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South Indian Convergence Zone Model: A new approach to seasonal forecasting of summer monsoon rainfall in India Part VI: merits of the model and limitations in seasonal forecasting of rainfall in India

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ABSTRACT
South Indian Convergence Zone (SICZ) and its role in the development of Indian summer monsoon, forecast of rainfall for India as a whole, in individual meteorological subdivisions of India and districts of the meteorological sub-division of Tamilnadu and Pondicherry, role of intra-seasonal changes in Tropical Pacific Ocean in inter-annual variability of Indian Summer Monsoon Rainfall (ISMR) and relative roles of Equatorial Pacific and Indian Oceans in inter-annual variability of ISMR had been discussed in Part I-V of the paper respectively. SICZ model appears to be a robust one as it has produced reasonably good forecasts, for the past 23 years, for India as a whole and in a number of meteorological subdivisions including the forecast of seasonal rainfall for the districts in the subdivision of Tamilnadu and Pondicherry for the past four years beginning from 2009. SICZ model has several advantages. Merits of SICZ model and limitations in long range forecasting of summer monsoon rainfall, because of large intra-seasonal changes in monsoon circulation system over Indian subcontinent more particularly during the second half of the season in some of the years, have been discussed in this concluding part of the paper. The Indian subcontinent experiences large variability in monsoon rainfall distribution at temporal and spatial scale. Subdivision and district level forecasts of monsoon rainfall available from the model could become an important input in planning of agricultural operations, water management and disaster mitigation strategies.

INTRODUCTION

SICZ and its role in the development of Indian Summer Monsoon (ISM), forecast of monthly, bimonthly periods (June+ July, July+ August and August+ September) and seasonal (June-September) rainfall for India as a whole, in meteorological sub-divisions of India (numbering 36) and forecast of seasonal rainfall for the districts in the meteorological subdivision of Tamilnadu and Pondicherry had been discussed in Part I, II and III of the paper respectively. Role of intra-seasonal changes in Equatorial Indo-Pacific region in modifying Indian Summer Monsoon rainfall (ISMR) and relative roles of major oscillations in Equatorial Pacific and Indian Oceans in inter-annual variability of summer monsoon had been discussed in Part IV and V respectively. South Indian Convergence Zone (SICZ) had also been referred to as Southern Hemispheric Equatorial Trough (SHET) earlier (Prasad, et al. 1988; Gupta and Prasad 1992, 1993). The influence of SHET on rainfall during southwest monsoon had been examined by De at al 1995. These studies had confirmed that SHET forms an important element of southwest monsoon circulation system and that there exists an, in general, inverse relationship between its intensity and rainfall over Indian subcontinent. SICZ model has produced reasonably good forecasts for different spatial and temporal resolutions for more than 2 decades now. However, it was noted that the difference between the forecast and ISMR was larger than the model error of $\pm$ 5% in 1992, 1999, 2001, 2005 (Prasad and Singh, 2012) and also in 2012. Such difference was seen in the forecast for some of subdivisions also. While rainfall scenario improved during the second half of the season (August-September) in 1992, 2005 and 2012 it deteriorated during 1999 and 2001. Model forecast was quite satisfactory for the first two months of the season, i.e., June and July in these years also. However, there were large intra-seasonal changes in monsoon circulation system over Indian sub-continent from the first half of the season to the second half in these years. Large intra-seasonal changes also occurred in the characteristic features of the activity of SICZ during these years during the second half of the season.

In this part of the paper we have discussed merits of SICZ model in respect of its data requirement and performance. Limitations in seasonal forecasting of summer monsoon rainfall, particularly in the years of large intra-seasonal changes in the characteristic features in the activity of SICZ which have generally occurred during the second half of the season, are also discussed. It may be mentioned here that the term intra-seasonal oscillations is used for variance in summer monsoon rainfall in the time scale of 10-15 and 30-60 days. These oscillations are a known feature of Indian summer monsoon and occur every year. What we have examined here is the appearance of new features in the activity of SICZ during summer monsoon months of August-September which were different than those observed during the period January-May and whether the appearance of the new features were linked to the ongoing changes over Equatorial Indo- Pacific region related to development of El Nino/ENSO neutral/La Nina conditions and vice versa. For this purpose we have examined the cloud features over Equatorial Indian Ocean (EIO), week-by-week progress of monsoon rainfall for India as a whole as an indicator of strengthening/weakening of monsoon circulation over Indian subcontinent and changes, if any, in SST anomalies in Nino 3.4 and/or other Nino regions during the summer monsoon months of June-September.

MERITS OF SICZ MODEL

Though seasonal forecast of ISMR is being issued by India meteorological Department since 1886 (Blandford,1984), foreshadowing extreme seasons (Excess/Drought) had remained a challenging task. None of the models, statistical or dynamical, could foreshadow the recent droughts of 2002, 2004 and 2009 and also the severe drought conditions during June and July 1992 and 2012. Monsoon rainfall shows large variation from one region of India to another. One forecast for four broad regions, where each broad region consists of several meteorological subdivisions, does not indicate likely rainfall scenario in individual meteorological subdivisions of any of the four broad regions (Prasad and Singh,2013a). Therefore, the need for availability of LRF of monsoon rainfall at meteorological subdivision level has been felt by user community for a long time. Preparing long range forecast of monsoon rainfall at meteorological subdivision level has remained a still bigger challenge. In the context of the above mentioned scenario of seasonal forecasting of summer monsoon rainfall in India, development of SICZ model in 1989 should be considered as an important development as the model has since produced reasonably good forecasts of summer monsoon rainfall for India as a whole as well as in several meteorological subdivisions for the past 23 years 1990-2012 including the recent droughts in 2002, 2004 and 2009 and drought conditions during June and July 2012. Real time forecast from SICZ model for ISMR as well as seasonal rainfall in meteorological sub-divisions are being issued since 1990. SICZ model has several advantages over other models of long range forecasting of ISMR. Some of the merits of the model are briefly discussed below.

Data requirement

Timely and easy availability of required data is one of the important issues in preparing LRF of summer monsoon rainfall. Operational models (Gowariker, et al. 1989) of India Meteorological Department (IMD) require data from different regions of the globe. Global data sets are required to run the dynamical models. Compared to both, SICZ model is simple and its data requirements are comparatively very small. Also the required data could be easily obtained. SICZ model requires satellite observed cloud/OLR data from IO region. As discussed earlier the forecasts were prepared using daily eye estimates of weekly mean cloud cover obtained from visible cloud imagery at 06 UTC. OLR data could easily replace cloud data. This is discussed below.

Plots of eye estimates of cloud cover and NOOA OLR (Total) for the period January-May 1975-2012 (data was missing in 1978 from 17th March onwards) have been prepared. A comparison of the plots of eye estimates of zonal weekly mean cloudiness and pentad OLR from IO region bounded by latitudes 20°S and 30°N and longitudes 40°E and 100°E for the past 38 years has shown that the features in the activity of SICZ as displayed in cloud data are identical in OLR data. For the sake of illustration we have reproduced here the plots of cloud and OLR data for two years each of an excess, a normal and a deficient ISM. Fig. 1(a) shows zonal mean cloudiness for the first 22 weeks (154 days, i.e., January-May) of an excess monsoon year-1988 (ISMR was 18% above normal). Development of alternate spells of active and weak SICZ, was the characteristic feature seen in the cloud field during January-March. Development of an equatorial trough close to equator and its progressive northward movement was the characteristic feature during pre-monsoon months of April and May. OLR data for the first 31 pentads (155 days) are shown in Fig. 1(b). It may be seen that the features as seen in cloud data are seen in OLR data also. Cloud cover and OLR data for the year 1994 (ISMR was 10% above normal) are shown in Figs. 2(a) and 2(b) respectively. Here also the features are nearly identical in cloud cover and OLR data. Fig. 3(a) shows cloud data for a normal monsoon year-1993 (ISMR was just normal (% departure 0 %)). Development of alternate spells of active and weak SICZ was the characteristic feature seen in cloud data during the period January-March 1993. This feature continued during April-May also. The MCZ associated with the active spell of May was located to the north of equator. OLR data for the period January-May 1993 are shown in Fig. 3(b). The features noted in cloud data are also seen in OLR data. Fig. 4(a) and 4(b) show cloud and OLR data respectively for

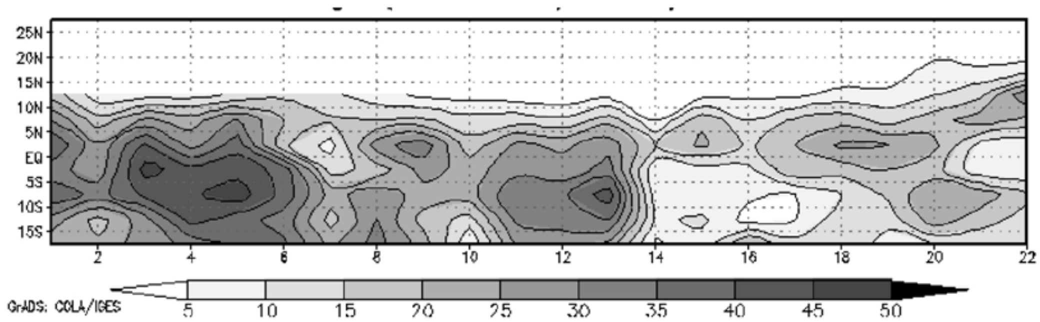

Figure 1(a). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May 1988.

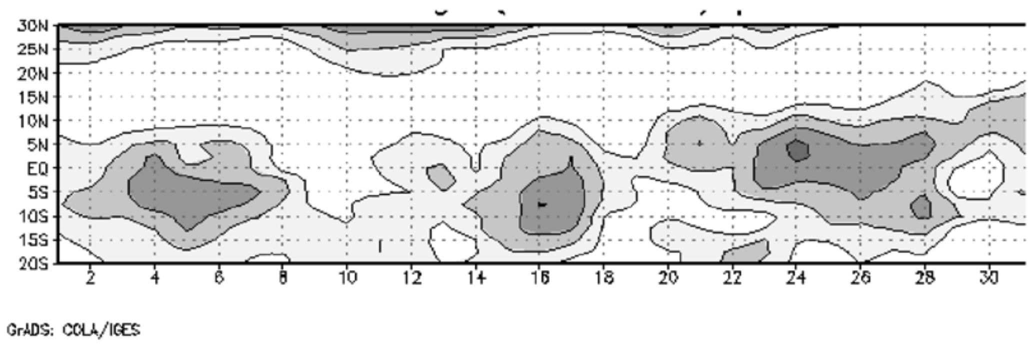

Figure 1(b). Zonal average (40°E-100°E) pentad OLR during Jan-May 1988.

