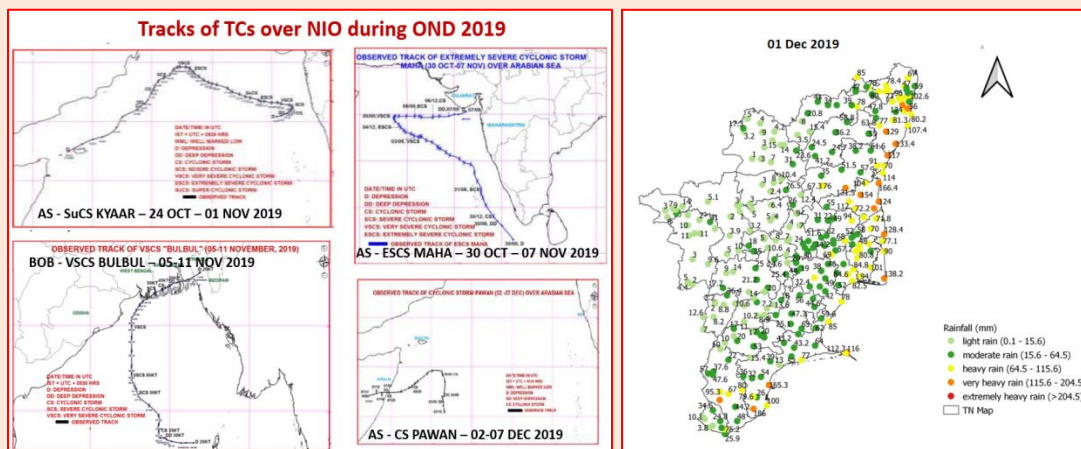
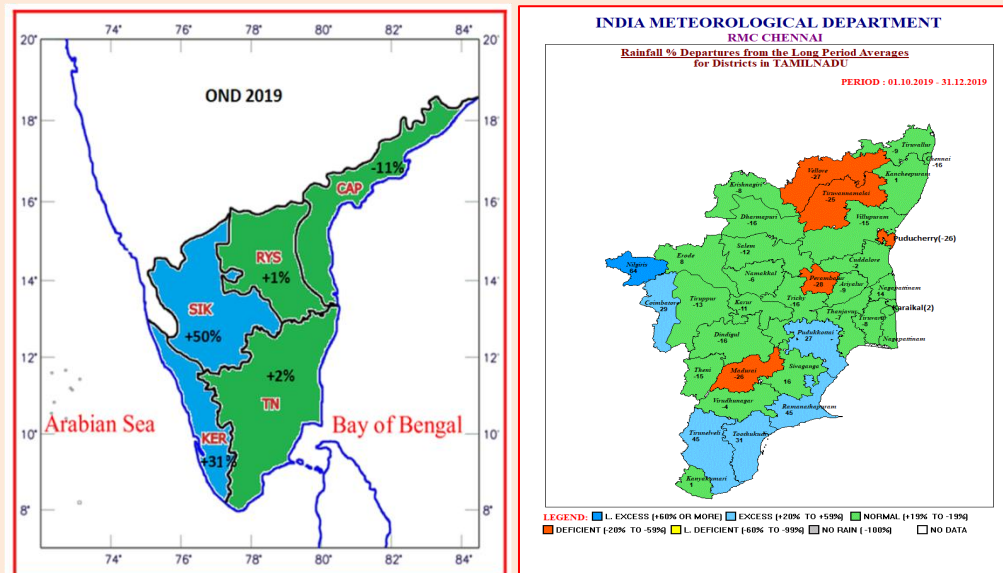




Government of India
Earth System Science Organisation
Ministry of Earth Sciences
India Meteorological Department



IMD Chennai Scientific Report No. IMDC-SR/08
REPORT ON NORTHEAST MONSOON – 2019



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Mar 2020

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Executive Summary

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Abstract

The Indian northeast monsoon (NEM) is a small scale monsoon confined to parts of southern peninsular India comprising of the meteorological sub-divisions of Tamil Nadu, Puducherry & Karaikal (TN), Kerala & Mahe (KER), Coastal Andhra Pradesh & Yanam (CAP), Rayalaseema (RYS) and South Interior Karnataka (SIK) and occurs during the months of October to December. It is the chief rainy season for the sub-division of TN and this regional agricultural activities depend on the NEM rainfall. The NEM season is also the chief cyclone season for the North Indian Ocean (NIO) region and the passage of cyclones and depressions over the NIO region significantly affect the NEM performance. As such, aside from the point of view of agricultural planning, this season also assumes significance from the disaster management perspective. Agricultural planners, disaster managers and others seek information on the NEM performance in various spatio-temporal scales. This report presents briefly, the salient features of NEM 2019 over the five meteorological sub-divisions benefitted by the NEM, including the onset phase, synoptic scale weather systems during the season, sub-divisional rainfall performance in seasonal, monthly, weekly and daily scales, monsoon activity and heavy rainfall events, district rainfall performance, standardized precipitation index and the large scale circulation features associated with the NEM activity.

1. Background

The Indian southwest monsoon (SWM) season of June to September is the chief rainy season for India and about 75% of the country's annual rainfall is realised during this season. Subsequent to the withdrawal of SWM, the northeast monsoon (NEM), a small scale monsoon confined to parts of southern peninsular India comprising of the meteorological sub-divisions of Tamil Nadu, Puducherry & Karaikal (TN), Kerala & Mahe (KER), Coastal Andhra Pradesh & Yanam (CAP), Rayalaseema (RYS) and South Interior Karnataka (SIK) occurs. For the subdivision of TN, the normal SWM seasonal rainfall realised is only about 35% (342.0 mm) of its annual rainfall (943.7 mm) as this subdivision comes under the rain-shadow region during the SWM. The northeast monsoon (NEM) season of October to December (OND) is the chief rainy season for this subdivision with 48% (447.4 mm) of its annual rainfall realised during this season and hence its performance is a key factor for this regional agricultural activities.

Further, the NEM season is also the primary cyclone season for the North Indian Ocean (NIO) basin comprising of the Bay of Bengal (BOB) and the Arabian Sea (AS) and cyclonic disturbances (CDs; low pressure systems (LPS) with maximum sustained surface wind speed (MSW) of 17 knots or more) forming over BOB and moving west/northwest-wards affect the coastal areas of southeastern peninsular India and also contribute significantly to NEM rainfall. As such, the NEM season assumes importance from the agricultural as well as cyclone disaster management perspectives.

Prior to the commencement of NEM rains, after the withdrawal of SWM up to 15°N, reversal of low level winds from southwesterly to northeasterly occurs. The normal date of setting in of easterlies over the southeastern peninsular India is 14th October. The normal date of onset of NEM over Coastal TN (CTN) and south CAP is 20th October. The normal rainfall received over the five NEM sub-divisions during OND is TN-447.4 mm, KER-491.6 mm, CAP-338.1 mm, RYS-223.3 mm and SIK-204.1 mm. However, the NEM seasonal rainfall shows a high degree of variability with 27% co-efficient of variation.

The NEM rainfall is influenced by global climate parameters such as ENSO (El Nino/La Nina & Southern Oscillation Index), Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO). El Nino, positive IOD and MJO in phase 2-4 with amplitude greater than one are generally associated with good NEM rainfall.

2. Onset phase

During October 2019, ENSO was neutral; but, IOD was strongly positive [>2] which was favourable for good NEM activity. MJO was in phase 1-2 during the third week of October. Reversal of surface and low level winds from westerly to easterly over the southeastern parts of peninsular India took place during 12th-14th October and the SWM withdrew up to 15°N on 15th

October and from the entire country on 16th October. Simultaneously, under the influence of a trough running from north Sri Lanka coast to a cyclonic circulation over eastcentral AS off south Karnataka coast in the lower levels and a trough in the easterlies running from southwest BOB off south Tamil Nadu to westcentral BOB in the lower levels, the NEM rains commenced over Tamil Nadu and adjoining areas of Andhra Pradesh, Karnataka and Kerala on 16th October. Pentad mean wind flow pattern depicting the reversal of wind from westerlies to easterlies during the third pentad of October 2019 are presented in Fig.1a. Surface isobaric analysis based on 0830 and 1730 IST and upper air streamline analysis based on 0830 IST observations of 16th October depicting the above synoptic features associated with the onset of NEM 2019 are presented on Fig.1b&c.INSAT-3D based cloudiness as on 0830, 1130, 1430 and 1730 IST of 15th and as on 0130, 0530, 1130 & 1730 IST of 16th October depicting the cloudiness over the southern peninsula during the onset period are presented in Fig.1d (i) & (ii).

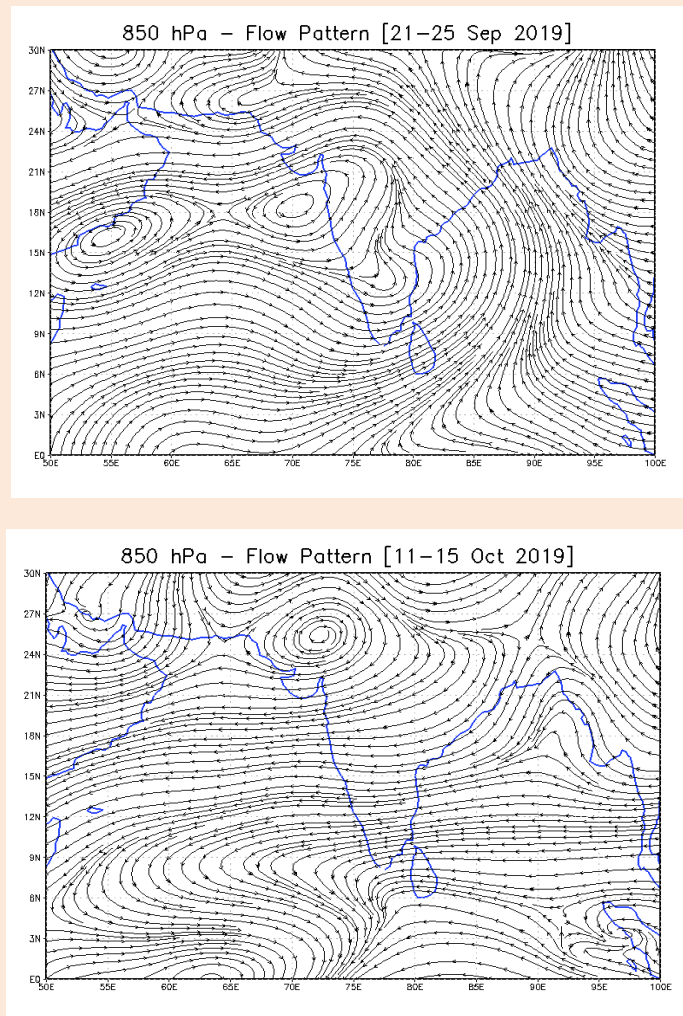


Fig.1a: NCEP reanalysis 850 hPa streamline pattern indicating reversal wind from westerly to easterly over peninsular India during the third pentad (11th-15th) of October 2019

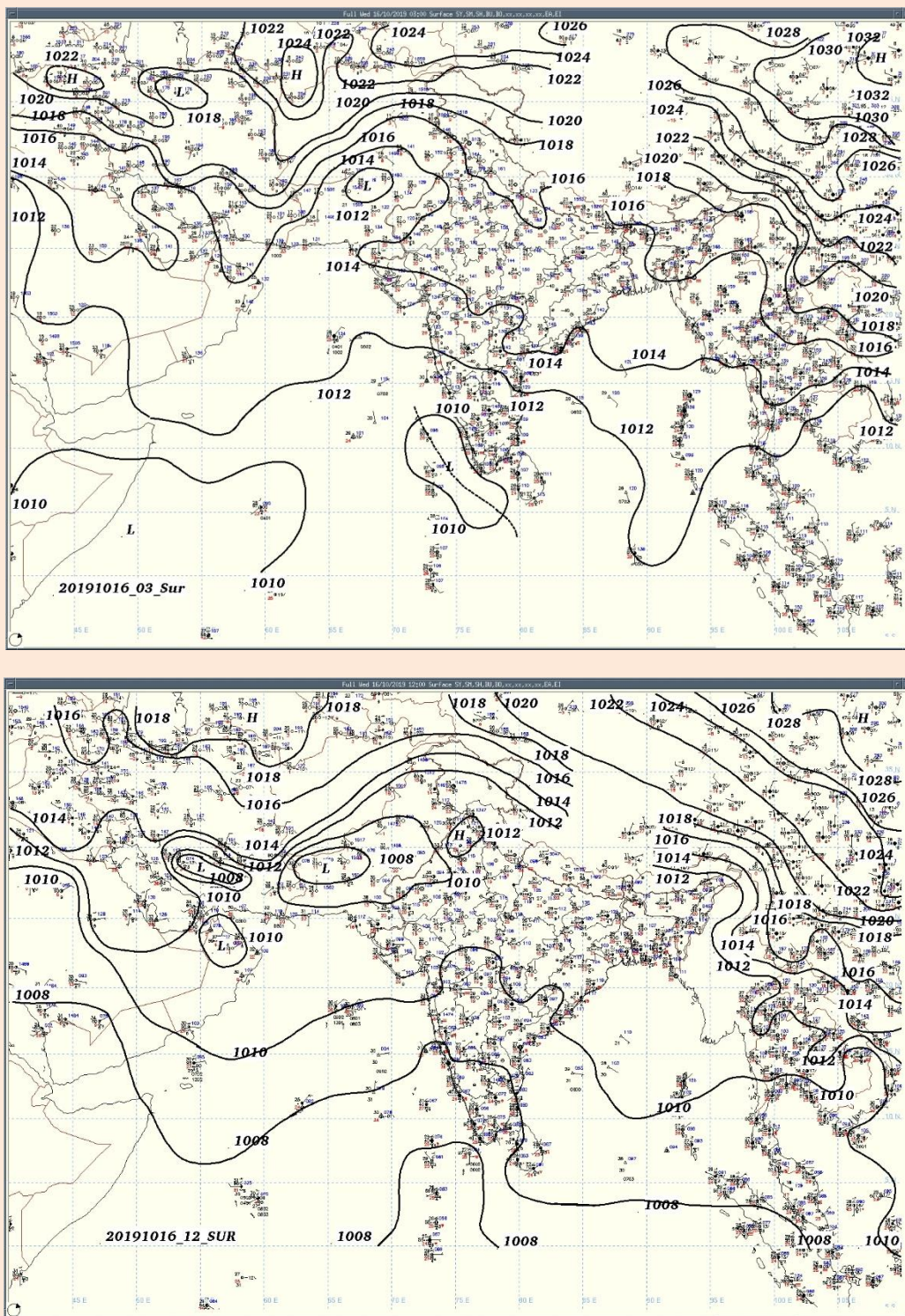


Fig.1b: Surface isobaric analysis based on 0830 IST and 1730 IST of 16th October 2019

