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Intra-seasonal changes and long range forecast of rainfall during 2013 southwest monsoon season based on South Indian Ocean Convergence Zone model

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ABSTRACT

Large intra-seasonal changes took place during 2013 southwest monsoon. An attempt had been made to capture the likely changes in rainfall scenario due to these intra-seasonal changes by issuing forecast updates. The forecast updates were able to capture the improvement in rainfall scenario during the first half of the season, i.e., June-July. However, reduction in rainfall during the second half of the season could not be captured in the forecast update issued in the first week of August. It has been shown, from an examination of weekly SST anomalies and the activity of South Indian Ocean Convergence Zone (SIOCZ) during the season that the availability of weekly forecast SST anomalies from the Indian Ocean region, at least one month in advance, is crucial to foreshadowing likely intra-seasonal changes in the activity of SIOCZ and thereby in rainfall scenario in forecast updates.

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

INTRODUCTION

During the period 1990-2012, for which Long Range Forecast (LRF) based on South Indian Ocean Convergence Zone (SIOCZ) model had been issued, intra-seasonal changes had taken place in 1992, 1999, 2001, 2005, 2010 and 2012. Because of the intra-seasonal changes, the difference between the forecast and the realized Indian Summer Monsoon Rainfall (ISMR) became larger than the model error (±5%): The forecast and the realized ISMR in these years were -16% & -8%, 9% & -4%, 11% & -9%, -16% & -1%, 10% & 2% and -16% & -8% respectively. Severe drought conditions prevailed during the first half of the season in 1992 and 2012. Monsoon circulation strengthened during the second half resulting in significant improvement in the rainfall scenario by the end of the season. In 1999, an active monsoon had been forecast but it turned out to be a 'Normal' one. In 2001, ISMR was 'Weak' though it had been foreshadowed as 'Active' one. Drought conditions had been forecast in 2005. However, the monsoon circulation strengthened during the second half, more particularly during the month of September, and monsoon finally turned out to be a 'Normal' one. The intra-seasonal changes in 2010 had been studied by Prasad and Singh (2013b). An attempt had been made in that study to quantify the impact of the intra-seasonal changes and incorporate the same in forecast updates. From that study it was shown that the forecast updates had been able to capture the subsequent rainfall scenario in 2010. The intra-seasonal changes in the years 1992, 1999, 2001 and 2005 had been discussed by Prasad et al (2014b).

Intra-seasonal changes are different from intra-seasonal oscillations during monsoon. The term intra-seasonal oscillation is used for variance in summer monsoon rainfall in the time scales of 10-15 and 30-60 days. These oscillations are a well known feature of summer monsoon. In the present study we have examined the appearance of new features in the activity of SIOCZ, during 2013 southwest monsoon season. As these features were different from those observed during January-May, one could evaluate the impact of the intra-seasonal changes on rainfall distribution and realistically issue forecast updates. Appearance of the new features in the activity of SIOCZ is linked to the changes in SST distribution over Indian Ocean region. Changes in SST distribution over Indian Ocean could take place in-situ or it could be related to the changes over Equatorial Pacific Ocean (Prasad et al, 2014b). The changes over equatorial Pacific Ocean are generally related to development of El Nino-Neutral-La Nina conditions and vice versa. Intra-seasonal changes have been identified in the activity of SIOCZ using weekly mean cloud data from the Indian Ocean region. Week by week progress of monsoon rainfall for country as a whole has been used as an indicator of strengthening/weakening of monsoon circulation system over Indian subcontinent. Weekly SST anomaly charts of Climate Prediction Centre have been used to monitor the changes in SST anomalies over Equatorial Indo-Pacific region.

