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Long range forecast and development of a weak southwest monsoon during 2017- Pt. II: Development

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ABSTRACT
2017 southwest monsoon was unique in several respects: (i) It was a weak monsoon, not over India alone, but over the monsoonal regions of the globe, (ii) Even with weak monsoon conditions, rainfall for India as a whole was on the higher side of normal during June by 4% (iii) Normal to above normal/excess rainfall occurred in July over different regions of India resulting in 2% above normal rainfall for the month for India as a whole, (iv) There was an intra-seasonal change in the activity of South Indian ocean Convergence Zone (SIOCZ) during the second half of the season, which was expected to bring improvement in rainfall over Central and Northwest India, but it did not happen and rainfall improved over south Peninsula, (v) Though not intense, SIOCZ remained generally active from the week ending on 5th July till the end of the season. Development of 2017 southwest monsoon has been studied with the help of OLR Total, OLR anomaly, cloudiness, daily and weekly rainfall and monthly precipitation anomaly data. It has been shown that the superimposition of intra-seasonal changes over intra-seasonal oscillation was responsible for the development of different features during 2017 monsoon as enumerated above. Further the activity of SIOCZ and rainfall distribution over India during 2017 monsoon have, once again, confirmed the validity of the results, which had formed the basis for proposing SIOCZ model of long range forecasting of monsoon rainfall in India.

Key words: Southwest monsoon, South Indian Ocean Convergence Zone model, Activity index, Intra-seasonal changes, OLR total, OLR anomaly, Monsoon Trough, Long range forecast, Updates.

INTRODUCTION

Two monsoons are never exactly the same, though the Intra-seasonal Oscillations (ISOs) and the main feature in the activity of South Indian Ocean Convergence Zone (SIOCZ), prior to the commencement of the season in two years, may be the same. This results due to superimposition of Intra-seasonal Changes (ISCs) over ISOs. The term ISO refers to variance of rainfall in the time scale of 10-15 and 30-60 days. These oscillations are well known. The features in the activity of SIOCZ corresponding to ISOs are also fairly known by now. The term ISC refers to the appearance of new features in the activity of SIOCZ, other than what had been identified as the main feature before the commencement of the season and used for preparing Long Range Forecast (LRF) of rainfall. The changes in the activity of SIOCZ cause changes in the Monsoon Trough (MT) and thereby impact the rainfall distribution. As a result of this, the forecast issued on the basis of the main feature does not get realised. During 1990 to 2016, for which LRF of rainfall based on SIOCZ model has been issued, ISCs had occurred in 1992, 1999, 2001, 2005, 2010, 2013 and 2016. The ISCs occurred in these years have been studied and documented (Onkari Prasad and Singh, 2013; Onkari Prasad et al., 2014, 2016a and 2018a). Because of the ISCs, the difference between the forecast and the realized rainfall in some of the districts of a state, some of the subdivisions and also for India as a whole become larger than the Model Error (ME). Except for the above mentioned years (7 out of 27 (26%)), SIOCZ model's LRF was reasonably good in the remaining years. Identification of ISCs, issuing of Update, and documenting the results has been done for the years 2013 and 2016 (Onkari Prasad et al., 2016a & 2018a). ISCs had also occurred during 2017 summer monsoon. 2017 monsoon had been foreshadowed as a normal one by the operational models of India Meteorological Department (IMD). SIOCZ model had foreshadowed 2017 monsoon as a weak one with 12% below normal seasonal rainfall for India as a whole with ME of ±5%. The performance of SIOCZ model during 2017 has been discussed in Pt.I (Onkari Prasad et al., 2018b). The verification results have shown that SIOCZ model's forecast was reasonably good in the districts of Tamilnadu, Andhra Pradesh, Telanagana, Himachal Pradesh, Maharashtra and Goa states. It was also reasonably good in meteorological subdivisions and also for the country as a whole.