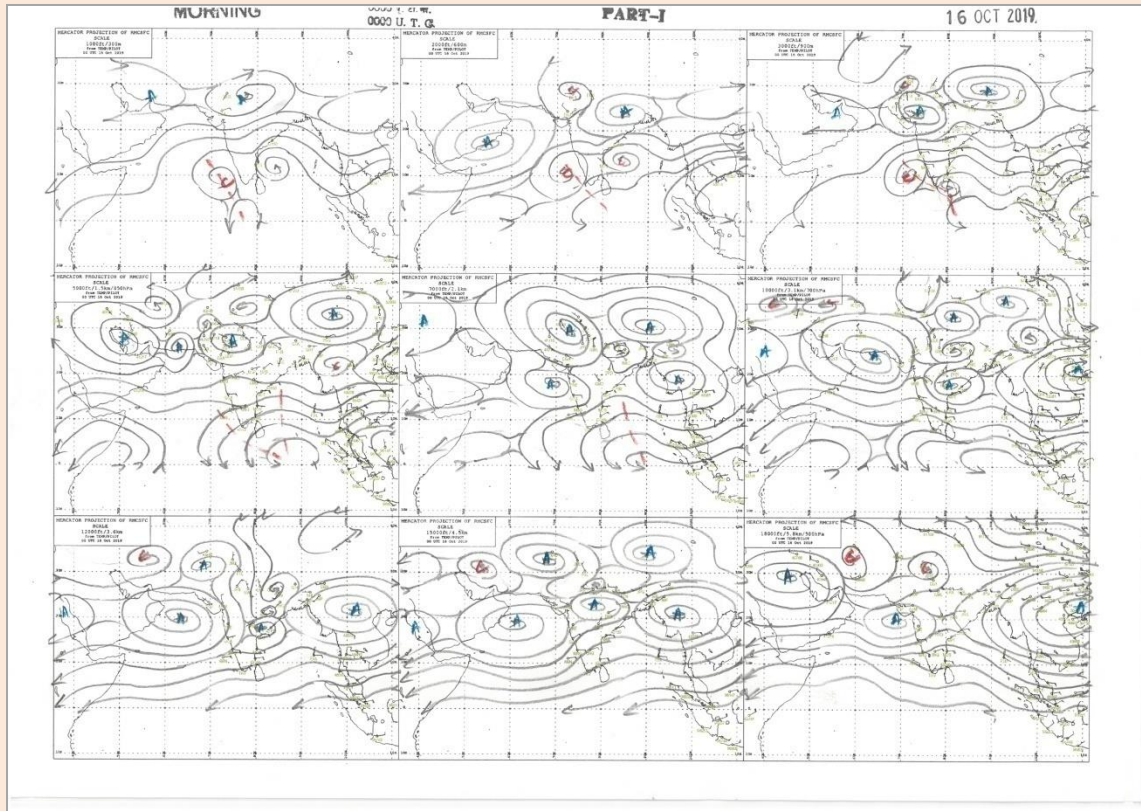


Fig.1c: Upper air (lower levels) streamline analysis based on 0530 IST of 16th October 2019

Spatial rainfall distribution over the NEM region depicted by the satellite based GPM-Gauge merged rainfall and that over TN subdivision based on gauge observation as on 24-hr ending 0830 IST of 16th and 17th October 2019 are presented in Fig.1e&f respectively.

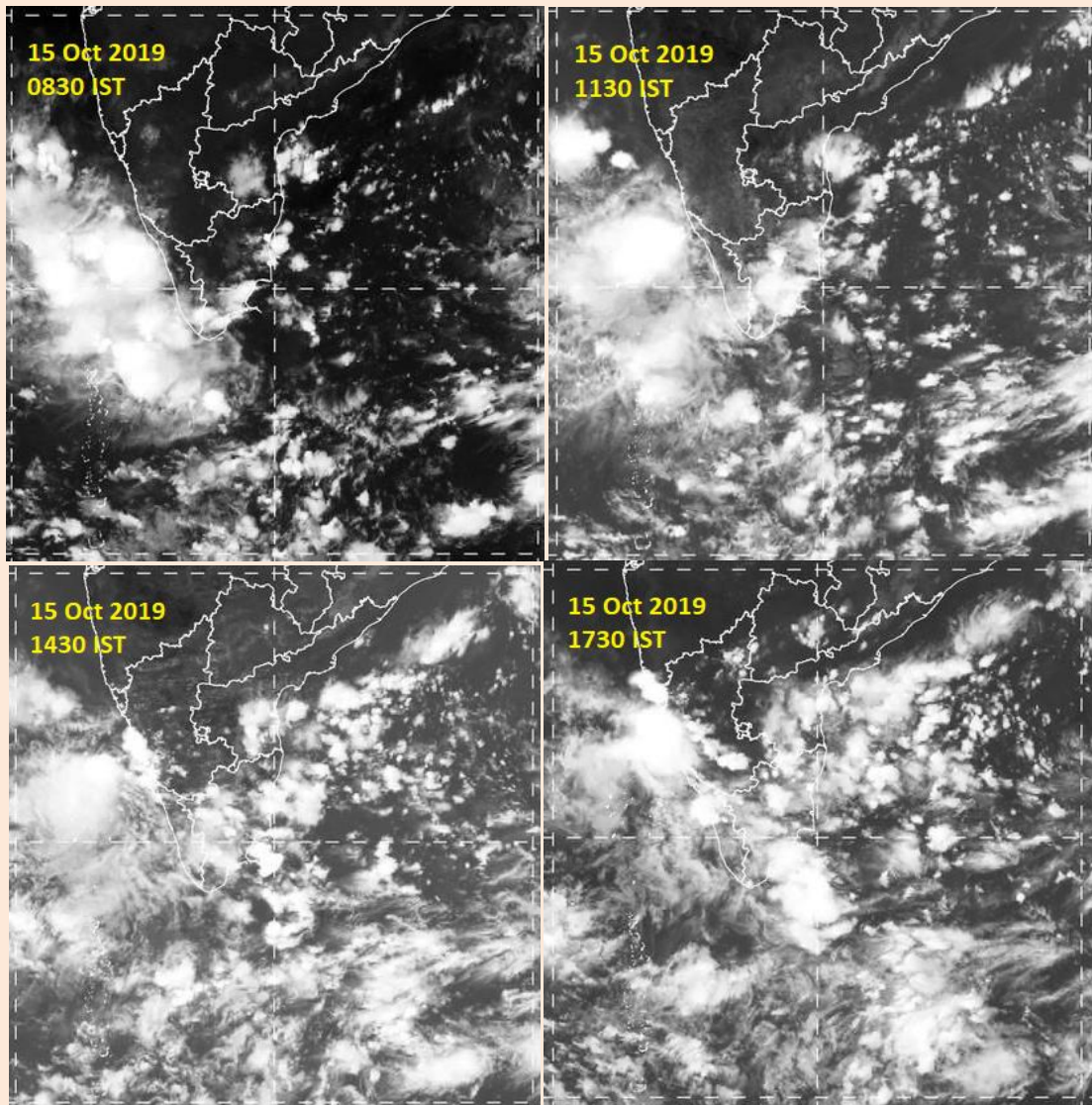


Fig.1d(i): INSAT-3D infra-red imageries as on 0830, 1130, 1430 & 1730 IST of 15 Oct 2019

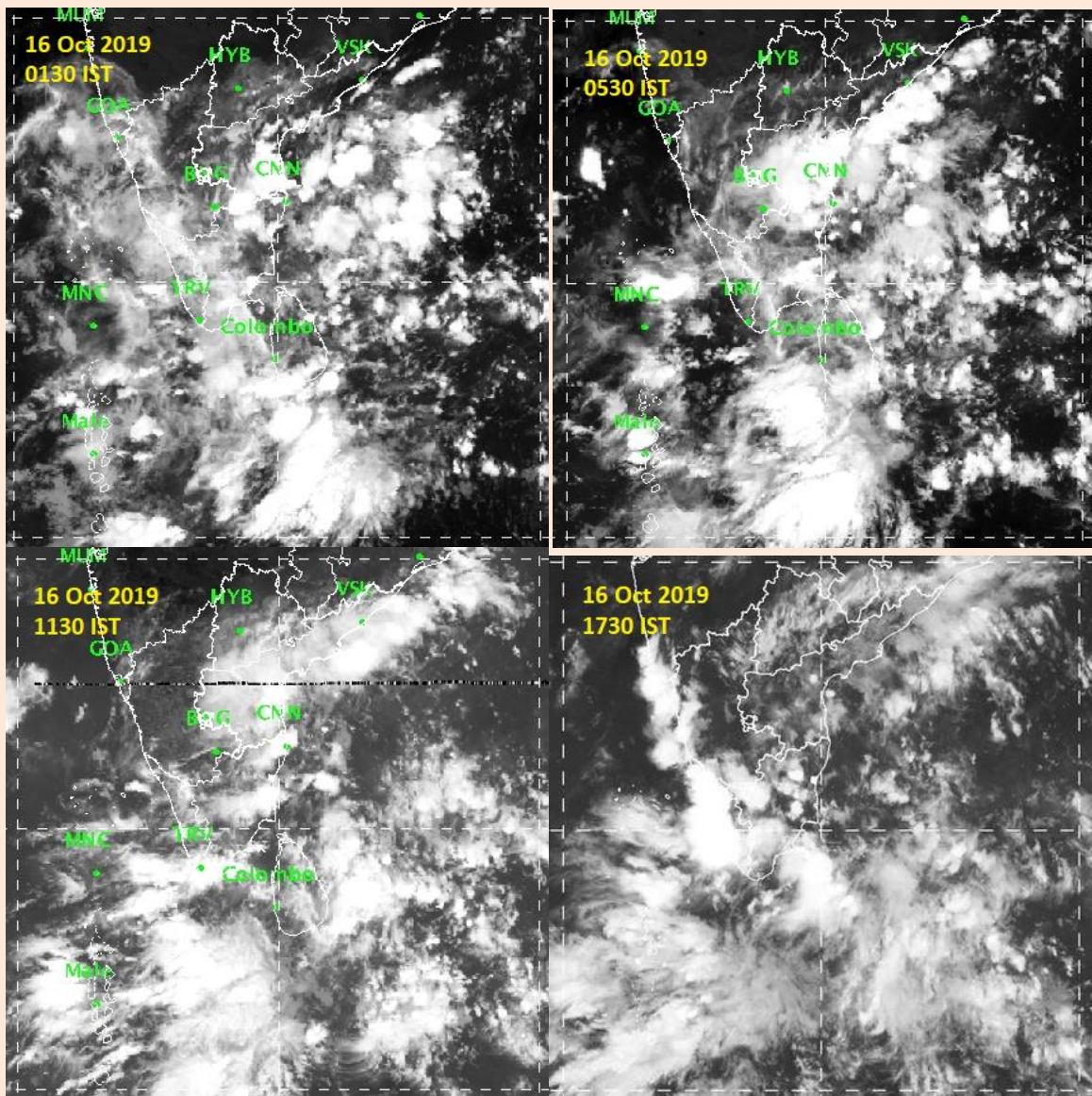


Fig.1d(ii): INSAT-3D infra-red imageries as on 0130, 0530, 1130 & 1730 IST of 16 Oct 2019

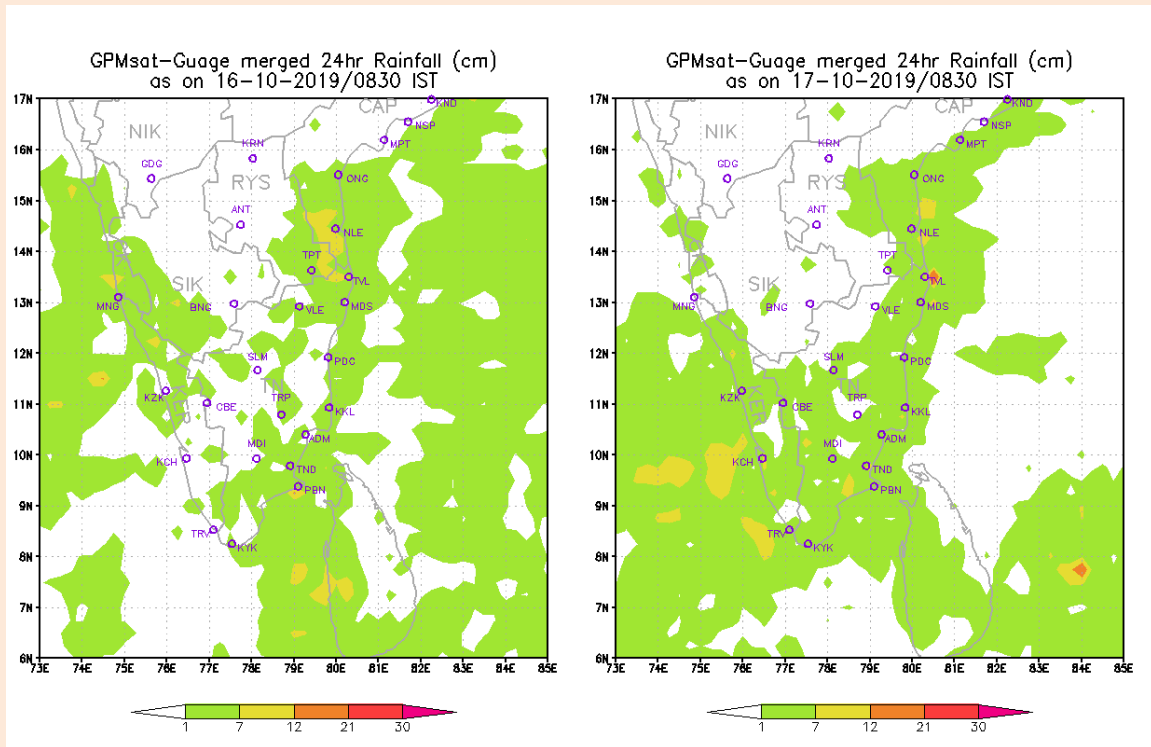


Fig.1e: GPM satellite+Gauge merged 24-hr rainfall (in cm) as on 0830 IST of 16 & 17 Oct 2019.

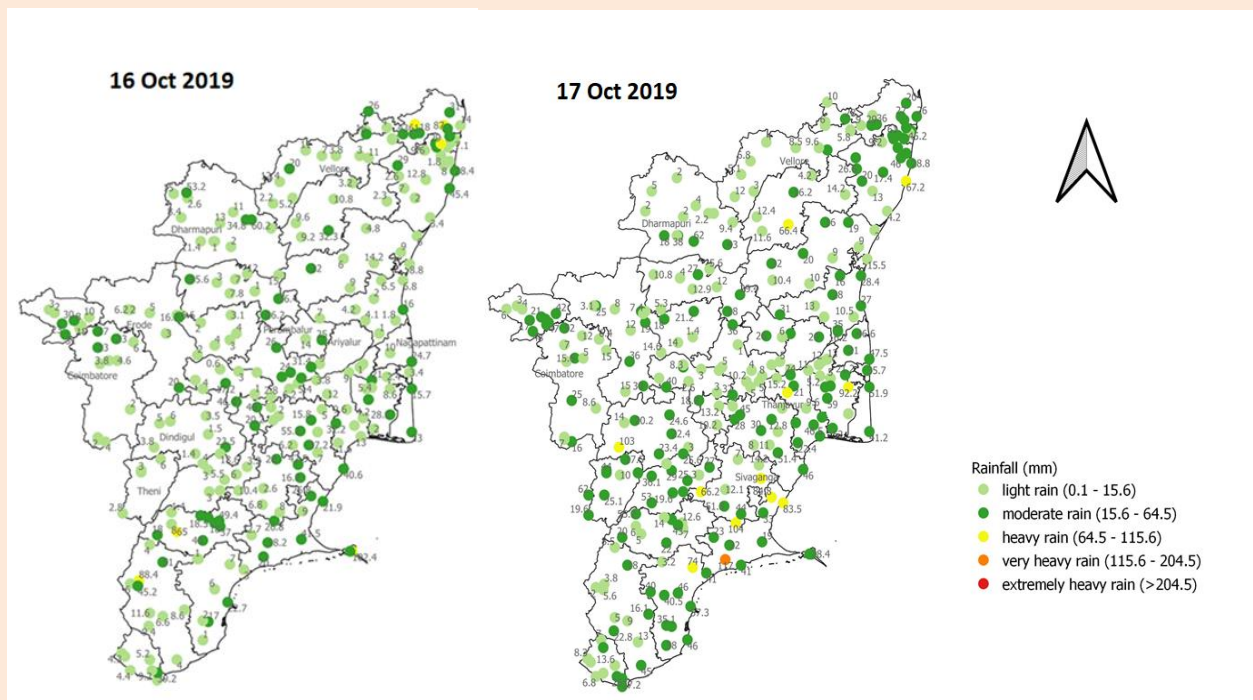


Fig.1f: Rainfall distribution (in mm) over TN based on point rainfall observation (raingauge) as on 24-hr ending 0830 IST of 16 & 17 Oct 2019.