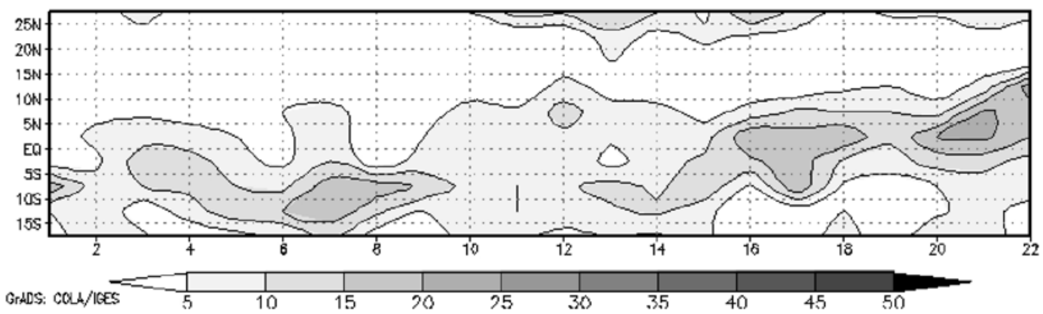

Figure 2(a). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May1994

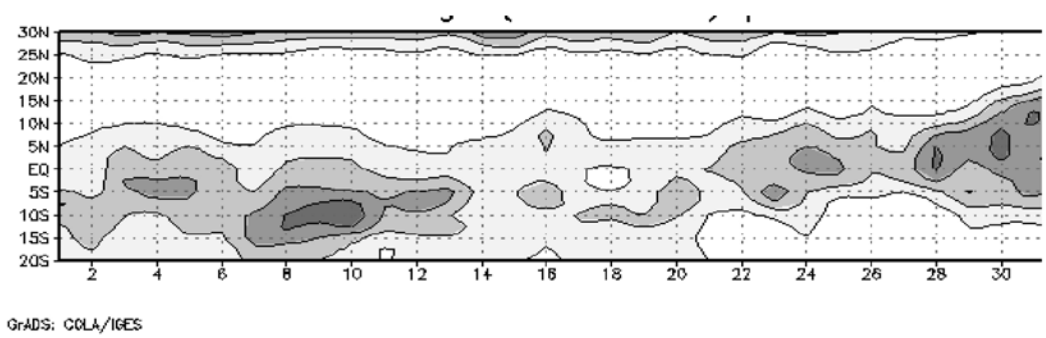

Figure 2(b). Zonal average (40°E-100°E) of pentad OLR during January-May 1994

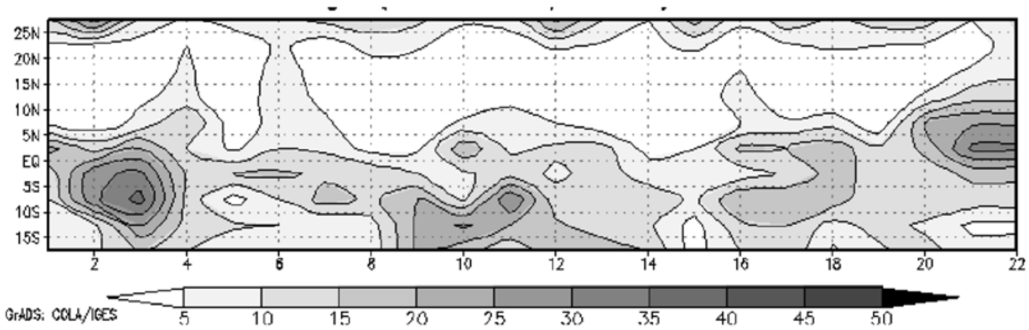

Figure 3(a). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May 1993

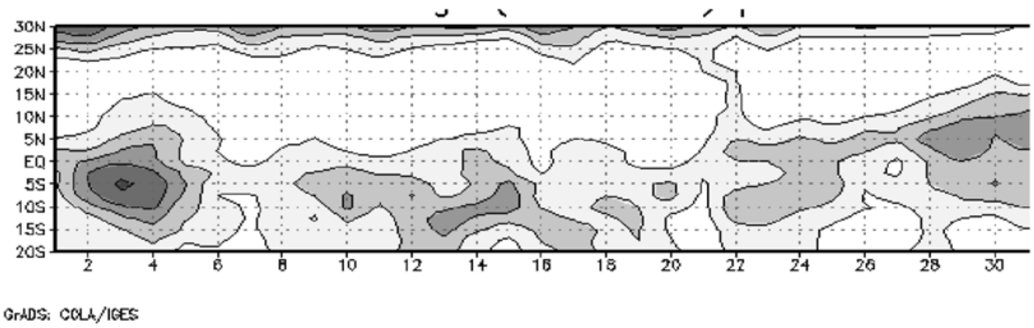

Figure 3(b). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May 1993

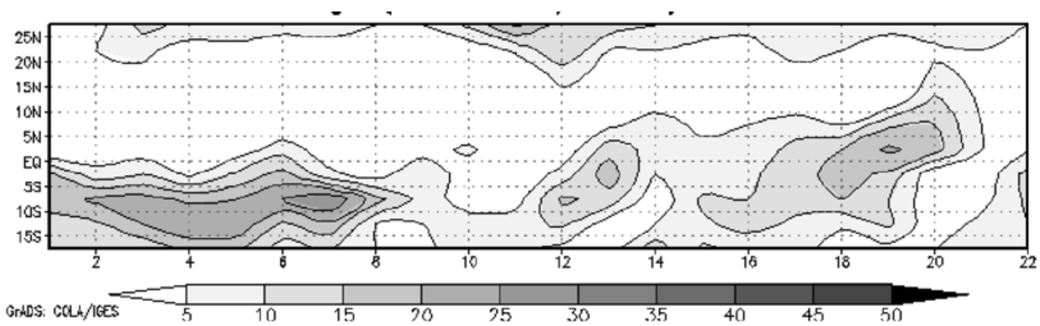

Figure 4(a). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May1997

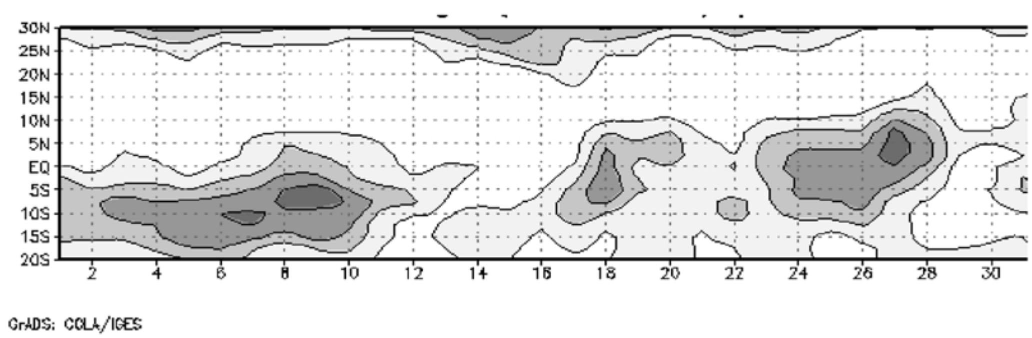

Figure 4(b). Zonal average (40°E-100°E) of pentad OLR during January-May 1997

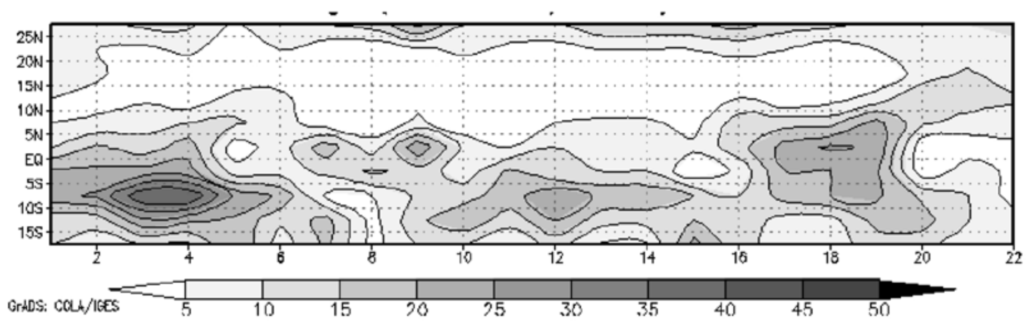

Figure 5(a). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May 2002

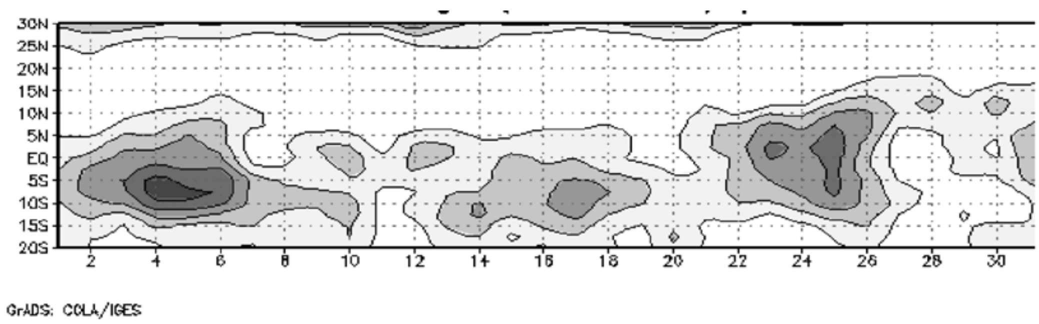

Figure 5(b). Zonal average (40°E-100°E) of pentad OLR during January-May2002

another normal monsoon year, 1997 (ISMR was 2% above normal). SICZ remained active during January-February. Alternate spells of weak and active SICZ developed during the period March-May. These features are seen in both the data, i.e., cloud and OLR. Fig. 5(a) and Fig. 5(b) show cloud cover and OLR data for drought year 2002 (ISMR was 19% below normal). Development of alternate spells of active and weak SICZ, lasting for 4 weeks in continuation, was the characteristic feature in cloud as well as OLR field during the period January-May. Fig. 6(a) and Fig. 6(b) show cloud cover and OLR data respectively during the period January-May 2009, which was another severe all India drought year (ISMR was 23% below normal). SICZ remained active from the beginning of the year till the end of April. The MCZ started moving northward from the beginning of May and could reach the latitude belt 10°N-15°N by the end of the month. These features are seen in OLR data also. Thus the features in the activity of SICZ during January-May used in the model are identical in cloud as well as in OLR data. Thus either of the two could be used for preparing forecasts. Like OLR, digital cloud amount data were not available from any satellite. However, it is believed that the features in the activity of SICZ as seen in eye estimate of clouds and OLR data shall also be seen in digital cloud amount cloud data.

Apart from its limited data requirements as discussed above, SICZ model has been able to provide monthly, bimonthly (June+ July, July+ August, August+ September) and seasonal forecasts for India as a whole, several subdivisions and seasonal forecasts for the districts of Tamilnadu and Pondicherry. This aspect is discussed below in brief.

Performance of SICZ model

SICZ model produces rainfall forecast at (i) spatial resolution of India as a whole, meteorological sub-divisions and districts of one of the subdivisions, i.e., Tamilnadu and Pondicherry and (ii) temporal resolutions of season, bi-monthly periods of June+ July, July+ August and August+ September and individual months of the season for India as a whole and a large number of meteorological subdivisions. The verification of the forecasts for the period 1998-2010 for India as a whole and in meteorological subdivisions had been discussed in Pt II and Pt III of the paper respectively. Performance of the model during the past two years, i.e., 2011-2012 is discussed below in brief. District level forecast of seasonal rainfall for the districts in Tamilnadu and Pondicherry are being prepared since 2009. Verification of forecasts for 2009 and 2010 had been included in Pt III of the paper and that for the years 2011 and 2012 are discussed below.

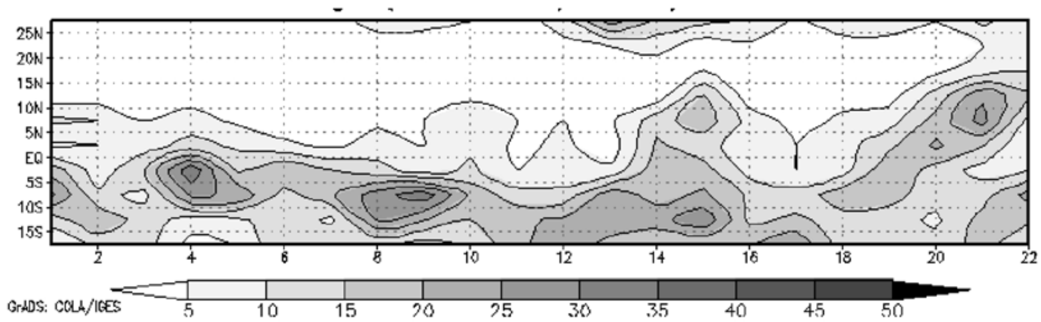

Figure 6(a). Zonal average (40°E-100°E) weekly cloud cover (%) during Jan-May 2009

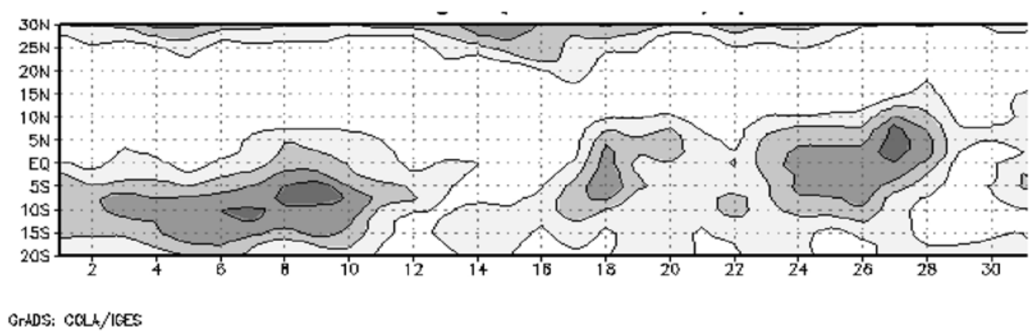

Figure 6(b). Zonal average (40°E-100°E) of pentad OLR during January-May 2009

Forecast for India as a whole

SICZ model has produced reasonably good forecasts of ISMR for the past 23 years including the forecast for drought in 2002, 2004 and 2009. There was no excess monsoon during the period, 1990-2012, except that ISMR was 10 % above normal in 1994. Though seasonal forecast of ISMR is being prepared by different national/ international centers, forecasts other than the operational one issued by India Meteorological Department (IMD), are not available for readily comparison. Performance of SICZ and operational model of IMD in producing LRF of ISMR for the period 1990-2010 had been discussed in Pt II of the paper. Forecasts for the past two years, 2011-2012 have been included in Table 1. During 2011, SICZ model forecast (model error ±5%) was slightly lower than the realized one in June, August and September and higher in July. However, bi-monthly and seasonal forecasts were very close to the realized one. SICZ model was able to forecast the severe all India drought conditions during June and July 2012. However, there was a large intra-seasonal change during the second half of Monsoon-2012. As a result the difference between the forecast and realized rainfall was larger than the model error in August, September, July+ August, August+ September and June-September. SICZ model had accurately forecast severe drought conditions which prevailed during the first half of the season. However, the improvement which took place during the second half of the season, and which were a result of intra-seasonal change, could not be foreshadowed from the features in the activity of SICZ during the period January-May 2012. This relates to one of the limitations in seasonal forecasting of monsoon rainfall in India. Large intra-seasonal changes had taken place in the second half of the season in 1992, 1999, 2001 and 2005 also. On going changes over Indo-Pacific region related to improvement/deterioration of rainfall scenario over Indian subcontinent during the second half of these years have been discussed below in detail. These discussions have shown that the large difference between some of the forecasts and realized rainfall in some of the years were not due to any weakness in the model.