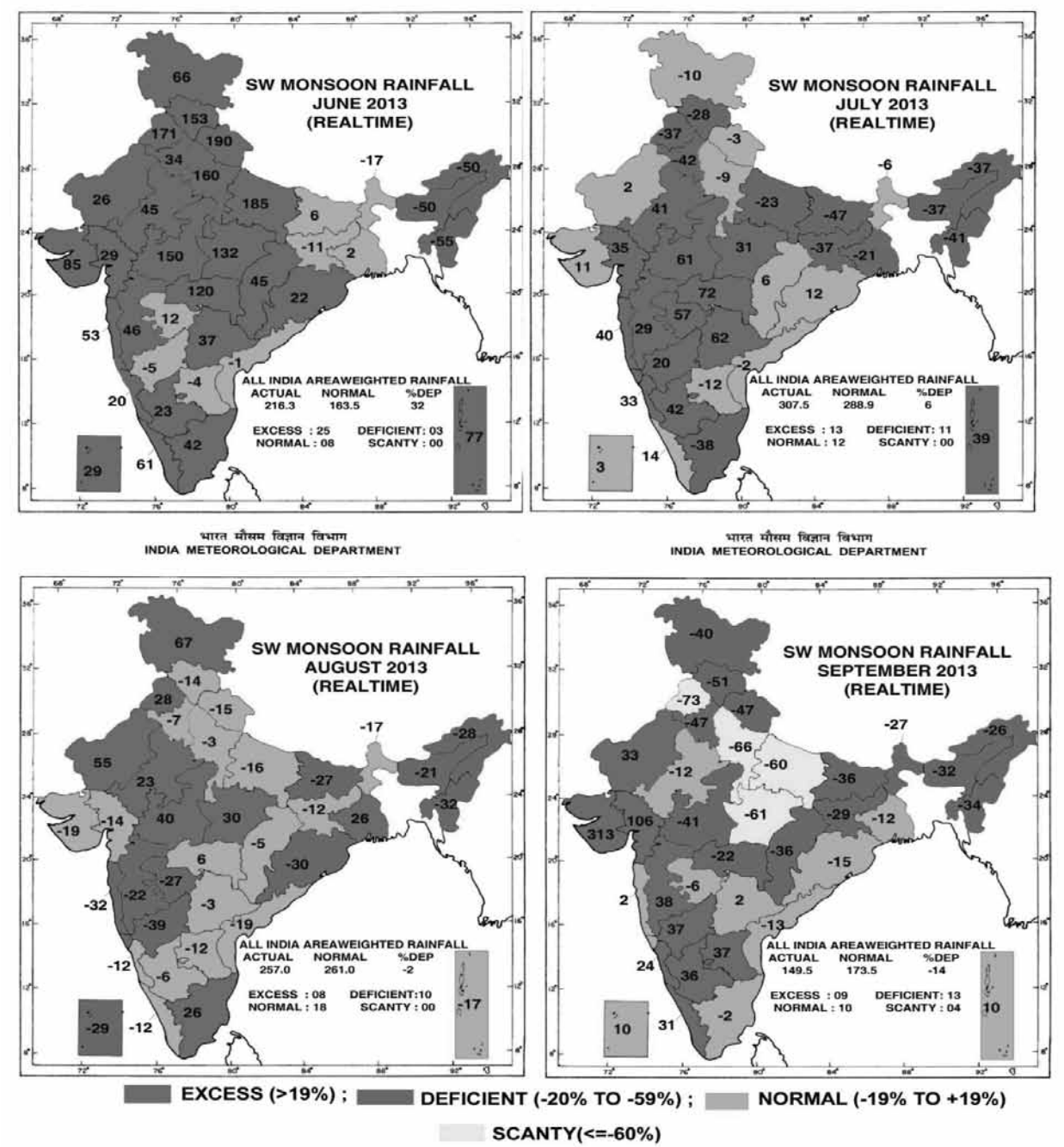

Figure 1. Monthly rainfall during 2013 southwest monsoon season

SIOCZ model provides forecasts of rainfall during southwest monsoon at sub-divisional and district levels. In order to achieve acceptable accuracy in forecasts at these spatial resolutions, gaining sufficient experience in updating the forecasts by incorporating modifications has been found necessary. Such incorporation is necessitated due to importance of intra-seasonal changes. Therefore, the basis for the modifications, the type of modifications made in the forecasts, and extent of usefulness of the modifications have proved helpful in improving the forecast. In view of this positive outcome all these factors are being studied and documented for each monsoon that witnessed large intra-seasonal changes. Beginning from the year 2009, this is the third such documentation. The earlier two documentations were for the years 2010 (Prasad and Singh, 2013b) and 2012 (Prasad et al, 2014b). There were no large intra-seasonal changes during 2009 and 2011 and the forecasts issued at the beginning of the season, based on the activity of SIOCZ during the period January-May, were satisfactory in both the years.

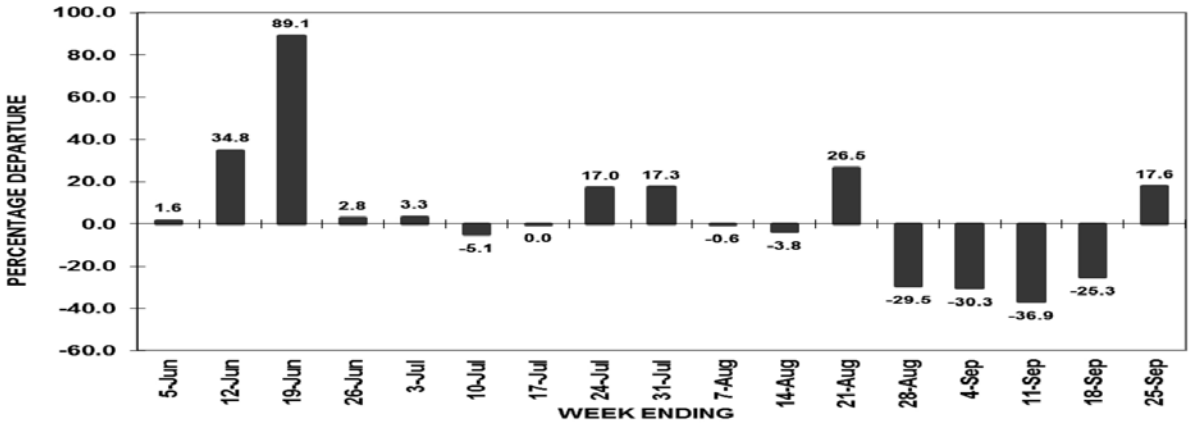

Figure 2. Week-by-week progress of 2013 southwest monsoon rainfall

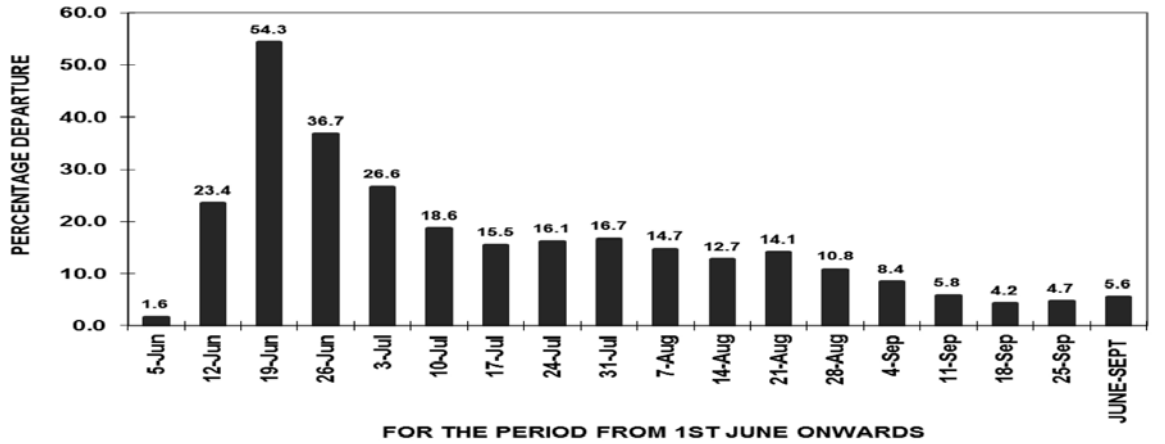

Figure 3. Week-by-week progress of 2013 southwest monsoon rainfall (cumulative)

Salient Features Of 2013 Southwest Monsoon

2013 southwest monsoon set in over Kerala on 1st June, i.e., on the normal date. It rapidly advanced over the country. The most rapid advance took place between 14th and 16th June when monsoon covered Bihar, U.P., Uttarakhand, H.P., J & K, Punjab, Haryana and Rajasthan and thus the entire country was covered by monsoon about a month earlier, instead of the normal date of 15th July. It was a record early onset during the past 72 years period (1941-2012) (IMD,2013).The withdrawal of monsoon from West Rajasthan commenced on 9th September and by 19th September it had withdrawn from some parts of Saurashtra and Kucth, parts of West Rajasthan, Punjab, H.P. and J & K. However, further withdrawal of monsoon was stalled by the continuation of rainfall due to formation of two low pressure areas in the Bay of Bengal and their westward movement across the central parts of the country.