3. Synoptic scale weather systems

3.1 Cyclones and Depressions

During October-December 2019, four major low pressure systems (LPS) formed over the BOB and AS (i) Super Cyclonic Storm (SuCS) *KYARR* over AS during 24th October - 02nd November 2019 (ii) Extremely Severe Cyclonic Storm (ESCS) *MAHA* over AS during 30th October -07th November 2019 (iii) Very Severe Cyclonic Storm (VSCS) *BULBUL* over BOB during 05th-11th November 2019 and (iv) Cyclonic Storm (CS) *PAWAN* over AS during 02nd -07th December 2019. Brief life history of these systems (based on IMD's preliminary reports on these systems) is presented below:

(i) ***SuCS KYARR over AS during 24th October - 02nd November 2019:*** SuCS *KYARR* originated from a low pressure area (LOPAR) that formed over southeast AS on the morning of 17th October (0830 IST). It concentrated into a depression (D) over eastcentral AS on 24th/ 0830 IST. Moving east-northeastwards, it intensified into CS 'KYARR' on 25th/0530 IST and further into a severe cyclonic storm (SCS) by 1730 IST of the same day (25th). It then recurved west-northwestwards and intensified into a VSCS over the eastcentral AS on the early morning of 26th (0530 IST) and further into an ESCS by 2030 IST of the same day over the same region. Continuing to move west-northwestwards, it further intensified into SuCS in the early morning (0530 IST) of 27th October. It attained the peak maximum sustained surface wind speed (MSW) of 235-245 kmph (130 kt) gusting to 260 kmph during 1430 to 2330 IST of 27th October over the eastcentral AS.

Subsequently, under unfavourable environmental conditions such as lesser ocean heat content, cold and dry air entrainment into the core of the system, it started weakening. It weakened into an ESCS by 29th/0830 IST and into VSCS by 30th/0530 IST. It then recurved west-southwestwards by 1130 IST of 30th under the influence of an anticyclone located to the northwest of the system and continued to weaken further. It weakened into an SCS by 2030 IST of 30th and further into CS over westcentral AS by 0830 IST of 31st and into a D in the early morning (0530 IST) of 1st November. Subsequently, moving towards Somalia coast, it weakened into a well marked LOPAR by the midnight of 2nd November 2019 off Somalia coast. The track of the system and INSAT-3D imagery as on 27th October / 1730 IST are presented in Fig.2a(i&ii).

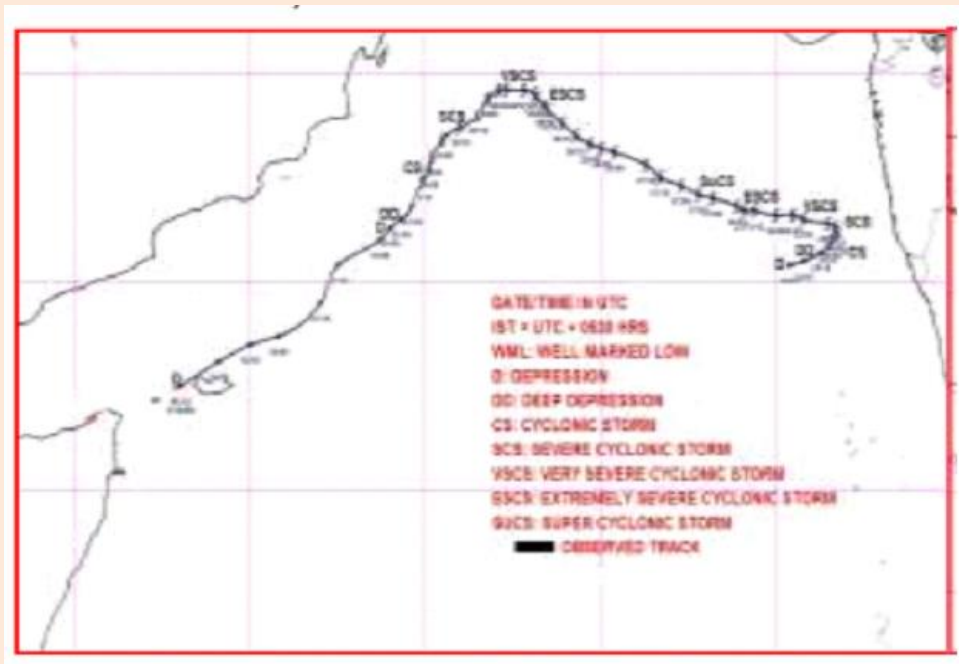


Fig.2a(i): Track of the SuCS KYARR during 24 Oct – 02 Nov 2019

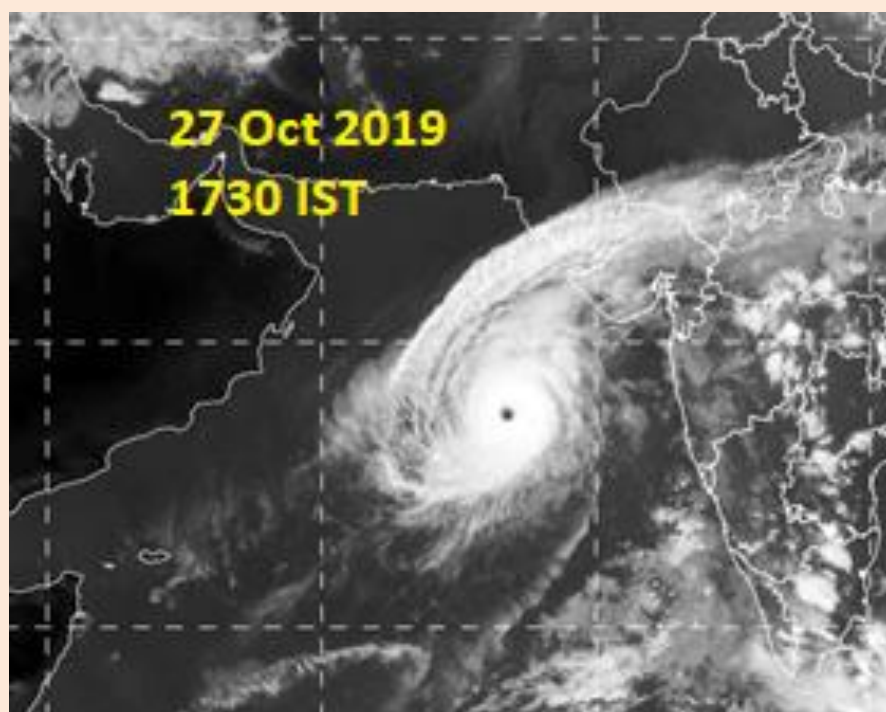


Fig.2a(ii): INSAT-3D imagery of SuCS KYARR as on 27th October 2019 / 1730 IST

(ii) ESCS MAHA over AS during 30th October – 07th November 2019 : ESCS MAHA formed as a LOPAR over equatorial Indian Ocean off south Sri Lanka coast on 28th October 2019 forenoon (1130 IST). It became well marked LOPAR over Comorin area and adjoining equatorial Indian Ocean on 29th /0530 IST. Moving west-northwestwards, under favourable environmental conditions, it concentrated into D over Maldives-Comorin Area on 30th /0530 IST. It intensified into a Deep Depression (DD) over Lakshadweep and adjoining Southeast AS& Maldives Area in the afternoon (1430 IST) of 30th and further into CS ‘MAHA’ in the evening (1730 IST) of 30th over Lakshadweep and adjoining Southeast Arabian Sea & Maldives Area. It intensified into SCS on 31st /1130 IST over Lakshadweep and adjoining Southeast AS. Moving across Lakshadweep Islands, it emerged into eastcentral AS by 2030 IST of the same day. Moving northwards it gradually intensified into a VSCS on 03rd November, 1430 IST over eastcentral AS. It then moved west-northwestwards and further intensified into an ESCS on 04th /0530 IST over the eastcentral & adjoining westcentral AS. Moving nearly north-northwestwards, it came under the influence of colder sea surface temperatures and increased vertical wind shear and weakened into a VSCS on 05th. Subsequently, under the influence of a mid-latitude westerly trough it started moving eastwards from the evening (1730 IST) of 05th .November. However, under the influence of increased vertical wind shear, it weakened into a SCS on 06th / 0530 IST over the eastcentral and adjoining northeast AS. Continuing to move eastwards, it further weakened into a CS on 06th / 1730 IST and further into a D on 07th/ 1130 IST over the eastcentral and adjoining northeast AS. By the evening of 07th November (1730 IST), it weakened into a well marked low pressure area over northeast AS and adjoining coastal Saurashtra. The track of the system is shown in Fig.2b(i) and INSAT-3D imagery showing the system as on 04th November 2019, 1730 IST is presented in Fig.2b(ii).

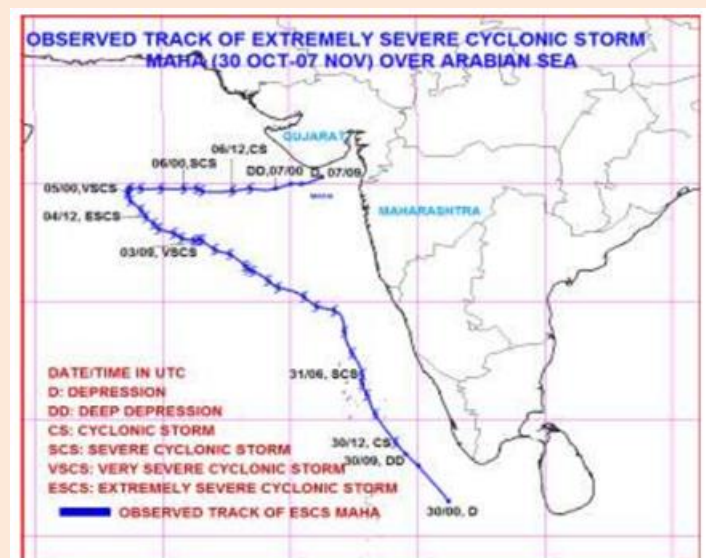


Fig.2b(i): Track of the ESCS MAHA during 30 Oct – 07 Nov 2019

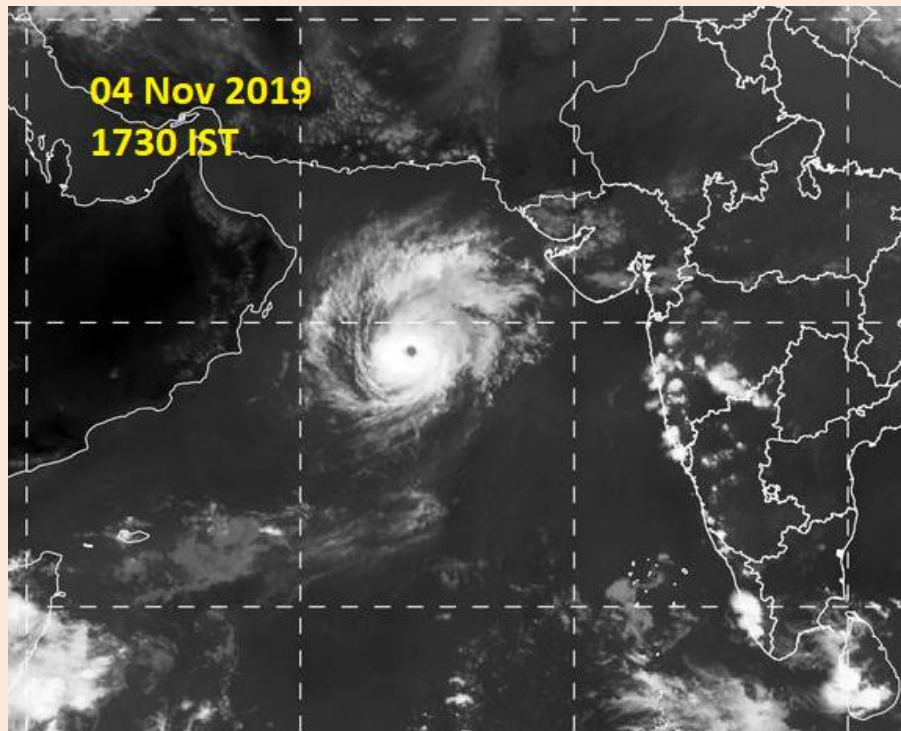


Fig.2b(ii): INSAT-3D imagery of ESCS MAHA as on 04th November 2019 / 1730 IST

Associated with the formation of MAHA over the Maldives-Comorin area during 29th-30th October, there was good rainfall activity over TN and adjoining areas during 29th-31st October. GPM-guage merged rainfall over the NEM region as on 24-hr ending 0830 IST of 30th October and guage rainfall over TN as on 24-hr ending 0830 IST on 30th& 31st October 2019 are presented in Fig.2b(iii).

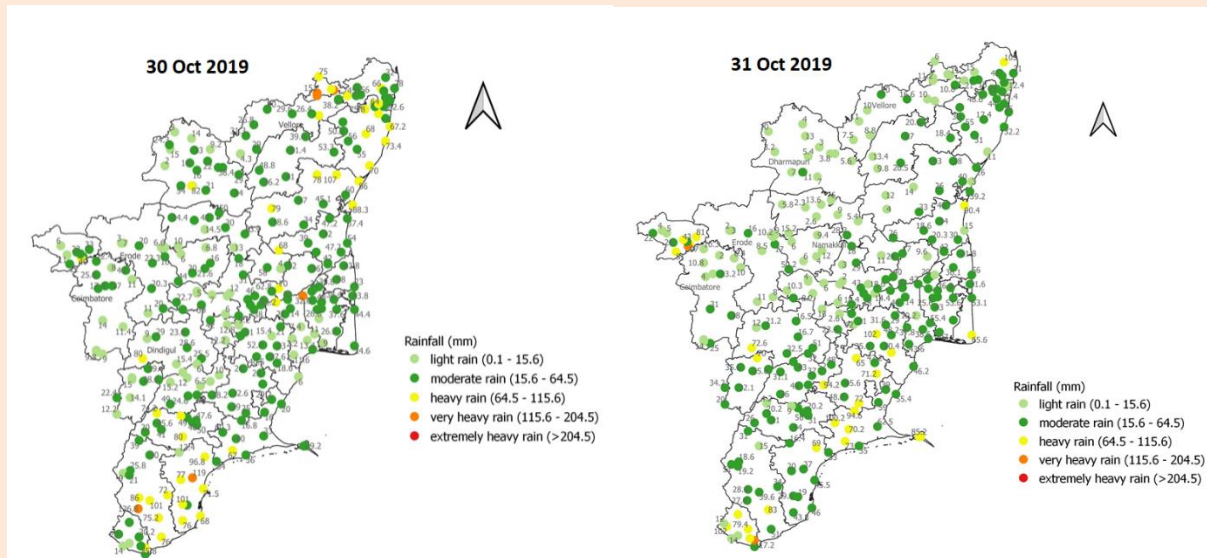
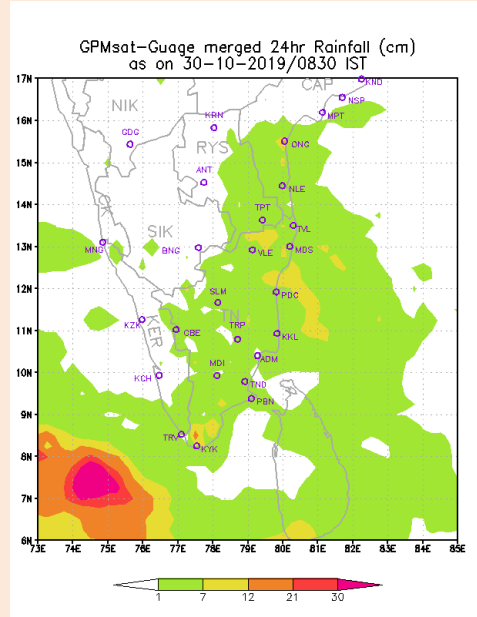


Fig.2b(iii): GPM-Guage merged rainfall over the NEM region as on 24-hr ending 0830 IST of 30th October and guage rainfall over the TN sub division as on 24-hr ending 0830 IST of 30th and 31st October 2019

(iii) VSCS BULBUL over BOB during 05th – 11th November 2019 : VSCS BULBUL formed as a LOPAR over north Andaman Sea in the early morning of 04th November 2019 (0530 IST). Moving west-northwestwards, under favourable environmental conditions it concentrated into D over eastcentral and adjoining southeast BOB on 05th morning (0530 IST). Moving nearly west-northwestwards, and then north-northwestwards, it gradually intensified into CS BULBUL in the late night (2330 IST) of 06th November over eastcentral and adjoining southeast BOB.