Forecast for meteorological subdivisions

A forecast, at meteorological subdivision level, is termed as 'Useful' if realized as well as forecast rainfall are in the same broad rainfall departure category of 'Excess'/'Normal' or 'Deficient'/'Scanty', or they become so after Model Error (M.E.) in forecast rainfall is taken into account. The number of subdivisions where correlation coefficients between SICZ Activity Index (SAI) and rainfall were significant at 95% level or more are different for different month/bi-monthly period (Table 1). On an average, the Percentage Of Useful forecast (POUF) for monthly forecasts

Table 1. Verification of forecasts for India as whole and meteorological subdivisions

Month / bi-monthly period/ season	India as a whole						Meteorological subdivisions		
	% departure of rainfall from normal and departure category						No. of Sub-divisions, out of 36, where CC between SAI and rainfall was significant at 95% level or more	% of 'Useful' forecast	
	2011			2012				2011	2012
	SICZ model forecast issued in May	IMD's operation-al forecast issued in April/ updated in June	Reali-zed rain-fall	SICZ model forecast issued in May	IMD's operation-al forecast issued in April/ updated in June	Reali-zed rainfall			
Jun	3 N	-/-	12 E	-15 D	-/-	-28 D	6	100	100
Jul	-3 N	-/-7±9 BN	-15 D	-21 D	-/-2±9 N	-13 D	19	73	80
Aug	2 N	-/-6±9 BN	10 N	-15 D	-/-4±9 N	1 N	9	100	100
Sep	0 N	-/-	8 N	-26 D	-/-	13 E	16	81	25
Jun+ Jul	1 N	-/-	-1 N	-20 D	-/-	-20 D	18	89	83
Jul+ Aug	2 N	-/-	-2 N	-19 D	-/-	-6 N	21	90	76
Aug+ Sep	2 N	-/- 10±8BN	9 N	-24 D	-/-9±8BN	7 N	19	90	58
Jun-Sep	3 N	-2±5 N/ -5± 4 BN	2 N	-20 D	-1±5 N/ -4±4 N	-8 N	26	100	84

SICZ Model forecast error: ± 5%   N: Normal   BN: Below Normal   D: Deficient   E: Excess

had varied from 77% to 100% and from 84% to 90% for bimonthly periods during the Forecast Verification Period (FVP) 1998-2010. The accuracy of the forecast for seasonal rainfall in subdivisions had varied from 85% to 100%. POUF forecasts for subdivisions in individual months, bi-monthly periods and season as whole for the period 2011-2012 are given in Table 1. Except for the month of July-2011, forecast was in 'Useful' category in 81-100% subdivisions in the remaining months/bi-monthly periods. The situation was same during June, July, August, June+ July and June-September 2012. Significant improvement in rainfall scenario during August and September -2012 had resulted into large drop in POUF during September, July+ August and August+ September. This was a result of large intra-seasonal changes in monsoon circulation system over Indian region. This has been discussed below in detail.

District level forecast

LRF of summer monsoon seasonal rainfall at district level had been attempted for the subdivision of Tamilanadu and Pondicherry (Prasad, et al., 2010a). To begin with, the districts of the subdivision other than Niligiri Hills and Kanyakumari had been clubbed into 8 clusters of districts, having similar rainfall pattern, for working out the relationship between SAI and seasonal rainfall. Therefore, except for the districts of Nilgiri and Kanyakumari, forecast rainfall in other districts is actually the forecast for the cluster of districts to which a district belongs to. Standard deviations of summer monsoon rainfall are large in the districts of Tamilnadu. Instead of using IMD's criterion of categorization of rainfall departures in meteorological subdivisions (with normal rainfall taken as ±19% of long period average), standard deviation criterion had been used for verification of forecasts at district level in Tamilnadu and Pondicherry. Verification of the forecasts for the period 1993-2008 had shown encouraging results. Verification of forecasts for the years 2009 and 2010 had been included in Pt III. POUF had varied from 70% in the year 2009 to 100% in the year 2010. Forecast and realized rainfall for 2011 and 2012 have been included in Table 2. Here also the standard deviation criterion has been used for categorization of rainfall departures. POUF has varied from 66% in 2011 to 60% in 2012. It may be mentioned here that the LRF at the highest spatial resolution, i.e., cluster of districts/district level had been attempted for Tamilnadu and Pondicherry as a test case as the subdivision experiences highest variability of summer monsoon rainfall at district level. Verification of cluster of districts/district level forecast for the past 20 years 1993-2012, which includes real time forecast for the past four years2009-2012, has shown that SICZ model could be used to produce district level LRF of seasonal rainfall. It is believed that the forecast may improve if the relationship between SAI and rainfall is developed for individual districts. This is being examined for the districts in Tamilnadu and Pondicherry and shall be attempted for other states also.

The results of verification of real time forecasts in

Table 2. Forecast of summer monsoon seasonal rainfall (% departure from normal and departure category (E/N/MD/D/S) for meteorological subdivision of Tamilnadu and Pondicherry

District	S.D. of summer monsoon seasonal rainfall	Model error (%) (±)	Forecast rainfall	Realized rainfall	Forecast rainfall	Realized rainfall
			2011		2012	
Ariyalur	21	8	-2 N	-31 D	-39 D	-23 D
Chennai	26	9	-6 N	75 E	-49 D	-21 N
Coimbatore	75	18	163 E	33 N	84 E	-15 N
Cuddalore	21	8	5 N	11 N	-32 D	-38 D
Dharmapuri	21	8	-4 N	-33 D	-40 D	-24 D
Dindigul	28	6	11 N	-39 D	-17 N	-40 D
Erode	75	18	163 E	-2 N	84 E	-19 N
Kanchipuram	26	9	-6 N	8 N	-49 D	-30 D
Kanyakumari	42	7	7 N	-47 D	-25 N	-46 D
Karur	21	8	-2 N	-28 D	-39 D	-58 D
Krishnagiri	21	8	-4 N	-22 D	-40 D	-39 D
Madurai	28	6	11 N	-43 D	-17 N	-44 D
Nagapattinam	21	8	5 N	-28 D	-32 D	-18 N
Namakkal	21	8	-4 N	-24 D	-40 D	-40 D
Nilgiri	25	7	10 N	21 N	-22 N	13 N
Perabmalur	21	8	-2 N	-12 N	-39 D	-49 D
Puddukottai	21	8	-2 N	10 N	-39 D	-15 N
Ramanathpuram	35	9	5 N	-33 N	-36 D	-32 N
Salem	21	8	-4 N	2 N	-40 D	0 N
Sivaganga	28	6	11N	22 N	-17 N	-25 N
Thanjavur	21	8	-2 N	-7 N	-39 D	-33 D
Theni	28	6	11N	84 E	-17 N	1 N
Tirunelveli	35	9	5 N	-25 MD	-36 D	-74 S
Thirupur	75	18	163E	-53 D	84 E	-51 N
Tiruvallur	26	9	-6 N	36 E	-49 D	1 N
Tiruvannamalai	24	8	-1 N	15 N	-39 D	6 N
Tiruvarur	21	8	5 N	-29 D	-32 D	-15 N
Trichy	21	8	-2 N	-60 D	-39 D	-30 D
Tuticorin	35	9	5 N	-10 N	-36 D	-99 S
Vellore	24	8	-1 N	0 N	-39 D	-20 N
Villupuram	24	8	-1 N	-8 N	-39 D	-11 N
Virudhunagar	28	6	11 N	-26 MD	-17 N	-59 D
Pondicherry	21	8	5 N	32 E	-32 D	-8 N
% of 'Useful' forecast			66		60	

respect of monthly, bi-monthly periods of monsoon season and for the season for India as a whole and in a large number of subdivisions for the past 23 years and seasonal forecast for cluster of districts/district in Tamilanadu and Pondicherry for the past four years, have shown that SICZ model has produced reasonably good forecasts at all spatial and temporal resolutions. The differences between forecast and realized rainfall were larger than the model error in 1992, 1999, 2001, 2005 and 2012 for some of the forecasts. As mentioned above these were the years of large intra-seasonal changes in summer monsoon circulation system over Indian region. The features in monsoon circulation system which appeared only during the second half of the season were responsible for large difference between forecast and realized rainfall. There was no way to take them into account while formulating the forecast at the end of May. Intra-seasonal changes in these years are discussed below.

LIMITATIONS IN SEASONAL FORECASTING OF RAINFALL IN INDIA

As mentioned above, the difference between some of the forecasts and the realized rainfall was larger than the model error in 5 years during the past 23 years period, 1990-2012, and the years were 1992,1999,2001,2005 and 2012. These were the years of large intra-seasonal changes in ISM. Failures of the models, statistical or dynamical, in foreshadowing the extreme seasons (Flood/Drought) have been often attributed to these intra-seasonal changes. In order to understand the reasons for large difference in forecast and realized rainfall during the years mentioned above, formulation of the forecast using the features in the activity of SICZ during January-May, week-by-week progress of cumulative rainfall for India as a whole and ongoing changes over Equatorial Indo-Pacific region during the season are discussed below in brief.

Monsoon-1992

Week-by-week progress of cumulative rainfall for India as a whole is shown in Fig. 7. Severe drought conditions prevailed over the country during the first half of the season. The weekly rainfall departure was less than 20% below normal till the end of July. Rainfall during the first half of the season was well captured in the real time forecast as well as in the forecast from the improved version of the model (Table 3). However, monsoon trough strengthened, thereafter, which was reflected in the development of low pressure areas in the Bay of Bengal (BoB) and increase in rainfall during the second half of the season (IMD, 1993). Rainfall was 8% below normal at the end of the season. As the discussions below shall show the intra-seasonal changes in Monsoon-1992 were a result of super imposition of the effect of on-going changes in the EPO over the features in the activity of SICZ during the second half of the season.

Zonal cloud cover during the period January-May 1992 (week Nos. 1-22) is shown in Fig. 8. SICZ remained active for 3-4 weeks in continuation during the pre-monsoon months of April and May. Appearance of this feature in the activity of SICZ was a precursor of drought. In addition, an equatorial trough developed to the north of equator during the first week of May, moved northward up to 10° N lat. during the next two weeks and weakened. This was a positive factor in the development of monsoon-1992. Based on these features in the activity of SICZ during pre-monsoon months of April and May, a value of 16 had been assigned to SAI which corresponds to forecast ISMR being 16% below normal with a model error of ± 4% (Table 3). In the improved version of the model, a value of 14 was assigned to SAI (Prasad and Singh, 2012). This was based on the activity of SICZ during the period January-May. The corresponding forecast of ISMR becomes 11% below normal with a model error of ± 5%. The realized rainfall was 8% below normal. Though the realized rainfall was in the range of a weak monsoon (% departure of ISMR between -5 % to -10 %), the summer monsoon-1992 displayed features of a drought (Gadgil, et al., 2007 and others). It may be mentioned here that for categorizing monsoon on the basis of % departure of ISMR from normal (100%), SICZ model uses 5 categories, namely, 'Excess' (% departure of ISMR ≥ 11%), 'Active' (% departure within 5% to 10%), 'Normal'(% departure within 4% to -4%), 'Weak' (% departure between -5% to -10%) and 'Deficient'/'Drought' (% departure ≤ -11%). Both the forecasts, i.e., the real-time one and the one from the improved version of the model, were able to foreshadow the deficiency of rainfall during Monsoon-1992.