Seasonal rainfall for country as a whole during 2013 southwest monsoon was 6% above normal. Rainfall was excess in 14 subdivisions, normal in 16 and deficient in 6. Monthly rainfall for the country as a whole was 32% above normal in June, 6% above normal in July, 2% and 14% below normal in August and September, respectively. Figure.1 shows monthly rainfall distribution in the subdivisions. Significantly excess rainfall during June, deficiency during September and normal rainfall during July and August were the main characteristic features of monthly rainfall distribution. Week-by-week progress of rainfall and cumulative rainfall for country as a whole is given in Figure. 2 and Figure. 3, respectively. Rainfall was 25% below normal or less during 4 consecutive weeks beginning from the week ending on 28 August (Figure.2). The characteristic feature of week-by-week cumulative rainfall (Figure.3) was that it remained above normal till the end of August and came down to normal category, still with positive departures, during September. It is important to mention here that the rainfall scenario improved once again beginning from the week ending on 25 September when country as a whole received 18% above normal rainfall. This situation continued in October also, when 22 out of 36 subdivisions received excess rainfall and rainfall

Table 1. Operational long range forecasts and actual rainfall during 2013 southwest monsoon

Region	Period	Date of issue	Forecast rainfall (% of LPA)	Actual rainfall (% of LPA)
All India	June to September	26th April	98 ± 5	106
All India	June to September	14th June	98 ± 4	
Northwest India	June to September		94 ± 8	109
Central India	June to September		98 ± 8	123
Northeast India	June to September		98 ± 8	72
South Peninsula	June to September		103 ± 8	115
All India	July		101 ± 9	106
All India	August		96 ± 9	98
All India	August to September	1st August	96 ±8	98
All India	September	1st September	96 ± 13	86

Table 2. Long range forecasts based on SIOCZ model and actual rainfall during 2013 southwest monsoon

Date of issue	Forecast/Update	Actual ISMR, rainfall in subdivisions and districts of Himachal Pradesh and Tamilnadu
28th March	Qualitative forecast indicating development a normal southwest monsoon	106%
1st June	Quantitative forecasts. March forecast upgraded from 'Normal' to 'Normal'- to - 'Active'.	106% and other forecasts for country as a whole, subdivisions and districts of Himachal Pradesh and Tamilnadu included in Tables 3-6.
22nd June	Update No.1. improvement in the performance of monsoon indicated.	-do-
10th July	Update No.2. Forecast upgraded to 'Active' monsoon.	-do-
5th August	Update No.3. Forecast further upgraded from 'Active' to 'Active' -to-'Excess'	-do-

for the country as a whole was 61% above normal. In other words, active southwest monsoon conditions prevailed over majority of the subdivisions during October 2013.

Long Range Forecast Of Rainfall

Operational long range forecast of rainfall during southwest monsoon is issued by India Meteorological Department (IMD). Forecast prepared by a number of other national/ international centers, are also taken into account before issuing the operational forecasts (IMD, 2013). However, in the discussions to follow only two forecasts, i.e., operational and the one based on SIOCZ model have been considered as the details of the forecasts of other centers were not readily available.

Operational Forecast

The operational forecasts for 2013 SWM rainfall for country as a whole were issued in two-stages: (i) on 26 April and (ii) forecast update on 14 June (Table 1). April forecast indicated normal rainfall (98% of normal with an error of ± 5%). The updated forecast also indicated a normal monsoon (98 % of normal with an error of ± 4). Operational forecasts and actual rainfall are included in Table 1.

Forecasts based on SIOCZ model

SIOCZ model's forecasts were also issued in two stages: (i) a qualitative forecast was issued on 28 March and (ii) a comprehensive quantitative forecast on 1 June (Tables 2-4). In addition, one qualitative and two quantitative forecast updates were also issued on 22 June, 10 July and 5 August, respectively (Table 2). The features in the activity of SIOCZ, which formed the basis for the forecasts are discussed below in brief.

Zonal weekly mean cloudiness and cloud anomalies for the period January-May are given in Figure.4(a) and Figure. 5(a), respectively. Based on the SIOCZ activity during the period January-March, development of a 'Normal' monsoon had been indicated in the qualitative forecast issued on 28 March 2013. Based on the SIOCZ activity during the period January-May, a value of 7 had been assigned to SIOCZ Activity Index (SAI), which corresponds to a 'Normal'-to-'Active' monsoon with forecast rainfall for country as a whole, i.e., Indian Summer Monsoon Rainfall