Continuing to move north-northwestwards it further intensified into SCS on 07th/1730 IST over westcentral and adjoining eastcentral BOB. Moving nearly northwards, it further intensified into a VSCS on 08th/0530 IST over westcentral and adjoining eastcentral BOB. It continued to move nearly northwards until the afternoon (1430 IST) of 09th and then re-curved northeastwards. Subsequently, it weakened into a SCS and crossed West Bengal coast, close to Sunderban Dhanchi Forest near 21.55°N/88.5°E during the night (2030-2330 IST) of 09th as a SCS with maximum sustained surface wind speed of 110-120 kmph gusting to 135 kmph. Continuing to move northeastwards, it weakened into a cyclonic storm over coastal Bangladesh & neighbourhood in the early morning of 10th November (0530 IST). It then moved east-northeastwards, weakened into a depression on 11th / 0530 IST over southeast Bangladesh & adjoining Tripura and further into a well marked LOPAR over southern parts of Tripura & neighbourhood by 0830 IST of 11th November 2019. The track of the system is shown in Fig.2c(i) and INSAT-3D imagery showing the system as on 04th November 2019, 1730 IST is presented in Fig.2c(ii).

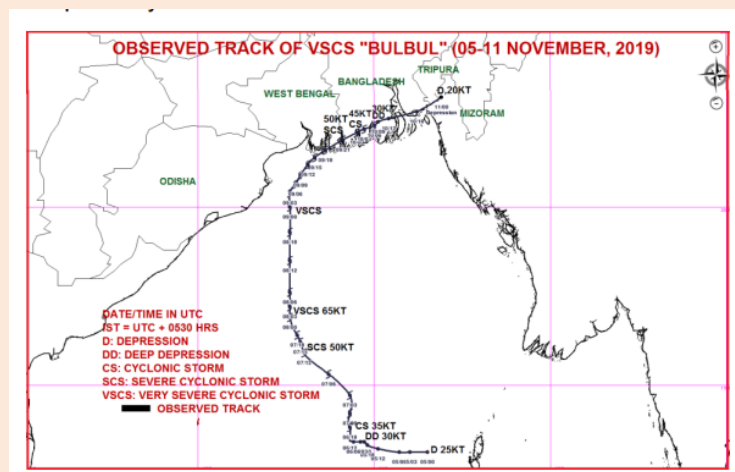


Fig.2c(i): Track of the VSCS BULBUL during 05th-11th November 2019

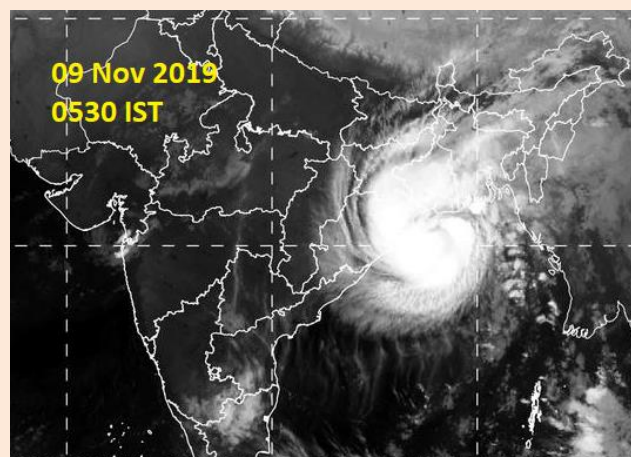


Fig.2c(ii): INSAT-3D imagery of VSCS BULBUL as on 09th November 2019 / 0530 IST

(iv) CS PAWAN over AS during 02nd– 07th December 2019 : CS PAWAN formed as a LOPAR over southwest AS and adjoining equatorial Indian Ocean (EIO) in the early morning (0530 IST) of 30th November, 2019. Under favourable environmental conditions, it concentrated into D over southwest AS & the adjoining EIO on 02nd December / 1730 IST. Moving north-northwestwards, it further intensified into a deep depression (DD) over southwest AS & adjoining EIO on 3rd/0530 IST. Continuing to move north-northwestwards, it intensified into CS “PAWAN” on 5th /0530 IST over southwest AS. It moved north-northwestwards till about noon of 5th and then moved nearly westwards till 2030 IST of 5th. Thereafter it exhibited west-southwestwards re-curvature. Moving west-southwestwards, it crossed Somalia coast near latitude 7.4°N and longitude 49.6°E during 0730-0830 IST of 07th December 2019 as a CS with maximum sustained wind speed of 60-70 kmph gusting to 80 kmph. Moving nearly westwards, it weakened into a DD on 07th /0830 IST over coastal Somalia & neighbourhood and further into a D by 07th/1430 IST. By the night of 07th December 2019 (2030 IST), it weakened into a well marked LOPAR over north Somalia & adjoining Ethiopia.

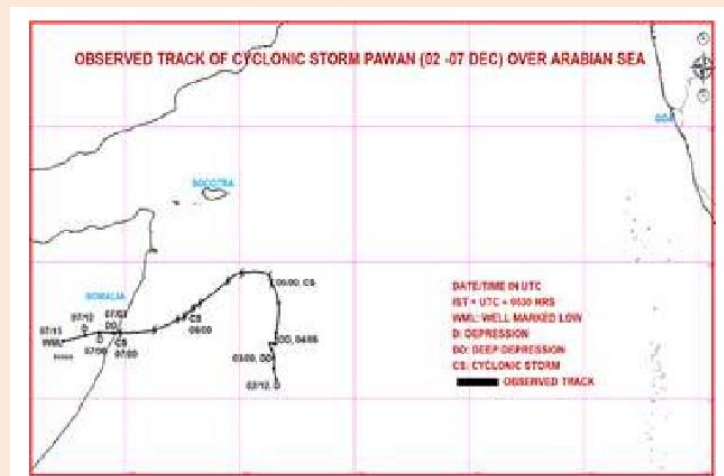


Fig.2d(i): Track of the CS PAWAN during 02nd-07th December 2019

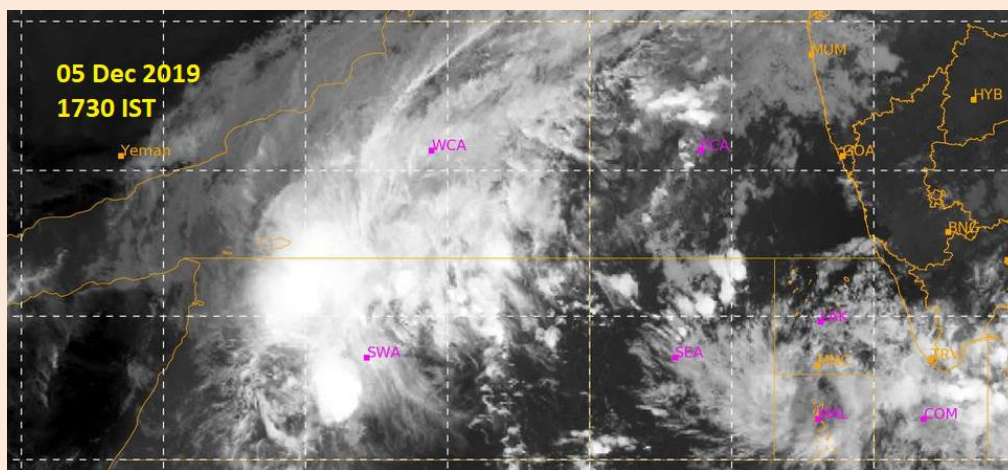


Fig.2d(ii): INSAT-3D imagery of CS PAWAN as on 05th December 2019 / 1730 IST

Excepting the CS PAWAN during the first week of December, the other three cyclones influenced the NEM rainfall considerably. Formation of the first three cyclones in quick succession – first, the SuCS *KYARR* over AS during 24th October - 02nd November, followed by the ESCS *MAHA* over AS during 30th October -07th November followed by the VSCS *BULBUL* over BOB during 05th-11th November 2019 affected the seasonal flow pattern as well as transported moisture away from the NEM region. In fact, two cyclones existed simultaneously twice - *MAHA* formed even when *KYARR* was existing over the AS; and *BULBUL* formed over the BOB even when *MAHA* was existing over the AS [Fig.2e(i)].The 00 and 12 UTC profiles of precipitable water over Chennai (based on upper air soundings) shown in Fig.2e(ii) shows the sharp reduction in precipitable water over Chennai (NEM region) from 55-60 mm to 35-40 mm due to sweeping away of moisture by these cyclones during the first half of the principal rainy month of NEM season (Nov 2019).

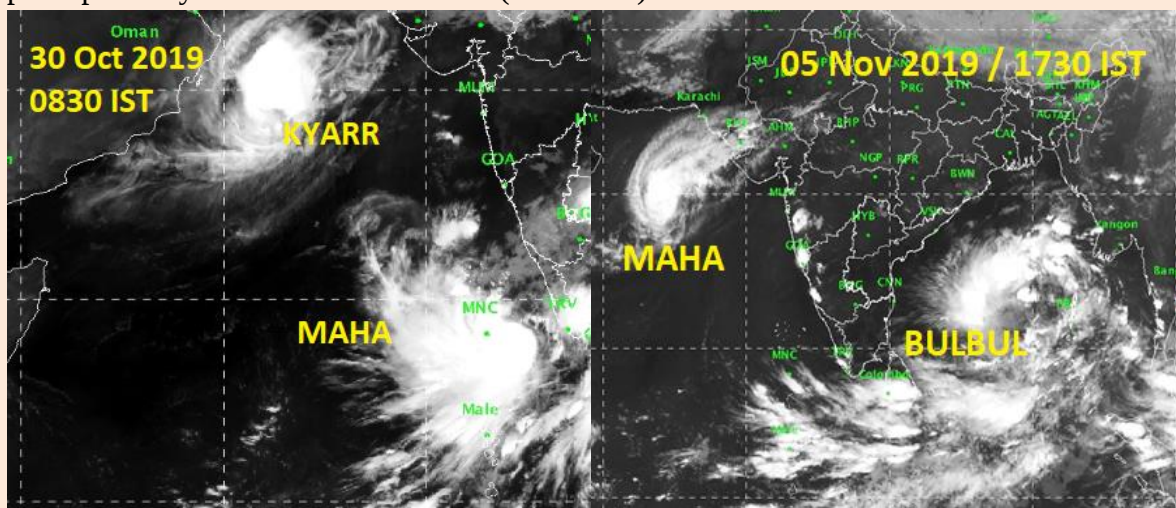


Fig.2e(i): Simultaneously occurrence of cyclones KYARR & MAHA; MAHA & BULBUL during the last week of October and first week of November 2019

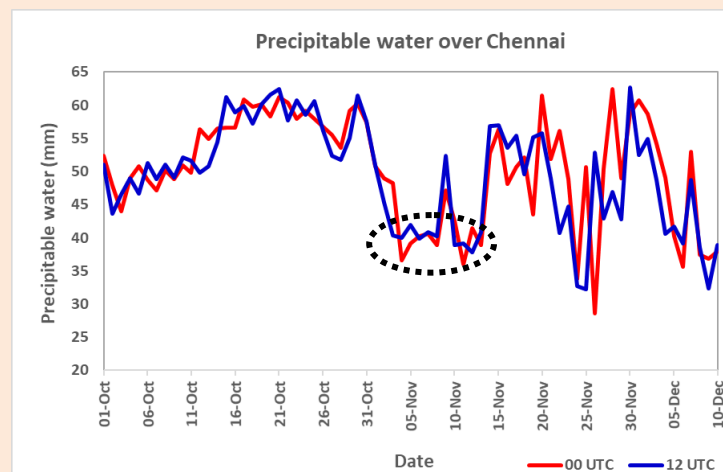


Fig.2e(ii): Precipitable water (mm) over Chennai

3.2 Other synoptic scale weather systems

The other major synoptic scale weather systems that influenced the NEM 2019 were the transient easterly wave troughs across the peninsular India. The commencement of NEM rains on 16th October took place under the influence of a westward moving trough in the easterlies across the southern peninsula during 15th-17th October [Fig.3a(i)]. Subsequently another trough in easterlies passed over the region during 27th-29th October [Fig.3a(ii)]. Later, during the last week of November, two more troughs in easterlies moved across the region in quick succession, one during 24th-26th November [Fig.3a(iii)] and another during 28th-30th November 2019 [Fig.3a(iv)]. Hovmoller plots of 6-hrly meridional wind at 700 hPa along 10°N depicting the passage of these four wave troughs are presented in Fig.3b. All these weather systems contributed significantly towards the NEM rainfall as depicted in Fig.3c.