The cloud cover data for monsoon season is shown in Fig.8 (week Nos. 23-39). The MCZ associated with the onset phase of monsoon could reach up to 20°N lat. by the week No. 27, i.e. in the first week of July. Thereafter SICZ developed for 3 weeks in continuation. SICZ remained

Table 3. Forecast of ISMR during years of large intra-seasonal changes

Year	SAI and Forecast ISMR (% departure from normal)				ISMR (% departure from normal)
	with initially proposed SICZ model (ISMR=-2.3*SAI+120.5) (Model Error = ± 4 %)		with improved version of the model (ISMR= -2.4*SAI+122.3) (Model Error = ± 5 %)		
	SAI	Forecast	SAI	Forecast	
1992	16	-16	14	-11	-8
1999	5	9	5	10	-4
2001	4	11	13	-9	-9
2005	16	-16	13	-9	-1
2012	-	-	18	-20	-8

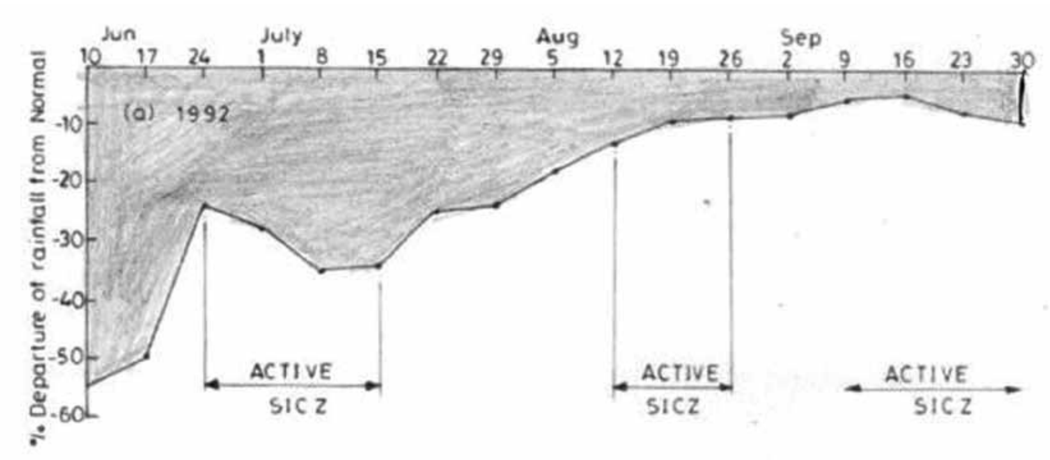

Figure 7. Week-by-week progress of cumulative rainfall for India as a whole during Monsoon-1992

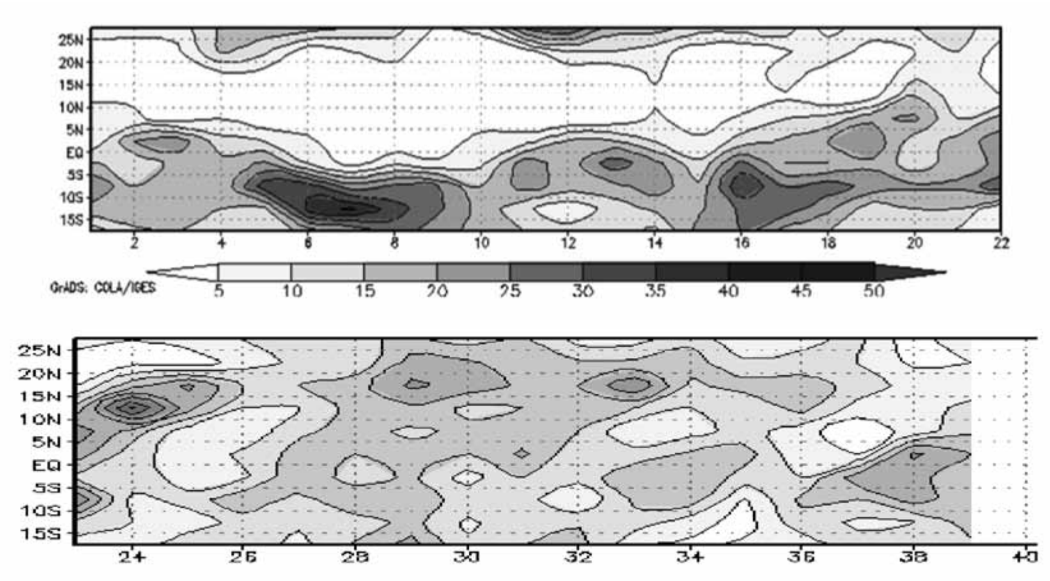

Figure 8. Zonal (40°-100°E) mean cloud cover (%) during January-May (Week Nos. 1-22) and June-September (week Nos. 23-39) -1992

weak/undeveloped during the next 4 weeks. This period saw improvement in the rainfall scenario and the deficiency in rainfall reduced from -20 % at the end of July to -8% by the week ending on 30th September (Fig. 7). The characteristic feature noted in the activity of SICZ during the period January-May, i.e., development of an active spell of SICZ for 3-4 weeks in continuation, continued up to August 1992. Thereafter there was a change in the feature of the activity of SICZ and the next active spell which developed during the week No. 33 could last for 2 weeks only. The next spell of active SICZ started developing in week No. 37, i.e. during the second week of September and continued up to the end of the month.

El Nino of 1991-92 which had been at its peak during December 1991-January-February 1992 (DJF 1991/1992) in Nino 3.4 region (Table 4) started weakening thereafter and ENSO-neutral conditions prevailed from the 3-months period of JAS till the end of the year. An examination of monthly SST anomalies from Nino 3.4 region (Table 5) and other Nino regions (Table 6) show that SST anomalies had already become negative (- 0.17) in Nino 1+2 in July itself and anomalies were 0.41, 0.54 and 0.10 in Nino 3, Nino 3.4 and Nino 4 region respectively. Anomalies further reduced in August and became -0.20, 0.15, 0.42 and -0.05 in Nino 1+2, Nino 3, Nino 3+4 and Nino 4 respectively. The intra-seasonal changes in the activity of SICZ and improvement in the rainfall scenario over India also began in August. Thus it appears that by August-1992, the ongoing changes in EPO, i.e., demise of El Nino and development of ENSO- neutral resulted in lowering down of SST anomalies over Equatorial Indian Ocean (EIO), more particularly over South East Indian Ocean (SEIO).

Table 4. 3-months running mean SST anomalies (°C) in Nino 3.4 region during the years of large intra-seasonal changes in Indian summer monsoon and one year before

Year	ISMR	3-months running mean SST anomalies (°C) in Nino 3.4 region											
		DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1991	-9	0.4	0.3	0.3	0.4	**0.6**	**0.8**	**1.0**	**0.9**	**0.9**	**1.0**	**1.4**	**1.6**
1992*	-8	**1.8**	**1.6**	**1.5**	**1.4**	**1.2**	**0.8**	**0.5**	0.2	0.0	-0.1	0.0	0.2
1998	4	**2.3**	**1.9**	**1.5**	**1.0**	**0.5**	0.0	**-0.5**	**-0.8**	**-1.0**	**-1.1**	**-1.3**	**-1.4**
1999*	-4	**-1.4**	**-1.2**	**-0.9**	**-0.8**	**-0.8**	**-0.8**	**-0.9**	**-0.9**	**-1.0**	**-1.1**	**1.3**	**1.4**
2000	-8	**-1.6**	**-1.4**	**-1.0**	**-0.8**	**-0.6**	**-0.5**	-0.4	-0.4	-0.4	**-0.5**	**-0.6**	**-0.7**
2001*	-8	**-0.6**	**-0.5**	-0.4	-0.2	-0.1	0.1	0.2	0.2	0.1	0.0	-0.1	-0.1
2004	-14	0.4	0.3	0.2	0.2	0.3	**0.5**	**0.7**	**0.8**	**0.9**	**0.8**	**0.8**	**0.8**
2005*	-1	**0.7**	**0.5**	0.4	0.4	0.4	0.4	0.4	0.3	-0.2	-0.1	-0.4	-0.7
2011	2	**-1.4**	**-1.3**	**-1.0**	**-0.7**	-0.4	-0.2	-0.2	-0.3	**-0.6**	**-0.8**	**-1.0**	**-1.0**
2012*	-8	**-0.9**	**-0.7**	**-0.5**	-0.3	-0.1	-0.1	0.0	0.3	0.4	0.6	0.4	-0.3

* Year of large intra-seasonal changes in Indian summer monsoon. Bold figures (+/-) pertain to El Nino/La Nina conditions.

Table 5. Monthly SST anomalies (°C) in Nino 3.4 region during the years of large intra-seasonal changes in Indian summer monsoon

Year	ISMR (%)	Monthly SST anomalies (°C) in Nino 3.4 region											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1992	-8	**0.87**	**0.92**	**0.86**	**0.75**	**0.71**	**0.59**	**0.54**	0.42	0.30	0.17	0.22	0.47
1999	-4	**-1.25**	**-1.16**	**-1.02**	**-0.74**	**-0.53**	**-0.62**	**-0.70**	**-0.72**	**-0.55**	**-0.56**	**-0.90**	**-1.03**
2001	-8	-0.65	-0.68	-0.47	-0.23	-0.02	0.24	0.51	0.47	0.59	0.57	0.48	0.41
2005	-1	**1.08**	**0.84**	**0.73**	**0.64**	**0.58**	**0.54**	0.35	0.29	0.34	0.36	0.22	0.03
2012	-8	**-1.11**	**-1.21**	**-0.66**	-0.39	-0.05	-0.11	0.55	0.73	0.51	0.29	0.36	0.25

Table 6. Monthly SST anomalies in Nino regions other than Nino 3.4 during 1992

Month	Nino 4	Nino 3	Nino 1+2
January	1.31	1.75	0.44
February	1.18	1.63	0.73
March	1.07	1.39	1.33
April	1.34	1.36	1.92
May	1.32	1.19	1.93
June	0.77	0.79	0.71
July	0.10	0.41	-0.17
August	-0.05	0.15	0.20
September	-0.12	-0.09	0.01
October	-0.39	0.30	0.01
November	-0.35	-0.06	0.05
December	-0.30	0.10	-0.13

This appears to have led to weakening of SICZ and in turn strengthening of monsoon trough as per the inverse relationship between the two troughs. As, SST anomalies charts were not available for the year 1992, physical propagation of negative SST anomalies from EWPO to SEIO could not be shown here. During this active phase of monsoon, as many as 5 low pressure areas developed over the BoB during the period beginning from the second half of August till the end of September. They all moved northwestward. In addition, one low pressure area also developed over land, in Rajasthan, and moved westward (IMD, 1993). It may be concluded here that the intra-

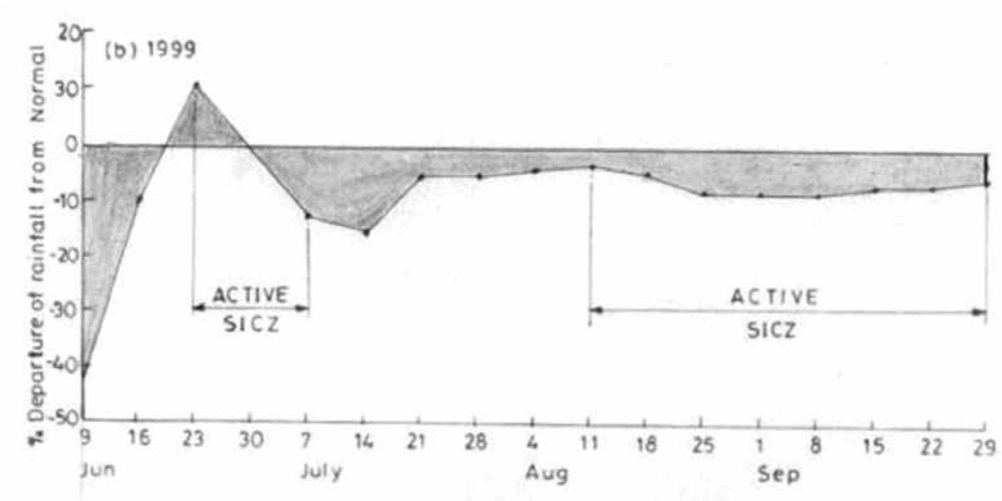

Figure 9. Week-by-week progress of cumulative rainfall for India as a whole during Monsoon-1999

seasonal changes in Monsoon-1992 were a result of super imposition of the effect of on-going changes in EPO over the features in the activity of SICZ during the second half of the season.

