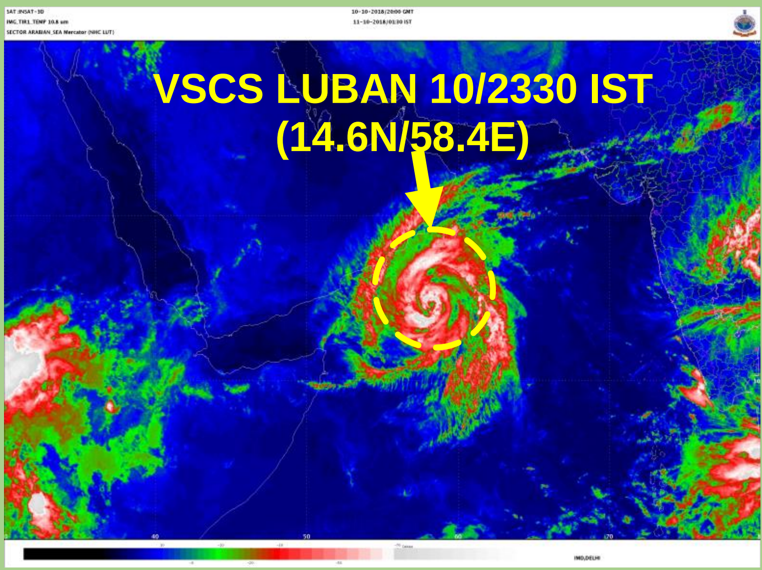
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Very Severe Cyclonic Storm, 'LUBAN' over the Arabian Sea (06 – 15 October 2018): A Report



INSAT-3D enhanced colored IR imagery of 10th October, 2018

Cyclone Warning Division

India Meteorological Department

New Delhi

December 2018

Very Severe Cyclonic Storm, 'LUBAN' over the Arabian Sea (06 – 15 October 2018)

1. Introduction

1. Brief Life History:

- Very Severe Cyclonic Storm (VSCS) Luban originated from a low pressure area (LPA) which formed over southeast Arabian Sea (AS) and neighbourhood in the morning (0830 IST/0300 UTC) of 5th October. It lay as a well marked low pressure area (WML) over southeast and adjoining eastcentral AS in the morning (0530 IST/0000UTC) of 6th October.
- Under favourable environmental conditions, it concentrated into a Depression (D) over southeast and adjoining eastcentral AS in the afternoon (1430 IST/0900 UTC) of 6th October. Moving west-northwestwards, it intensified into a deep depression (DD) over the same region in the afternoon (1430 IST/0900 UTC) of 7th October. It further intensified into a cyclonic storm (CS) **"Luban"** in the early morning (0530 IST/0000 UTC) of 8th October over westcentral and adjoining south & eastcentral AS.
- Moving further west-northwestwards it intensified, into a severe cyclonic storm (SCS) in the afternoon (1430 IST/0900 UTC) of 9th over westcentral AS.
- It then moved northwestwards and further intensified into a very severe cyclonic storm (VSCS) in the early morning (0530 IST/0000 UTC) of 10th over westcentral AS. It attained it's peak intensity of 75 kts around noon (1130 IST/0600 UTC) of 10th.It maintained it's peak intensity till early morning(0530 IST/0000 UTC) of 11th.
- Thereafter, it experienced unfavourable environment like colder sea and dry & cold air advection from Arabian Peninsula and hence, it started weakening. It weakened into an SCS in the morning (0830 IST/0300 UTC) of 12th and into a CS in the same midnight (2330 IST/1800 UTC).
- It crossed Yemen and adjoining south Oman coasts near 15.8^0N and 52.2^0E during 1100-1130 hrs IST (0530 to 0600 UTC) of 14th as a CS with the wind speed of 70-80 gusting to 90 kmph.
- After landfall, it weakened quickly into a DD in the afternoon (1430 IST/0900 UTC) of 14th, into a D in the same midnight (2330 hrs IST/1800 UTC) and into a WML over Yemen and adjoining Saudi Arabia in the morning (0830 IST/0300 UTC of 15th)**.**

The observed track of the system during 06th-15th October is presented in **Fig.1**. The best track parameters of the system are presented in **Table 1**.

2. Salient Features:

The salient features of the system were as follows:

- Luban was the third cyclonic storm to cross Arabia & African coasts after CS Sagar and extremely severe cyclonic storm (ESCS) Mekunu during May 2018. Thus there had been three landfalling cyclones over Arabia & African coasts during 2018 against 8 such cyclones during the entire satellite era (1961-2017). Hence, the frequency of landfalling cyclones over the region has been significantly higher this year.
- Similarly there has been genesis of three cyclonic storms over the AS so far during 2018 against about one cyclone per year over the AS. 62 cyclones developed over the AS during the satellite era (1961-2017).

- Just after the genesis of VSCS, Luban over Arabian Sea, another cyclonic storm Titli developed over Bay of Bengal simultaneously. It was one of the rarest of rare events that simultaneously two very severe cyclonic storms developed over Arabian Sea and Bay of Bengal. Simultaneous occurrence of such two VSCSs last occurred in November 1977, viz. (i) Bay of Bengal Super Cyclonic Storm (14-20 Nov., 1977) which crossed Andhra Pradesh coast near Chirala on 19th Nov. and (ii) Bay of Bengal VSCS (09-23rd Nov., 1977) which crossed Tamil Nadu coast close to south of Nagapattinam on 12th Nov. and then emerged into Arabian Sea, made a looping track, intensified into an SCS, weakened thereafter and crossed Karnataka coast to the north of Mangalore on 29th Nov. as a depression. The observed track of these simultaneous systems viz. Titli and Luban is presented in **Fig. 2**.
- The system exhibited rapid intensification during 0600 UTC of 9th to 0600 UTC of 10th Oct with increase in maximum sustained wind speed from 45 knots at 0600 UTC of 9th to 75 knots at 0600 UTC of 10th.
- The peak maximum sustained surface wind speed (MSW) of the cyclone was 135-145 kmph gusting to 160 kmph (75 knots gusting to 85 knots) during 0600 UTC of 10th to 0000 UTC of 11th Oct. The lowest estimated central pressure was 978 hPa during the period.
- The system crossed Yemen and adjoining Oman coasts near 15.8^{0}N and 52.2^{0}E during 0530 to 0600 UTC of 14th as a cyclonic storm with maximum sustained wind speed of 40 kts (70-80 kmph gusting to 90 kmph) .
- The life period (D to D) of the system was 210 hours (8 days & 18 hours) against long period average (LPA) (1990-2013) of 107 hours for VSCS over Arabian Sea during post monsoon season.
- It moved slower with 12 hour average translational speed of 10.4 kmph against LPA (1990-2013) of 13.8 kmph for VSCS over Arabian Sea.
- The Velocity Flux, Accumulated Cyclone Energy (ACE) and Power Dissipation Index (PDI) were 14.1 X10^2 knots, 8.11 X 10^4 knots^2 and 4.92 X10^6 knots^3 respectively.
- The track of the system was unique in the sense that the system experienced very slow movement and multiple recurvatures during 0000 UTC of 9th to 0600 UTC of 12th and change from westward to northwestward movement on 14th Oct. (six hours before landfall).

2. Monitoring of VSCS, 'LUBAN'

The cyclone was monitored & predicted continuously by India Meteorological Department (IMD) prior to it's genesis as low pressure area over Arabian Sea from 8th October onwards. The system was monitored mainly with satellite observations from INSAT 3D and 3DR, SCAT Sat, ASCAT, polar orbiting satellites, scatterometer observations and available ships & buoy observations in the region. Various national and international numerical weather prediction models and dynamical-statistical models were utilized to predict the genesis, track and intensity of the cyclone. Tropical Cyclone Module, the digitized forecasting system of IMD was utilized for analysis and comparison of various models guidance, decision making process and warning product generation. IMD issued regular bulletins to World Meteorological Organisation (WMO), WMO/ESCAP Panel member countries including Yemen, Oman, Saudi Arabia, Iran, Qatar, Sri Lanka, Maldives, National & State Disaster Management Agencies, general public along the west coast of India and media since inception of the system over AS. Typical satellite imageries are presented in **Fig.4**.

3. Brief life history

3.1. Genesis (04/03)

An upper air cyclonic circulation lay over southeast AS and adjoining Lakshadweep & Maldives area extending upto mid-tropospheric levels at 0300 UTC of 4th October 2018. Under it's influence, an LPA formed over southeast AS and neighbourhood at 0300 UTC of 5th October 2018. Considering the environmental conditions at 0300 UTC of 5th, the Madden Julian Oscillation (MJO) index was in phase 1 with amplitude more than 1. The sea surface temperature (SST) was 29°-31˚C over southeast and eastcentral AS. It was around 26°-29°C over westcentral and southwest AS. The SST was decreasing slightly towards Oman coast. The tropical cyclone heat potential was about 60-80 KJ/cm^2 over southeast and adjoining eastcentral AS off Oman coast. It was less than 50 KJ/cm^2 to the north of 17.0^o N and west of 60.0^{0}E. The low level relative vorticity was east-west oriented and was around 50-70 x10^{-5} sec^{-1} over south AS. The lower level convergence and upper level divergence were about 20 x10^{-5}sec^{-1} over southeast AS and was east-west oriented. The vertical wind shear was low (5-10 knots(kt)) over central & south AS and Lakshadweep. It was increasing becoming more than 20 kt to the north of 20^{0}N over north AS & near Oman coast. The upper tropospheric ridge ran along 15^{0}N. The similar environmental conditions prevailed and the LPA lay as a WML over southeast and adjoining eastcentral AS at 0000 UTC of 6th October.