The linkage between SIOCZ and Monsoon Trough (MT) had been explained by proposing a circulation model (Figure 1d) during 'break' in monsoon (Onkari Prasad, 1981). The model differs in one aspect from the earlier models (Koteswaram,1960; Asnani,1973 and Rao & Datta,1975). It has an additional circulation cell close to

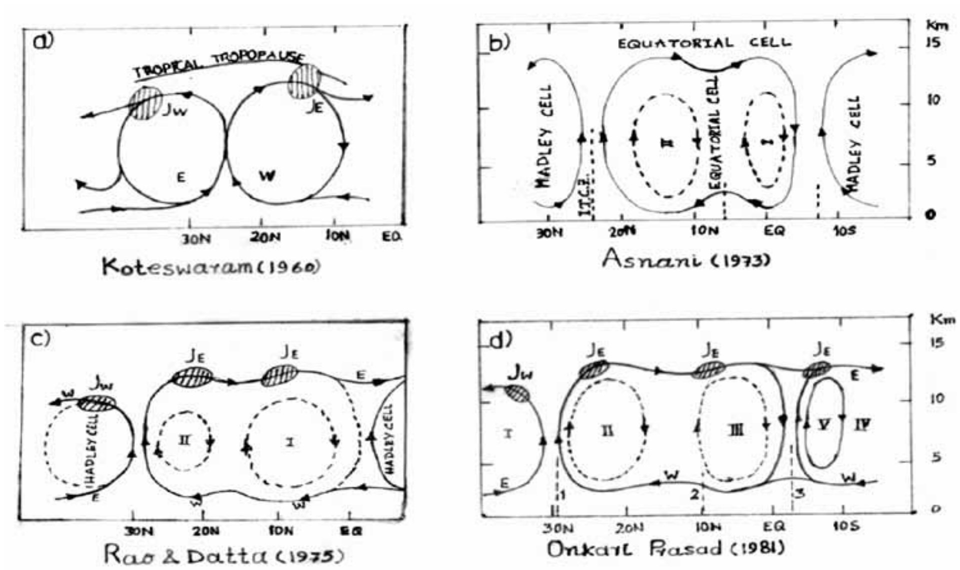

Figure 1 a): Circulation of the 'monsoon cell', b): Meridional circulation in summer monsoon over South East Asia, c): Circulation model for 'break monsoon', d): Circulation during 'break' in monsoon over India. W: Westerly, E: Easterly, Jw: Westerly Jet stream, JE: Easterly Jet stream, I.T.C.Z.: Inter Tropical Convergence Zone. In Figure 1 c): I&II: Equatorial sub-cell I & II. In Fig.1d): I: Hadley cell of Northern Hemisphere, II: Circulation cell associated with the Monsoon Trough, III: Circulation cell associated with the secondary trough, IV: Hadley cell of Southern Hemisphere, V: Circulation cell associated with South Indian Ocean Convergence Zone, 1- Monsoon Trough, 2- Secondary equatorial trough, 3- South Indian Ocean Convergence Zone.

south of equator, associated with SIOCZ. An experiment on the interaction between SIOCZ and MT using a zonal numerical model extending from South Pole to North Pole along 80^{o}E meridian (Onkari Prasad, 1982) had shown that the revival of monsoon was associated with the weakening of SIOCZ, strengthening of the secondary trough in south Bay of Bengal around 10^{o}N, its northward movement and establishment around 20^o N latitude in the head Bay as a fresh MT. Thus it could be said that the circulation model proposed by Onkari Prasad (1981) depicts an important feature of monsoon circulation system over Southeast Asia. A reference to the circulation model is made here basically to explain the development of a weak southwest monsoon during 2017, when simultaneous existence of 3 troughs are seen a feature seen during 'break' in monsoon (Figure 1D). Such a phenomenon was seen as 3 distinct west-east oriented regions of positive precipitation anomaly, in precipitation anomaly charts for the months of July-September 2017. The charts are reproduced below.

Development of a weak summer monsoon during 2017 has been studied with the help of OLR Total, OLR anomaly, cloudiness, daily and weekly rainfall and monthly precipitation anomaly data. Salient features of these fields have been described. Changes in the features in the activity of SIOCZ have been discussed in relation to the performance of 2017 monsoon. The results of forecast verification, included in Pt. I (Onkari Prasad et al., 2018b), had shown that SIOCZ model's forecast was reasonably good in the districts of Tamilnadu, Andhra Pradesh, Telanagana, Himachal Pradesh, Maharashtra and Goa states, in meteorological subdivisions and also for the country as a whole. However, the impact of the ISCs, which took place during 2017 monsoon, on rainfall could not be captured well in the Update issued in August. These aspects are discussed below in brief.