Monsoon-1999

Week-by-week progress of cumulative rainfall is shown in Fig. 9. On 23 June rainfall was 10% above normal. Rainfall decreased sharply thereafter and it was -16% at the week ending on 14 July. Though there was an improvement in rainfall from the second half of July till the second half of August, rainfall remained below normal till the end of the season and it was 5% below normal at the end of the season. The case of 1999 is an excellent example of the linkage between the ongoing changes in SST anomaly field over EPO and EIO, activity of SICZ and rainfall distribution over India. The on-going changes in EPO acted as a trigger for intra-seasonal changes over EIO during the second half of the season, i.e., increase in positive SST anomalies, development of spells of active SICZ, weakening of monsoon circulation and thereby reduction in rainfall over Indian subcontinent. Formulation of LRF, real time as well as the one with the improved version of the model and ongoing changes in Equatorial Indo-Pacific region during the season are discussed below.

Weekly mean cloudiness during the period January-May 1999 (week Nos. 1-22) are shown in Fig. 10. A prominent spell of MCZ developed to the north of equator during April and another one in May. May spell reached up to 20°N lat. by the end of the month. These features in the activity of SICZ were precursors of an active monsoon. A value of 5 had been assigned to SAI with forecast ISMR being 9% above normal (Table 3). In the improved version of the model also a value of 5 only could be assigned to SAI which was based on the activity of SICZ during the period January-May 1999 (Prasad and Singh, 2012). The corresponding forecast of ISMR becomes 10% above normal with a model error of ± 5%. In both the forecasts Monsoon-1999 was expected to be an 'Active' one. However, Monsoon-1999 turned out to be a weak monsoon with the realized rainfall being 8% below normal.

The activity of SICZ during the season (week No. 23-39) are shown in Fig. 10. The MCZ associated with the onset phase of monsoon could reach up to 30°N lat. by the end of June. SICZ developed close to equator for two weeks in continuation, during the last week of June and the first week of July. The next spell of active SICZ developed for four weeks in continuation from the week No. 33, i.e., in the second week of August. With slight weakening in between yet another spell of active SICZ developed for another 4 weeks in continuation lasting up to the last week of September. Thus SICZ remained active from middle of August till the end of Monsoon-1999. SICZ remaining active for 4 weeks in continuation during August-September was a new feature in the activity of SICZ which was absent during the period January-May 1999. This feature, if it were present during the period January-May, would have been taken as a precursor of drought/weak monsoon.

In the EPO La Nina conditions which began during June-July-August (JJA) 1998 (Table 4) showed slight weakening in May-1999 and strengthened during JJA-1999 (Table 5). It weakened slightly in September-October and again strengthened during November-December 1999. SST anomaly field over equatorial strip during the period June-September 1999 are shown in Fig. 11(a)-(d). During the month of June both positive as well as negative anomalies were not significant from Nino 1+2 region up to the east coast of Africa. Negative anomalies over all the 4 Nino regions and positive anomalies from date line to the east coast of Africa occupied the anomaly chart for the month of July. Signature of warming of EIO was seen in

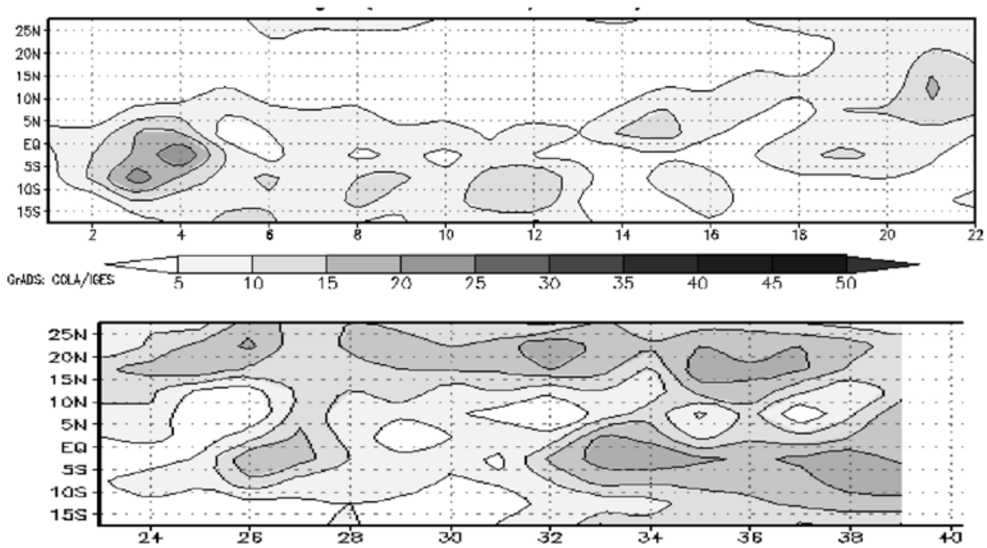

Figure 10. Zonal average (40°-100°E) of weekly cloud cover (%) during January-May (Week Nos. 1-22) and June-September (Week Nos. 23-39) - 1999

the development of SICZ for 2 weeks in July. There was an increase in the intensity of negative anomalies over the EPO and positive anomalies over EIO during August-September. Development of 2 spells of active SICZ for 4 weeks, in continuation, during this period coincides with the increase in the positive SST anomalies over EIO. The on-going changes in EPO appear to had acted as a trigger for increase in positive SST anomalies, development of spells of active SICZ and thereby weakening of monsoon circulation. This in turn led to reduction in rainfall over India. This situation is very similar to the on-going changes in EPO and EIO during June-July 2010 also (Prasad and Singh, 2013b).

Monsoon-2001

Week-by-week progress of cumulative rainfall for India as a whole is shown in Fig. 12. Rainfall departures were on the positive side during the first half of the season. On 1 August rainfall was 5% above normal. Thereafter the rainfall for India as a whole started decreasing and it was 9% below normal at the end of the season. As discussed below, the difference between the forecast and realized ISMR (Table 3) was large for the real time assigned value of SAI (=4) which was based on the cloud data for the pre-monsoon months of April and May only. The difference got reduced with the re-assigned value of SAI (=13), in the improved version of the model (Prasad and Singh, 2012). Re-assigned value of SAI was based on the cloud data for the period January-May 2001. Thus considering data for the entire period of January-May is essential for arriving at appropriate value of SAI. Formulation of LRFs, real time and the one with the improved version of the model and aspects related to intra-seasonal changes during Monsoon-2001 are discussed below.

Fig.13 gives zonal weekly mean cloudiness during January-May 2001. A prominent MCZ developed in the zone of SICZ in April as well as in May. May spell moved northward and reached up to 20°N lat. by the end of May. These features were indicative of an active monsoon. Based on these features in cloud data, a value of 4 had been assigned to SAI with corresponding ISMR being 11 % above normal (Table 3). As seen in the mean cloudiness for the period January-May, SICZ remained generally active during the period January-March. SICZ remained active for 3 weeks in continuation during April-May and the MCZ associated with this spell moved both to the south and north of equator. This feature was seen prominently in cloud anomaly field (not shown here). These features were pre-cursors of a moderate drought (Prasad and Singh, 2012). Accordingly, a value of 13 was assigned to SAI. The corresponding forecast of ISMR was 9% below normal with a model error of ± 5%. In other words the reworked out forecast was for a weak monsoon/moderate drought. Thus using cloud and cloud anomaly data for the period January-May is essential for arriving at the appropriate SICZ Activity Index.

The activity of SICZ during the season could be seen in cloudiness for the weeks 23-39 (Fig. 13). The MCZ associated with the onset phase of monsoon moved up to the latitude belt 20° N-25° N by week No. 26, i.e., in the fourth week of June. SICZ remained weak during the next 4 weeks. Thus SICZ displayed features of a normal monsoon in the first half of the season. Thereafter SICZ developed for 3 weeks (Week Nos. 30-33) in continuation and remained generally active till the end of the season.

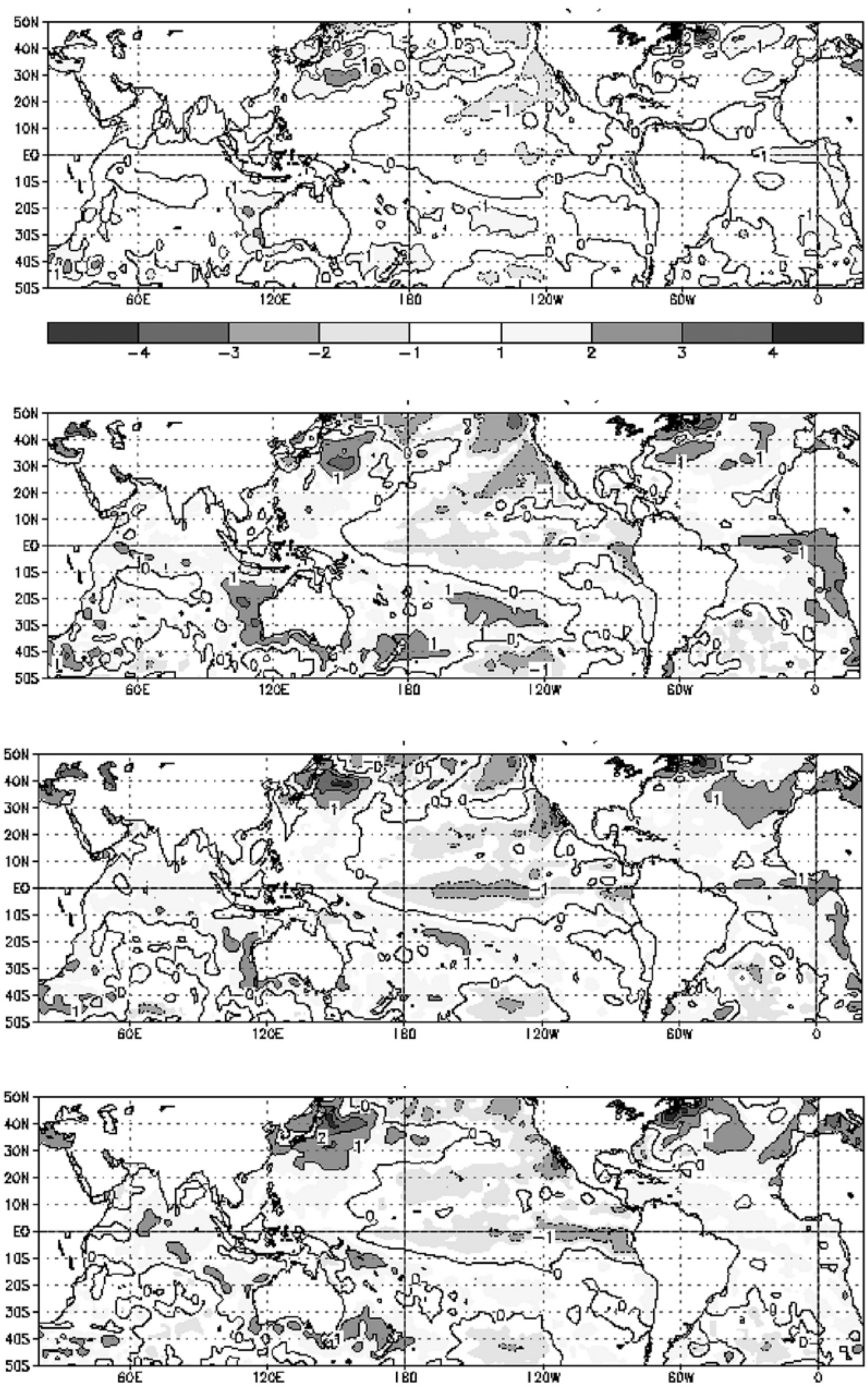

Figure 11(a-d). Sea surface temperature anomaly field during (a) June, (b) July, (c) August and (d) September- 1999