Under the favourable environmental conditions, at 0900 UTC of 6th, the system intensified into a depression over the same region and lay centered near 11.2°N and longitude 67.0°E, 730 km west-northwest of Minicoy (43369). The MJO index lay in phase 1 with amplitude more than 1. Similar thermodynamical conditions prevailed over the AS like previous day. The low level relative vorticity organised during previous 12 hours. The low level relative vorticity was around 50 x10^{-5} sec^{-1} to the south of system centre. The positive vorticity zone was extending upto 500 hpa level. The lower level convergence was about 10 x10^{-5}sec^{-1} over southeast AS to the southwest of system centre. The upper level divergence was the same about 20 x10^{-5}sec^{-1} to the northwest of system centre. The vertical wind shear was low to moderate (5-15 kt) around the system centre and (10-20 kt) over central parts of AS. It was increasing becoming more than 25 kt to the north of 15^{0}N over AS & near Oman coast. The upper tropospheric ridge runs along 16^0 N.

3.2. Intensification and movement

The depression moved west-northwestwards, intensified into a DD and lay centered at 0900 UTC of 7th over southeast & adjoining eastcentral AS near latitude 12.0°N and longitude 64.8°E, about 1280 km east-southeast of Salalah (41316), 1180 km east-southeast of Socotra Islands (41494) and 980 km west-northwest of Minicoy (43369). The MJO index lay in phase 1 with amplitude more than 1. The low level relative vorticity increased significantly and was around 100 x10^{-5}sec^{-1} to the south of system centre. The vorticity zone was extending upto 500 hpa level. The lower level convergence was about 10 x10^{-5}sec^{-1} to the south and 20 x10^{-5}sec^{-1} to the west of system centre. The upper level divergence increased and was of the order 30 x 10^{-5} sec^{-1} to the northwest of system centre. The vertical wind shear was moderate (10-15 kt) around the system centre. The animation of total precipitable water (TPW) imageries indicated, the warm and moist air advection to the core of the system. The upper tropospheric ridge ran along 16^{0}N. Hence, during it's west-northwestwards movement, the system intensified gradually. However, it was expected that as the system would reach near the coast, it would experience unfavourable conditions like high wind shear, lower SST & ocean heat content and cold air advection from land areas and would weaken.

At 0000 UTC of 8th, the system moved west-northwestwards, intensified into a CS and lay centered over westcentral and adjoining southwest AS near latitude 12.3°N and longitude 62.4°E, about 1040 km east-southeast of Salalah (Oman), 920 km east-southeast of Socotra Islands (Yemen). The low level relative vorticity increased significantly and was around 200 $x10^{-5}sec^{-1}$ around system centre. Tthe vorticity zone extended upto 200 hpa level. The lower level convergence increased significantly and was about 40 $x10^{-5}sec^{-1}$ to the southwest of the system centre and divergence also increased and was of the order 40 $x10^{-5}sec^{-1}$ to the southwest of the system centre. The vertical wind shear was moderate (15-25 kt) around the system centre. The animation of TPW imageries indicated the warm and moist air advection to the core of the system. The upper tropospheric ridge continued to run along 16^0 N making system to move west-northwestwards.

The CS further intensified into an SCS and lay centered at 0900 UTC of 09th October, over westcentral & adjoining southwest AS, near latitude 13.2°N and longitude 60.0°E, about 760 km east-southeast of Salalah (41316), 660 km east of Socotra Islands (41494) and 900 km eastsoutheast of Al-Ghaidah (41398). The MJO lay in phase 1 with amplitude more than 1. The low level relative vorticity increased and was around 250 $x10^{-5}sec^{-1}$ around the system centre. The lower level convergence was about 30 $x10^{-5}sec^{-1}$ to the southwest of the system centre and divergence was of the order 30 $x10^{-5}sec^{-1}$ to the southwest of the system centre. The vertical wind shear was low to moderate (10-15 kt) around the system centre.

Thereafter, the system moved northwestwards, intensified into a VSCS and lay centered at 0000 UTC of 10th, over westcentral AS, near latitude 14.1°N and longitude 59.0°E, about 610 km east-southeast of Salalah (Oman), 570 km east-northeast of Socotra Islands (Yemen) and 770 km east-southeast of Al-Ghaidah (Yemen). The MJO lay in phase 1 with amplitude more than 1. The SST was around 28-29^0C around the system centre. TCHP was about 60-80 KJ/cm^2 near the system centre. It was less than 50 KJ/cm^2 to the north of 17.0^0N and west of 60.0^0E. The low level relative vorticity was about 250 $x10^{-5}sec^{-1}$ around the system centre and was extending upto 200 hpa level. The lower level convergence was about 20 $x10^{-5}sec^{-1}$ around the system centre and upper level divergence was of the order 30 $x10^{-5}sec^{-1}$ around the system centre. The vertical wind shear was low to moderate (10-15 kt) around the system centre and also along the forecast track. The animation of TPW imageries indicated the warm and moist air advection to the core of the system. The upper tropospheric ridge lay along 18^0 N. These features indicated the system would experience low to moderate wind shear, warmer SST & low ocean heat content and cold air advection from land areas while moving west-northwestwards. Under these conditions, the system moved west-northwestwards reached it's peak intensity of 75 kts at 0600 UTC of 10th. Thereafter, from 0300 UTC of 11th, it started weakening. At 0300 UTC of 11th, the system lay over westcentral AS, near latitude 14.5°N and longitude 58.0°E, about 500 km east-southeast of Salalah and 670 km eastsoutheast of Al-Ghaidah. MJO lay in phase 2 with amplitude more than 1 and was favouring of convective activity. The SST was 26-27^0C over westcentral and southwest AS. TCHP was less than 50 KJ/cm^2 to the west of 63.0^0E. The low level relative vorticity was around 300 x10-5sec-1 around the system centre and was extending upto 200 hpa level. The lower level convergence was about 20 $x10^{-5}$ sec^{-1} to the southeast of the system centre and upper level divergence was of the order 30 $x10^{-5}$ sec^{-1} to the southwest of system centre. The vertical wind shear was low (05-10 kt) around the system centre and also along the forecast track. The animation of TPW imageries indicated a relative reduction in the warm and moist air advection to the core of the system. The upper tropospheric ridge lay along 17^0 N. Lower SST and TCHP and decrease in warm moist air incursion into the core of system led to its gradual weakening.

At 0300 UTC of 12th, it weakened into an SCS. The low level relative vorticity decreased and was around 250 $x10^{-5}sec^{-1}$ around the system centre. The lower level convergence was about 30 x10-5sec-1 and upper level divergence was of the order 30 $x10^{-5}$ sec^{-1} around the system centre. The vertical wind shear was low (05-10 kt) around the system centre and also along the forecast track. TPW imageries indicated a further reduction in the warm and moist air advection to the core of the system. In addition, it also indicated cold and dry air entrainment from the northwest reaching upto southern sector of the system. As a result the system showed disorganisation of clouds and hence slight weakening was expected during next 12 hrs.

At 1800 UTC of 12th, similar conditions prevailed and the system weakened further into a CS. Continuing to move west-northwestwards, it crossed Yemen and adjoining Oman coasts near 15.8^0N and 52.2^0E during 0530 to 0600 UTC of 14th as a CS with wind speed of 70-80 kmph gusting upto 90 kmph. The system weakened rapidly into a DD at 0900 UTC and into D at 1800 UTC of 14th due to land interaction and cold and dry air incursion from the west.

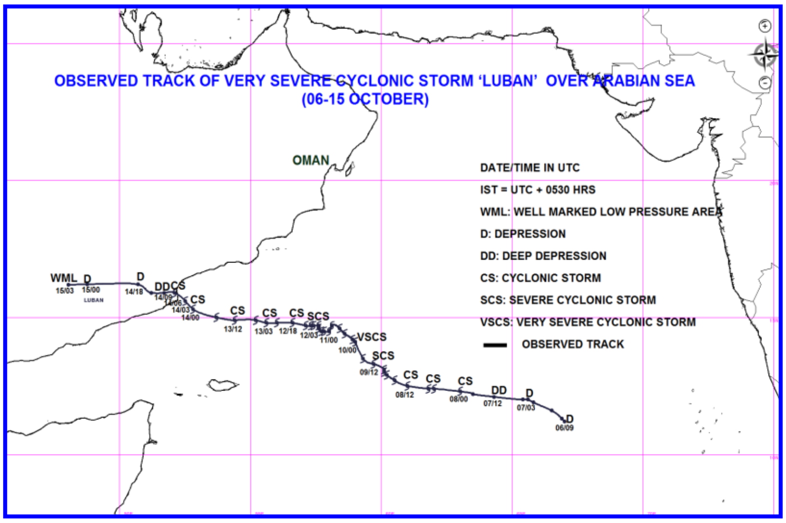


Fig.1 Observed track of VSCS Luban (06-15 October, 2018) over Arabian Sea

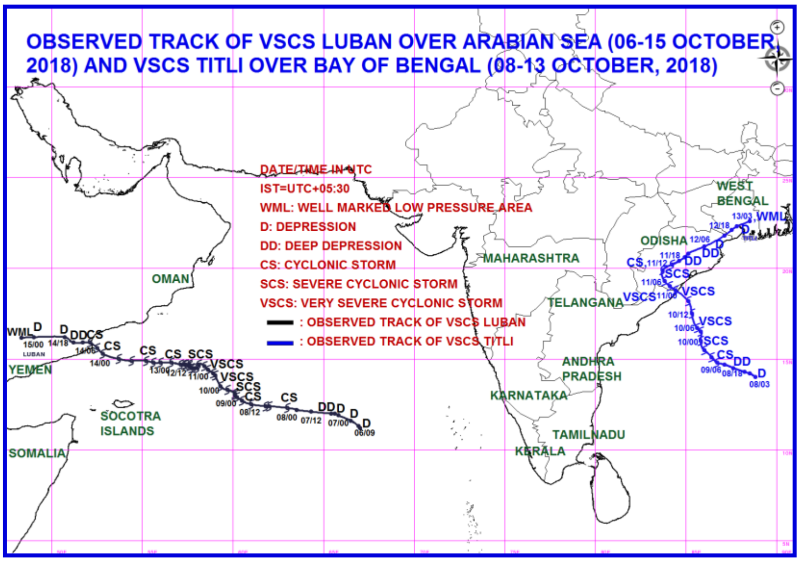


Fig.2: Observed track of simultaneous systems viz. VSCS Luban over Arabian Sea (06-15 October, 2018) and VSCS Titli over Bay of Bengal (08-13 October, 2018)