Salient Features of 2017 southwest monsoon

2017 Southwest Monsoon (SWM) advanced over Kerala on 30th May, around its normal date of 1st June. It covered the entire country by 19th July, i.e., 4 days after its normal date of 15th July. There were hiatuses in the progress of monsoon for 7 days in June (2nd -5th & 28th-30th) and 8 days in July (4th -11th). Cyclo-genesis was highly subdued during the season and more particularly during the second half of the season. During the first half of 2017 SWM, 11 Low Pressure Systems (LPSs) comprising Low Pressure Areas (LPAs) and Depressions, were formed. Only 3 of the Low Pressure Systems intensified into a Depression. During the second half of the season, even though 3 LPSs formed, none of them intensified into a depression. There were only 39 days of LPSs (June:11,July:12, August:10 & September:6) as against a normal of 58 days (Jun:11, July:14, August:17 & September:16). A well marked Low Pressure Area (LPA), during 11-16th July and two well marked LPAs in August, 18th – 21st and 27th Aug – 1st Sep, moved across central India and dissipated over Kutch & neighbourhood and over south Pakistan, respectively.

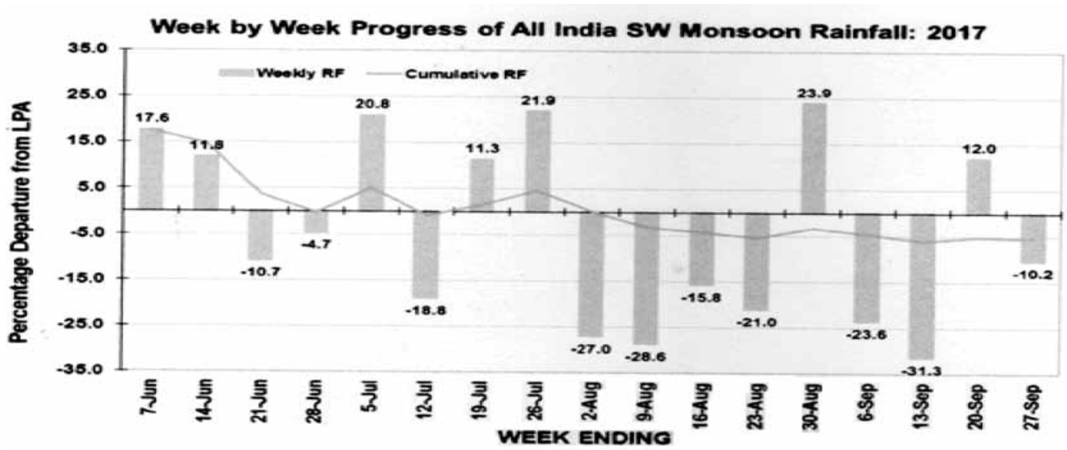

Figure 2. Week-by-week rainfall, for India as a whole, during 2017 summer monsoon. [Source: 'End of season report on 2017 southwest monsoon' by IMD].

These 3 LPAs had a southward shift in their track. The only system, which developed during 19th and 24th September was a well marked LPA. It had formed over northwest Bay of Bengal and neighbourhood and dissipated over west Uttar Pradesh and adjoining Uttarakhand. 2017 SWM started withdrawing from west Rajasthan from 27th September, i.e., much later than the normal date of 1 September. The linkage between southward shift of the track of LPSs during July -August and the location of SIOCZ is discussed below.

During the whole season, there was only one spell in July when normal to excess rainfall occurred over different regions of India: 13th -28th over Central India, 22nd -26th over Northwest India, 23rd -26th over East & Northeast India, 18th-20th over South Peninsula and 13th -25th for India as a whole, as per the daily rainfall series (www.imd.gov.in/pages/monsoon_main.php). Thus 2017 monsoon was most active over Central India during the spell. The weekly rainfall for India as a whole during 2017 monsoon is shown in Figure 2. The rainfall during this spell in July had made an important contribution in improving the seasonal rainfall scenario for India as a whole. But for this spell of good rainfall, 2017 monsoon would have slipped into a severe drought category. During this spell SIOCZ was active in a location to the south of its mean location for July, i.e. around 5° S. Spells of above normal rainfall, one each in August and September, were short lived and they did not affect the rainfall over all the four regions of India. The linkage between the spell of above normal rainfall during July and the location and intensity of SIOCZ is discussed below.