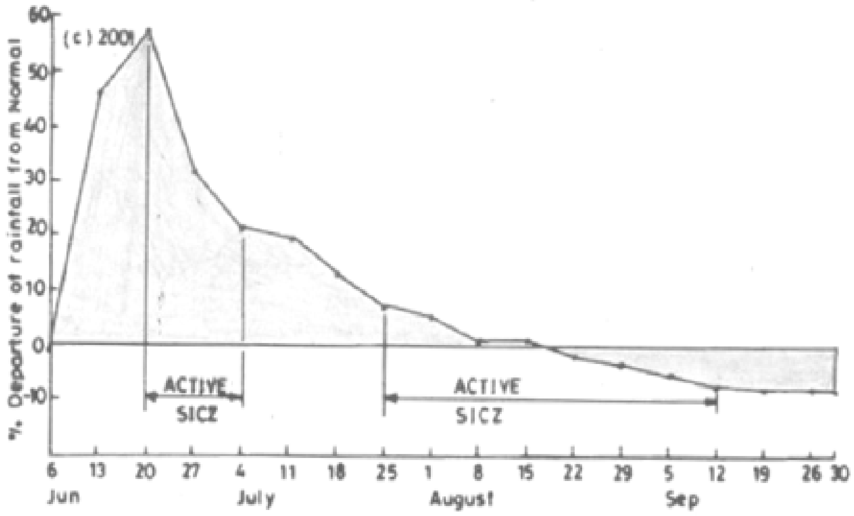

Figure 12. Week-by-week progress of cumulative rainfall for India as a whole during Monsoon-2001

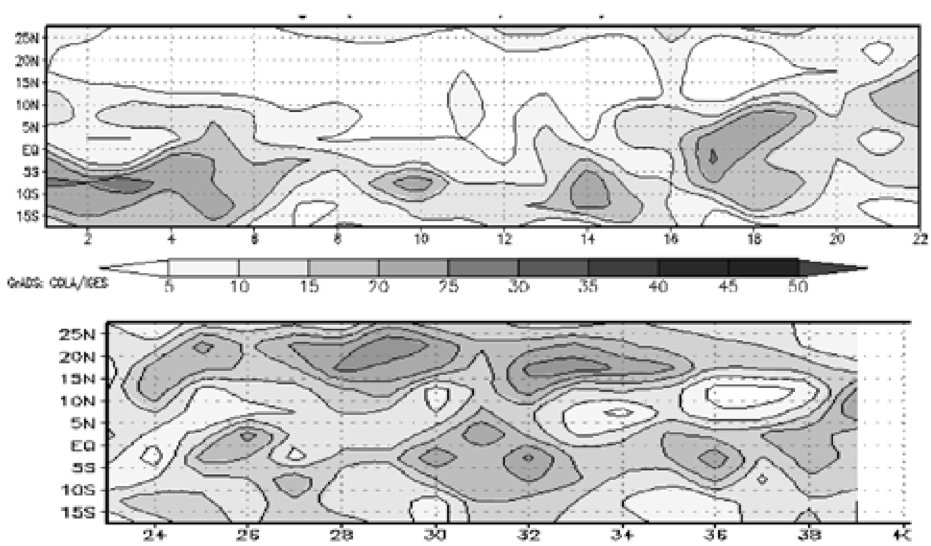

Figure 13. Zonal average (40°-100°E) of weekly cloud cover (%) during January-May (Week Nos. 1-22) and June-September (Week Nos. 23-39) - 2001

This feature in the activity of SICZ is found to related to a drought. The features in the activity of SICZ during the period January-May related to development of a moderate drought did not repeat during the first half of the season but they did appear during the second half.

SST anomaly field over equatorial strip during June-September 2001 are given in Fig. 14 (a)-(d) In EPO moderate La Nina developed during September-November-2000 and subsided during January-March-2001. ENSO-neutral conditions prevailed thereafter from May till the end of the season. In IO, SST anomalies were mainly positive and of the order of +0.5°C to +2.0°C in June. The higher values were in pockets near equator and west of 80°E in SIO south of 20°S. Positive anomalies reduced considerably in July in WIO being of the order of -0.5°C to -1.0°C. However, SST anomalies remained positive and of the order of +0.5° to +2.0°C over SEIO. There was not much change in SST anomaly pattern in SIO east of 80°E from July to August. It appears that the development of active spells of SICZ during the second half of the season was in response to positive SST anomalies which prevailed in SEIO. Thereafter there was, an in general, reduction in positive SST anomalies over IO in September. There were no indications of propagation of positive SST anomalies from EWPO to SEIO during the second half of Monsoon-2001. It could be concluded here

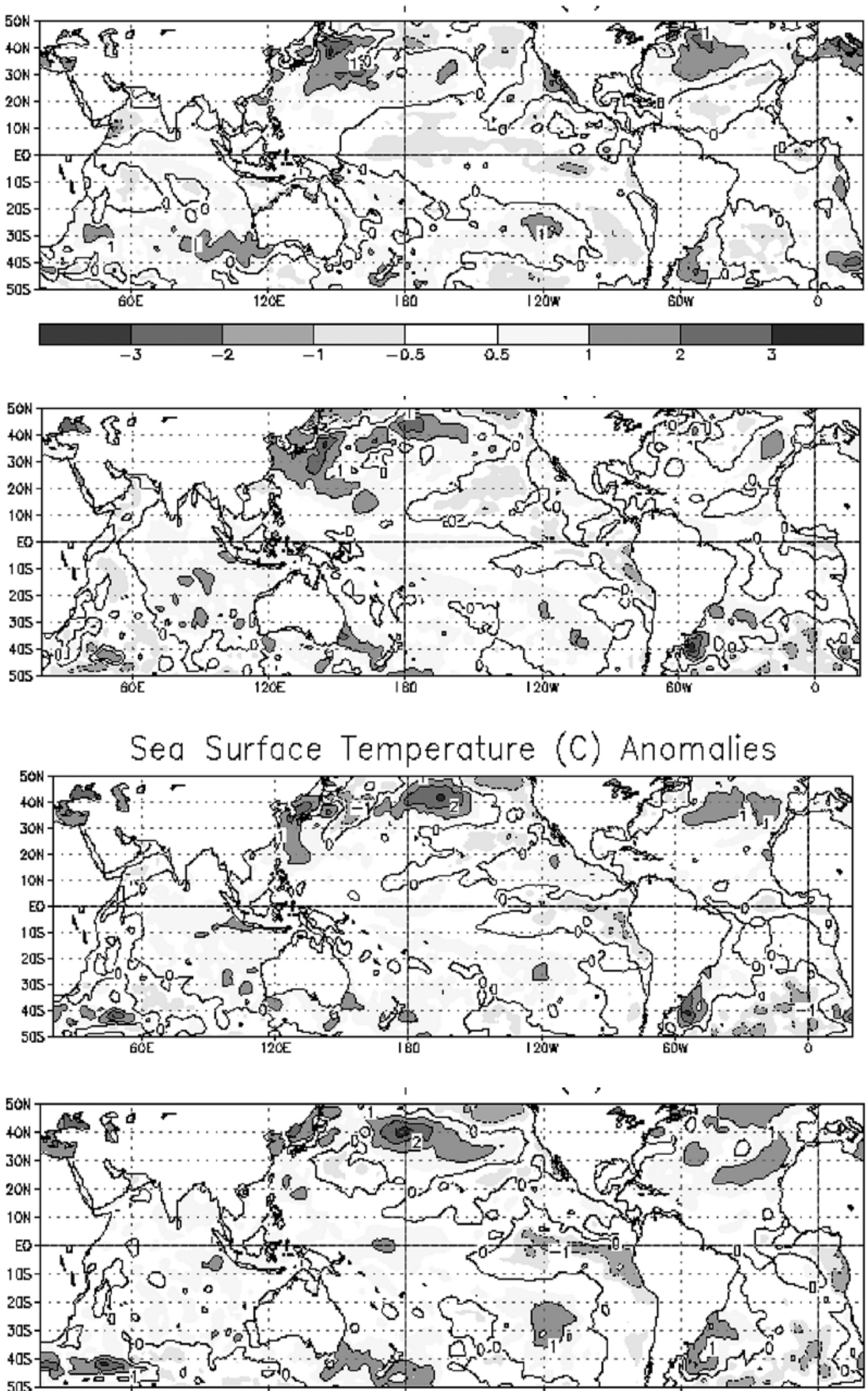

Figure 14(a-d). Sea surface temperature anomaly field during (a) June, (b) July, (c) August and (d) September- 2001

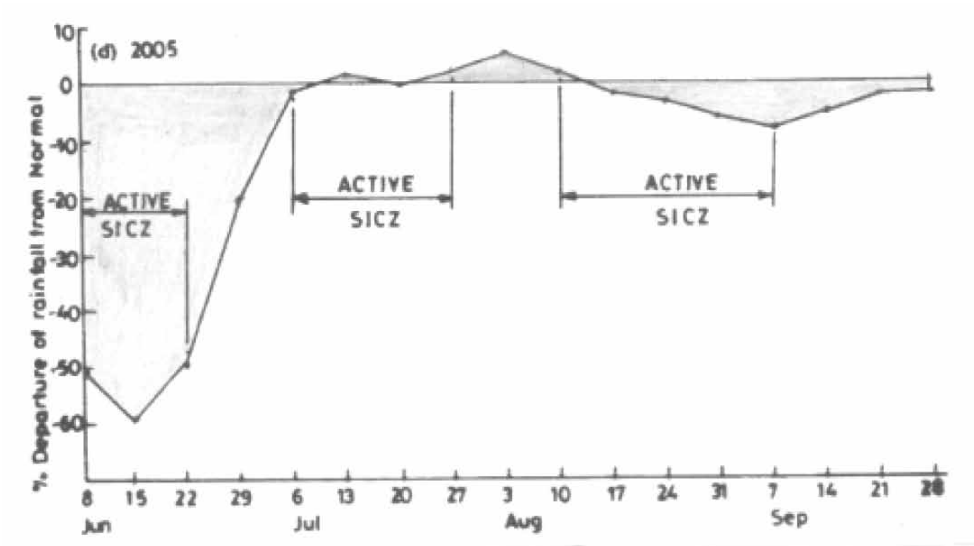

Figure 15. Week-by-week progress of cumulative rainfall for India as a whole during Monsoon-2005

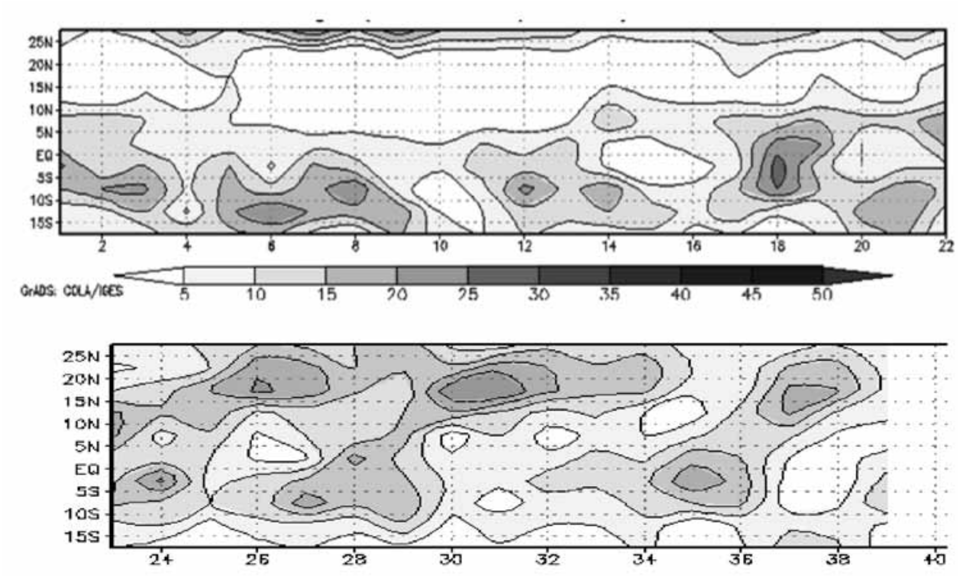

Figure 16. Zonal average (40°-100°E) of weekly cloud cover (%) during January-May (Week Nos. 1-22) and June-September (Week Nos. 23-39) - 2005

that the occurrence of spells of active SICZ during the second half of Monsoon-2001 were perhaps due to, in-situ, development of positive SST anomalies in SEIO.