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm, 'LUBAN' over the Arabian Sea during 06-15 October, 2018

Date	Time (UTC)	Centre lat.^{0} N/ long. ^{0} E		C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
06/10/2018	0900	11.2	67.0	1.5	1003	25	3	**D**
	1200	11.3	66.9	1.5	1002	25	4	D
	1800	11.6	66.5	1.5	1002	25	4	D
07/10/2018	0000	11.9	65.8	1.5	1002	25	4	D
	0300	12.0	65.6	1.5	1002	25	4	D
	0600	12.0	65.4	1.5	1002	25	4	D
	0900	12.0	64.8	2.0	1001	30	5	**DD**
	1200	12.1	64.3	2.0	1001	30	5	DD
	1800	12.2	63.5	2.0	1000	30	6	DD
08/10/2018	0000	12.3	63.0	2.5	999	35	7	**CS**
	0300	12.4	62.0	2.5	998	40	8	CS
	0600	12.4	61.8	2.5	997	40	9	CS
	0900	12.5	61.5	3.0	996	45	10	CS
	1200	12.5	61.0	3.0	996	45	10	CS
	1500	12.6	60.8	3.0	996	45	10	CS
	1800	12.7	60.5	3.0	994	45	12	CS
	2100	12.8	60.2	3.0	994	45	12	CS
09/10/2018	0000	12.9	60.2	3.0	994	45	12	CS
	0300	13.0	60.1	3.0	994	45	12	CS
	0600	13.1	60.1	3.0	994	45	12	CS
	0900	13.2	60.0	3.5	992	50	14	**SCS**
	1200	13.3	59.7	3.5	990	55	16	SCS
	1500	13.4	59.5	3.5	990	55	16	SCS
	1800	13.5	59.3	3.5	990	55	16	SCS
	2100	13.6	59.1	3.5	988	60	18	SCS
10/10/2018	0000	14.1	59.0	4.0	985	65	21	**VSCS**
	0300	14.1	59.0	4.0	984	65	22	VSCS
	0600	14.2	58.9	4.5	978	75	28	VSCS
	0900	14.4	58.7	4.5	978	75	28	VSCS
	1200	14.4	58.6	4.0	978	75	28	VSCS
	1500	14.5	58.5	4.0	978	75	28	VSCS
	1800	14.6	58.4	4.0	978	75	28	VSCS
	2100	14.6	58.4	4.0	978	75	28	VSCS
11/10/2018	0000	14.7	58.1	4.0	978	75	28	VSCS
	0300	14.5	58.0	4.0	980	70	26	VSCS
	0600	14.5	57.8	4.0	980	70	26	VSCS
	0900	14.5	57.8	4.0	980	70	26	VSCS

	1200	14.5	57.7	4.0	980	70	26	VSCS
	1500	14.5	57.7	4.0	980	70	26	VSCS
	1800	14.6	57.6	4.0	980	70	26	VSCS
	2100	14.7	57.6	4.0	980	70	26	VSCS
12/10/2018	0000	14.7	57.6	4.0	984	65	22	VSCS
	0300	14.7	57.4	3.5	987	60	25	**SCS**
	0600	14.7	57.3	3.5	990	55	16	SCS
	0900	14.7	57.2	3.5	990	55	16	SCS
	1200	14.7	57.1	3.5	991	50	15	SCS
	1500	14.7	56.9	3.0	992	50	14	SCS
	1800	14.8	56.6	3.0	994	45	12	**CS**
	2100	14.8	56.3	3.0	994	45	12	CS
13/10/2018	0000	14.8	56.0	3.0	994	45	12	CS
	0300	14.8	55.6	3.0	994	45	12	CS
	0600	14.9	55.2	3.0	994	45	12	CS
	0900	14.9	54.8	3.0	994	45	12	CS
	1200	14.9	54.4	3.0	994	45	12	CS
	1500	14.9	54.0	3.0	994	45	12	CS
	1800	15.0	53.7	3.0	996	45	10	CS
	2100	15.1	53.3	3.0	996	45	10	CS
14/10/2018	0000	15.3	52.8	2.5	998	40	8	CS
	0300	15.6	52.5	2.5	998	40	8	CS
		Crossed Yemen and adjoining Oman coasts near 15.8^{0}N and 52.2^{0}E during 0530 to 0600 UTC						
	0600	15.9	52.1	**-**	999	35	7	CS
	0900	15.9	51.7	**-**	1000	30	6	**DD**
	1200	15.9	51.2	**-**	1001	30	5	DD
	1800	16.2	50.7	**-**	1002	25	4	**D**
15/10/2018	0000	16.2	49.0	**-**	1003	25	3	**D**
	0300	**Weakened into a well-marked low pressure area over Yemen and adjoining Saudi Arabia**						

The total precipitable water imageries (TPW) during 6-14 Oct. 2018 are presented in **Fig.3**. These imageries indicated continuous warm and moist air advection from the southeast sector into the system during 8-11 and cold air advection thereafter from the northwest.

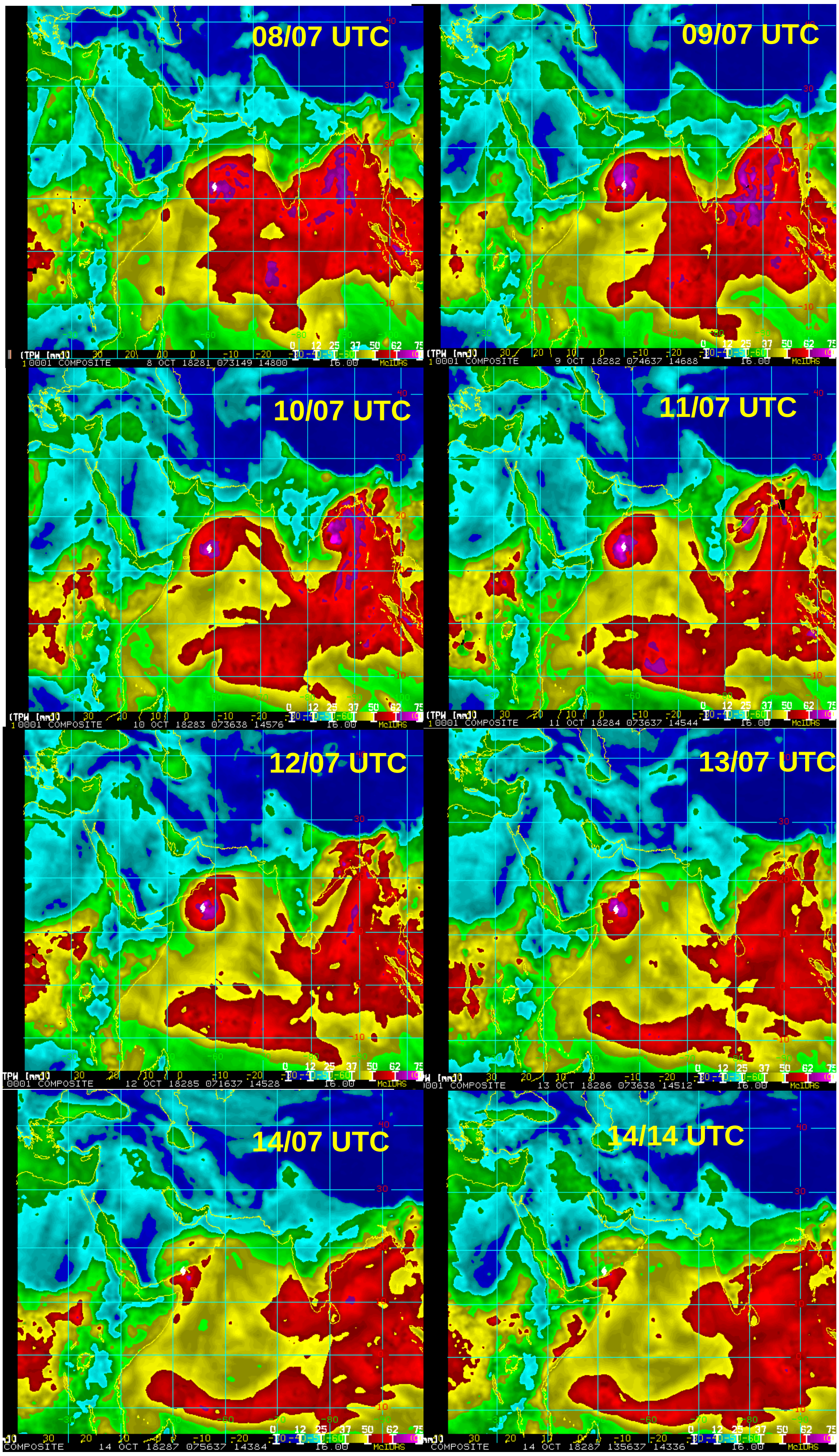


Fig. 3: Total Precipitable Water Imageries during 06-15 October, 2018

The mean wind speed in middle and deep layer around the system centre is presented in **Fig.4**. The wind shear between lower to upper tropospheric levels around the system centre was less than 10 kt throughout the life period of the system since 9th morning. It was 10-20 kt during 6th-9th. However, the wind shear was minimum, less than 5 kt from 10th afternoon to 12th morning. This very low wind shear alongwith other environmental features helped in rapid intensification of the system attaining maximum intensity of 75 kts during this period. With increase in wind shear alongwith colder SST, system started weakening from 12th onwards. The wind shear variation between 850-500 hPa level showed similar variations. Considering the mean wind speed between 200-850 hPa levels, the mean wind speed was 5-10 kt till 9th morning. It then decreased gradually becoming less than 5 kt during 10th & 11th. It then increased gradually during 12th-14th becoming more than 5 kt on 14th. Considering the mean wind speed between 500-850 hPa level, wind speed was similar to above and the mean wind direction suggested west-northwestwards movement till 11th morning and thereafter, the mean wind was variable indicating practically stationary system. From 12th onwards, the mean wind speed increased and the system moved northwestwards as per the mean wind speed between 200-850 hPa level. Hence the system was mainly steered by 200-850 hPa level.