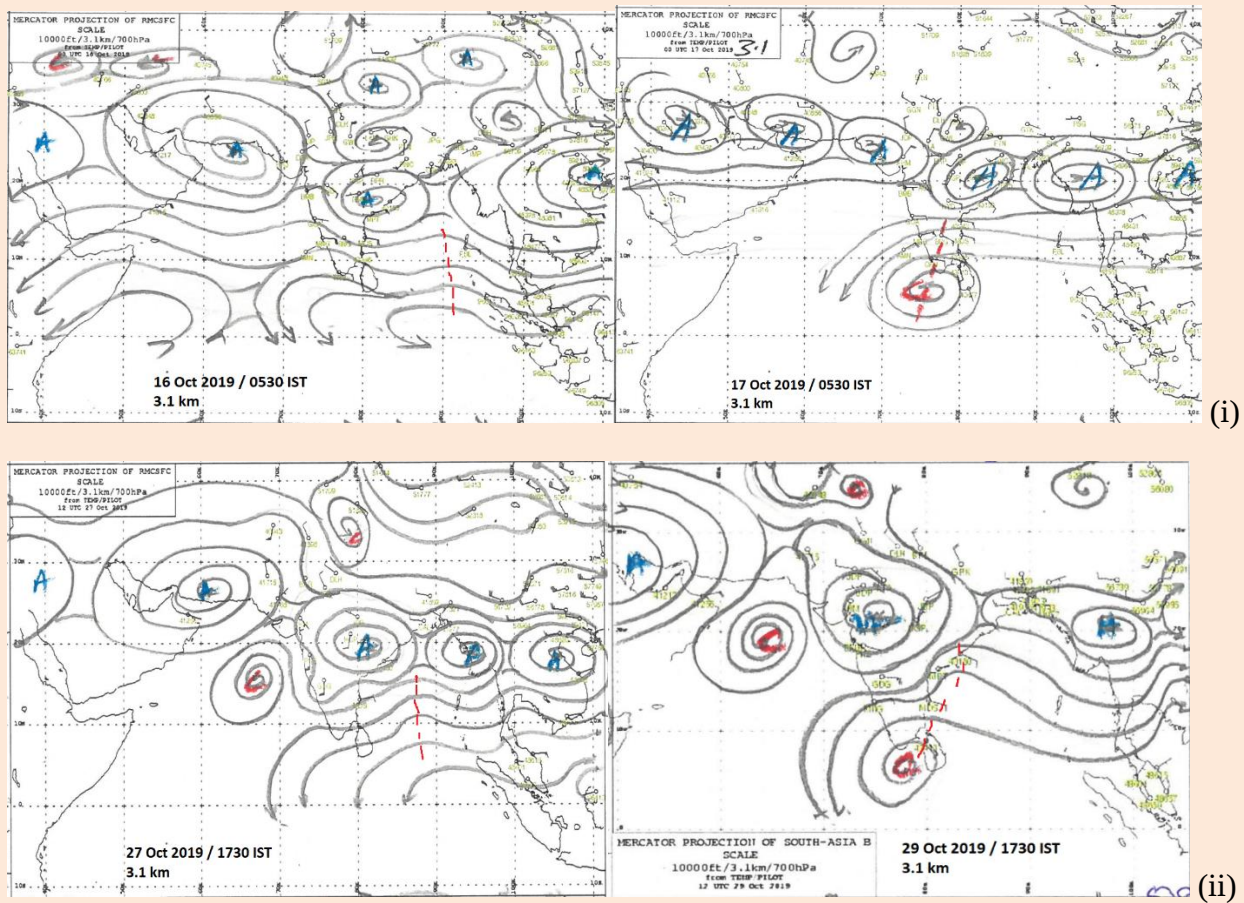
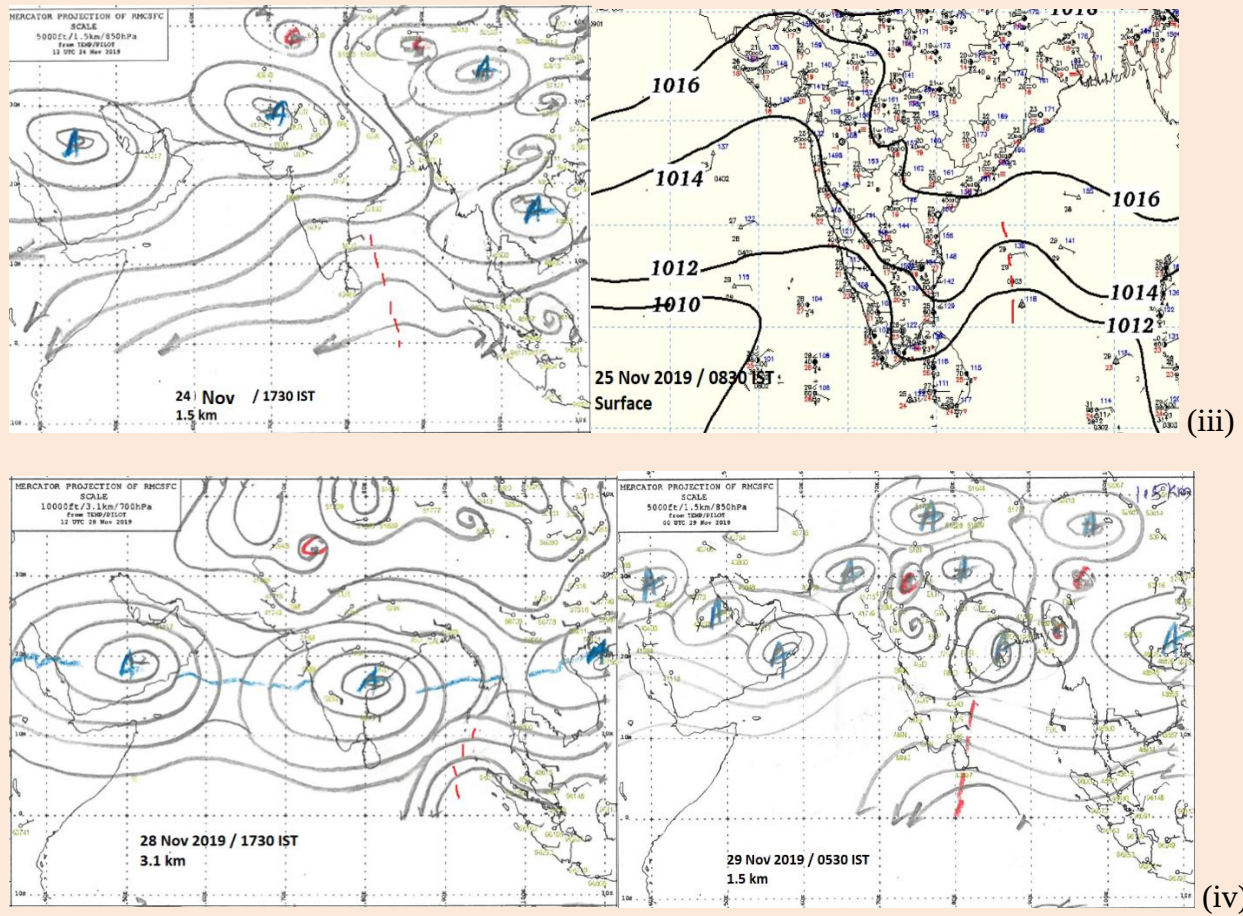


Fig.3a: Upper air / surface charts depicting westward moving troughs in easterlies across the NEM region during (i) 15th-17th Oct, (ii) 27th-29th Oct, (iii) 24th-26th Nov & (iv) 28th-30th Nov 2019



(Fig.3a: contd.)

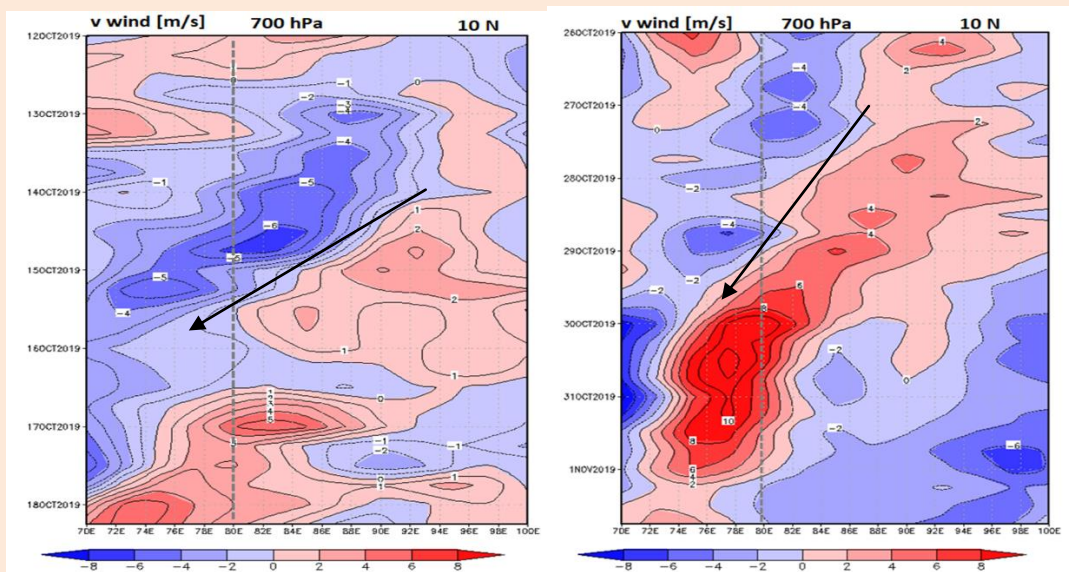
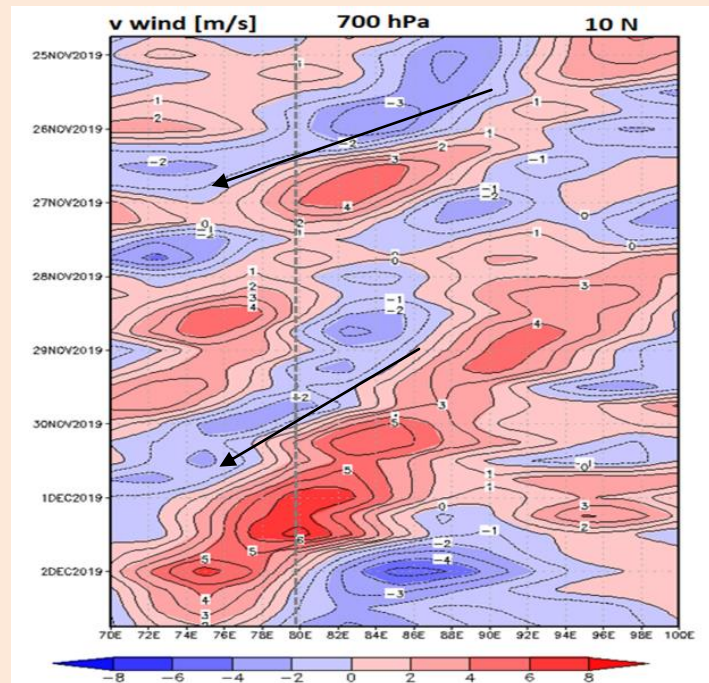


Fig.3b: Hovmoller plot of meridional wind (m/s) along 10°N. Arrows indicate the westward moving wave troughs across 80°E longitude



(Fig.3b: contd.)

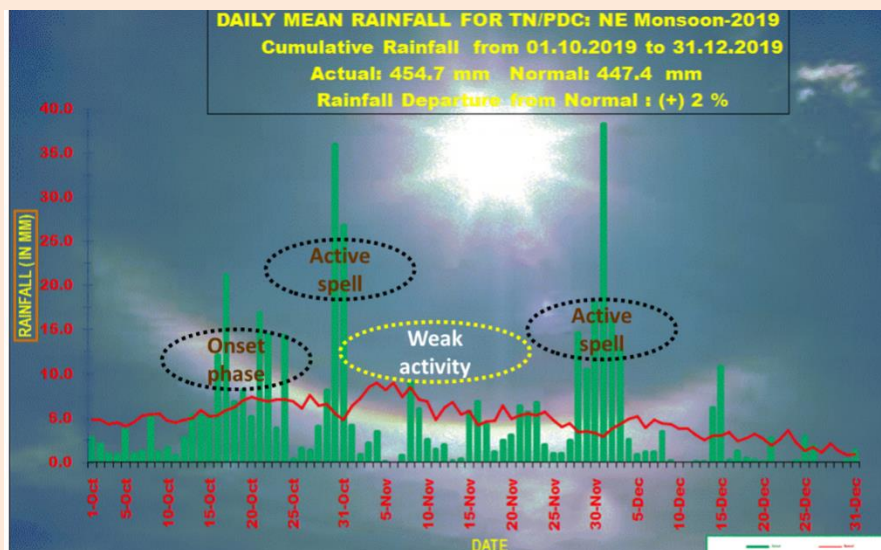


Fig.3c: Daily mean rainfall over TN subdivision during October-December 2019

Associated with the passage of the easterly wave trough heavy rainfall activity was observed over the NEM region. The spatial rainfall distribution and the heavy rainfall events over TN on 30th November and 01st December 2019 are depicted in Fig.3d. INSAT-3D IR imagery and DWR Chennai reflectivity product as on 01st December 2019 / 0300 UTC depicting the heavy rainfall event are presented in Fig.3e(i&ii).

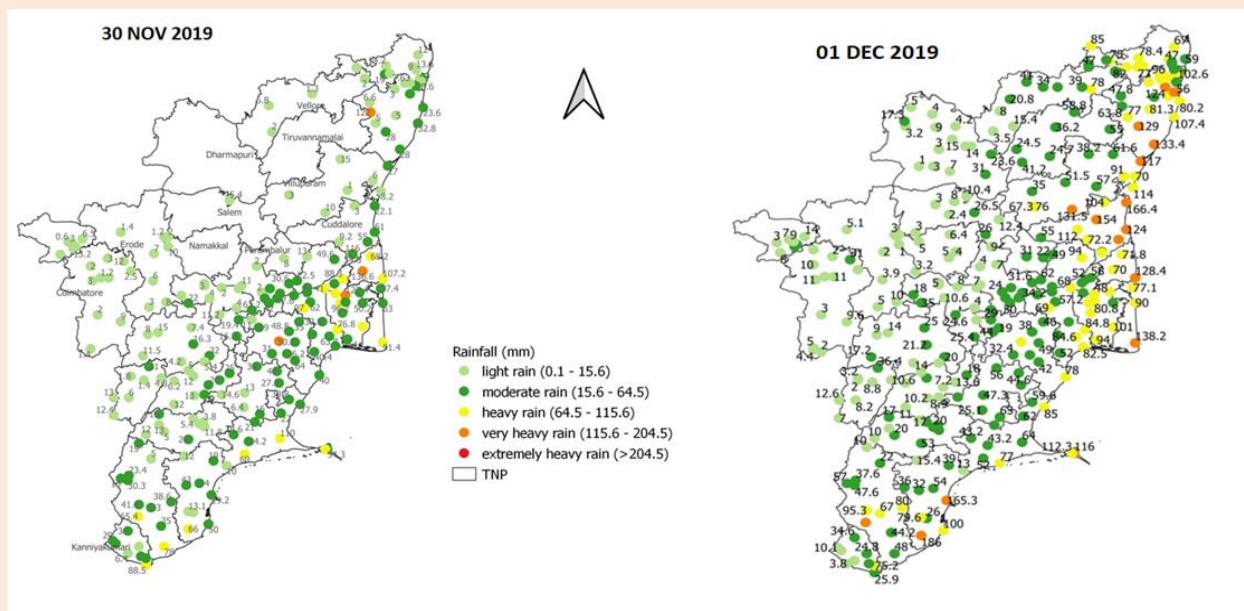


Fig.3d: Rainfall distribution and heavy to very heavy rainfall events over TN sub-division on 30th November and 01st December 2019

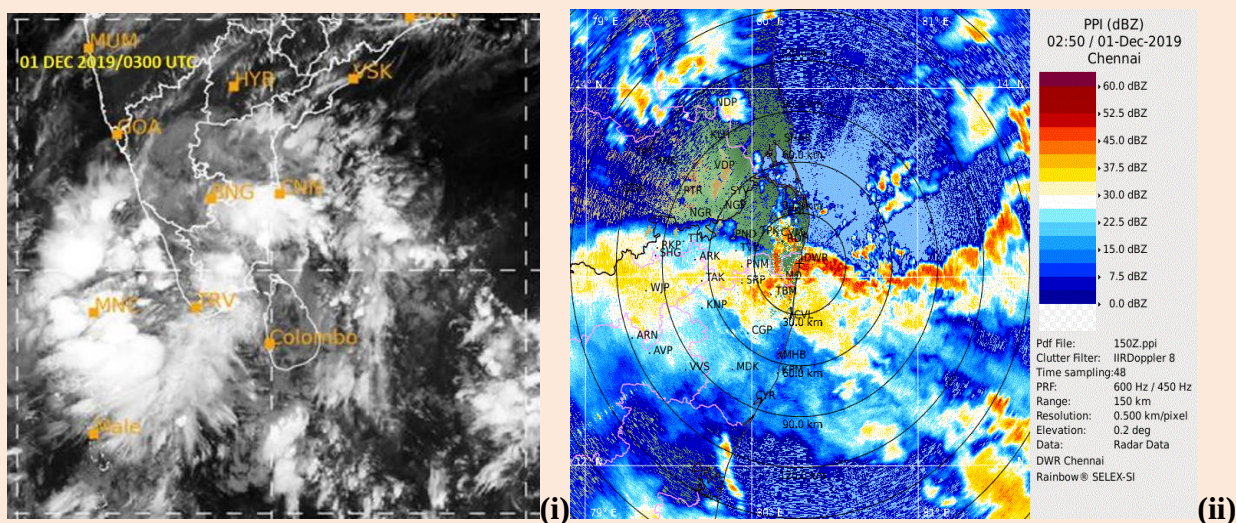


Fig.3e: (i) INSAT-3D IR imagery and (ii) Doppler Weather Radar- Chennai, reflectivity product as on 01st December 2019 / 0300 UTC.