On daily basis the rainfall, for India as a whole, was on the lower side of normal on 62(51%) days (Jun:11, Jul:13, Aug:19 & Sep:19) out of 122 days of the season. The number of days with rainfall on the lower side of normal in four broad regions was: Northwest India, 75(61%) days (Jun:15, Jul:13, Aug:23 & Sep:24); East & Northeast India, 72(59%) days (20,16,17&19); Central India, 68(56%) days (14,14,22&18),South Peninsula, 67(55%) days (16,27,14&10). On monthly basis rainfall was deficient in 7 subdivisions in June, 15 in July, 12 in August and 14 in September. The rainfall, for India as a whole was 4% and 2% above normal in June and July, 13% and 12% below normal in August and September. Severe drought like conditions prevailed over south Peninsula during July, Northwest and Central India during August and over parts of Northwest, Central, Northeast and Peninsular India during September. South Peninsula received normal-to-excess rainfall during August and September. For the season as a whole, rainfall was 5% below normal for India as a whole and it was in deficient category in 6 out of 36 subdivisions of India.

Development in equatorial Indo-Pacific region

La Nina conditions, which had prevailed over Nino 3.4 from JAS 2016-NDJ 2016/17 changed to ENSO normal, with negative anomalies up to JFM 2017 and positive anomaly thereafter. However, the positive anomalies did not reach 0.5°C, the threshold for declaring El Nino. The monthly anomaly in Nino 3.4 region was the highest in May (0.48° C) and it reduced to 0.35°C in Jul, -0.14 °C in Aug, -0.45 in Sep and Oct. In West South Indian Ocean (WSIO), the region of Indian Ocean (IO) to the west of 90°E, SST anomalies, as monitored on real time basis in weekly SST anomaly charts made available by NOAA on their website (www.esrl.noaa.gov/pst/map/clim/sst_shtml), remained positive from February 2017 till October. The 2016-17 SWIO cyclone season, 15th November 2016-30th April 2017, was a below average season. Out of five tropical storms (tropical storms as named in WSIO, are equivalent to tropical depressions in North Indian Seas- Arabian Sea and the Bay of Bengal), three intensified into tropical cyclones. Important thing to note in the development of these cyclones is that they originated south of 15°S. This is

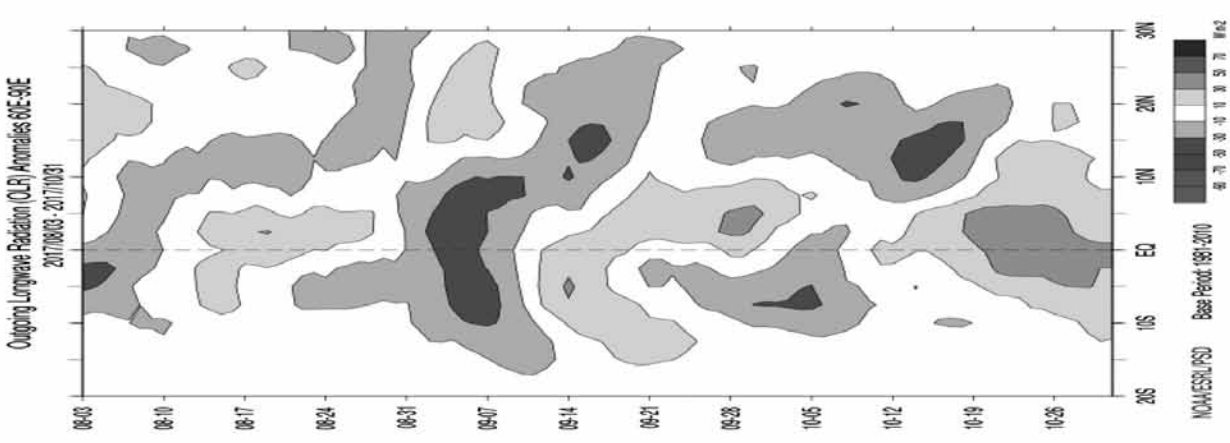

Figure 3. OLR anomaly over the region bounded by 30°N-20°S and 60°E-90°E during Aug-Oct 2017.