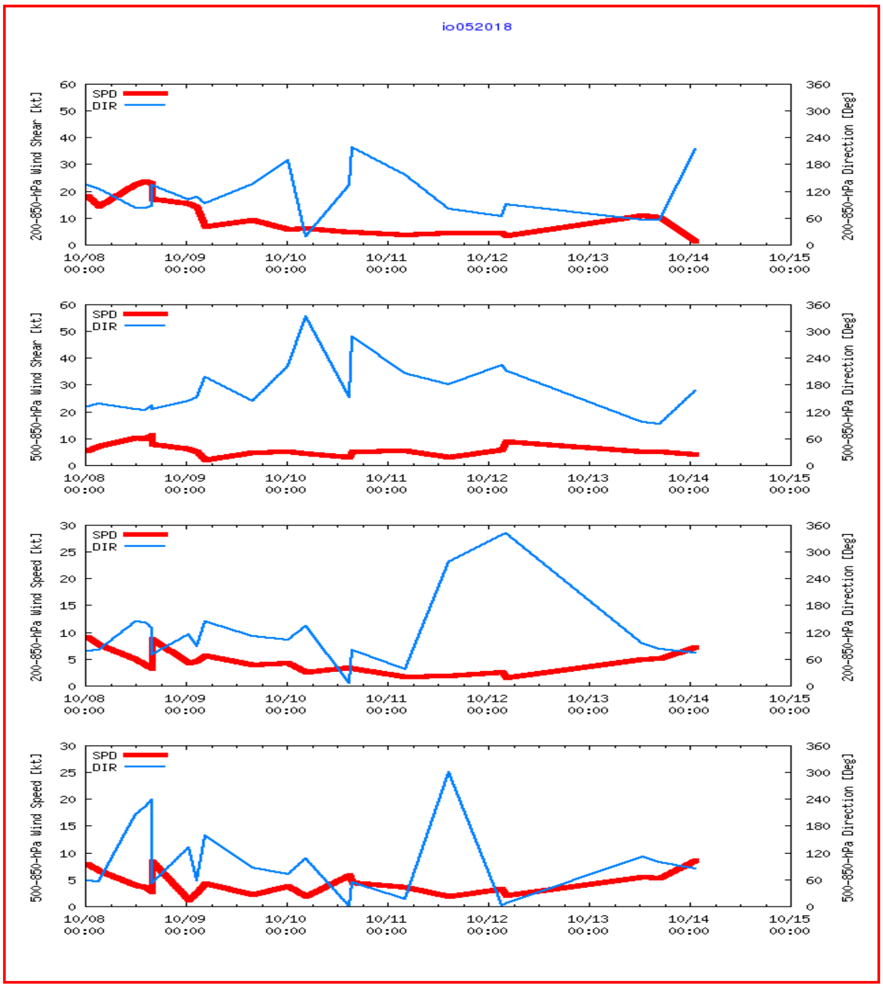


Fig.4 Wind shear and wind speed in the middle and deep layer around the system during 10th to 15th October 2018.

The six hourly movement of VSCS Luban is presented in **Fig.5**. The six hourly average translational speed of the cyclone was about 10.5 kmph and hence was slow moving in nature. The system had a track length of about 1385 km during its life period.

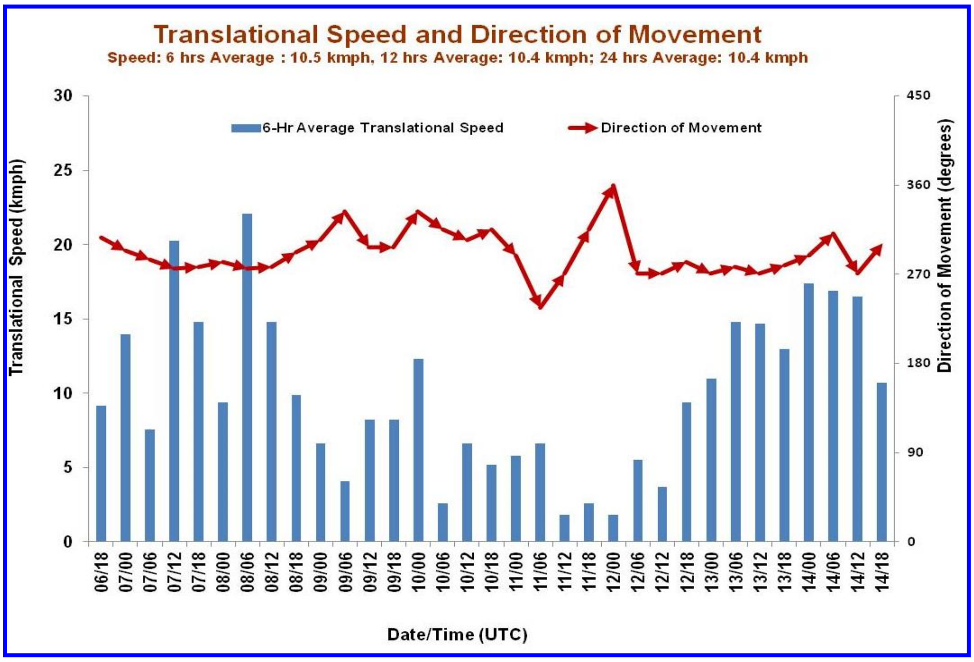


Fig.5. Twelve hourly average translational speed (kmph) and direction of movement in association with VSCS Luban

3.3. Maximum Sustained Surface Wind speed and estimated central pressure:

The lowest estimated central pressure and the maximum sustained wind speed are presented in Table 1. The lowest estimated central pressure (ECP) had been 978 hPa during 0600 of 10th to 0000 UTC of 11th. The ECP gradually decreased from 1003 hPa at 0900 UTC of 6th to 994 hPa at 0600 UTC of 9th. Thereafter, there was a rapid decrease from 994 hPa to 978 hPa (16 hPa) during 0600 UTC of 9th to 0600 UTC of 10th (within 24 hrs). There was rise in ECP from 978 hPa (at 0300 UTC of 11th) to 994 hPa at 1800 UTC of 12th. Thereafter it increased gradually to 1003 hPa at 0000 UTC of 15th. Similarly, in the wind field it is seen that there was gradual increase in maximum sustained wind speed (MSW) till 0600 UTC of 9th. There was rapid intensification by 30 knots as it increased from 45 knots at 0600 UTC of 9th to 0600 UTC of 10th. The system maintained its peak intensity of 75 knots during 0600 UTC of 10th to 0000 UTC of 11th. The system then weakened gradually.

4. Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 & MTSAT, microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops and SCAT SAT imageries were considered for monitoring the system.

4.1 INSAT-3D features

Typical INSAT-3D visible/IR imageries, enhanced colored imageries and cloud top brightness temperature imageries are presented in **Fig.6 (a-d)**.

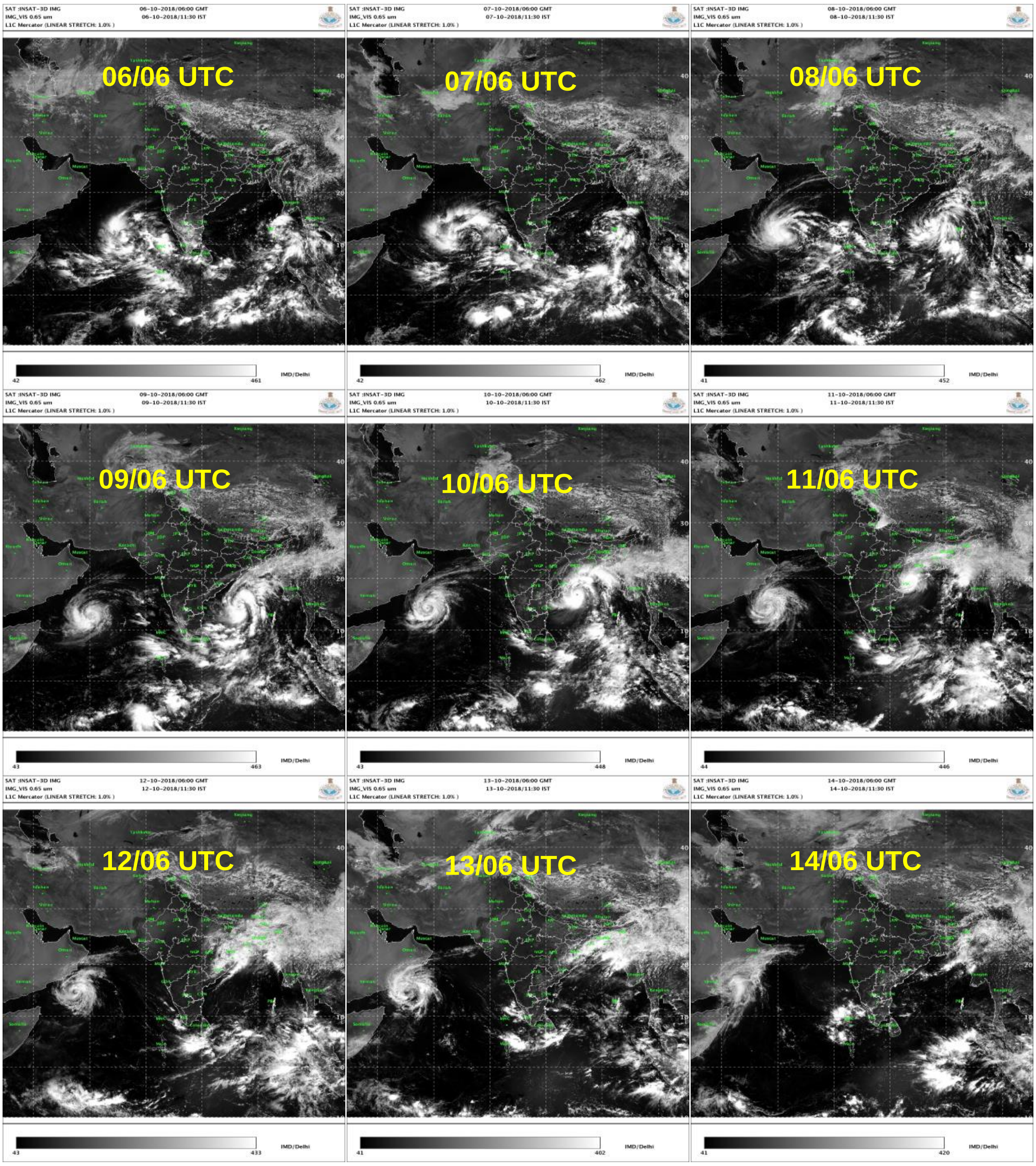


Fig. 6a: INSAT-3D visible imageries during life cycle of VSCS LUBAN (06-15 October, 2018)