Monsoon-2005

Week-by-week progress of cumulative rainfall for India as a whole is shown in Fig. 15. Based on the activity of SICZ during the period April-May the real time forecast for Monsoon-2005 was 16% below normal and that as per the improved version of the model it was 9% below normal (Table 3). However, the realized rainfall was only 1% below normal. Interesting aspect of Monsoon-2005 was that the precursors of a moderate drought/weak monsoon continued throughout the season. Also the cumulative rainfall was 8% below normal till the week ending on 7 September. However, the rainfall which occurred during the next two weeks of September in association of the Bay of Bengal cyclonic storm of 17-21 September 2005 was able to reduce the deficiency from 8% below normal to 1% below normal. Assigning of SAI and intra-seasonal changes during Monsoon-2005 are discussed below.

Zonal cloud cover during the period January-May 2005 is shown in Fig.16. As mentioned earlier, the real time forecasts for the period 1990-2008 had been formulated using cloud cover data for the pre-monsoon months of April and May only. In the improved version of the model, SAI is assigned using cloud and cloud anomaly data for the period January-May. During 2005, SICZ developed in the week No. 14, i.e., during the first week of April. The next spell of active SICZ developed during the last week of April-first week of May. This spell moved up to 10° deg. N lat. till the last week of May. Its northward movement was rather slow, i.e., 10° deg. lat. in 5 weeks as against normal northward movement of about 1° deg. lat./per day. While the MCZ associated with the second spell was still in the latitude belt between 5° -10°N, third spell of active SICZ developed during the week No. 21, i.e., in the third week of May in the lat. belt 10°-15°S, i.e., south of the zone of development of SICZ during April-May (Equ-10°S). This spell of SICZ remained active for 3 weeks in continuation. These features in the development of SICZ during pre-monsoon months of April-May were indicative of development of a drought. Accordingly a value of 16 had been assigned to SAI. The corresponding forecast of ISMR was 16% below normal with an error of ± 4%. Three spells of active SICZ are seen in the cloud data for the period January-March, and each spell lasted for 3-4 weeks. Thus a drought signal in the activity of SICZ, i.e., SICZ developing for 3-4 weeks in continuation, was present from January-2005 onwards. However, each active spell of SICZ was followed by a weak spell of SICZ. Development of a weak spell of SICZ in between active spells was a positive factor in the development of Monsoon-2005. Because of the presence of the second factor, a value of 13 only could be assigned to SAI (Table 3). The corresponding forecast of ISMR was a moderate drought/weak monsoon with forecast rainfall expected to be 9 % below normal with an error of ± 5%.

Rainfall during the first half of Monsoon-2005 was well captured by the forecast as rainfall was 8 % below normal till the week ending on 7 September (Fig.15). The rainfall which occurred during the next two weeks, i.e., during the week ending on 14 and 21 September, changed the rainfall scenario. This rain occurred due to the strengthening of monsoon circulation leading to development of the Bay of Bengal cyclonic storm of 17-21 September 2005 (IMD,2006). It initially moved across central India and then re-curved to north giving heavy rainfall in a number of subdivisions where rainfall was deficient. Rainfall during these two weeks was able to make up much of the deficiency in rainfall. Month-wise % departure of rainfall and number of subdivisions in different category of % departure of rainfall are given in Table 7. June rainfall was deficient in 16 subdivisions and out of 14 subdivisions which received normal rainfall, deficiency was ≤ -10% in 4 of them. There was significant improvement in rainfall during July. August witnessed drastic reduction in rainfall when as many as 22 subdivisions received deficient rainfall and in 5 subdivisions where rainfall was in normal category, rainfall was ≤ -10%. An examination of monthly rainfall during drought years beginning from the year 1901 has shown that improvement/deterioration in rainfall in alternate months was present in 60 % of the drought years. This feature was present during 2005 also. It is of particular interest to note that the precursors of drought/weak monsoon as seen in the activity of SICZ during January-May, continued during June-September also, Even then Monsoon-2005 terminated as a normal monsoon with ISMR being only 1% below normal. As mentioned above, this situation resulted mainly because of rainfall in September which occurred in association of a cyclonic storm. How the superimposition of the effect of ongoing changes in EPO over EIO resulted in significant improvement in rainfall during September-2005 are discussed below.

Monthly SST anomalies in Nino regions during the year 2005 are given in Table 8. El Nino of 2004 had started weakening in 2005. It may be noted that the cooling trend in SST anomalies had set in Nino 1+2 region in June which intensified during the following months. The cooling trend was also seen in Nino 3 and Nino 4 regions. Rapid cooling in Nino 4 from August to September affected areas of EWPO to the west of the western boundary of Nino 4 and further west up to EIO. These changes could be seen in monthly SST anomaly field (Figs. 17(c)-(d)). There was no change in the characteristic feature in the activity of SICZ, i.e., SICZ developing for 3-4 weeks in continuation continued up to the second half of Monsoon-2005. The last spell of active SICZ which developed during August, weakened by 7 September and the associated MCZ had moved northward up to 10°N. It further moved northward up to 20°N lat. during the next 2 weeks. The Bay of Bengal cyclone of 17-21 September 2005 developed during this period. A comparison of cloud amounts from the second half of April till the third week of July (Week No. 16 -30) with that during the rest of the weeks of the season, i.e., from week No. 30 to 39 (Fig.16) shows that there was a general reduction in cloudiness in the zone of SICZ (Equ.- 10°S) during the latter period. It appears that the strengthening of Indian summer monsoon during September-2005 might have been caused by the on-going changes in Equatorial Indo-Pacific region related to demise of El Nino of the year-2004 and setting in of ENSO- neutral conditions. In more or less similar situation the influence of on-going changes related to demise of El Nino of the year-2009 and setting in of ENSO- neutral conditions in EPO on the changes over SEIO leading to development of active spells of SICZ and reduction in rainfall over India during June-July 2010 had been discussed earlier by Prasad and Singh 2013b.

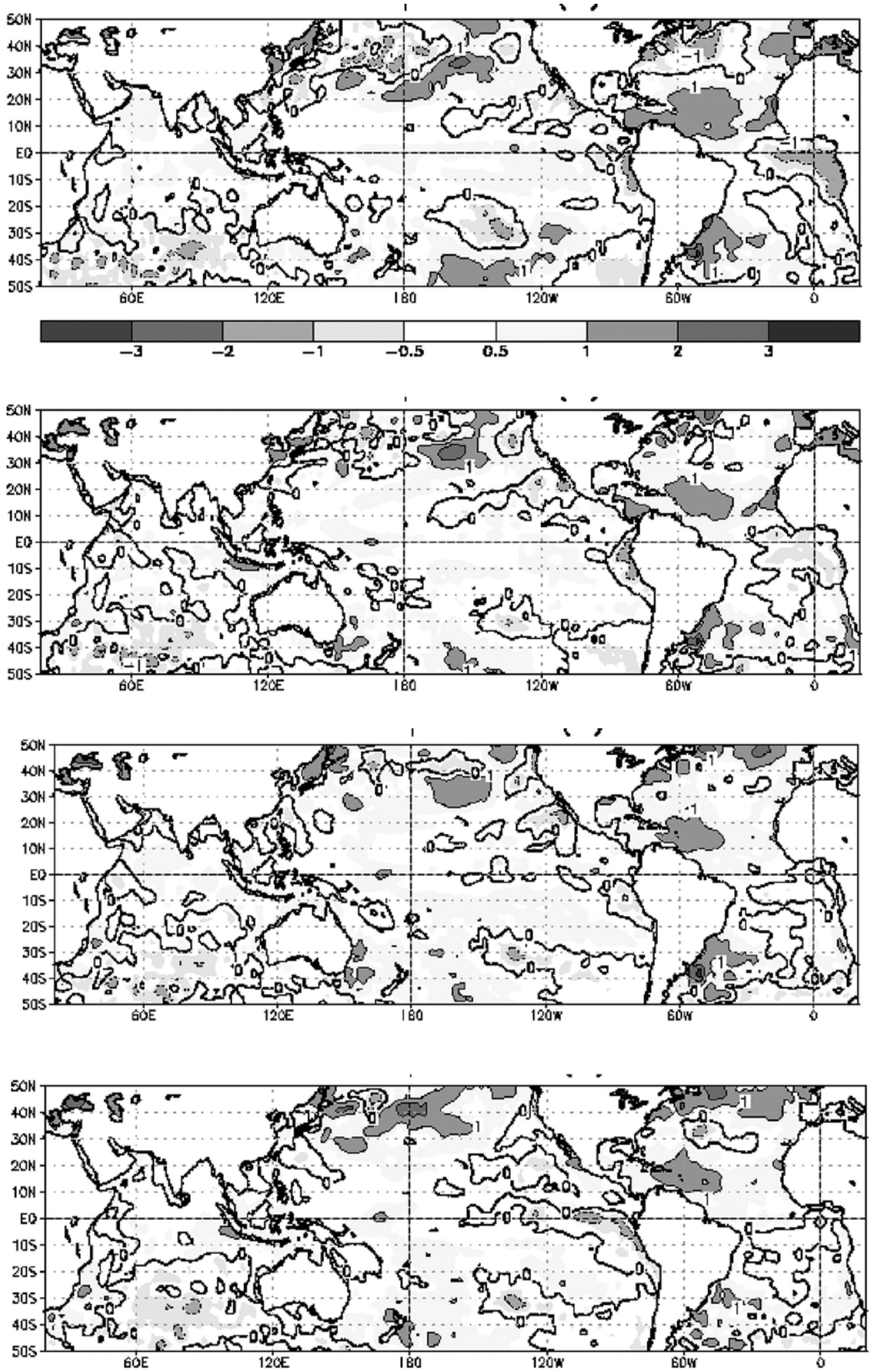

Figure 17(a-d). Sea surface temperature anomaly field during (a) June, (b) July, (c) August and (d) September- 2005

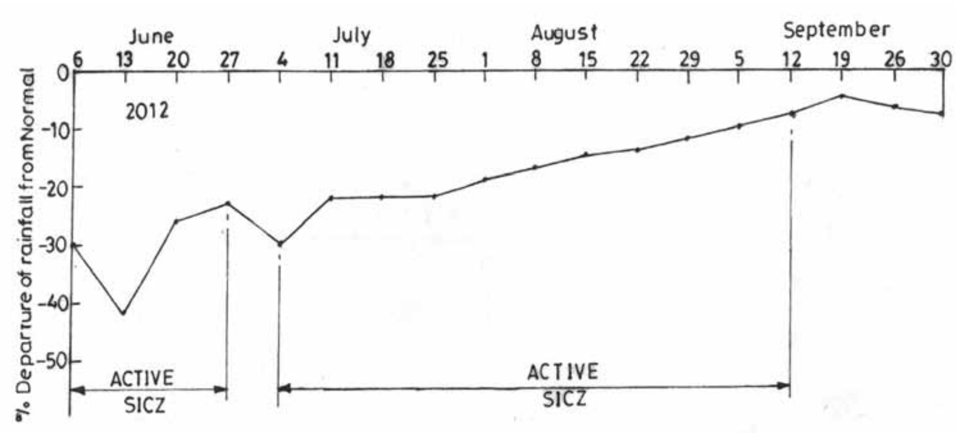

Figure 18. Week-by-week progress of cumulative rainfall for India as a whole during Monsoon-2012

Monsoon-2012

Week-by-week progress of cumulative rainfall during Monsoon-2012 is shown in Fig. 18. Monsoon-2012 displayed features of a severe all India drought during June and July. Rainfall for India as a whole was 28% below normal in June (Table 1). No low pressure area formed during June and such a situation had not occurred during the past 31 years' period of 1981-2011 (IMD, 2012). The severity of drought was such that 27 sub-divisions out of 36 received deficient/scanty rainfall. July rainfall, for country as a whole , was 13% below normal. 13 subdivisions recorded deficient/scanty rainfall. Monsoon Trough (MT) strengthened beginning from August and this situation continued up to the middle of September. During the month of August, as many as 5 low pressure areas developed in succession. Formulation of LRF of Monsoon-2012 and possible reasons for large intra-seasonal changes during the season are discussed below in detail. The reason for including detailed discussions on the developments that took place during Monsoon-2012 is that they were rare and had not taken place during the past 30 years period for which cloud data were available with the authors.

