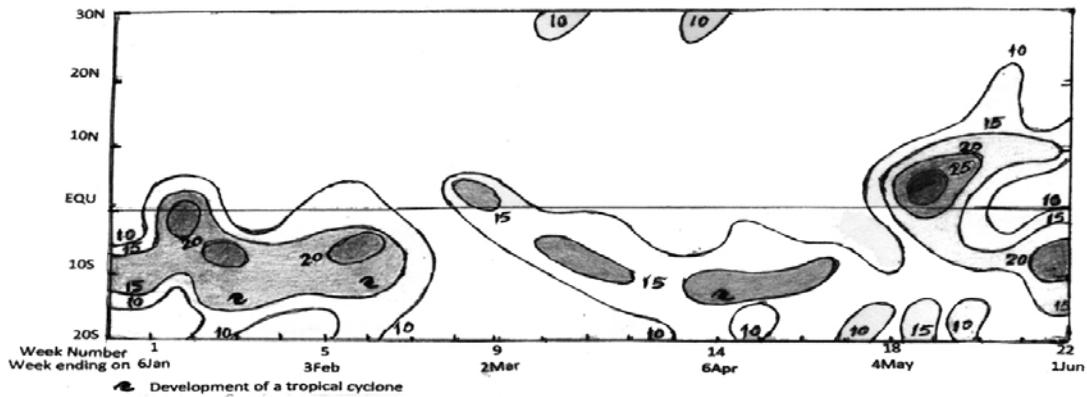


Figure 4. Zonal weekly mean cloudiness over the region bounded by 30°N-20°S and 40°E-100°E during Jan-May 2016 (Week Nos.1-22). The contours represent cloud amount in %.

period November 2015– February 2016. This feature, unambiguously, suggested development of a normal southwest monsoon. However, a new feature appeared during March 2016: SIOCZ, though weak, developed for 4 weeks in continuation. Development of an active spell of SIOCZ for 3-4 weeks in continuation was a precursor for weak monsoon to follow. The first stage forecast had taken into account both the features and the forecast issued on 30th March was “2016 southwest monsoon is expected to develop as a normal one with ISMR on the lower side of its long period average (100%)”. Reappearance of an active spell of SIOCZ for 3-4 weeks in continuation during pre-monsoon months of April-May or otherwise had, therefore, become crucial for foreshadowing 2016 southwest monsoon. Thus there was an uncertainty about the likely performance of 2016 monsoon at the time of issuing the first stage forecast by the end of March.

Monitoring of SST field, with the help of the real time charts of SST anomalies provided by NOAA/ESRL/PSD on their web-site, had shown continued presence of positive SST anomaly field over the equatorial regions of SIO during April. This led to the development of an active spell of SIOCZ for 3-4 weeks in continuation during April. This spell of SIOCZ was more intense compared to the March spell. As mentioned above, a very intense tropical cyclone “Fantala” developed to the south of Diago Garcia on 11th April, moved westward for several days gaining strength aided by warm waters. It weakened and moved northwest wards and then dissipated on 24th. Development of a spell of active SIOCZ during March and its reappearance in April was a precursor for a weak monsoon/drought. Accordingly, for preparing the quantitative forecast, a value of 16 had been assigned to South Indian Ocean Convergence Zone (SIOCZ) Activity Index (SAI). A value of 16 to SAI corresponds to 16% below normal seasonal rainfall for India as a whole. SAI for the subdivision of Tamilnadu and Puducherry differs from that for India as a whole. The value assigned to SAI for Tamilnadu and Puducherry was

12. The quantitative forecasts were computed using the value of SAI=16 for country as a whole, in subdivisions and the districts of the states of Andhra Pradesh, Telangana, Himachal Pradesh, Maharashtra and Goa. The forecast for the state of Tamilnadu and its districts was computed with SAI=12. Due to lack of space, it could not be possible to reproduce the table showing forecast rainfall in individual subdivisions for the monthly, bimonthly periods and the season as a whole. The forecast for seasonal rainfall in the districts have been included in Table 3.