Intensity estimation using Dvorak's technique suggested that the system attained the intensity of **T 1.5** at 0900 UTC of 06th. The convection over south AS further organised and indicated curved banding features from northeast to southwest sector across northwest sector. Minimum cloud top temperature was -93^{0}C. At 0900 UTC of 7th, the convection further organized and the system attained the intensity of

T2.0. The convection showed curved banding features from northeast to southwest sector across northwest sector. Minimum CTT was -93^{0}C.

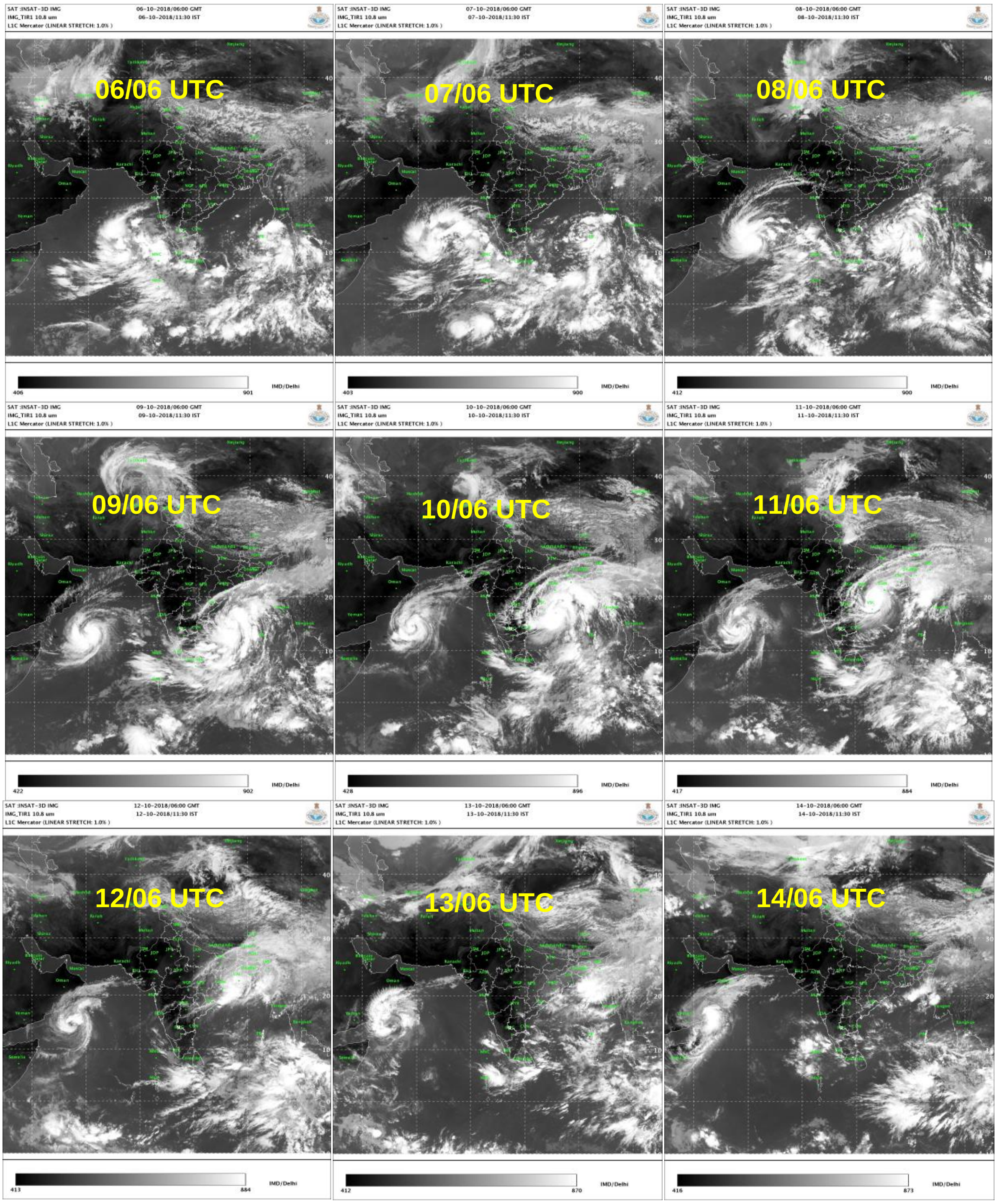


Fig. 6b: INSAT-3D IR imageries during life cycle of VSCS Luban (06-15 October, 2018)

At 0000 UTC of 08th, the system attained the intensity **T 2.5**. The cloud pattern indicated banding features from northeast to southwest sector across northwest sector. The intensity of the system was **T3.5** at 0900 UTC of 9th with a central dense overcast (CDO) pattern. The convection showed curved banding features. At 0000 UTC of 10th, the system attained the intensity **T 4.0** with a CDO and embedded eye pattern. The convection increased over western and southern sector. With the consolidation of central dense overcast, satellite imagery indicated appearance of eye. It indicated intensification of the system. Minimum CTT was -93^{0}C. At 0300 UTC of 24th, the system further intensified and attained the intensity **T4.5** at 1200 UTC of 10th. The convection showed central dense overcast pattern with well defined spiral bands and eye. Minimum CTT was -93^{0}C.

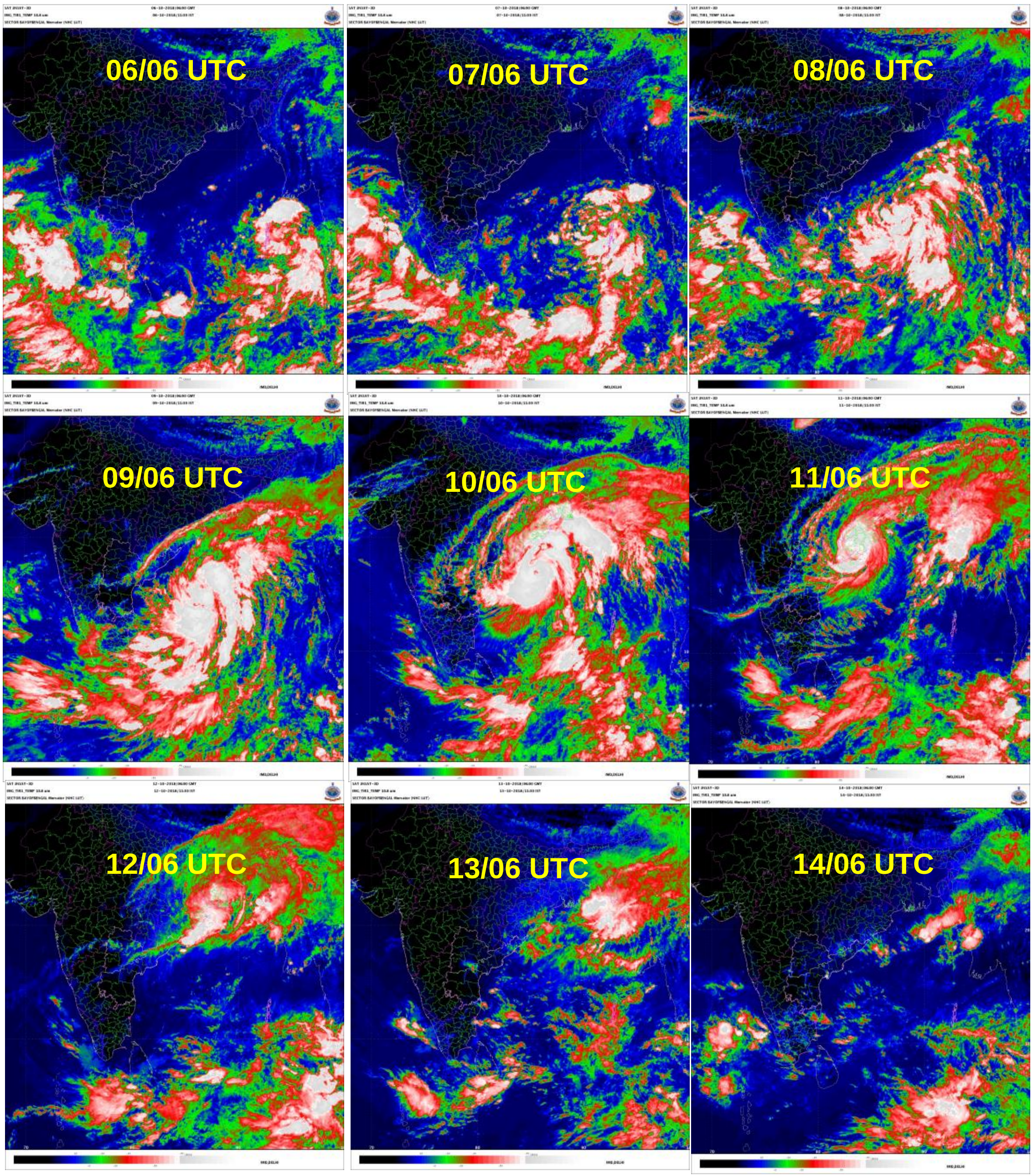


Fig. 6c: INSAT-3D enhanced colored imageries during life cycle of VSCS Luban (06-15 October, 2018)

At 0300 UTC of 11th, the intensity of the system was **T 4.0** with weakening of the system. It further decreased to T 3.0 at 1500 UTC of 12th and T 2.5 at 0000 UTC of 14th.