4. Sub-divisional rainfall performance

4.1 Seasonal rainfall

During 2019, the northeast monsoon rainfall was normal (-19% to +19%) to excess(+20% to +59%)over the 5 meteorological subdivisions benefitted by the NEM (TN, KER, CAP, RYS and SIK). It was *excess* over SIK (+50%) and KER (+31%) and *normal* over TN, RYS and CAP (+2%, +1% & -11% respectively). Fig.4 and Table-1 present the season ending (01st Oct-31st Dec) rainfall figures over these subdivisions.

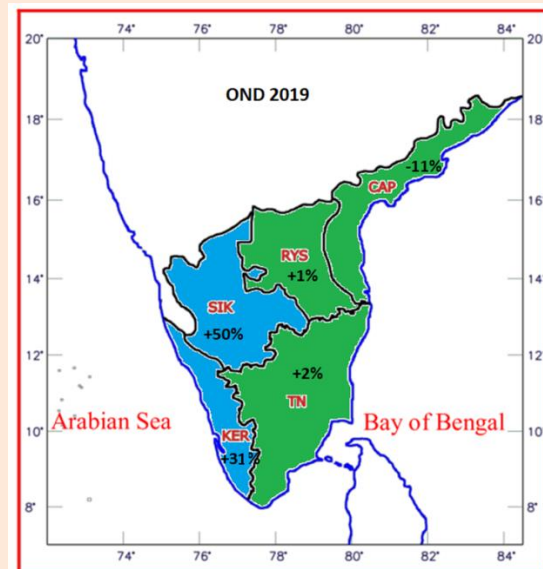


Fig.4: Seasonal rainfall performance of NEM 2019 over the five meteorological subdivisions benefitted by the NEM

Table-1: Sub-divisional seasonal rainfall during October-December 2019

Subdivision	01 st October – 31 st December 2019		
	Actual (mm)	Normal (mm)	PDN (%)
TAMIL NADU, PUDUCHERRY & KARALKAL	454.7	447.4	+2%
KERALA& MAHE	645.7	491.6	+31%
COASTAL ANDHRA PRADESH& YANAM	300.7	338.1	-11%
RAYALASEEMA	225.4	223.3	+1%
SOUTH INTERIOR KARNATAKA	307.1	204.1	+50%

PDN: Percentage Departure from Normal

Legend:

<i>Largely Deficient</i>	<i>Deficient</i>	<i>Normal</i>	<i>Excess</i>	<i>Large Excess</i>
≤ -60%	-20% to -59%	-19% to +19%	+20% to +59%	≥ +60%

4.2 Monthly, Weekly & Daily rainfall performance

The intra-seasonal rainfall distribution over various sub-divisions during Oct-Dec 2019 is presented in monthly, weekly and daily scales. Month-wise rainfall statistics are presented in Table-2. Table-3a&b depicts the weekly rainfall scenario (weekly & cumulative).

Table-2: Sub-divisional monthly rainfall during NEM 2019

Sub-division	OCT			NOV			DEC		
	Actual (mm)	Normal (mm)	PDN (%)	Actual (mm)	Normal (mm)	PDN (%)	Actual (mm)	Normal (mm)	PDN (%)
TN	223.1	177.2	+26%	125.8	178.5	-30%	105.8	91.7	+15%
KER	490.3	303.4	+62%	119.2	153.4	-22%	36.3	34.8	+4%
CAP	252.6	191.3	+32%	20.2	117.3	-83%	28.0	29.5	-5%
RYS	168.9	129.8	+30%	20.8	70.2	-70%	35.6	23.3	+53%
SIK	259.3	141.6	+83%	31.3	50.6	-38%	17.2	11.9	+44%

(TN, KER, CAP, RYS, SIK and Legend: same as Table-1)

Table-3a: Week by week rainfall departures (%) during NEM 2019

	02/10/2019	09/10/2019	16/10/2019	23/10/2019	30/10/2019	06/11/2019	13/11/2019	20/11/2019	27/11/2019	04/12/2019	11/12/2019	18/12/2019	25/12/2019
TN		-56	-4	61	43	-28	-53	-32	-31	335	-77	-6	-64
KER		-35	3	175	74	43	-13	-46	-46	164	-94	380	-77
CAP		-45	29	112	69	-66	-99	-50	-96	129	-77	-58	-99
RYS		42	30	9	47	-73	-88	-34	-80	296	-71	29	-99
SIK		66	48	203	54	-33	46	-69	-74	267	-97	-81	-100

Table-3b: Weekly cumulative rainfall departures (%) during NEM 2019

	02/10/2019	09/10/2019	16/10/2019	23/10/2019	30/10/2019	06/11/2019	13/11/2019	20/11/2019	27/11/2019	04/12/2019	11/12/2019	18/12/2019	25/12/2019
TN		-55	-32	3	14	4	-6	-9	-11	13	6	1	3
KER		-34	-17	40	47	47	40	33	29	33	29	29	28
CAP		-53	-23	20	30	11	-1	-5	-11	-7	-9	-10	-11
RYS		21	30	24	29	12	-1	-2	-6	6	3	3	2
SIK		53	50	88	82	68	66	58	53	57	54	52	51

(TN, KER, CAP, RYS, SIK & Legend: same as Table-1)

TN: Tamil Nadu & Puducherry;
CAP: Coastal Andhra Pradesh;

KER: Kerala;
RYS: Rayalaseema; SIK: South Interior Karnataka

Table-4a&b present the daily rainfall scenario in terms of spatial rainfall distribution (*Widespread: WD, Fairly widespread: FWD, Scattered: SCT, Isolated: ISOL and DRY*). In the monthly scale, there was vast difference in the October and November rainfall performance. Whereas, in October, *excess to large excess* rainfall was received in all the five sub-divisions with KER and SIK recording *large excess*, in November, *deficient to largely deficient* rainfall was recorded in all the five sub-divisions with CAP and RYS coming under *largely deficient* category. In December, *normal to excess* rainfall was received in all the five sub-divisions with RYS and SIK recording *excess* rainfall.

In the weekly scale, during the week ending 04th December, *large excess* rainfall (+125% to +335%) was realized in all the 5 sub-divisions with 335% *excess* rainfall over TN. Further there was *normal to large excess* rainfall activity over all the 5 sub-divisions during the three weeks ending 16th October, 23rd October and 30th October. Associated with this rainfall activity, the cumulative seasonal rainfall over all the 5 sub-divisions was *normal to large excess* during all the weeks from the week ending 23rd October. By and large, all sub divisions received *deficient to largely deficient* rainfall during the four weeks ending 06th November, 13th November, 20th November and 27th November excepting KER which received *normal* and *excess* rainfall during the weeks ending 06th and 13th November respectively and SIK that received *excess* rainfall during the week ending 13th November.

In the daily scale, whereas KER, TN and SIK received scattered to widespread rainfall during 45%-55% of the days in the season, CAP and RYS experienced only isolated rainfall to dry conditions on 66% of the occasions.

Table-4a: Spatial rainfall distribution during Oct-Dec 2019

Subdivision	No. of days				
	WD	FWD	SCT	ISOL	DRY
TN	11	13	21	46	1
KER	24	8	18	31	11
CAP	2	7	22	38	23
RYS	1	10	20	33	28
SIK	11	18	13	28	22

WD: Widespread
(76-100% of stations reporting rainfall)
SCT: Scattered
(26-50% of stations reporting rainfall)
DRY: No rain

FWD : Fairly widespread
(51-75% of stations reporting rainfall)
ISOL: Isolated
(≤25% of stations reporting rainfall)

4.3 Monsoon activity and heavy rainfall statistics

Frequency of active and vigorous monsoon days and frequency of heavy rainfall days (**Heavy** rainfall $\geq 7\text{cm/day}$; **Very Heavy** rainfall $\geq 12\text{cm/day}$; **Extremely Heavy** rainfall $\geq 21\text{ cm/day}$).

Table-4b: Frequencies of active and vigorous monsoon days and heavy rainfall days

Subdivision	No. of days				
	Activity		Heavy Rainfall		
	Vigorous	Active	Extremely Heavy	Very Heavy	Heavy
TN	7	8	0	22	50
KER	5	20	0	8	29
CAP	2	4	1	7	22
RYS	2	6	0	0	14
SIK	4	14	0	5	19

Active: Fairly widespread to widespread sub-divisional rainfall with rainfall more than $1\frac{1}{2}$ to 4 times the normal with at least two stations reporting more than or equal to 5 cm in coastal Tamil Nadu, south coastal Andhra Pradesh and 3 cm elsewhere in the NEM region.

Vigorous: Fairly widespread to widespread sub-divisional rainfall with rainfall more than 4 times the normal with at least two stations reporting more than or equal to 5 cm in coastal Tamil Nadu, south coastal Andhra Pradesh and 3 cm elsewhere in the NEM region.

Heavy: rainfall $\geq 7\text{cm/day}$; **Very Heavy:** rainfall $\geq 12\text{cm/day}$; **Extremely Heavy:** rainfall $\geq 21\text{ cm/day}$

It is observed that 15-25 days of *active to vigorous* monsoon conditions prevailed over KER, SIK and TN during the season; however, there were only 6-8 days of *active to vigorous* activity over CAP and RYS during the season.

Regarding heavy rainfall occurrences ($\geq 7\text{ cm/day}$), TN experienced isolated *heavy* rainfall activity on 50 days during the season, out of which, 22 days were with isolated *very heavy* falls. In KER, CAP and SIK there were 29, 22 and 19 days respectively of isolated *heavy* rainfall activity with 8, 7 and 5 days respectively of isolated *very heavy* rain. Of the 7 days of *very heavy* rain in CAP, there was one day of isolated *extremely heavy* rainfall on 24th October. RYS experienced 14 days of isolated *heavy* rain. List of very heavy rainfall events is presented in Table-4c.

Table-4c: List of very heavy to extremely heavy rainfall events

District	Date, Station and 24-hr accumulated rainfall (in cm) (ending 0830 IST of the specified date)
COASTAL ANDHRA PRADESH & YANAM	
East Godavari	Oct : 19 th : Amalapuram -18, 23 rd : Amalapuram-16
Krishna	Oct : 19 th :Avanigada-18
Vishakhapatnam	Oct : 23 rd :Visakhapatnam-13, Anakapalle-12; 24 th : Bheemunipatnam-23
Prakasam	Oct : 30 th :Ongole-12
Nellore	Oct : 16 th : Gudur-12 Nov : 15 th :Gudur-12
Srikakulam	Oct : 23 rd :Kalingapatnam-12; 24 th :Mandasa-22, Sompeta-20, Ichchapuram-18, Palasa-16, Tekkali-12
Vizianagaram	Oct : 24 th : Balajipeta-14, Mentada-14, Nellimarla-14,Garividi-14, Bondapalle-14, Gajapathinagaram-13; 26 th : Garugubilli-13
Yanam	Oct: 19 th :Yanam-16
TAMIL NADU, PUDUCHERRY & KARAİKAL	
Nilgiris	Oct : 18 th : K Bridge-12; 19 th : Devala-13, K Bridge-12; 31 st Kodanad-14,Kadaikanal Boat club-14, Coonoor PTO-13 Nov : 17 th :Coonoor Pto-17, Coonoor-14 Dec : 02 nd :Coonoor Pto-13; 03 rd : Coonoor-13
Coimbatore	Oct : 21 st :Periyanaickenpalayam-12 Dec : 02 nd :Mettupalayam-18
Vellore	Oct : 30 th : Sholingur-14
Cuddalore	Oct : 24 th :Kilacheruvai-15; 30 th : Kilacheruvai-14 Nov : 29 th :Kattumannar Koil-12; 30 th : K.m.koil-12 Dec : 01 st :Cuddalore-17, Kurinchipadi-17, Chidambaram-13, Kuppanatham-13, Bhuvanagiri-13, Parangipettai-12, Annamalai Nagar-12
Nagapattinam	Nov : 29 th :Talaigayar-16, Mayiladuthurai-14 Nov : 30 th :Anaikaranchatram(kollid)-12 Dec : 01 st :Vedaranyam-14, Trangambadi(or)tranqueb-13 ; 25 th : Nagapattinam-14
Thanjavur	Nov : 29 th :Lower Anaicut-12
Tiruvannamalai	Oct : 30 th :Kalasapakkam-14
Tiruvallur	Oct : 30 th :Tiruttani-19, R.k.pet-15
Dindigul	Oct : 17 th : Kodaikanal Boat club-13
Villupuram	Dec : 01 st :Ulundurpet-13, Marakkanam-12
Ramanathapuram	Oct : 07 th : R.s.mangalam-16; 17 th :Kadaladi-12; 22 nd :Pamban and Mandapam-18, Thankachimadam-17 Dec : 01 st :Pamban-12
Thoothukudi	Oct : 17 th : Ettayapuram-14; 30 th :Ottapadiram-12 Nov : 15 th :Tiruchendur-13, Kayalpatinam-13 Dec : 01 st :Satankulam-19, Tuticorin-17

Erode	Oct : 13 th : Gobichettipalayam-13
Kanyakumari	Oct : 13 th : Kottaram-13; 19 th : Sivalogam-12; 21 st : Kuzhithurai-14; 31 st : Mylaudy-12
Chennai	Oct : 18 th : Ayanavaram-13, Perambur-12
Tirunelveli	Oct : 30 th : Papanasam-14, Manimutharu-14 Dec : 01 st : Manimutharu-15
Salem	Nov : 08 th : Sankaridurg-12
Namakkal	Nov : 09 th : Sendamangalam-14
Kancheepuram	Nov : 23 rd : Cheyyur-14; 28 th : Tambaram-15, IAF Tambaram-13 Dec : 01 st : Cheyyur-13, Maduranthagam-13, Tambaram-12, SatyabamaUty Arg-12
Pudukkottai	Nov : 30 th : Pudukkottai-13
Tiruvarur	Nov : 30 th : Kodavasal-13
Karur	Dec : 02 nd : Palaviduthi-12
Karaikal	Dec : 25 th : Karaikal-13
SOUTH INTERIOR KARNATAKA	
Chikkamagaluru	Oct : 21 th : Ajjampura-17, Lakkavalli-13, Yegati-13, Shivani-12
Mandya	Nov : 09 th : Krishnarajasagara-16
Shivamogga	Oct : 09 th : Hosanagar-16
KERALA & MAHE	
Ernakulam	Oct : 21 st : Ernakulam South-20, Kochi AP-16
Kasargod	Oct : 24 th : Kudulu-14
Malappuram	Oct : 20 th : Perinthalmanna-12
Kottayam	Oct : 13 th : Kozha-14; 21 st : Vaikom-19, Kozha-15, Kanjirappally-12
Thrissur	Oct : 14 th : Chalakudy-13; 22 nd : Chalakudy-15
Kannur	Oct : 21 st : Taliparamba-13
Palakkad	Oct : 19 th : Pattambi-12
Alapuzha	Oct : 21 st : Alappuzha-17, Mancompu-17
Kollam	Oct : 21 st : Punalur-12

5. District rainfall performance

The seasonal rainfall was well distributed in all the five sub-divisions. All districts in the NEM sub-divisions excepting Madurai, Perambalur, Vellore, Thiruvannamalai and Puducherry in TN sub-division and Prakasam, Krishna and West Godavari districts in CAP which came under *deficient* category received *normal* to *large excess* rainfall during the season. Davangere (+117%), Chikkamagaluru (+107%), Shivamogga (+103%), Chitradurga (+92%) and Mandya (+65%) in SIK, Kasargod(+83%) in KER and Nilgiris (+64%) in TN received *large excess* rainfall during the season. Fig.5 presents the district rainfall (in percentage departures from normal) in the sub-divisions of TN, CAP & RYS, SIK and KER.