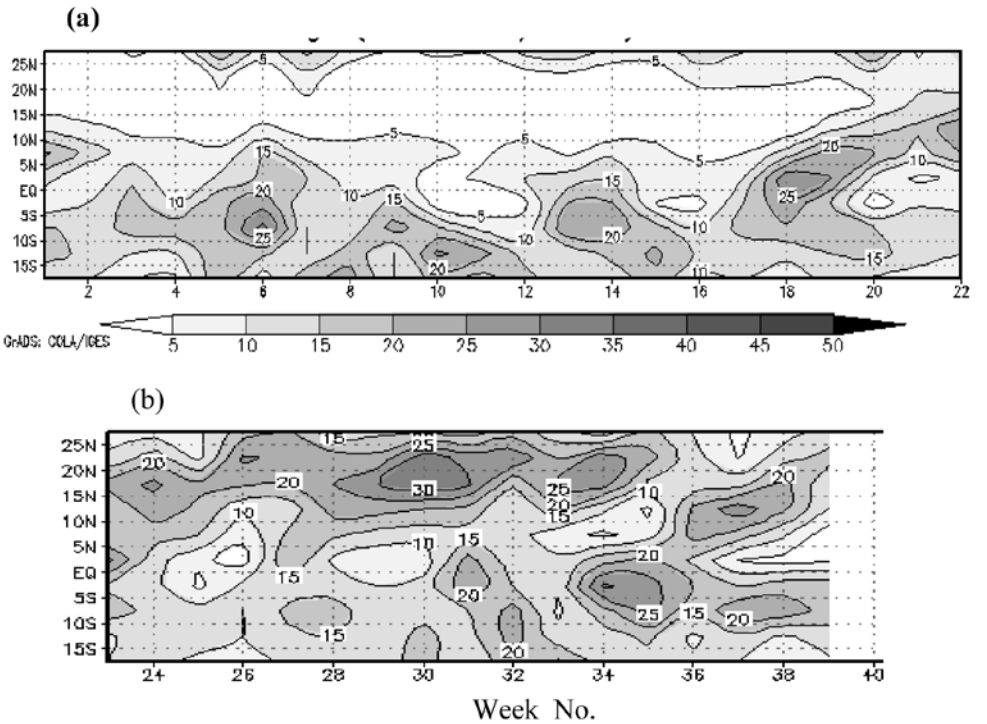

Figure 4. Zonal weekly mean cloud cover (%) between 40E and 100E (a) January-May (week Nos.1-22) and (b) June-September (week Nos. 23-39)

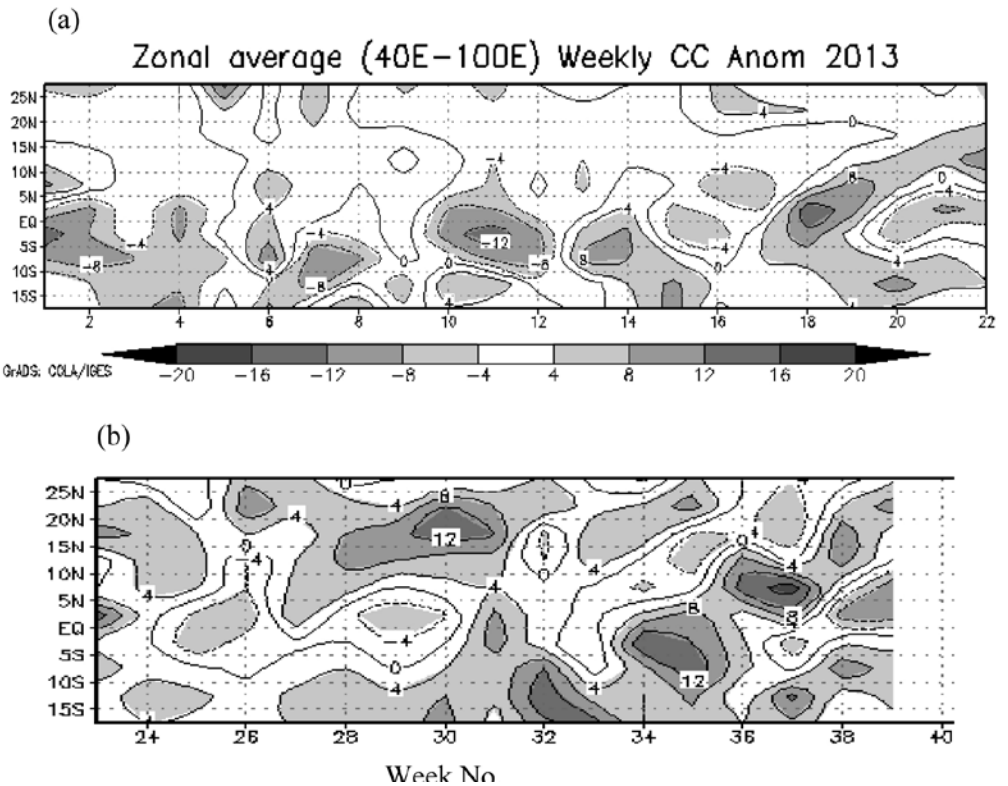

Figure 5. Zonal weekly mean cloud anomaly between 40E and 100E. (a) January-May (week Nos. 1-22) and (b) June-September (week Nos. 23-39).

Table 3. SIOCZ model forecast and updated forecasts for India as a whole (Model error ±5 %)

Month/Period	Date of issue of Forecast /Updated forecast and forecast % departure of rainfall from its normal (100%)			% departure of actual rainfall from its normal (100%)
	Forecast	Updated forecast		
	1 Jun	10 Jul	5 Aug	
June	8N	-	-	32E
July	2N	6N		6N
August	5N	9N	11E	-2N
September	6N	13E	16 E	-14D
June- September	4N	9N	11E	6N

Excess : ISMR > 10 % , 'Active': 9% - 5%, Normal: 4%- -4%%, Weak: -5%- -10%, Deficient/Drought: ≤ -11%.

(ISMR) being 4% above normal with an error of ±5 % (Table 2). Other forecasts issued are listed in Table 2.

Forecast Verification

For country as a whole

The seasonal forecast for country as a whole was close to the realized one and within the error limit of the model (±5%) (Table-3). The difference between forecast and actual rainfall was large in June and September. While June rainfall was on the higher side of the forecast, September rainfall was on the lower side of it. Forecasts as well as actual rainfall in July and August were normal. August rainfall was slightly outside the model error. September forecast was completely out of range. Large intra-seasonal changes took place during 2013 monsoon. This aspect is discussed below.