Updates

Zonal weekly mean cloudiness for the period Jun-Oct 2016 is shown in Figure 5. The first update, issued on 26th June, was based on the observation that SIOCZ had remained active for 4 weeks, in continuation, from the week ending on 1st June till the week ending on 22nd June. A Maximum Cloud Zone (MCZ) had already developed between Equator and 5°N lat. during the last week of June. Development of a MCZ to the north of equator was a precursor for revival of monsoon. Accordingly, the first update issued on 26th June was “2016 Southwest monsoon, which was weak during the past 3 weeks, shall strengthen now and shall remain active for the next 3-4 weeks”. The MCZ weakened and SIOCZ remained weak for 3 weeks in continuation, i.e., up to the week ending on 6th July. Another spell of active SIOCZ began developing on 9th July. This spell was also expected to continue for 3-4 weeks, in continuation, i.e., up to 3rd or 10th August. The reason behind this conclusion was that the SST anomalies had not yet shown significant reduction over Equatorial South Indian Ocean (ESIO), a factor which was expected to keep SIOCZ active, irrespective of cooling of SST anomalies over Nino 3.4 region of East Pacific. Accordingly, the second update was issued on 11th July mentioning that “There shall be an overall reduction in rainfall for country as a whole and more particularly over Central, North and Northwest India, from the week

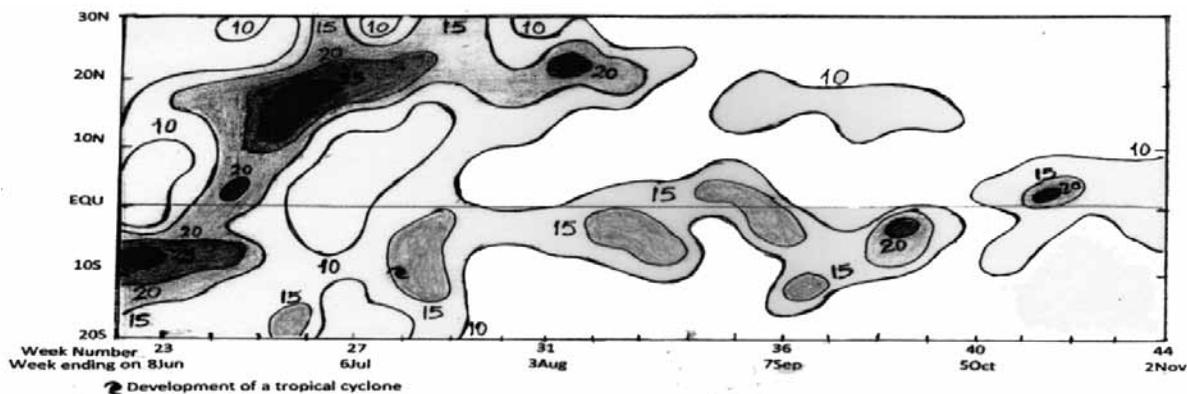


Figure 5. Same as Figure 4 but for the period Jun-Oct 2016.

beginning from 14th July. Rainfall may increase over south peninsula and northeast India. This situation is likely to continue up to the week ending on 3rd or 10th August 2016". The active spell of SIO CZ, which had started developing on 9th July, could continue up to 24th July only, i.e., for two weeks only. As mentioned above, a severe tropical storm, "Abela", developed to the south of Diago Garcia on 15th July (Figure 5). It tracked westward and dissipated near the east coast of Madagascar on 20th July. Formation and westward movement of this storm caused sufficient cooling of sea surface over the near equatorial regions of SIO, particularly to west of 70°E.

Reduction in the duration of an active spell of SIO CZ from 4 weeks, in continuation, to two weeks only was a precursor for an improvement in rainfall scenario in days to come. Development of this feature was concurrent to reduction in SST anomaly over ESIO during the second half of July and more particularly after the weakening of the tropical storm "Abela" on 24th July. However, the SST anomalies over the region close to equator but south of it and east of 80°E were still high enough to support deep layer convection. Thus, development of an active spell of SIO CZ was still possible. However, considerable weakening of the equatorial trough to the north of equator (Monsoon Trough) was not expected. Resultantly, the overall scenario of improvement in rainfall over India was not expected to be affected much. Accordingly, the forecasts for the next two months had been upgraded in Update No. 3, issued on 1st August, using a value of 9 assigned to SAI. This value of SAI had been used to compute the updated rainfall for India as a whole, in meteorological subdivisions and the seasonal rainfall in the districts of Himachal Pradesh, Andhra Pradesh, Telangana, Maharashtra and Goa. There was no change in forecast for Tamilnadu and its districts. The table containing the quantitative forecast in the subdivisions could not be reproduced, due to lack of space. Updated forecasts and realized rainfall in the districts of the states is given in Table 3.