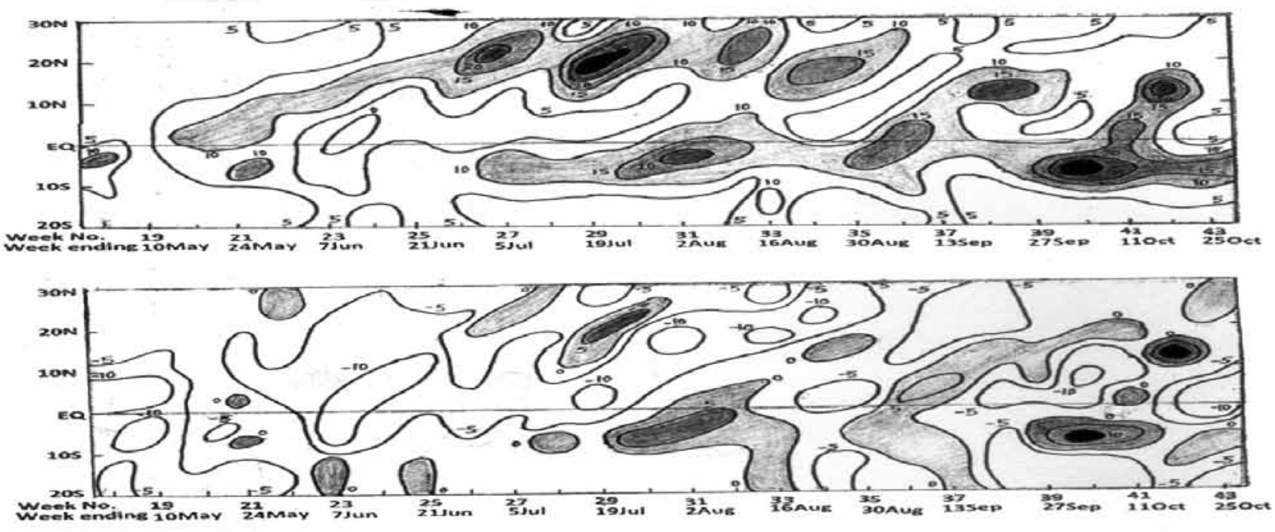

Figure 4. Upper panel: Zonal weekly mean cloudiness over the region bounded by 30ºN-20ºS and 40ºE-100ºE. Contours of total cloud amounts have been drawn at increments of 5%, 10%, 15%, 20%,....80%. **Lower panel**: Cloud anomaly. Contours have been drawn at increments of +/- 5%, 10%,15%, 20%, 30%, 40%, ...80%.[Base period: 1973-2012 except 1978 & there were some missing data during 1979 also]

in contrast to the cyclone season of 2015-16, when cyclogenesis took place to the north of 15ºS (Onkari Prasad et al., 2018a).This implies a southward shift of the region of maximum positive SST anomaly and the location of SIOCZ- the zone of origin of tropical storms in WSIO. The implications of SIOCZ remaining active to the south of its normal position during Jul-Sep and the location of MT and distribution of rainfall over India are discussed below.

Features in the activity of SIOCZ

OLR Total, OLR anomaly, Zonal Weekly Mean Cloudiness (ZWMC) and Zonal Weekly Mean Cloud Anomaly (ZWMCA) have been used to identify the features in the activity of SIOCZ. OLR anomaly and ZWMC & ZWMCA are reproduced in Figures 3 & 4, respectively. Figure 3 shows OLR anomaly data for the period Aug-Oct 2017. OLR anomaly data for the period Feb-Jul 2017 have been included in Pt. I (Onkari Prasad et al., 2018b). As mentioned in Pt. I, the main feature identified in the activity of SIOCZ before the commencement of 2017 monsoon season was the development of an active spell of SIOCZ for 3-4 weeks, in continuation. The other important feature was considerable reduction in the intensity of convection as seen in the dominance of positive areas in OLR anomaly and negative areas in cloud anomaly charts. These features had formed the basis for formulating SIOCZ model's LRF as discussed in Pt. I (Onkari Prasad et al., 2018b) Normally, the features in the activity of SIOCZ, which had occurred during the pre-monsoon months of April-May repeat during the season also. However, the features do change during the season in some of the years. This happened during 2017. The active spell of SIOCZ, which had started developing during the week ending on

12th April continued up to the week ending 10th May (Figure 1 of Pt. I). The next active spell of SIOCZ was expected to develop during the week ending on 14th June. However, this did not happen. An active spell of SIOCZ started developing only during the week ending on 5th July. This spell, in general, continued up to the end of October 2017. This feature is not clearly seen in OLR anomaly charts (Figure 3 and Figure 1 of Pt. I). However, in this generally active period of SIOCZ, 3 spells of intense convection developed: (i) for 4 weeks in continuation, from the week ending on 26th July to the week ending on 16th August, (ii) for 1 week only, during the week ending on 6th September, and (iii) for 3 weeks in continuation, from the week beginning from 27th September to 18th October. The interval between the development of all the 3 spells was fairly stable; around 3 weeks. The first and the third active spells lasted for 3-4 weeks, in continuation.