In meteorological subdivisions

Operational forecasts for seasonal rainfall for 4 broad regions are given in Table1 (IMD, 2013). SIOCZ model forecasts in subdivisions for the season as a whole and in individual months are included in Table 4. Forecasts for individual subdivisions are not available from any other model for comparison. A forecast, in meteorological subdivision, is termed 'Useful' if the forecast as well as actual rainfall are in the same broad departure category of 'Excess (E) / Normal (N)' or ' Deficient(D)/Scanty(S)' or they become so after Model Error (M.E.) is taken into account. The sub-division level forecast is termed 'Useful' if the forecast is in 'Useful' category in 60% subdivisions of India. Seasonal forecast was in 'Useful' category in 92% (83%) subdivisions, where the first Figureure corresponds to the number of subdivisions where the Correlation Coefficients (CCs) between SAI and seasonal rainfall are significant at 95% level or more. The second Figureure in the bracket refers to the % of 'Useful' forecasts when all 36 subdivisions were considered. The % of 'Useful' forecasts was 100% (92%), 92% (90%), 80% (72%) and 47% (53%), respectively for the months of June, July, August and September (Table 4). Except for September, forecasts were reasonably good in the remaining 3 months. Large intra-seasonal changes, which took place during the second half of the season, were responsible for the forecast going out of range in September. These changes are discussed below.

Intra-Seasonal Changes And Forecast Updates

As mentioned above, large intra-seasonal changes took place during 2013 monsoon. There was a sharp increase in rainfall during the weeks ending on 12 and 19 June and a sharp decrease, for 4 weeks in continuation, from the week ending on 28 August to week ending on 18 September (Figure.2). Twenty five subdivisions (out of 36) received excess rainfall in June and 16 subdivisions received deficient/scanty rainfall in September. Figure. 4(b) and Figure. 5(b) show the zonal mean cloudiness and cloud anomaly respectively during the period June-September 2013. An active Equatorial Trough (ET), seen in zonal mean cloud data as a Maximum Cloud Zone (MCZ), developed to the north of equator between equator and 5° N. This feature relates to an intra-seasonal change in the activity of SIOCZ. Development of an ET to the north of equator was a precursor for strengthening of monsoon and thereby an improvement in rainfall scenario in days to come. Accordingly Update No.1 was issued on 22 June (Table 2) in which likely improvement in rainfall scenario was indicated in a qualitative way. The situation repeated with the development of yet another active 'ET' to the north of equator during the week ending on 8 July. These developments formed the basis for issuing updated quantitative forecasts (Update No.2) on 10 July. Rainfall for this update was computed with SAI= 5. A reduction in SAI by 2 numbers (i.e., from 7 to 5), corresponds to an increase in ISMR by 5% and corresponding changes in the forecasts in the subdivisions (Table 4). The next spell of SIOCZ developed during the week ending on 5 August. This time SIOCZ and ET to the north of equator were not distinctly separated as the MCZ associated with this spell was extending between 5° N and 5°S. This development was also favorable for likely continuation of good rainfall

Table 4. Forecast and updated forecast rainfall

Met. Subdivision	Seasonal				June		July		
	Forecast 1 Jun	Update 10 Jul	Update 5 Aug	Actual rainfall	Forecast 1 Jun	Actual rainfall	Forecast 1 Jun	Update 10 Jul	Actual rainfall
Bay Islands	-6N +	-3N	-2N	28E	-13N	77E	-2N	1N	39E
Arun. Pradesh	2N	3N	4N	-36D	-6N	-50D	-1N	-4N	-37D
Assm. Megh.	-1N	0N	0N	-34D	-8N	-50D	6N	6N	-37D
N.M.M.T.	-7N	-6N	-5N	-35D	-12N/MD	-55D	-4N	-4N	-41D
SHWBSikkim	0N	1N	2N	-15N	-7N	-17N	6N	4N	-6N
GW Bengal	12N	14N	16N	-1N	13N	2N	18 N	19E	-21D
Orissa	4N +	6N	7N	-3N	10N	22E	-11N	-13N	12N
Jharkhand	6N +	9N	11N	-23D	16N	-11N	6N	11N	-37D
Bihar	4N	5N	6N	-30D	3N	6N	18N	19N	-47D
East U. P.	2N +	7N	9N	-4N	25E +	185E	6N	12N	-23D
West U. P.	-1N +	4N	6N	-1N	28E +	160E	1N +	7N	-9N
U'khand	-4N +	-1N	0N	12 N	7N +	190E	-9N	-8N	-3N
Har.,Cha.Del.	18N +	28E	32E	-22D	77E	34 E	26E +	37E	-42D
Punjab	18N +	27E	31E	-2N	73E	171E	23E +	33E	-37D
H. P.	-8N +	-3N	-1N	-6N	23E	153E	-11N +	-6N	-28D
J. and K.	17N +	25E	29E	22E	20E	66 E	23E +	34E	-10N
West Raj.	23E +	35E	41E	28E	78E	26E	28E +	39E	2N
East Raj.	6N +	13N	17N	26E	49E +	45E	4N +	10N	41E
West M. P.	5N +	10N	13N	46E	14N +	150E	-4N	-1N	61E
East M.P.	1N +	6N	8N	28E	17N +	132E	-11N +	-6N	31E
Guj. Region	22E +	32E	37E	31E	38E	29E	10N +	21E	35E
Saur,Kut Diu	15N +	24E	29E	64E	47E	85E	2N +	12N	11N
Kon. &Goa	7N +	10N	12N	20E	5 N	53E	-4 N +	-2N	40E
Madh. Maha.	15N +	20E	23E	21E	31E	46E	0N +	5N	29E
Marathwada	10N +	17N	21E	9N	-11N	12N	5N +	11N	57E
Vidarbha	2N +	7N	10N	43E	2N	120E	-2N +	3N	72E
Chhattisgarh	-5N +	-1N	1N	1N	0N	45E	-8N +	-5N	6N
Coastal AP	11N +	17N	21E	-10N	16N	-1N	6N +	14N	-2N
Telangana	8N +	14N	17N	26E	0N	37E	5N +	12N	62E
Rayalaseema	22E +	29E	32E	6N	32E	-4N	17N +	26E	-12N
T. Nadu	34E +	34E	34E	1N	6N	42E	14N	14N	-38D
Coastal Kar.	9N +	13N	15N	17N	7N	20E	-2N +	0N	33E
NIK	8N	11N	12N	5N	30E	-5N	-7N +	-3N	20E
SIK	10N	13N	14N	25E	20E	23E	-2N +	3N	42E
Kerala	-1N	1N	2N	26E	-8N	61E	-9N	-8N	14N
Laksha.	9 N	12N	13N	6N	5N	29E	12N	18N	3 N
% of 'Useful' Forecast	92 (83)	92 (83)	92 (83)		100 (92)		92 (70)	89 (70)	