Zonal cloud cover during the period January-September 2012 is shown in Fig. 19. SICZ remained generally active from the beginning of January till the end of April-2012 with 3 active spells, each spell lasting for 4 weeks in continuation. The MCZ associated with the second and the third spells of active SICZ gradually moved southward. In April the MCZ had moved up to the latitude belt of 15°-20°S. This was an unusual development in the activity of SICZ. Generally, the MCZ does not move south of 15°S during pre-monsoon months of April and May. Its normal location during pre-monsoon months of April and May is between 5° and 10°S. These two features, i.e., SICZ remaining active for 4 weeks in continuation and the MCZ moving southward suggested development of a severe all India drought during June-September. In addition a weak equatorial trough developed to the north of equator in the week Nos. 7, 16 and 17. This was a positive factor in the development of Monsoon-2012. Based on these features, a value of 18 had been assigned to SAI which corresponds to forecast ISMR being 20% below normal with a model error of ± 5% (Table 3). Monthly, bi-monthly and seasonal forecasts and realized rainfall, for India as a whole, have been included in Table 1.

Zonal cloud cover during Monsoon-2012 are shown in Fig. 19 (week Nos. 23-39). Three spells of active SICZ developed during June-September. The first one was the continuation of the May spell which moved southward up to 20°S by the last week of June. The second spell developed during the first week of July, moved southward and remained active in the lat. belt 15° -20°S for four weeks in continuation (week Nos. 30-33), i.e., from the last week of July till the middle of August. The third spell developed close to equator (Equator-5°S) during week No. 34, i.e., during the beginning of the second half of August. It also remained active for the next four weeks. The MCZ associated with this active spell of SICZ moved progressively northward up to 30°N. However, SICZ did not show any weakening during the first 3 weeks. Thus the characteristic features noted in the activity of SICZ during the period January-May, i.e., (i) development of an active spell of SICZ for 4 weeks in continuation and (ii) MCZ moving southward were present during monsoon months also. To the north of equator, the MCZ associated with the onset was very weak and its northward movement was rather slow. It could reach up to 20°N by week No. 27, i.e. in the first week of July. It could reach up to 30°N during week No. 29, i.e., by the middle of July only. Rainfall was deficient by 28% in June and by 13% in July. Rainfall improved thereafter and it was 8% below normal at the end of the season. The on-going changes in Equatorial Indo-Pacific region are discussed below.

La Nina of the year 2011 continued up to FMA of 2012 (Table 4). SST anomalies which were slowly

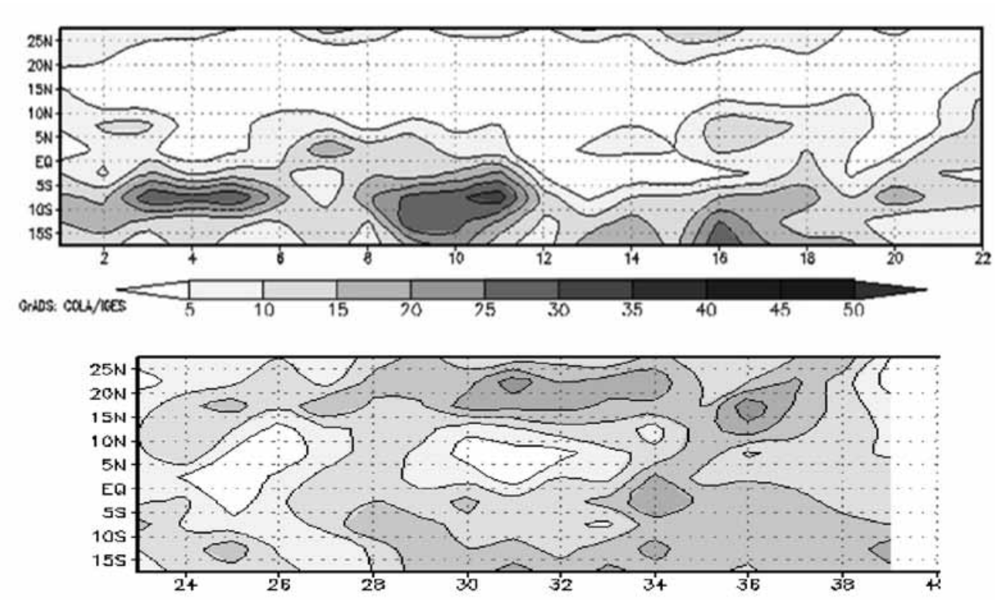

Figure 19. Zonal average (40°-100°E) of weekly cloud cover (%) during January-May (Week Nos. 1-22) and June-September (Week Nos. 23-39) - 2012

increasing from the beginning of the year became zero during 3-months period of JJA, 0.3 during JAS, 0.4 during ASO and 0.6 during SON. It is interesting to compare the ongoing changes in EPO and IO during 1992 and 2012 as both the monsoons were very similar in rainfall distribution over India from June to September: In both the years, severe rainfall deficiency had occurred during June and July, rainfall improved during the second half and the seasonal rainfall was 8% below normal. EL Nino conditions prevailed over Nino 3.4 region from the beginning of 1992 till 3-monthly period of JJA (Table 4) and ENSO neutral conditioned prevailed thereafter till the end of the year with SST anomalies remaining close to zero. Thus the on-going changes in Nino 3.4 region in 2012 were nearly opposite to that in 1992. An examination of monthly SST anomalies in other Nino regions (Tables 9) shows that there was no propagation of negative SST anomalies from EWPO to SEIO during the second half of monsoon-2012. Improvement in rainfall during the second half of 1992 was associated with westward propagation of negative SST anomalies from EWPO to SEIO. This factor was absent during Monsoon-2012. Thus the improvement in rainfall during the second half of Monsoon-2012 could not be attributed to on-going changes over EPO.

As mentioned above, the characteristic feature noted in the activity of SICZ during the period January-May were present during monsoon months also. As per inverse relationship between SICZ and MT, improvement in rainfall was not expected during the second half of Monsoon-2012 also as SICZ remained generally active during that period (Fig.19). In other words the inverse relationship between SICZ and MT was nearly ineffective during the second half of Monsoon-2012.The unusual feature seen over the Indian Ocean during this period was the location of active SICZ in the latitude belt 15°-20°S. This period of extreme southern location of an active spell of SICZ coincides with strengthening of MT. It appears that an active SICZ in its farthest most southern location (15°-20°S) was unable to weaken the MT, which it normally does while active in its usual location during the season, i.e., close to equator (Equ-5°S). Mean cloudiness for the period, 1972-2011 (except 17th March- 31 May 1978) has shown that SICZ is active between 5°-15°S during January-March and between 5°-10°S during April-May. Similarly, mean cloudiness for the past 30 years period, 1982-2011, have shown that SICZ, though generally weak, lies between Equ-5°S during June-September. This is in agreement with the observations of De and Mukhopadhyay 2002 who studied 'breaks' in monsoon and their related precursors. They found that major epochs of 'break' in Indian monsoon coincide with active Southern Hemispheric Equatorial Trough epochs and negative OLR anomaly which corresponds to the area of convective activity are seen around the equatorial regions of Indian ocean. They considered 11 'breaks' between 1987 and 1996 and the total 'break' days were 45. In their composite latitudinal time section of OLR anomalies, the maximum negative OLR anomaly (20 W/M2) was found to be located around 2.5°S lat.. Thus SICZ moving to the latitudinal belt of 15°-20°S and remaining active there for several weeks in continuation during the second half of Monsoon-2012 was an unusual development. We may, therefore, conclude that MT strengthened during the second half of Monsoon-2012 (as many as 5 low pressure areas developed over the Bay of Bengal in succession and moved northwestward during August-2012) not because of a strong south-to-north surge but mainly because of the extreme southern location of SICZ. It may be mentioned here that this feature in the activity of SICZ was present during the pre-monsoon months of April and May (Fig. 19, week Nos. 1-22) also when the MCZ associated with an active SICZ had moved to the latitude belt 15°-20°S during April. However, this feature could not be taken into account while formulating the forecast, at the end of May 2012, mainly because it was not known that such a situation may repeat during monsoon months also when the long period mean location of SICZ moves close to equator. Secondly there was no previous example of SICZ moving to that farthest location and remaining active there for several weeks in continuation in the cloud data for the past 30 years' period (1982-2011) available with the authors. As to what caused the monsoon trough to become active during the second half is discussed below.

An examination of cloud data for the period January-May-2012 (week Nos. 1-22, Fig. 19) shall show that the MCZ associated with an active spell of SICZ which developed during week No.21 moved both to the north and south of equator during subsequent weeks. This feature repeated during monsoon months also (week Nos. 23-39). The next such spell developed in week No.27, i.e., during the week ending on 4 July. Cloud as well as cloud anomaly (not shown here) data suggest propagation of a weak MCZ from the zone of SICZ to Monsoon Trough zone during the week ending on 11 and 18 July. Though weak, this appears to have worked as a trigger to activate the MT. During the same period a MCZ, relatively more active, moved from the zone of SICZ (Equ.-5°S) towards southward. Weekly rainfall during these two weeks was 1% above normal and 22% below normal for India as a whole. However, there was no improvement in cumulative rainfall which remained at 22% below normal. Rainfall situation remained the same during the next week also. Improvement in rainfall commenced from the week ending on 1st August. By this time the MCZ associated with an active SICZ had reached its southern most location in the latitude belt of 15°-20°S. SICZ remained active in this location for the next 4 weeks in continuation, i.e., from week No. 30 to week No. 33 (week ending on 25 July to 15 August). Weekly rainfall, during these 4 weeks, was below normal by 20%, 4% , 1% and 2% respectively. In other words, close to normal weekly rainfall occurred during the three weeks period when SICZ was in its southern most location. This led to cumulative rainfall improving from 22% below normal at week ending on 25 July to 15 % below normal at the week ending on 15 August. Cumulative rainfall till this date was within the limit of model error (20% ± 5%). Difference between forecast and realized rainfall increased thereafter due to yet another unusual development in the zone of SICZ. This is discussed below.

The third and the last active spell of SICZ during the season developed close to equator during week Nos. 33-35, i.e., during the weeks ending on 15, 22 and 29 September. The unusual feature was that a MCZ moved northward during this period while SICZ also remained active in its usual location (Equ-5°S). In a normal situation, SICZ weakens and MCZ moves northward. Significant improvement in rainfall occurred during the next 3 weeks (week Nos. 36-38) ,i.e., during the weeks ending on 5,12 and 19 September when weekly rainfall was above normal by 31%, 20% and 44% respectively. This led to cumulative rainfall improving to 6% below normal by the week ending on 19 September. There was deterioration in rainfall during the remaining days and rainfall was 8% below normal at the end of the season. Though displaying features of a severe all India drought during the first half of the season, two unusual developments during the second half made Monsoon-2012 to go in records as a weak monsoon only.

The discussions relating to ongoing changes during 5 monsoon seasons, i.e., 1992, 1999, 2001, 2005 and 2012, have revealed some of the intriguing features of Indian summer monsoon. While the intra-seasonal changes in Indian summer monsoons during 1992, 1999 and 2005 were due to the influence of the on-going changes over Indo-Pacific region, the changes in 2001 and 2012 occurred due to ongoing changes over Indian Ocean itself. Indian summer monsoon appears to be a critically balanced system where the influence of the ongoing changes during the season over Equatorial Pacific and Indian Oceans are operating simultaneously and which influence shall become more important in a particular year and in what manner is difficult to be foreseen at the time of formulating its long range forecast at the beginning of the season. This puts a limitation on foreshadowing summer monsoon rainfall in India in some of the years.

CONCLUSIONS

(i) OLR data could easily replace cloud data in identifying the features/precursors in the activity of SICZ. Precursors to Indian summer monsoon start developing as early as January and continue developing through winter to pre-monsoon months of Aril-May. It is, therefore, necessary to consider cloud/OLR data for the period of January-May for identifying the precursors.
(ii) Both, cloudiness/OLR and their anomalies should be considered for extracting maximum information on the features in the activity of SICZ.
(iii) On-going changes over Equatorial Indo-Pacific region play an important role in intra-seasonal changes in Indian summer monsoon in some of the years, more particularly during the second half of the season. As the intra-seasonal changes could not be foreseen at the time of formulating the forecast at the end of May, an explanatory note about

the likely impact of intra-seasonal changes should be appended to the forecast, particularly during a year when the forecast indicates development of an extreme season (Excess/drought) or when demise of El Nino and setting in of ENSO –neutral / La Nina conditions or vice versa are expected to take place during the season.

(iv) SICZ model appears to be a robust one as it has produced reasonably good forecasts of summer monsoon rainfall in India for the past 23 years including the extreme seasons. The difference between the forecast and the realized rainfall may become larger than the model error in some of years due to large intra-seasonal changes. This is not due to any weakness of the model. These intra-seasonal changes may be considered as one of the limitations in long range forecasting of monsoon rainfall in India.

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