The features as noted in the activity of SIOCZ during the pre-monsoon months did not repeat during the season in the same manner. Additional features got superimposed over the main feature during the season and they were (i) SIOCZ remained weak for about 8 weeks during May-June, (ii) SIOCZ remained generally active for about 16 weeks, beginning from the first week of July till the end of October and (iii) convection associated with the active spell, which developed during the first week of September quickly moved to the north of equator during the next week. The implications of these changes on the performance of 2017 monsoon are discussed below.

Precipitation anomaly

The precipitation anomaly charts (https://iridl.ldeo.columbia.edu/maproom/Global/Precipitation) for the months of June, July, August and September-2017 are reproduced below (Figure 5).The maps show anomaly (mm/month) based upon precipitation estimates from the Climate Anomaly Monitoring System (CMAS)'s Outgoing longwave radiation Precipitation Index (OPI).The satellite precipitation estimates are based on emitted longwave radiation observed by polar-orbiting satellites. The period used for computing the climatology is 1979-2000. Green areas on the maps indicate where precipitation was above the long-term normal for the month and brown areas indicate where precipitation was below normal. Contours have been drawn at increments of +/- 10, 25, 50, 100,200,300,400 and 500 mm/month. The maps are available for the Globe as well as for Asia. During the month of June, the region of reduction in precipitation extends from the Arabian Sea up to the date line and further east. The maximum reduction is seen over the Indian Seas. Reduction also occurred over parts of Northwest India, Central, East and Northeast India. A region of positive anomaly runs from Pakistan to central Pacific. While the negative anomaly resulted due to weak monsoon conditions during the month, the positive anomaly was a result of the increased westerly influence over Northwest India and further east up to date line. In July, reduction in precipitation occurred over Peninsula, parts of Central, Northwest and Northeast India. The positive anomaly to the south of equator extending from 60°E to 90 °E is due to the presence of an active SIOCZ. During August, precipitation was deficient over a major portion of India, except over Parts of North, Northeast and south Peninsula. The 3 trough structure during 'break' in monsoon as shown in Fig. 1D, is more clearly seen in August as compared to that in July. In September, precipitation deficit occurred over Northwest, Central and parts of East and Northeast India. The 3 trough structure could be seen during September also.

DISCUSSIONS

As noted above a well marked LPA, during 11th-16th July, moved across central India and dissipated over Kutch and neighbourhood and over south Pakistan. Two well marked LPAs in August, 18th–21st and 27th Aug–1st Sep had also moved across Central India and dissipated over Kutch & neighbourhood and over south Pakistan, respectively. Normal to excess rainfall had occurred in July over Central India for 16 days (13-28 July) and for 3-5 days over the remaining 3 regions. This had resulted into rainfall becoming above normal for country as a whole for about 2 weeks (13 days, between 13-25 July) (Figure 2). Southward shift of MT and the track of LPSs during July and August and an active spell of rainfall for about two weeks over Central India during 13-28 July were linked to (i) southward shift of SIOCZ and (ii) SIOCZ remaining relatively weak as seen in convection, which remained moderate in the zone of SIOCZ. To support the above conclusions**,** zonal weekly mean cloud data for 4 weeks from the week beginning from 6th July till the week ending on 2nd August are reproduced below in Figure 6.

Normally, during the month of July, SIOCZ remains close to equator. But, SIOCZ remained active close to 5°S or south of it, from the week beginning 6th July till the week ending on 26th July (Figure 6a-c). It was only during the week ending on 2nd August that SIOCZ moved close to equator (Fig.6d). A southward shift in the location of SIOCZ results in a similar southward shift in MT. This gets confirmed from the existence of the Maximum Cloud Zone (MCZ) to the south of 20°N during the week, 13-19 July (Figure 6b) and between 20°N and 25°N during the week 20-26 July (Figure 6c). Central India received normal to above normal rainfall during these two weeks. This also explains the southward shift in the track of LPSs during July and increased rainfall over Gujarat in their association. With slight northward shift in MT, LPAs in