Table 4. (contd.) Forecast and updated forecast rainfall

Met. Subdivision	August				September			
	Forecast 1 Jun	Update 10 Jul	Update 5 Aug	Actual rainfall	Forecast 1 Jun	Update 10 Jul	Update 5 Aug	Actual Rainfall
Bay Islands	-5N	-4 N	-4 N	-17N	-6N	-3N	-2N	10N
Arun. Pradesh	6N	11N	14 N	-28D	13N	10N	8N	-26D
Assm. Megh.	-5N	-3N	-2N	-21D	2N	3N	3N	-32D
N.M.M.T.	-7N	-5N	-5N	-32D	-3N	-5N	-6N	-34D
SHWBSikkim	0 N	2N	3N	-17N	-1N	0N	0N	-27D
GW Bengal	2N	3N	3N	26E	13N	17N	19E	-12N
Orissa	9N	12N	13N	-30D	9N	16N	19E	-15 N
Jharkhand	-9N	-8N	-8N	-12N	19N	23E	25E	-29D
Bihar	-5N	-4N	-4N	-27D	-5N	-4N	-3N	-36D
East U. P.	-10N +	-5N	-3N	-16N	5N	7N	9N	-60S
West U. P.	-7N	-5N	-4N	-3N	1N	9N +	13N	-66S
U'khand	-10N	-8N	-7N	-15N	5N	12N +	15N	-47D
Har.,Cha.Del.	10N	15N	18N	-7N	-1N	10N +	15N	-47D
Punjab	14N	21E	24E	28E	-7N	4N +	9N	-73S
H. P.	-14N	-10N	-9N	-14N	-6N	2N +	6N	-51D
J. and K.	35E +	47E	54E	67E	-13N	-6N +	-3N	-40D
West Raj.	10N	21E	26E	55E	5N	14N	18N	33E
East Raj.	-4N	-2N	-1N	23E	44E	72E +	86E	-12N
West M. P.	6N	6N	5N	40E	12N	28E +	36E	-41D
East M.P.	10N	15N	17N	30E	-2N	1N	3N	-61S
Guj. Region	29E	36E	40E	-14N	22E	41E +	50E	105E
Saur,Kut Diu	14N	17N	18N	-19N	23E	39E +	47E	313E
Kon. &Goa	17N	21E	23E	-32D	26E	41E +	48E	2N
Madh. Maha.	17N	21E	22E	-22D	24E	33E +	38E	38E
Marathwada	29E +	40E	45E	-27D	19E	32E +	38E	-6N
Vidarbha	9N	10N	11N	6N	4N	17N +	23E	-22D
Chhattisgarh	-7N	-5N	-4N	-5N	2N	11N +	16N	-36D
Coastal AP	17N +	28E	25E	-19N	5N	8 N +	11N	-13N
Telangana	5N +	21E	32E	-3N	1N	1N +	12N	2N
Rayalaseema	38E +	50E	56E	-12N	8N	9N	10N	37E
T. Nadu	11N	11N	11N	26E	5N	5N	-2N	-2N
Coastal Kar.	24E	28E	31E	-12N	24E	37E	43E	24E
NIK	17N +	23E	26E	-39D	4N	5N	6N	37 E
SIK	17N +	24E	27E	-6N	14N	11N	10N	36 E
Kerala	0N	2N	2N	-12N	18E	25 E	29E	31 E
Laksha.	14 N	18N	20E	-29D	10N	13 N	15N	10 N
%'Useful' Forecast	80 (72)	80 (72)	80 (72)		47 (53)	47 (47)	47 (53)	

+ Correlation coefficients between SIOCZ activity index and rainfall significant at 95% level, Excess (E): R/F 20% or more, Normal (N): 19%- -19%, Moderately Deficient (MD): -20%- -30%, Deficient(D):-31% - -59%, Scanty: -60% - -99% , No Rain: -100%.. The first Figureure of 'Useful' forecast % refers to the number of sub-divisions where C Cs are significant and the second Figureure in the bracket corresponds to % of 'Useful' forecasts when forecast in all (36) subdivisions were taken into account.In the districts of Himachal Pradesh and Tamilnadu Seasonal forecasts and actual rainfall for the districts of Himachal Pradesh are given in Tables 5. The Table for Tamilnadu could not be included here. Forecasts were in 'Useful' category in 90% of the districts of Himachal Pradesh and in 75% districts of Tamilnadu. Thus, the forecasts were satisfactory in both the states. No updated forecasts had been issued for the districts of Tamilnadu. Performance of updated forecasts for the districts of Himachal Pradesh are discussed below.

Table 5. Forecasts, updated forecasts and actual seasonal rain fall during 2013 southwest monsoon for the districts of Himachal Pradesh

District	S.D.	M.E.	Forecast 1 Jun	Update 10 Jul	Update 5 Aug	Actual
Bilaspur	30	3	2N	4N	5N	-5N
Chamba	22	3	-24D	-21D	-19MD	-43D
Hamirpur +	30	7	21N	28E	31E	1N
Kangra +	21	4	-1N	3N	5N	23E
Kinnaur +	32	6	-9N	-3N	0N	74E
Kullu +	19	4	14N	18N	20E	23E
Mandi	25	3	-8N	-5N	-4N	9N
Simla +	23	4	-5N	-1N	1N	-9N
Sirmur	19	3	-26D	-23D	-22D	5N
Solon +	26	5	-11N	-6N	-4N	-19N
Una	50	5	28E	33E	36E	38E
Lahol-Spiti	Regression Constants not available. Data was not adequate.					
% of 'Useful' Forecast			100(90)	100(90)	100(90)	