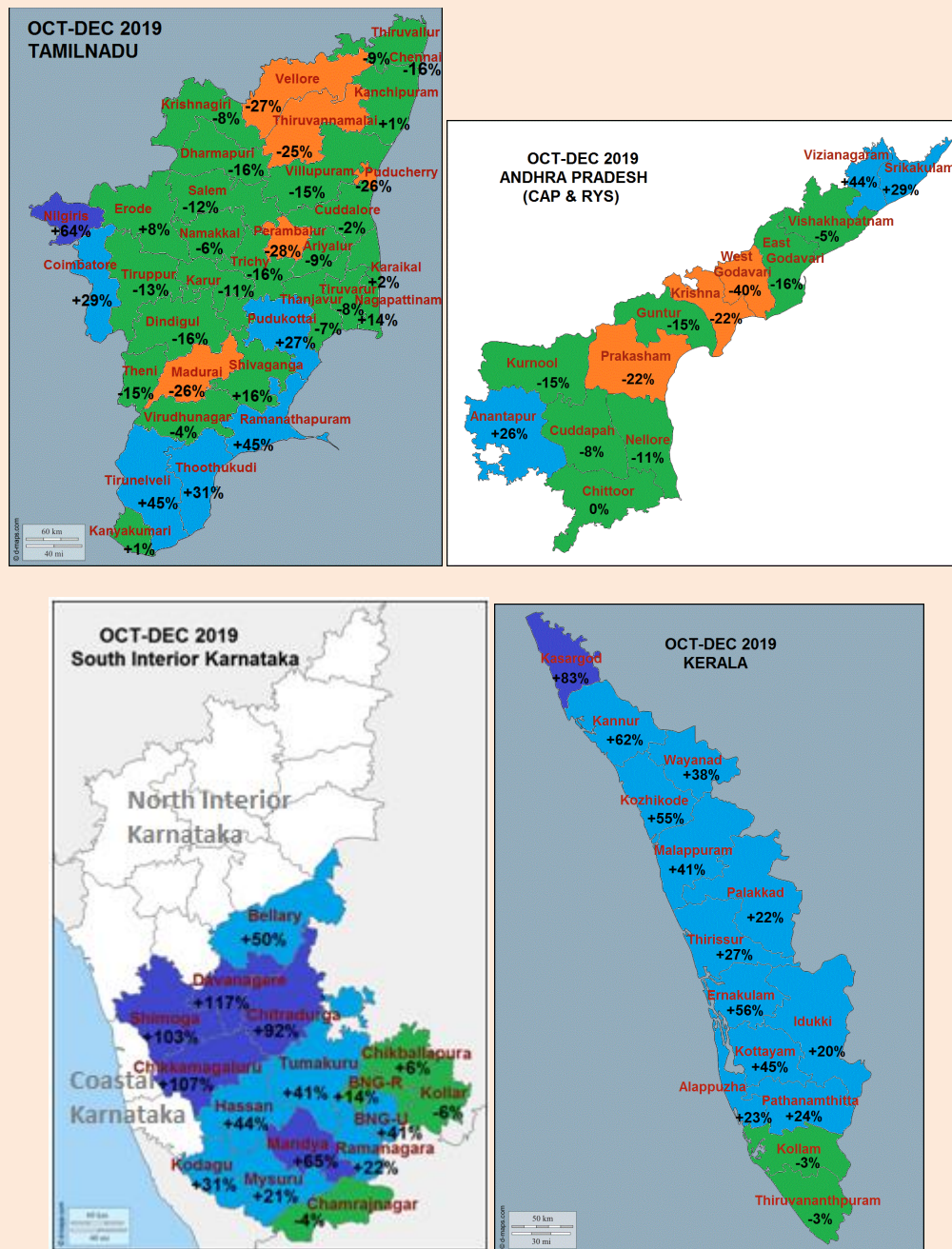


Fig.5 District-wise seasonal rainfall performance over the sub-divisions of TN, CAP & RYS, SIK and KER during the NEM 2019

6. Standardised Precipitation Index

The Standardized Precipitation Index (SPI) is an index used for monitoring drought and is based on precipitation. This index is negative for dry and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. For October–December 2019, SPI indicated wet conditions over many parts of the NEM region (Fig.6). In TN, excepting Virudunagar, Madurai, Theni, Tiruppur, Dindigul, Salem, Dharmapuri, Krishnagiri, Karur, Thiruchirapalli, Perambalur, Villupuram, Thiruvannamalai, Vellore & Thiruvallur districts which came under *mildly dry* category, all other districts were under *mildly to severely wet* categories. In KER, excepting Idukki (*mildly dry*), all districts came under *mildly to moderately wet* categories. In CAP, Nellore, Prakasham, Guntur, Krishna, West Godavari and East Godavari districts became *mildly dry* while the other three districts in the extreme northern parts – Visakhapatnam, Vizianagaram and Srikakulam came under *mildly wet* category. In SIK and RYS, excepting Cuddapah (*mildly dry*), all districts were under *mildly to moderately wet* categories.

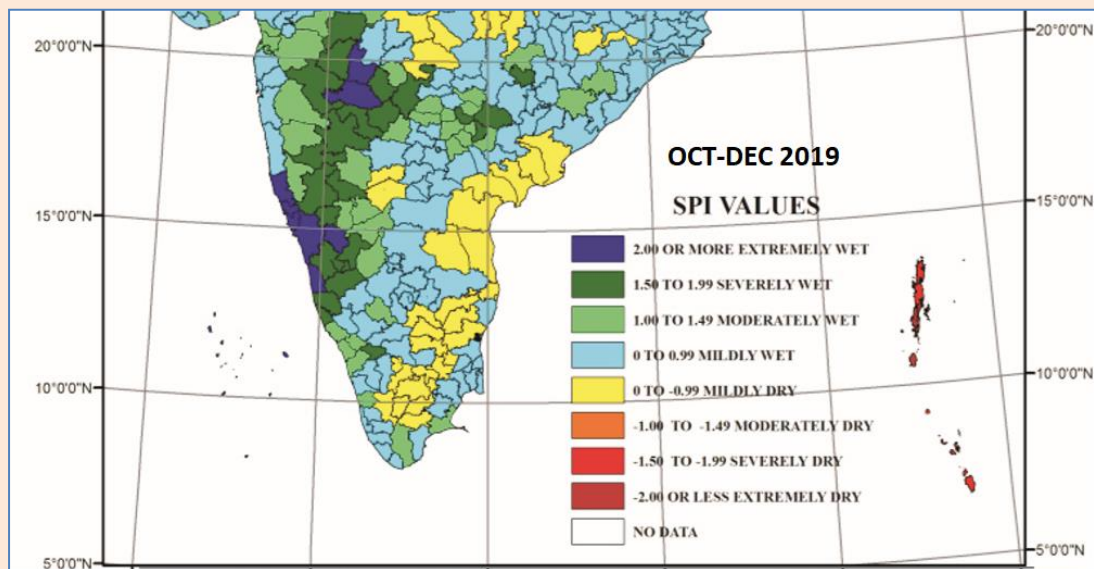


Fig.6: Standardised Precipitation Index for October–December 2019 over the southern peninsular India.

7. Chief circulation features

(a) **Synoptic scale features:** The mean and anomalous wind pattern over the Indian region at 850 hPa, 500 hPa and 250 hPa levels during October –December 2019 (Fig.7a-c) indicate the following:

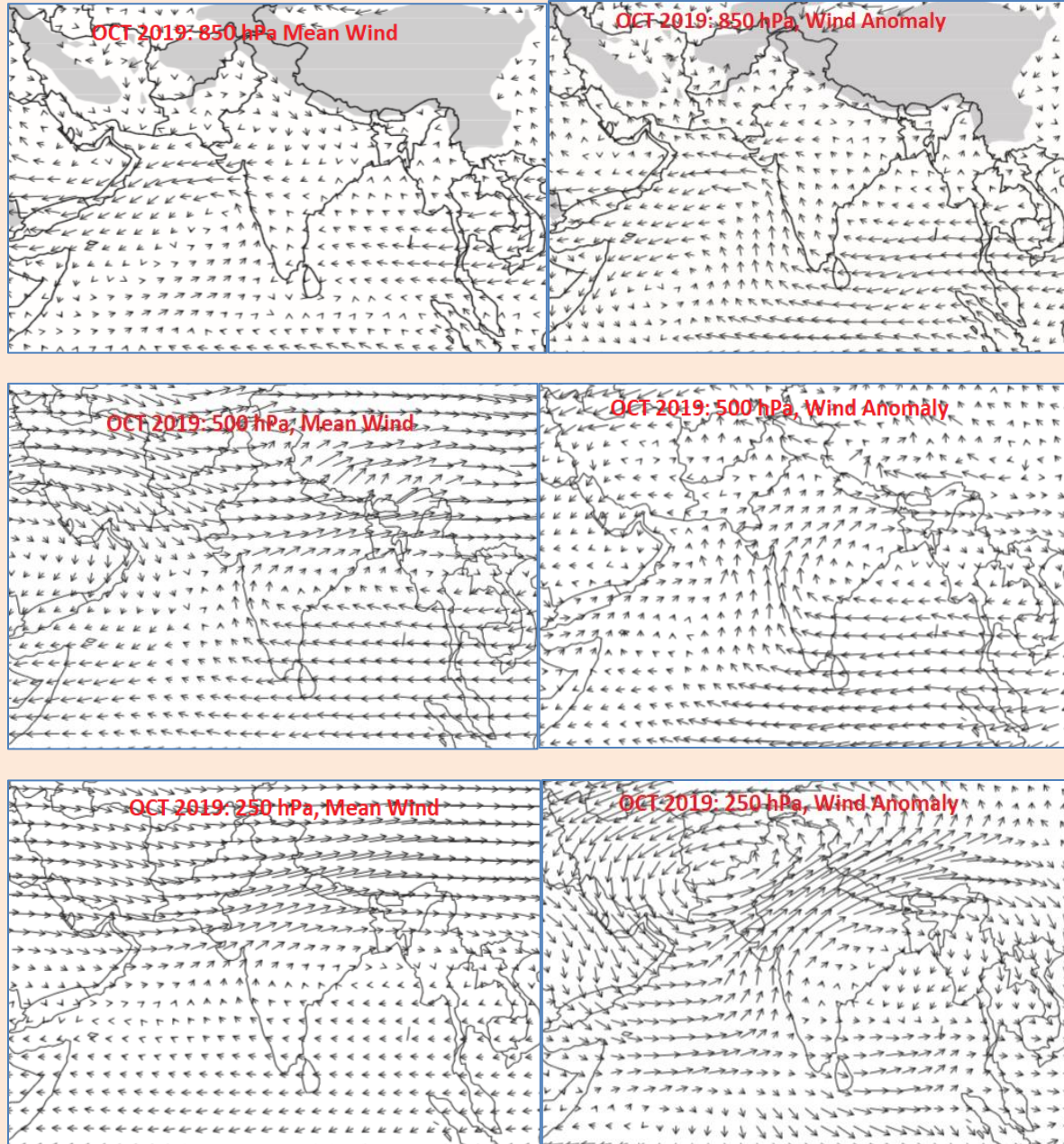


Fig.7a: Mean and anomalous wind pattern over the Indian region at 850 hPa, 500 hPa and 250 hPa levels during October 2019 (Source: Climate Diagnostic Bulletin of India, IMD Pune)

In October, anomalous easterlies are observed over the southern parts of India and anomalous trough in the easterlies over the Arabian Sea. At 500 hPa, anomalous easterlies are present over the southern and central Bay of Bengal and adjoining southern peninsula and a ridge over the head Bay of Bengal. At 250 hPa, anomalous cyclonic circulation is observed over Afghanistan, Pakistan and adjoining areas with a deep amplitude anomalous westerly trough extending southwards over the Arabian Sea.

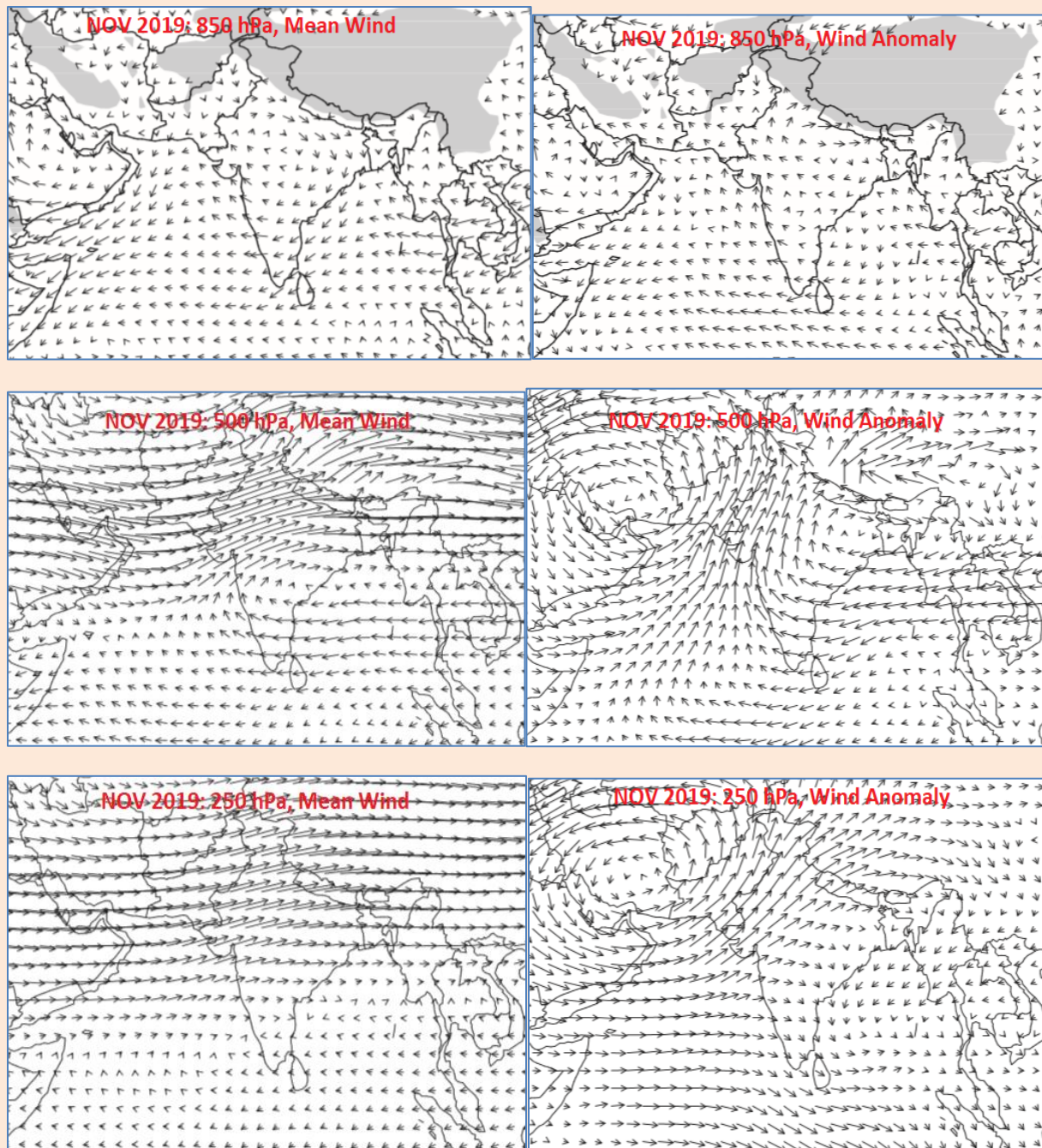


Fig.7b: Mean and anomalous wind pattern over the Indian region at 850 hPa, 500 hPa and 250 hPa levels during November 2019 (Source: Climate Diagnostic Bulletin of India, IMD Pune)

In November, at 500 hPa level, anomalous easterlies are observed over the Bay of Bengal, anomalous cyclonic circulation to the west of Pakistan and anomalous southerlies over the Arabian Sea. The anomalous cyclonic circulation to the west of Pakistan at 500 hPa level extends upto 250 hPa level.