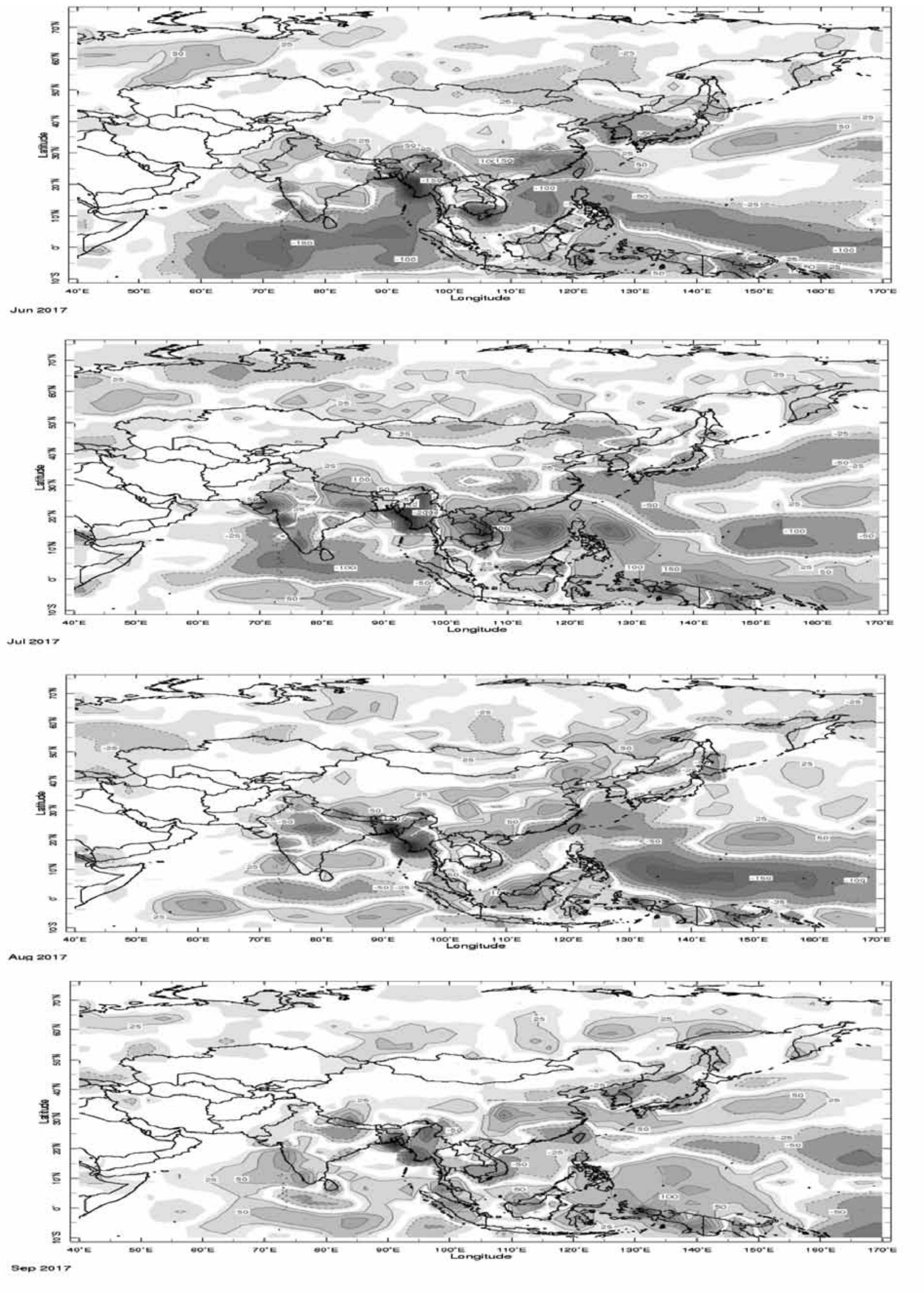

Figure 5. Monthly precipitation anomaly over Asia during Jun-Sep2017.Green- positive, brown- negative.