+ CCs between SIOCZ activity index and rainfall significant at 95% level.

activity. Accordingly, SAI was further reduced from 5 to 4 for issuing the third update on 5th August. Forecast rainfall for Update No.3, computed with SAI=4, are given in Tables 3 and 4. Two more intra-seasonal changes took place in the activity of SIOCZ after Update No.3 had already been issued on 5th August: (i) development of an active spell of SIOCZ during the week ending on 12 August (Week No. 32) between 5° S and 10° S. The MCZ associated with this spell moved southward. Movement of the MCZ southward was an indication of likely reduction in rainfall. (ii) Development of an active spell of SIOCZ for 3 weeks in continuation from the week ending on 26 August (Week No.34) to the week ending on 9 September (week No.36). Presence of an active spell of SIOCZ for 3-4 weeks in continuation during the season weakens the Monsoon Trough (MT) and causes reduction in rainfall over a major part of the country, particularly in the subdivisions around the MT zone. Thereafter, SIOCZ continued to remain active till the week ending on 23 September (Week No.38). Thus 2013 southwest monsoon season witnessed large intra-seasonal changes in the activity of SIOCZ. While changes during the period 1 June to 5 August were favorable for good rainfall activity, the changes thereafter were opposite to it. How far the updates, issued on the basis of the appearance of features in the activity of SIOCZ, were helpful in capturing the future rainfall scenario are discussed below.

Verification Of Updated Forecasts

As mentioned above, the first update was issued on 22 June, which indicated improvement in the rainfall scenario in the days to come. Improvement in the performance of monsoon was seen in its rapid advance over central and northwest India during the second half of June and also in rainfall amounts. This spell witnessed unprecedented floods in Uttarakhand, and more particularly in Badrinath, during the night of 16th June. Country as a whole received 32% excess rainfall and rainfall was excess in as many as 25 subdivisions (Figure.1).The second update issued on 10th July, was a follow up of the first one and it included updated quantitative forecasts for country as a whole (Table 3), in subdivisions (Table 4) and the districts of Himachal Pradesh (Table 5). No updates were issued for rainfall in Tamilnadu. A comparison of the forecasts for seasonal rainfall issued on 1 June and the updated one issued on 10th July for country as whole with the actual rainfall shows that the updated forecast was closer to the realized rainfall in July and also for the season as a whole. At subdivision level the forecast for the month of July improved in as many as 19 subdivisions. However, at the same time the difference between the updated forecast and actual rainfall increased in 14 subdivisions. This is obvious as monsoon rainfall does not improve/deteriorate uniformly over different regions of India. The third update was issued on 5 August. Forecast, updated forecasts for the months of August and September have been included in Table 4. The rainfall for the country as a whole in August and September was 2% and 14% below normal respectively, a situation which was opposite to what had been expected in the forecast as well as in the updates. The difference between the updated forecast rainfall and the actual rainfall increased in as many as 25 subdivisions in August and 23 subdivisions in September, respectively. A comparison of % of 'Useful' forecast in individual months shows that the updated forecasts were reasonable good during June, July and August but not so in September. As