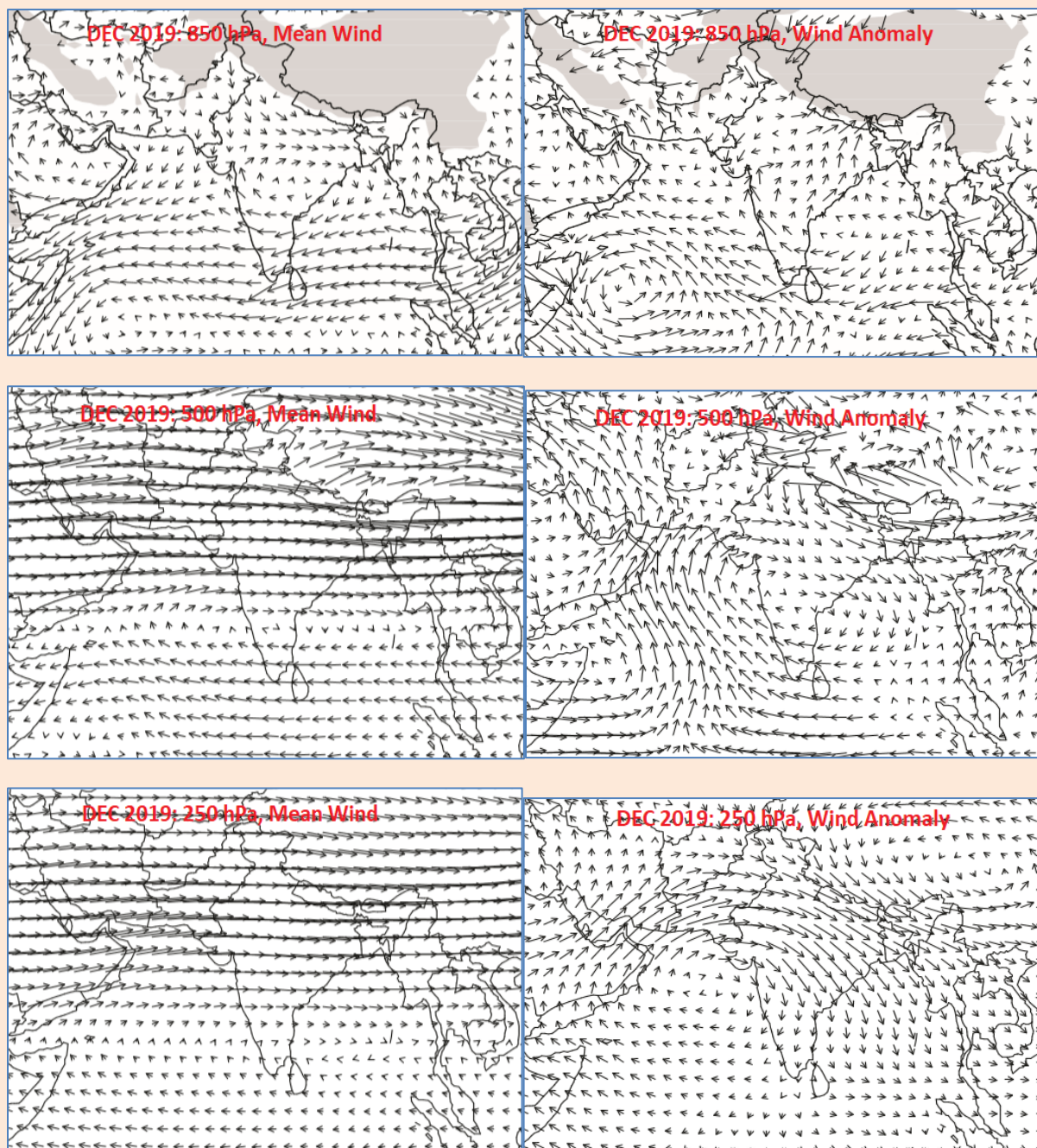


Fig.7c: Mean and anomalous wind pattern over the Indian region at 850 hPa, 500 hPa and 250 hPa levels during December 2019 (Source: Climate Diagnostic Bulletin of India, IMD Pune)

In December, at 850 hPa level, anomalous cyclonic circulation was observed over the southwest Arabian Sea. At 500 hPa, anomalous southerlies over the Arabian Sea and anomalous anti-cyclone over the central parts of India were observed. In the upper troposphere, anomalous anti-cyclone was present over the northern parts of the Arabian Sea.

(b) **Large scale features:** Based on the reports of various global climate monitoring centres, it was noted that during October-December 2019, neutral ENSO conditions prevailed over the equatorial Pacific region (Fig.8a). Indian Ocean Dipole was strongly positive (>2) and was favourable for good NEM activity (Fig.8b). MJO was in phase 2-3 during the 2nd half of October and during the first week of December and was favourable for NEM activity. But during November, it was in phase 5-8, over the other half of the hemisphere and was not favourable for good NEM activity (Fig.8c).

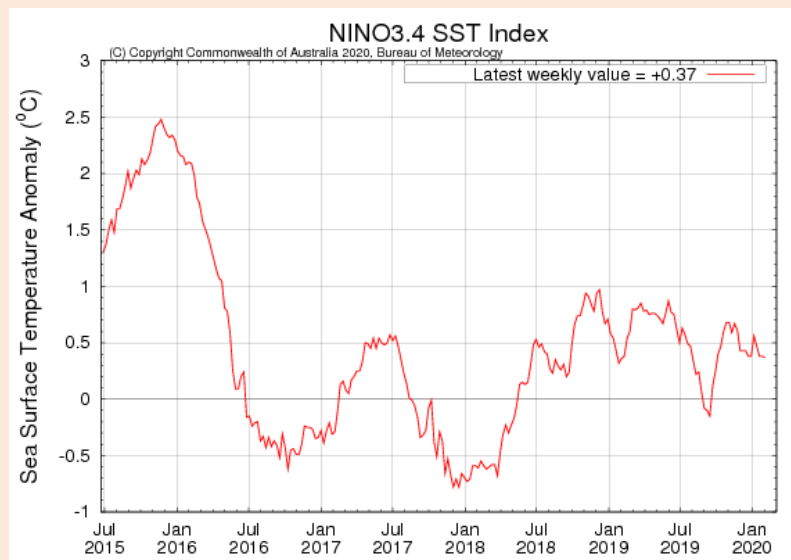


Fig.8a: Sea surface temperature anomaly over the Nino 3.4 region depicting neutral ENSO during October-December 2019 (Source: Bureau of Meteorology, Australia)

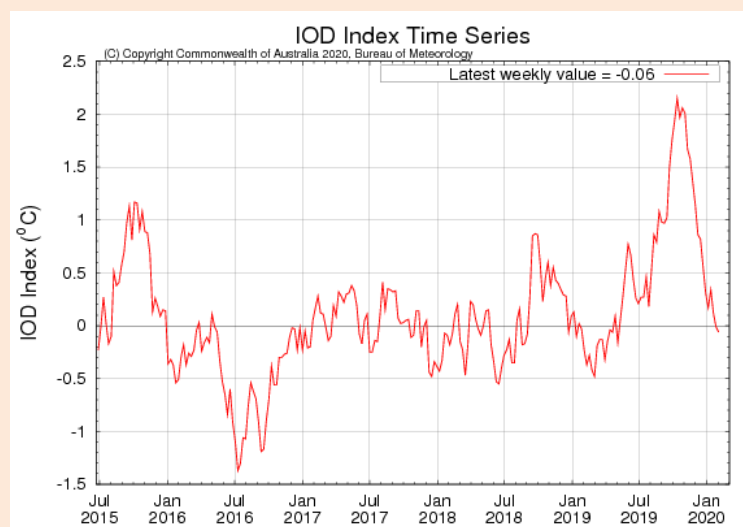


Fig.8b: Positive IOD index during October-December 2019 (Source: Bureau of Meteorology, Australia)

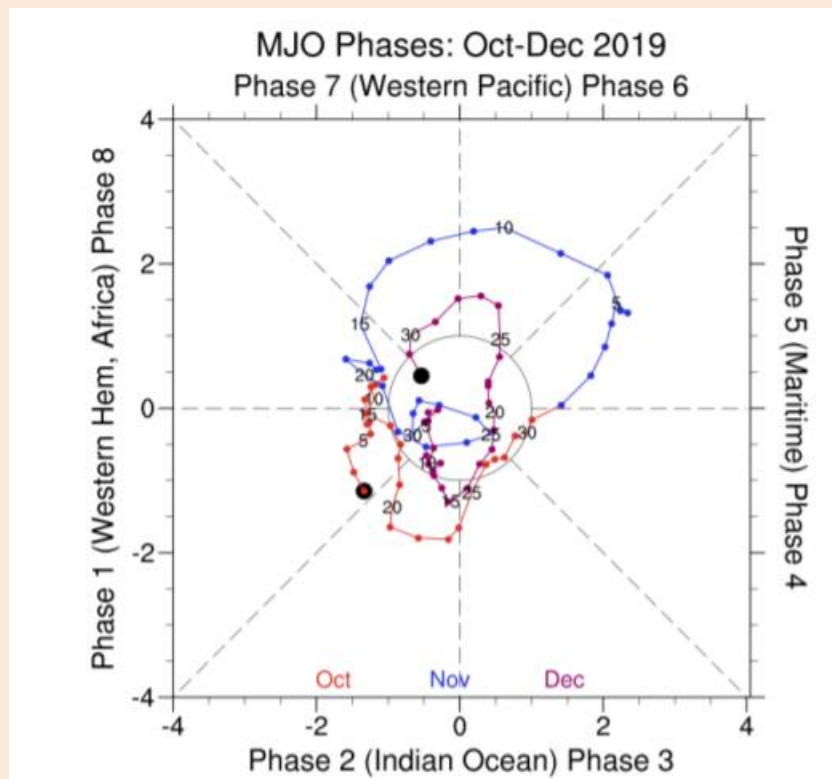


Fig.8c: MJO during Oct-Dec 2019 (Source: Annual Climate Assessment Report-2019, Meteorological Service, Singapore)

8. Summary

The onset of NEM 2019 over the southeastern parts of peninsular India took place on 16th October, 4 days prior to the normal date of onset (20 October)]. All the five meteorological sub-divisions benefitted by the NEM (TN, KER, CAP, RYS & SIK) received normal to excess rainfall during the season (October-December 2019). All the five sub-divisions received *normal to large excess rainfall* in October and December. However, all of them came under *deficient to largely deficient* categories in November. Four major low pressure systems (LPS) formed over the BOB and AS during the season - (i) Super Cyclonic Storm (SuCS) *KYARR* over AS during 24th October - 02nd November 2019 (ii) Extremely Severe Cyclonic Storm (ESCS) *MAHA* over AS during 30th October -07th November 2019 (iii) Very Severe Cyclonic Storm (VSCS) *BULBUL* over BOB during 05th-11th November 2019 and (iv) Cyclonic Storm (CS) *PAWAN* over AS during 02nd -07th December 2019. The first three LPS that formed in quick succession modulated the NEM circulation features and transported moisture away from the NEM region leading to large deficiency in NEM rainfall during the first three weeks of November. Good rainfall activity during the second half of October, last week of November and first week of

December were associated with passage of easterly wave troughs over the NEM region. Strongly positive IOD was favourable for good NEM activity during the season.

Acknowledgements

This report is a compilation of real-time observational data and analytical products generated by various IMD offices including IMD New Delhi, Pune, Hyderabad, Bangalore and Thiruvananthapuram as well as raingauge networks of state government departments. Contribution from all officials involved in generation of data and analytical products used for preparation of this report is duly acknowledged. Use of US-NCEP reanalysis data, analytical products of Bureau of Meteorology, Australia and National Meteorological Service, Singapore are also duly acknowledged.

APPENDIX-(i): Terminologies for Spatial rainfall distribution

WD - Widespread (Most places): 75 % or more number of stations of a region (sub-division) reporting at least 2.5 mm rainfall.

FWD- Fairly widespread (Many places): 51% to 74 % number of stations of a region (sub-division) reporting at least 2.5 mm rainfall.

SCT- Scattered (at a few places): 26 % to 50% number of stations of a region (sub-division) reporting at least 2.5 mm rainfall.

ISOL- Isolated (At isolated places): 25% or less number of stations of a region (sub-division) reporting at least 2.5 mm rainfall.

DRY: No station of a region reported rainfall

APPENDIX-(ii): Terminologies for description of intensity of rainfall

S No.	Terminology	Rainfall range In mm	Rainfall range In cm	Percentile
1	Very light rainfall	Trace -2.4		
2	Light rainfall	2.5-15.5	Upto 1	Upto 65
3	Moderate rainfall	15.6-64.4	02-06	65-95
4	Heavy Rainfall	64.5- 115.5	07-11	95-99
5	Very Heavy Rainfall	115.6-204.4	12-20	99.0-99.9
6	Extremely heavy rainfall	Greater or equal to 204.5 mm	21 cm or more	>99.9
7	Exceptionally Heavy Rainfall	When the amount is a value near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.		

APPENDIX-(iii): Description of NEM rainfall activity

Active: Fairly widespread to widespread sub-divisional rainfall with rainfall more than 1½ to 4 times the normal with at least two stations reporting more than or equal to 5 cm in coastal Tamil Nadu, south coastal Andhra Pradesh and 3 cm elsewhere in the NEM region.

Vigorous: Fairly widespread to widespread sub-divisional rainfall with rainfall more than 4 times the normal with at least two stations reporting more than or equal to 5 cm in coastal Tamil Nadu, south coastal Andhra Pradesh and 3 cm elsewhere in the NEM region.