Forecast Verification

Verification results have been discussed below, in brief, for those districts and subdivisions where CC between SAI and rainfall is significant at 95% level or more. As mentioned above, the table containing the forecast, update as well as the realised rainfall in individual subdivisions could not be included due to lack of space. The summary of verification has been included in Table 5.

In the districts

At district level, a forecast is considered useful, if it is in 'Useful' category in 60% districts or more. Details of the forecast as well as realised rainfall in the districts of Tamilnadu, Andhra Pradesh, Telangana, Himachal Pradesh and Maharashtra & Goa are included in Table 3. At district level, a forecast is considered useful, if both the forecast as well as the realised rainfall were in the same departure category or they become so when model error is taken into account. The model error is different for different districts. Model error could not be accommodated in Table 3. The same is available in earlier publications on district level LRF of rainfall (Prasad and Singh, 2007; Prasad, Singh and Subramanian, 2010; Prasad, Singh and Prasad, 2016 b,c,d). In the state of Andhra Pradesh, the % of 'Useful' forecast was 92% for the forecast issued on 5th June as well as for the update issued on 1st August. The updated forecast of rainfall was closer to realised one. But the realised rainfall was, in general, higher than the updated values. In Telangana, the forecast was in 'Useful' category in 90% districts and the updated forecast was in 'Useful' category in all the 10 districts of the state. In Himachal Pradesh, forecast was in 'Useful' category in 66% districts and the updated forecast in all the 6 districts, where CC is significant. In Tamilnadu, forecast was in 'Useful' category in 56% districts only. No update was issued for the districts of Tamilnadu. In Maharashtra & Goa, forecast was in

Table 3. Forecast (FC), Update (UD) and Realized Rainfall (RR) as % of long period average (100%). No update had been issued for the districts of the state of Tamilnadu. Name of those districts, where CC between SAI and rainfall is not significant at 95% level, has been shown in bold Italics.

District	FC	UD	RR	District	FC	RR	District	FC	UD	RR
Andhra Pradesh (12*/13)				Tamilnadu (30*/32)			Maharashtra & Goa (32*/36)			
Srikakulam	96	109	100	Ariyalur	84	81	Thane	99	102	109
Vizianagram	88	90	119	Chennai	102	114	Mumbai city	90	112	122
Vishakhapatnam	99	89	121	Coimbatore	124	150	Raigarh	93	102	125
East Godavary	87	106	117	Cuddalore	93	91	Ratnagiri	96	101	134
West Godavary	82	102	126	Dharmapuri	97	68	Sindhudurga	92	102	114
Krishna	81	114	114	Dindigul	102	56	North Goa	98	107	96
Guntur	85	108	141	Erode	127	76	South Goa	95	105	104
Prakasham	88	85	104	Kanchipuram	95	100	Nandurbar	85	113	84
Nellore	93	95	69	<i>Kanyakumari</i>	106	70	Dhule	92	108	80
Kurnool	84	102	113	Karur	95	59	Jalgaon	84	101	99
Anantpur	80	85	81	Krishnagiri	97	81	Nasik	111	105	125
Cuddapah	82	103	109	Madurai	110	63	Ahmednagar	92	106	124
Chittoor	92	123	86	Nagapattinam	93	86	Pune	96	103	125
No. & % of districts where F/C and Update were in useful category	11 & 92	11 & 92		Namakkal	101	71	Satara	93	111	138
Telangana (10*/10)				Nilgiri Hills	87	68	Solapur	93	104	108
Adilabad	86	112	108	Perambalur	69	97	Sangli	102	103	118
Nizamabad	75	98	126	Pudduottai	88	67	Kolhapur	85	120	93
Karimnagar	95	111	126	Ramanathpurnm	85	67	Aurangabad	78	96	98
Medak	80	101	121	Salem	91	79	Jalna	79	99	128
Warangal	87	107	128	Sivganga	94	126	Beed	80	104	137
Khammam	89	106	116	Thanjavur	86	91	Parbhani	79	98	121
Rangareddy	75	99	121	Theni	123	84	Hingoli	71	102	94
Hyderabad	89	105	130	Thiruvallur	102	72	Osmanabad	73	91	120
Nalgonda	80	102	139	Thiruvarur	100	52	Latur	73	95	134
Mahbubnagar	74	91	103	Thoothukudi	92	91	Nanded	74	101	125
No. & % of districts where F/C and Update were in useful category	9 & 90%	10 & 100%		Trichirapally	102	90	Buldhana	88	101	114
Himachal Pradesh (6*/12)				Tirunelveli	100	70	Akola	89	104	110
Bilaspur	91	93	95	Tirupur	91	25	Wasim	81	102	97
Chamba	64	74	46	Tiruvanmalai	89	72	Amraoti	85	101	114
Hamirpur	90	114	92	Vellore	96	91	Yeotmal	79	98	102
Kangra	81	95	85	Villupuram	87	91	Wardha	89	95	110
Kinnaur	65	85	44	Virudhunagar	105	60	Nagpur	85	97	86
Kullu	95	109	103				Bhandara	83	92	78
Mandi	78	89	96	No. & % of districts where F/C and Update were in useful category	18 & 56%		Gondia	88	97	101
Simla	75	90	104				Chandrapur	88	94	121
Sirmur	60	71	66				Gadchiroli	79	102	124
Solon	70	85	89				No. & % of districts where F/C and Update were in useful category	28 & 87%	32 & 100%	
Una	106	123	96							
Lahol-Spiti	NA	NA	22							
No. & % of districts where F/C and Update were in useful category	4 & 66%	6 & 100%								