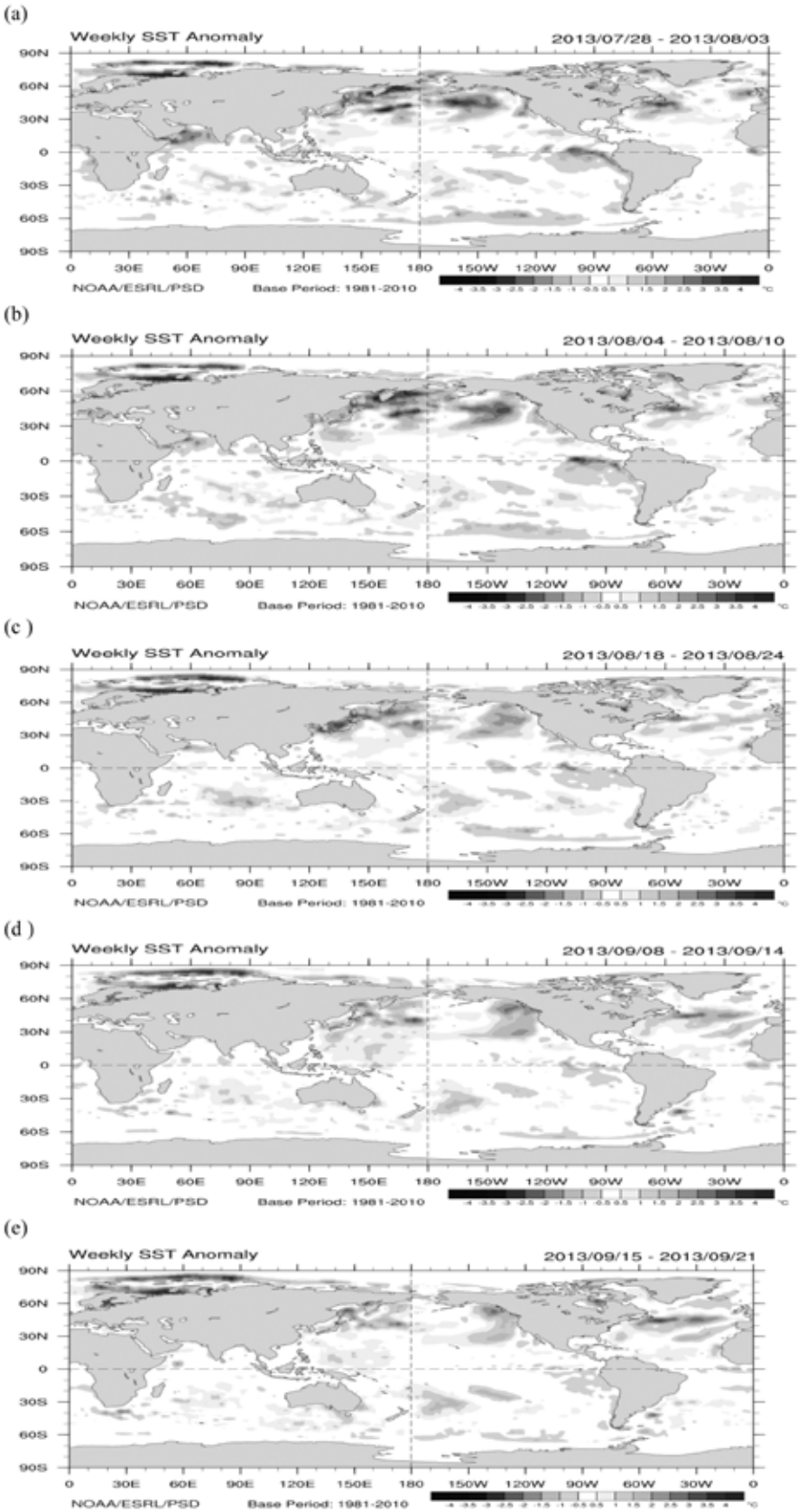

Figure 6. Weekly SST anomaly.

mentioned above, forecasts at sub-divisional level in a year are considered satisfactory if they are in 'Useful' category in at least 60% of the subdivisions, i.e., in 22 subdivisions out of 36. In September the % of 'Useful' forecast was as low as 47% (53%).

Updated forecasts for the districts of Himachal Pradesh are included in Table 5. The difference between forecast and actual rainfall decreased in 6 districts and increased in the remaining 4 districts in the case of both updates as compared to 1 June forecast. However, both updated seasonal forecasts were in 'Useful' category in 91% districts of the state, as was the case for 1 June forecast. Thus both, the forecast as well as updated forecasts, were satisfactory.

Intra-seasonal changes, which took place during the second half of the season have been examined in relation to ongoing changes in sea surface temperature over Equatorial Indo-Pacific region. The results are discussed below. Need for yet another update to help in taking needed precautionary steps to face repercussions due to reduction in rainfall during September is also discussed.

Ongoing Changes In Sea Surface Temperature Over Equatorial Indo-Pacific Region

The information on Sea Surface Temperature (SST) distribution discussed here are based on the real time weekly SST anomaly maps of NOAA/ESRL/PSD, which were made available on their web site (www.esrl.noaa.gov/psd/map/images/sst.anoma.gif). Equatorial strip of Indian and Pacific Oceans, except for the region from date line westward up to 100° E, was dominated by negative SST anomalies in the beginning of June 2013. With slight changes in some weeks, this situation continued up to July. During the week ending on 3 August anomalies were negative to the east of date line and again from 100° E to east coast of Africa and positive anomalies over the region in between (Figure.6a). Negative anomalies started reducing thereafter (Figure.6b) and anomalies became positive over Indian Ocean by the week ending on 24 August (Figure.6c). This situation continued up to the week ending on 14 September (Figure. 6d). Thereafter positive anomalies reduced over Indian Ocean (Figure. 6e). Details of changes in SST anomalies and the resultant impact on SIOCZ during August-September 2013 are discussed below.

SIOCZ remained generally active during August-September. A MCZ developed between 5° N and 5° S during the week ending on 5 August (Week No. 31, Figure. 4b and Figure. 5b) moved southward during the next 2 weeks. After a gap of one week, yet another active spell of SICZ developed between equator and 5° S and remained active in that location for the next two weeks (week Nos. 35-36). SIOCZ again developed during the next two weeks but in a relatively southern location. These developments in the activity of SIOCZ affected rainfall distribution over India: Cumulative rainfall for the country as a whole was 17% above normal at the week ending on 31 July (Figure. 3). It decreased week-by-week up to the week ending on 18 September, except for one week period in between, i.e., 15-21 August. Reduction in rainfall occurred due to development of an active spell of SIOCZ, which was in association with the presence of positive SST anomalies in SIO. These developments, i.e., development of positive SST anomalies and active spells of SIOCZ, were concurrent and hence there was no way to foresee this situation when Update No.3 was issued on 5 August. Update No.3 had indicated continuation of good rainfall activity. On the contrary the reduction in rainfall was rather large beginning from the week ending on 28 August. Thus, in the absence of the availability of weekly forecast SST anomaly charts from the Indian Ocean region, it was not possible to issue an update for reduction of rainfall, which occurred in September. Such a situation was also noted earlier in the study of intra-seasonal changes during 2012 southwest monsoon (Prasad et al, 2014b). A reasonably good updated forecast for likely reduction in rainfall during the second half of 2013 monsoon could have been possible had the weekly SST anomaly charts for the months of August and September been available in the beginning of August. Thus, before hand information on likely development of positive (negative) anomalies in weekly SST anomaly charts for SIO at least one month in advance, appears to be crucial for foreshadowing likely intra-seasonal changes in the activity of SIOCZ and thereby the likely rainfall scenario over India.

Rainfall During October

As mentioned above, the rainfall scenario improved beginning from the week ending on 25 September, when country as a whole received 18% above normal rainfall. This situation continued further as rainfall was above normal by 41%, 53% and 46% during the weeks ending on 9th, 16th and 23rd October, respectively. Rainfall was above normal by 61% in October. This was yet another intra-seasonal change during 2013 monsoon that commenced by the end of the monsoon season and continued during October. Once the positive SST anomalies over SIO reduced considerably, the active spell of SIOCZ that was continuing for 3 weeks ended, during the week ending on 25th September. Thus, 2013 southwest monsoon was an interesting case for its large intra-seasonal changes.

CONCLUSIONS

- SIOCZ model forecasts issued on 1 June were reasonably good for country as a whole, including majority of the subdivisions and the districts of Himachal Pradesh and Tamilnadu.
- The Updates issued on 22 June and 10 July were able to capture the rainfall scenario up to the end of August. However, slight improvement in rainfall included in the third Update, issued on 5 August, was just opposite to the reduction in rainfall, which occurred during August-September.
- Forecast weekly SST anomaly charts are crucial for foreshadowing intra-seasonal changes in the activity of SIOCZ and thereby in issuing forecast updates.

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