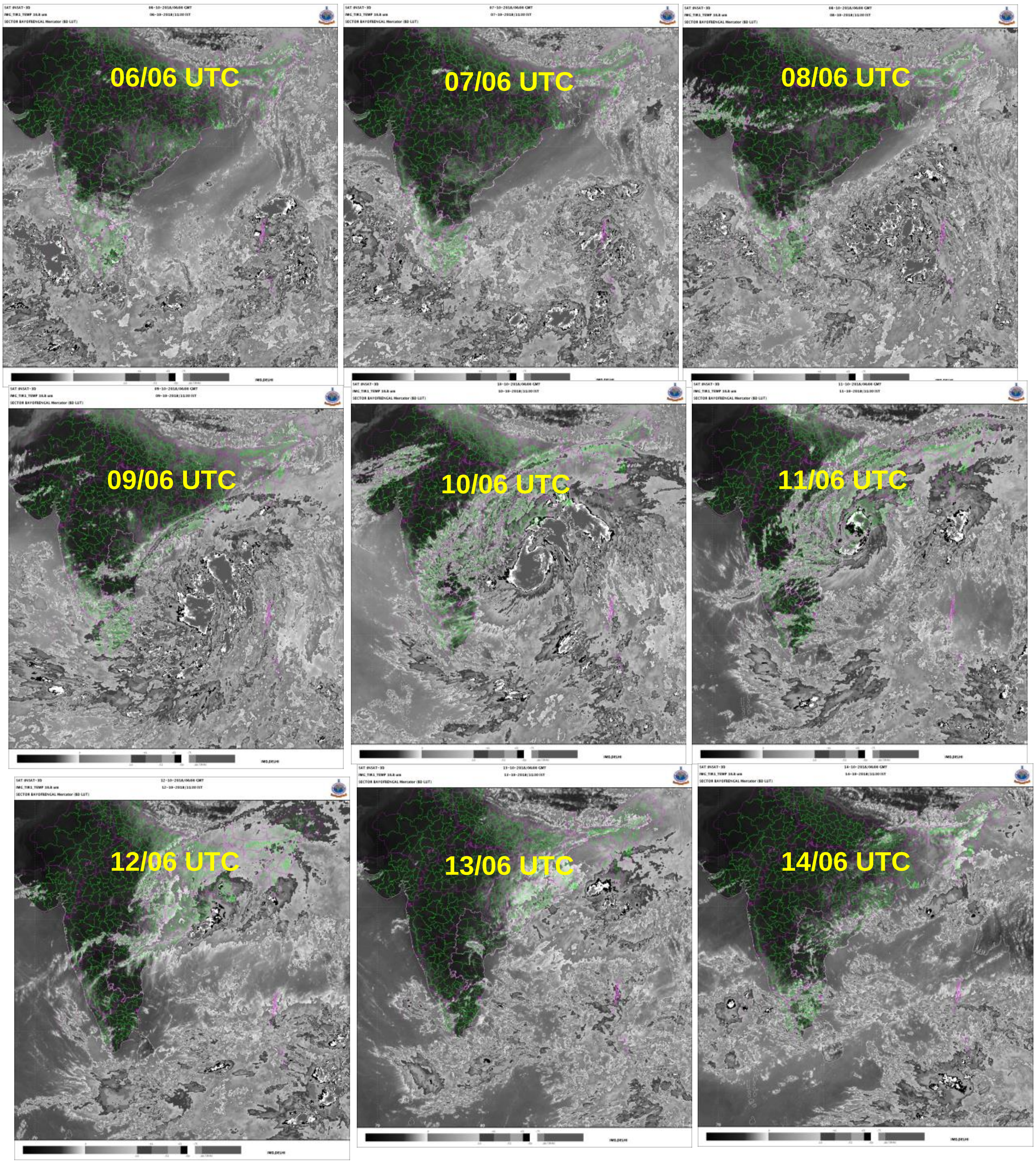


Fig. 6d: INSAT-3D cloud top brightness imageries during life cycle of VSCS Luban (06-15 October, 2018)

4.2. Microwave Imageries:

Microwave imageries from polar orbiting satellites F-15, F-16, F-18, GCOM W1, GPM 89, NOAA-19 were utilised for determining the centre and area of intense convection. Typical microwave imageries during the life cycle of VSCS Luban are presented in **Fig. 6 (e).** The eye was visible since 0000 UTC of 10th Oct.

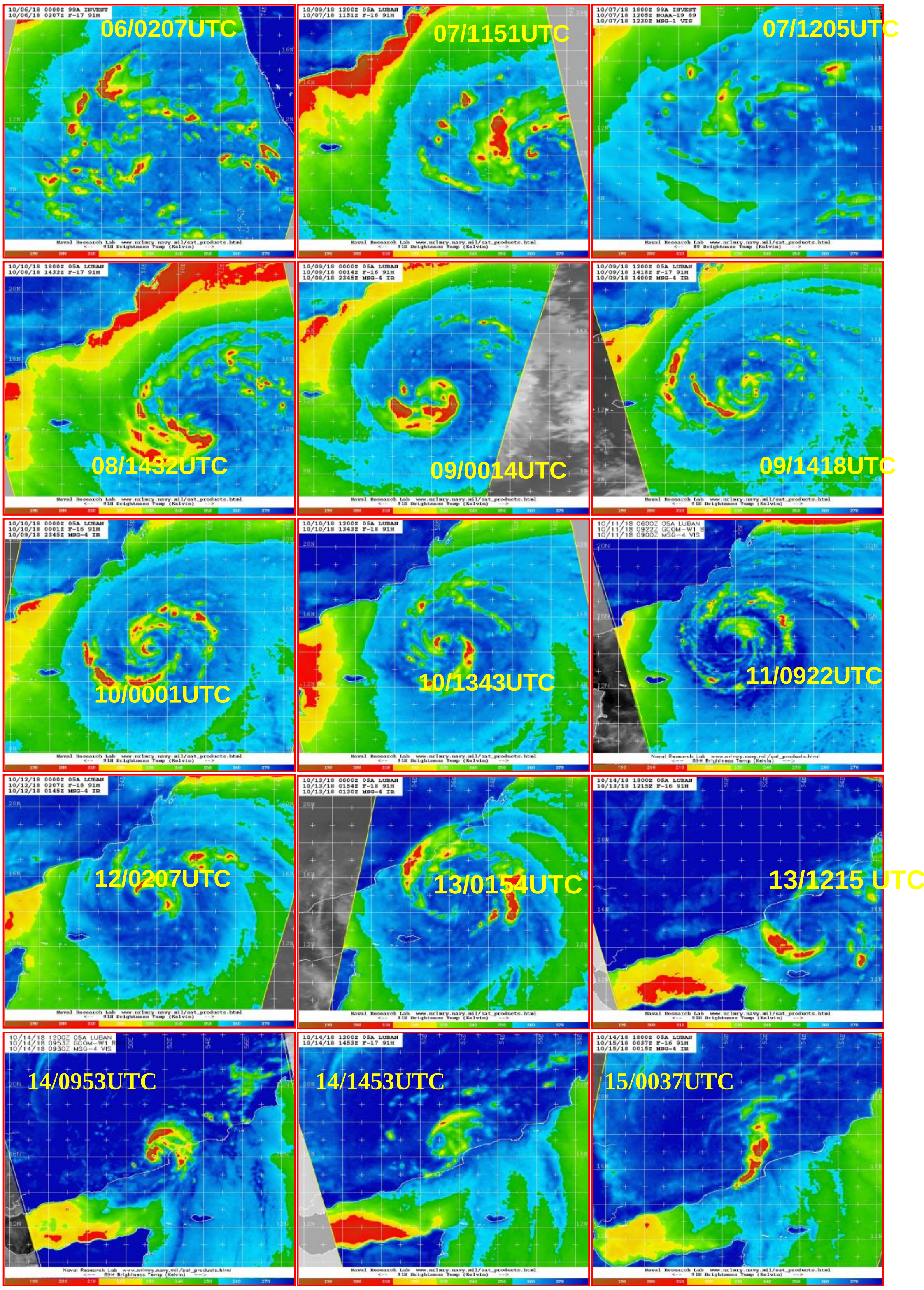


Fig. 6e: Microwave imageries during life cycle of VSCS Luban (06-15 October, 2018)

4.3. Scatterometer observations

When the system was over sea, imageries from ASCAT were also utilized for determination of centre, intensity and wind distribution around the centre of the system. Typical ASCAT imageries from Metop-B are presented in Fig. 6(f).