* Number of districts where CC between SAI and seasonal rainfall is significant at 95% level or more.

'Useful' category in 87% districts and updated forecast in all 32 districts, where CC is significant. Thus the forecast as well as the update of rainfall during 2016 monsoon was in 'Useful' category in Andhra Pradesh, Telangana, Himachal Pradesh and Maharashtra & Goa, except in the state of Tamilnadu, where it was in 56% districts only, i.e., slightly below the mark for 'Useful' forecast.

In subdivisions

At sub-divisional level also, a forecast is considered 'Useful' if both, the forecast as well as the realised rainfall, are in the same departure category or they become so after model error is taken into account. The model error is different for different subdivisions and the same could not be reproduced here for lack of space. The model error in subdivisions is available in an earlier publication (Prasad and Singh, 2013). It is interesting to note that the forecast issued on 5th June and the quantitative update issued on 1st August were able to capture the rainfall scenario in the subdivisions: Except for the month of August, the forecast was in 'Useful' category in other months, all the three bi-monthly periods and also for the season as a whole Table 5.

For India as a whole

For India as a whole a forecast is considered 'Useful', if the forecast as well as the realised rainfall are in the same departure category or they become so after model error ($\pm 5\%$) is taken into account. The forecast, update and the realised rainfall for country as a whole are included in Table 4. With forecast ISMR at 14% below normal, the forecast issued on 5th June was for a weak monsoon. It is interesting to note that the forecast as well as the realised rainfall was below normal (<96%) in June and August

Occurrence of comparatively increased/decreased rainfall in alternate months is a characteristic feature of a weak monsoon. This type of monthly rainfall distribution has been observed in about 60% of the drought years. The droughts in 2002 (Jun: 9%, Jul: -54%, Aug: -2%, Sep:-13%, and Jun-Sep: -19%), 2004 (-1%, -20%, -4%, -30% and -14%) and 2009 (-47%, -4%, -26%,-20% and -22%) are some of the examples. The updated forecast issued on 1st August was in 'Useful' category in September, bimonthly periods of Aug+ Sep and for the season as a whole.

Table 4. Forecast (FC), Update (UD) and Realized Rainfall (RR) as % of long period average (100%) for India as a whole.

Month/Period	Jun	Jul	Aug	Sep	Jun+Jul	Jul+Aug	Aug+Sep	Jun-Sep
Forecast	82	85	89	80	86	88	88	86
Update	-	-	101	100	-	93	100	100
Realised	89	107	95	97	98	101	96	97

Table 5. Summary of verification of SIOCZ model forecasts and updates.