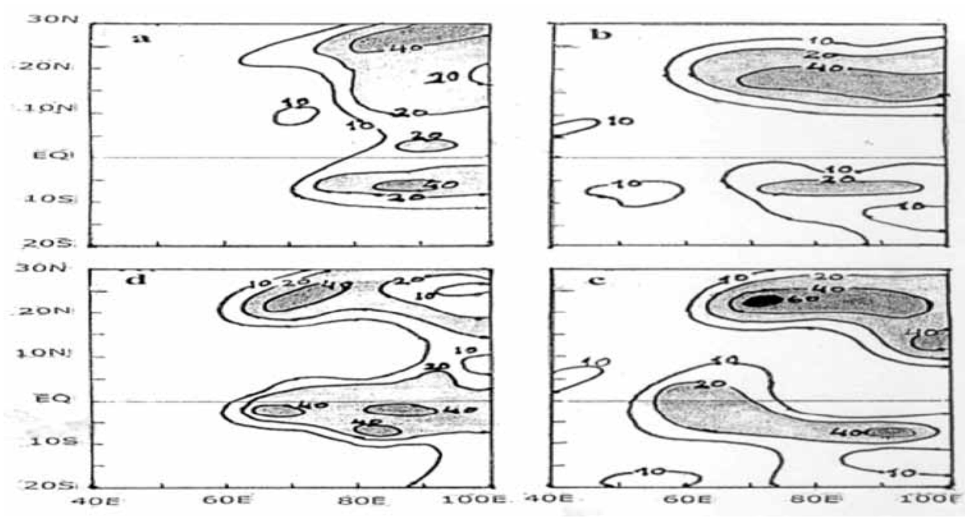

Figure 6. Zonal weekly mean cloudiness for the week (a) 6-12 July (b) 13-19 July (c) 20-26 July& (d) 27Jul-2 August. Contours of total cloud amounts have been drawn at increment of 10%, 20%, 40%, 60% & 80%.

August moved across Central India and dissipated over Kutch and neighbourhood and south Pakistan.

The main feature as noted in the activity of SIOCZ during the pre-monsoon months, i.e., development of an active spell of SIOCZ lasting for 3-4 weeks, did repeat during August-October. But July spell was very weak. Additional features got superimposed over the main feature during the season and they were (i) SIOCZ remained weak for about 8 weeks during May-June, (ii) SIOCZ remained generally active for about 16 weeks, beginning from the first week of July till the end of October and (iii) The convection associated with the active spell of SIOCZ which began in the first week of July was not intense (iv) The convection associated with the active spell, which developed during the first week of September quickly moved to the north of equator during the next week. The MCZ associated with it could move up to 15°N only and got terminated there. As a result, this active spell could not activate/revive the MT. This also happened to the spell, which moved northward during the end of September/beginning of October. The ISC during July, which had been seen in the weakening of SIOCZ, had formed the basis for issuing an Update for improved rainfall during the second half of the season. However, that did not happen and an active spell of SIOCZ developed for 3 weeks in continuation beginning from the week ending on 26th July. August spell of active SIOCZ moved northward up to 15°N, and then to the south of equator up to 20°S. Having terminated around 15° N it could not activate the MT. In cloud anomaly field, the positive anomaly contour of 5% was confined to the areas south of 5°N. As the main feature in the activity of SIOCZ, i.e., SIOCZ developing for 3-4 weeks, reappeared during August, the improvement of rainfall during the second half remained confined to South Peninsula only. Thus the Update issued in August could not capture the rainfall scenario during August-September. As noted earlier (Onkari Prasad et al., 2018a,b), Update/Updates could be improved, for which the information on the relationship between SST and SIOCZ and forecast SST anomaly field from SIO are required at least a month in advance. Due to various reasons this is presently not available. Need for a comprehensive study, on the relationship between SST distribution over SIO and the location and intensity of SIOCZ, is essential to obtain precise details.

CONCLUSIONS

1. Large deficiency in precipitation anomaly occurred not only over India but over the globe during 2017- a year of weak summer monsoon.
2. Prevalence of positive SST anomaly over West South Indian Ocean during the season resulted in southward shift of South Indian Ocean Convergence Zone and the track of tropical storms developing over west South Indian Ocean.
3. Southward shift of Monsoon Trough and the track of Low Pressure Systems over Indian sub-continent during July and August had occurred in response to southward shift of South Indian Ocean Convergence Zone.
4. The intra-seasonal Changes in 2017 monsoon had resulted due to changes in the location and intensity of South Indian Ocean Convergence Zone.
5. Intra-seasonal changes got superimposed over the main feature, as identified in the activity of South Indian Ocean Convergence Zone during pre-monsoon months. However, the main feature did persist and reappeared during August-October.
6. Investigations, on the relationship between SST field over South Indian Ocean and the location and intensity of South Indian Ocean Convergence

Zone, are required for a better understanding of the mechanism of development of intra-seasonal changes in summer monsoon.

7. Further improvement in SIOCZ model is possible by issuing Update/Updates incorporating the impact of intra-seasonal changes on rainfall. However, the same depends on the availability of reasonably good weekly forecast SST anomaly field from South Indian Ocean, at least a month in advance.

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Compliance with Ethical Standards

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

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