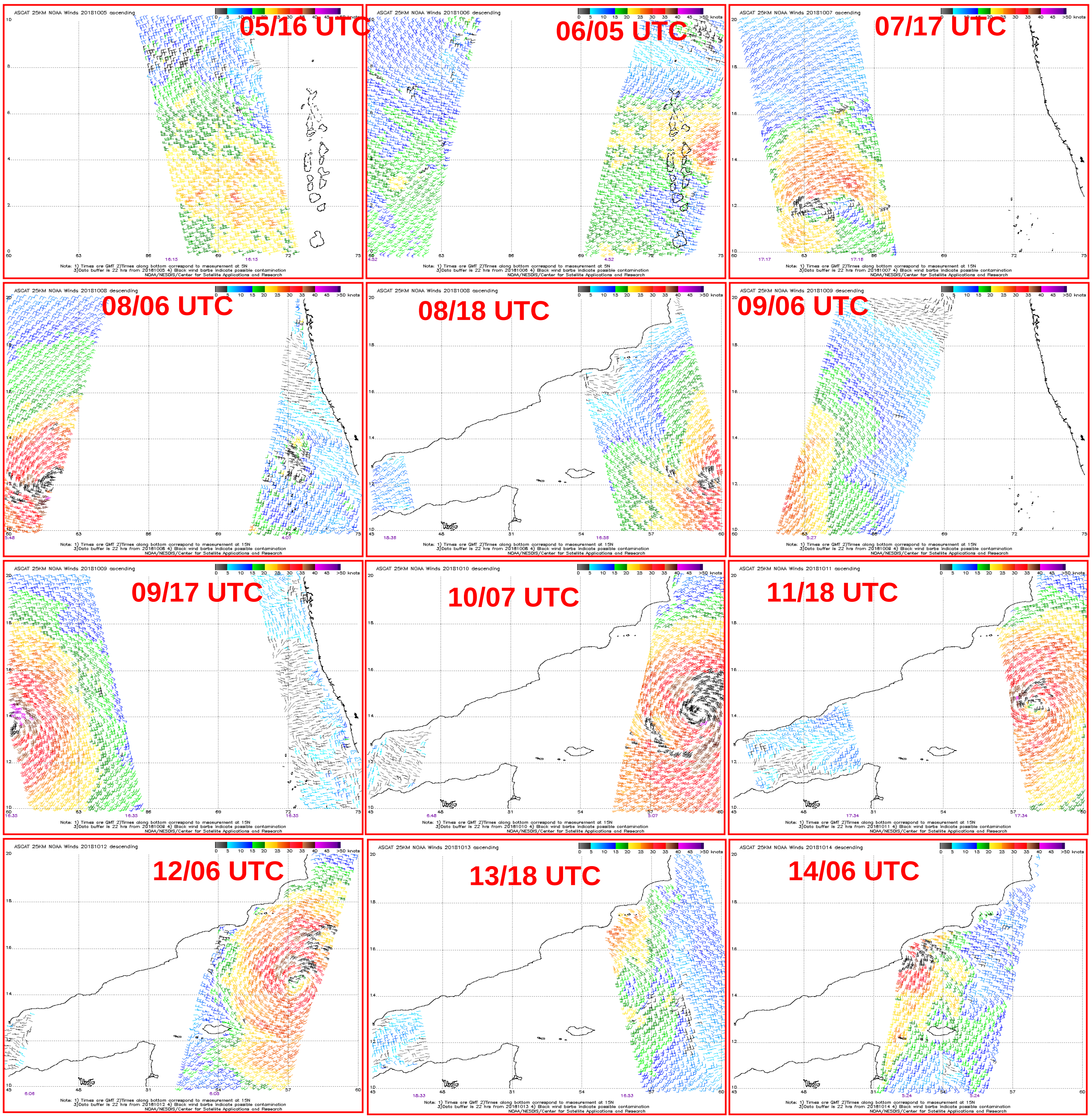


Fig. 6(f): ASCAT (Met-Op B) imageries during life cycle of ESCS Mekunu (06-15 October, 2018)

Typical imageries from polar satellite, SCATSAT are presented in Fig.6 (g). SCATSAT passes are available twice a day at 0454 UTC and 1636 UTC at http://mosdac.gov.in/scorpio/SCATSAT_Data. The observations from both the satellites were very useful in determining the surface wind structure. Stronger winds were seen in northeast and southeast sectors. The imagery also indicated large scale cross equatorial flow, inflow of warm and moist air into the system centre from southeast sector. SCAT Sat imageries helped in determination of centre to a good extent. Intensity estimates beyond 50 kts cannot be done with the help of these imageries. The analysis of the matching index (MI) shows that it could not predict cyclogenesis till observation based on 0200 UTC of 8th Oct. while the system intensified into a CS at 0000 UTC of 8th Oct.

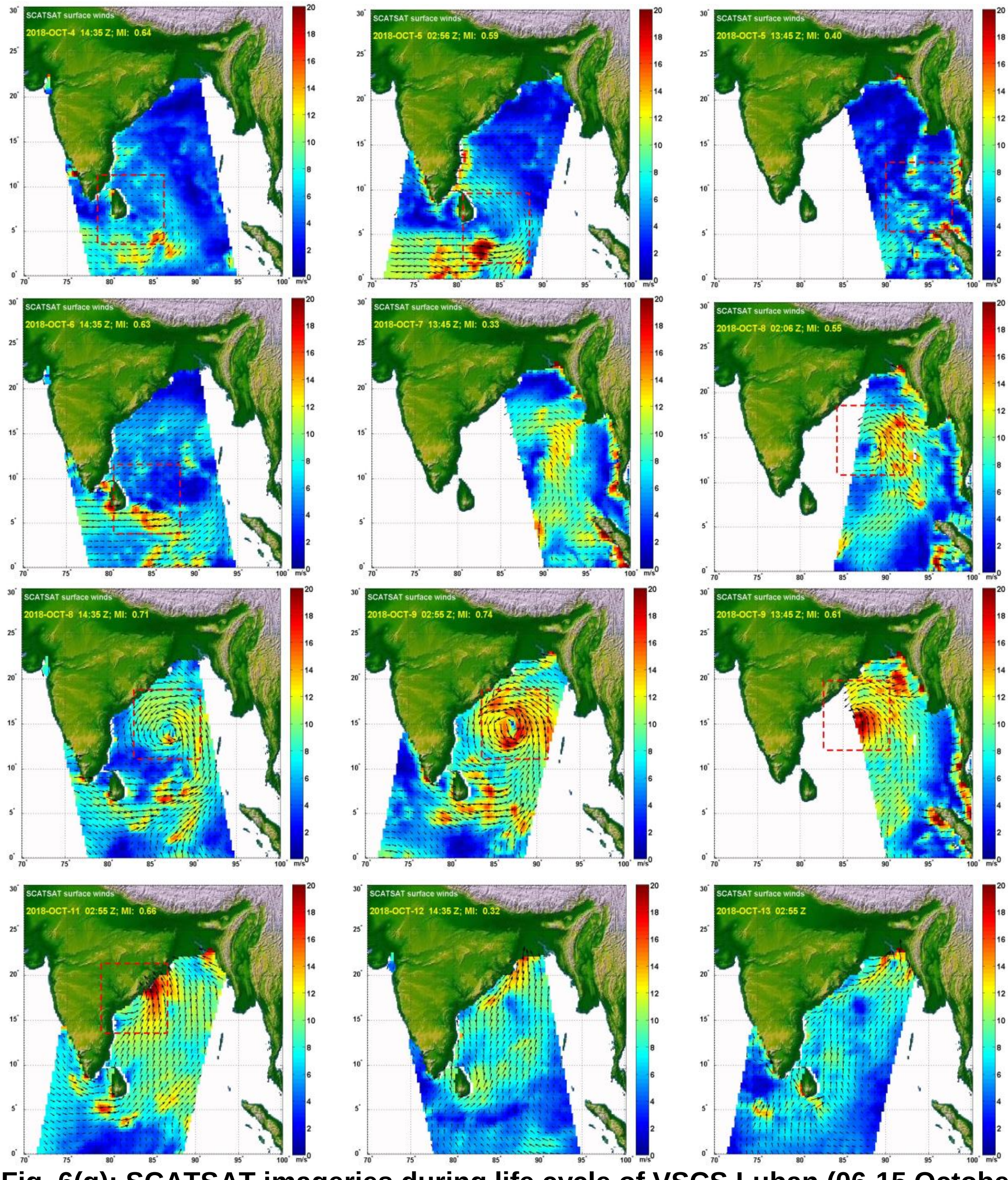


Fig. 6(g): SCATSAT imageries during life cycle of VSCS Luban (06-15 October, 2018)

5. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 6th to 15th October are presented in Fig.7. Based on 0000 UTC observations of 6th, the model predicted a low pressure area over southeast and adjoining southwest AS. It indicated a cyclonic circulation over southeast AS extending upto 500 hPa level.