Region	Forecast/Update	Month				Bi-monthly period			season
		Jun	Jul	Aug	Sep	Jun+ Jul	Jul+ Aug	Aug+ Sep	Jun- Sep
India as a whole	Forecast	IUC	NIUC	IUC	NIUC	NIUC	NIUC	NIUC	NIUC
	Update	-	-	NIUC	IUC	-	IUC	IUC	IUC
Sub-divisions of India (36)	No. of subdivisions where CC between SAI and rainfall is significant at 95% level								
		7	21	12	17	20	24	19	26
	% of subdivisions where forecast/update was IUC, out of those subdivisions only where CC is significant								
	Forecast	100	90	42	76	90	87	80	88
	Update	-	-	25	59	-	83	80	85
Districts of the state	Himachal Pradesh		Andhra Pradesh		Telangana		Maharashtra & Goa		Tamilnadu
	No. of districts where CC between SAI and rainfall is significant at 95% level / Total No. of districts								
	6/12		12/13		10/10		32/36		30/32
	% of districts where forecast/update of seasonal (Jun-Sep) rainfall was IUC, out of those districts where CC is significant								
	Forecast	Update	Forecast	update	Forecast	Update	Forecast	Update	Forecast
	66	100	92	92	90	100	94	97	56

IUC: Forecast/Update was 'In Useful Category', NIUC: Forecast/Update was 'Not In Useful Category'. No Update was issued for the districts of Tamilnadu.

DISCUSSIONS

As mentioned earlier, a mid-season transition from ENSO neutral-to-La Nina had taken place in equatorial Pacific during 2016 southwest monsoon. La Nina condition prevailing during August-September has been found to be generally associated with active SWM conditions over India during the second half of the season, e.g., in 1992 and 2012. But this did not happen in 2016. A probable reason could be that sufficient cooling of SST did not take place over ESIO. This did not allow considerable weakening of SIOCZ during the second half of the season. This highlights the comparative importance of changes in SST field over the Equatorial Pacific and Indian Oceans in intra-seasonal changes during SWM. An interesting aspect, which has forecasting implications, comes out of the rainfall distribution during August-September 2016. As mentioned above, occurrence of comparatively increased/decreased rainfall in alternate months is a characteristic feature of a weak monsoon and it has been seen in about 60% of the drought years. This feature was seen in the rainfall during Aug-Sep 2016 also. This feature in rainfall distribution has been found to be related to the development of an active spell of SIOCZ for 3-4 weeks in continuation. Accordingly, decreased rainfall was expected in August and subsequently rainfall was expected to improve in September 2016. The realised rainfall for India as a whole was below normal from the week ending on 10th August till the week ending on 14th September (Figure 2). Rainfall improved only during the second half of September. This shows that the features as seen in the activity of SIOCZ, or in other words, the changes which took place in SST field over ESIO played more important role in the distribution of rainfall over India during 2016 monsoon than the changes in SST field over Equatorial Pacific. Therefore, Equatorial SEIO is recognized as an important region and changes in SST field over this region requires to be watched carefully for foreshadowing changes in monsoon circulation system and thereby in rainfall over India. SIOCZ model forecasts issued on 30th March, 5th June and the update issued on 22nd June, 11th July and 1st August were able to capture most of the features of rainfall distribution during 2016 monsoon season.

CONCLUSIONS

1) Though 2016 southwest monsoon, with 3% below normal seasonal rainfall for India as a whole, has gone in records as a normal monsoon, rainfall distribution during the season was similar to that for a weak monsoon.

2) In contrast to the forecasts of above normal/excess rainfall for India as a whole issued by other centers, SIOCZ model forecasts for below normal rainfall issued on 30th March, for a weak monsoon on 5th June and the update

issued on 1st August for improvement in rainfall, were able to capture most of the features of rainfall distribution during 2016 monsoon season.

3) The performance of SIOCZ model forecast was better in the districts, compared to that in the subdivisions and for the country as a whole.

4) Improvement in rainfall during the second half of the season, which generally happens in the years of mid-season transition from ENSO- ENSO Neutral-La Nina in equatorial Pacific, did not take place during 2016 southwest monsoon.

5) Changes in the activity of SIOCZ were more closely related to the distribution of rainfall over India during the second half of 2016 southwest monsoon than the mid-season transition from El Nino-ENSO Neutral-La Nina conditions in equatorial East Pacific.

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Compliance with Ethical Standards:

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

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