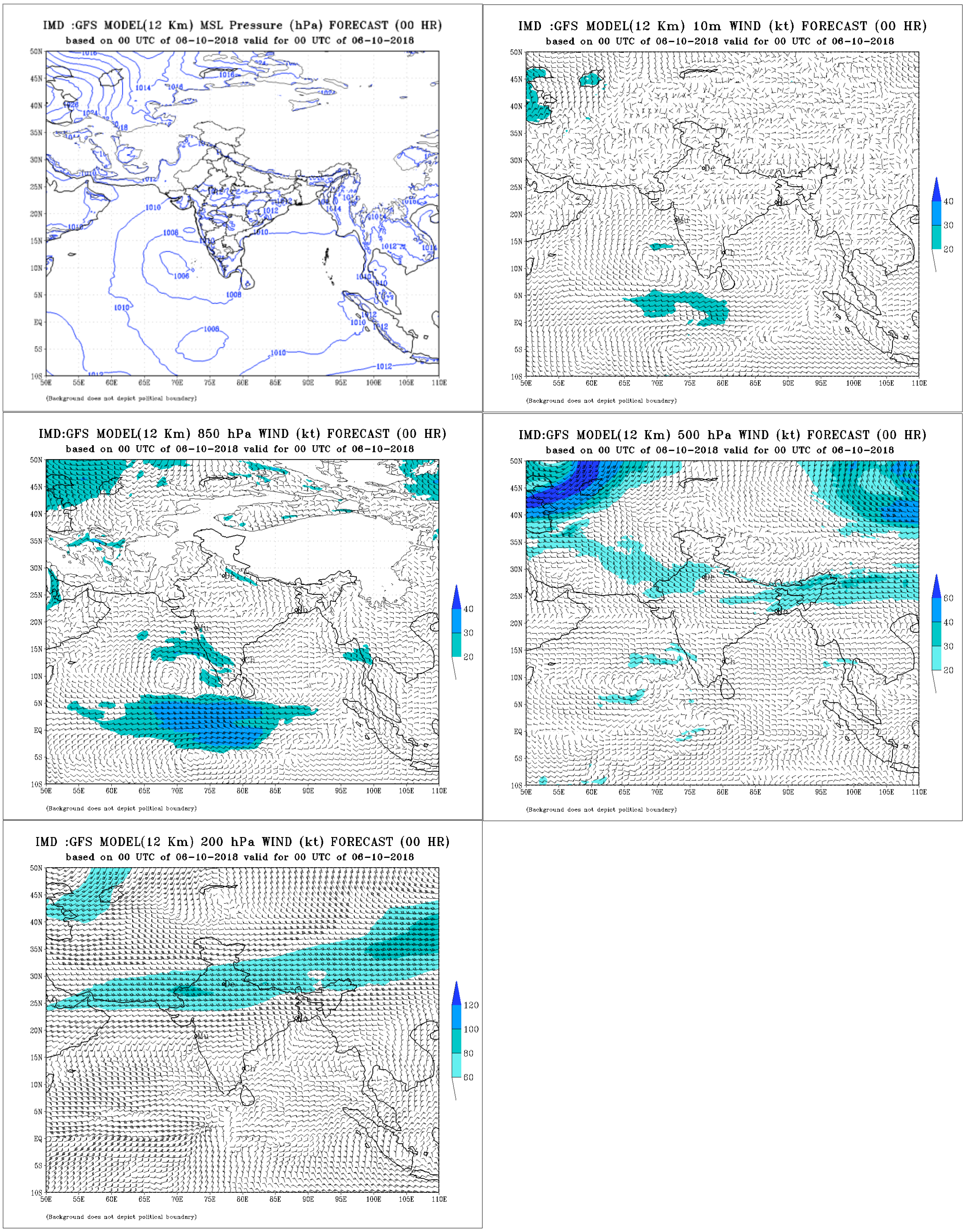


Fig 7 (i): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 6th October 2018.

Analysis based on 0000 UTC of 7th Oct., predicted intensification of system into a depression over southeast AS. Vertically the system extended upto 500 hPa levels.

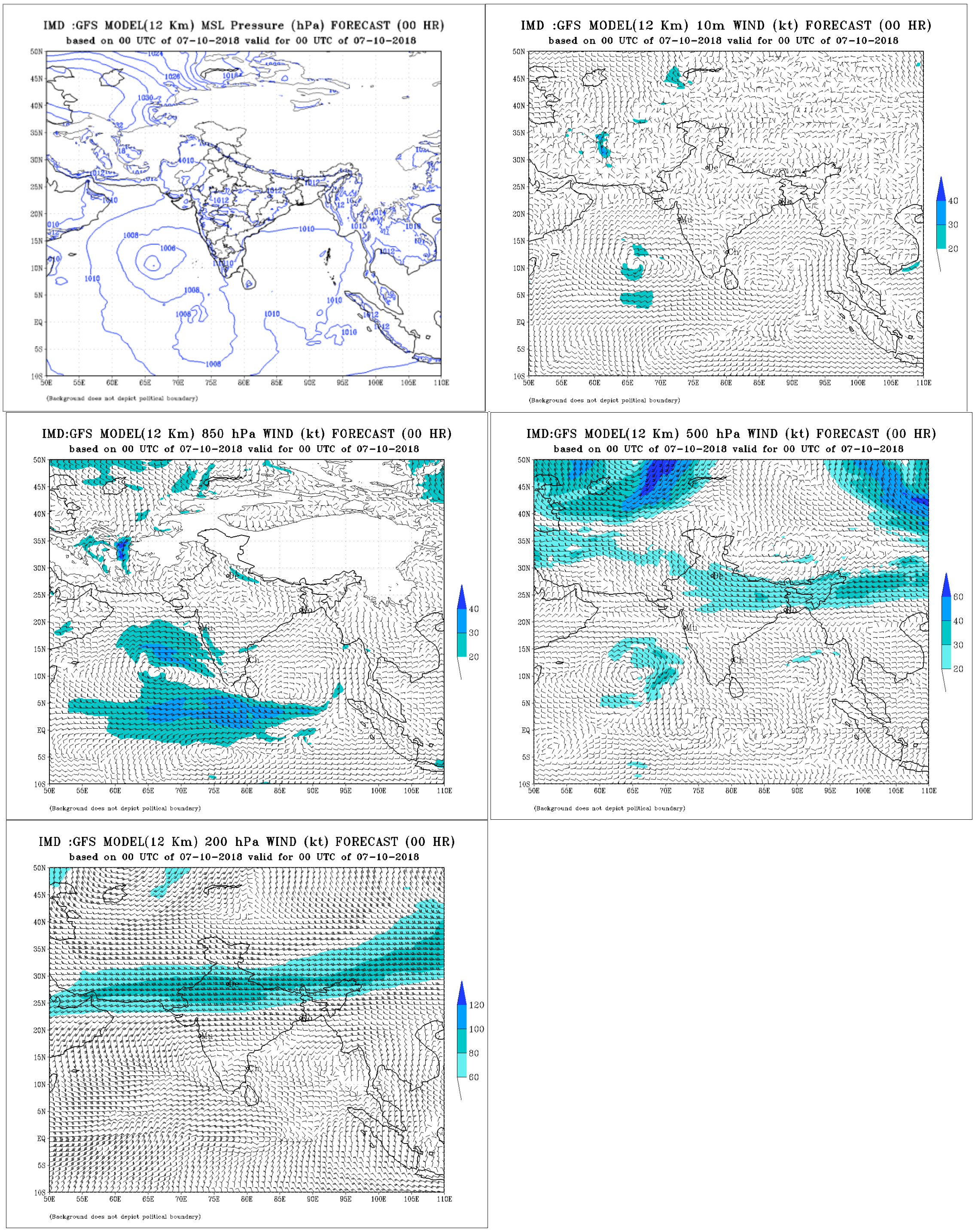


Fig.7 (ii): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 7th October 2018.

Analysis based on 0000 UTC of 8th Oct. predicted northwards movement and further intensification of system into a cylonic storm over southeast AS. The circulation extended upto 500 hpa levels.

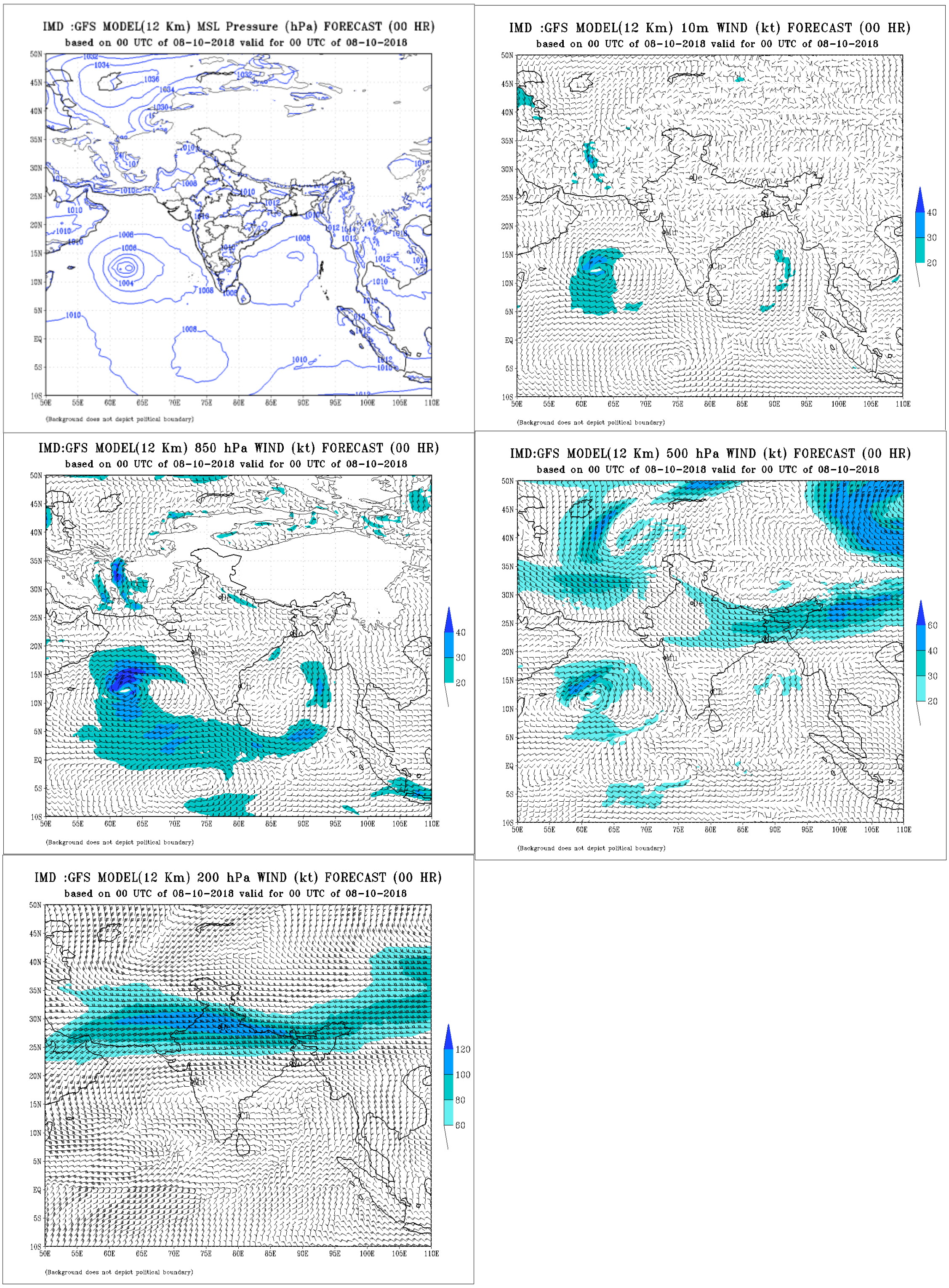


Fig. 7 (iii): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 8th October 2018.

Initial conditions based on 0000 UTC of 9th Oct. indicated further intensification of the system into a severe cyclonic storm (SCS) to the east of Socotra Islands.

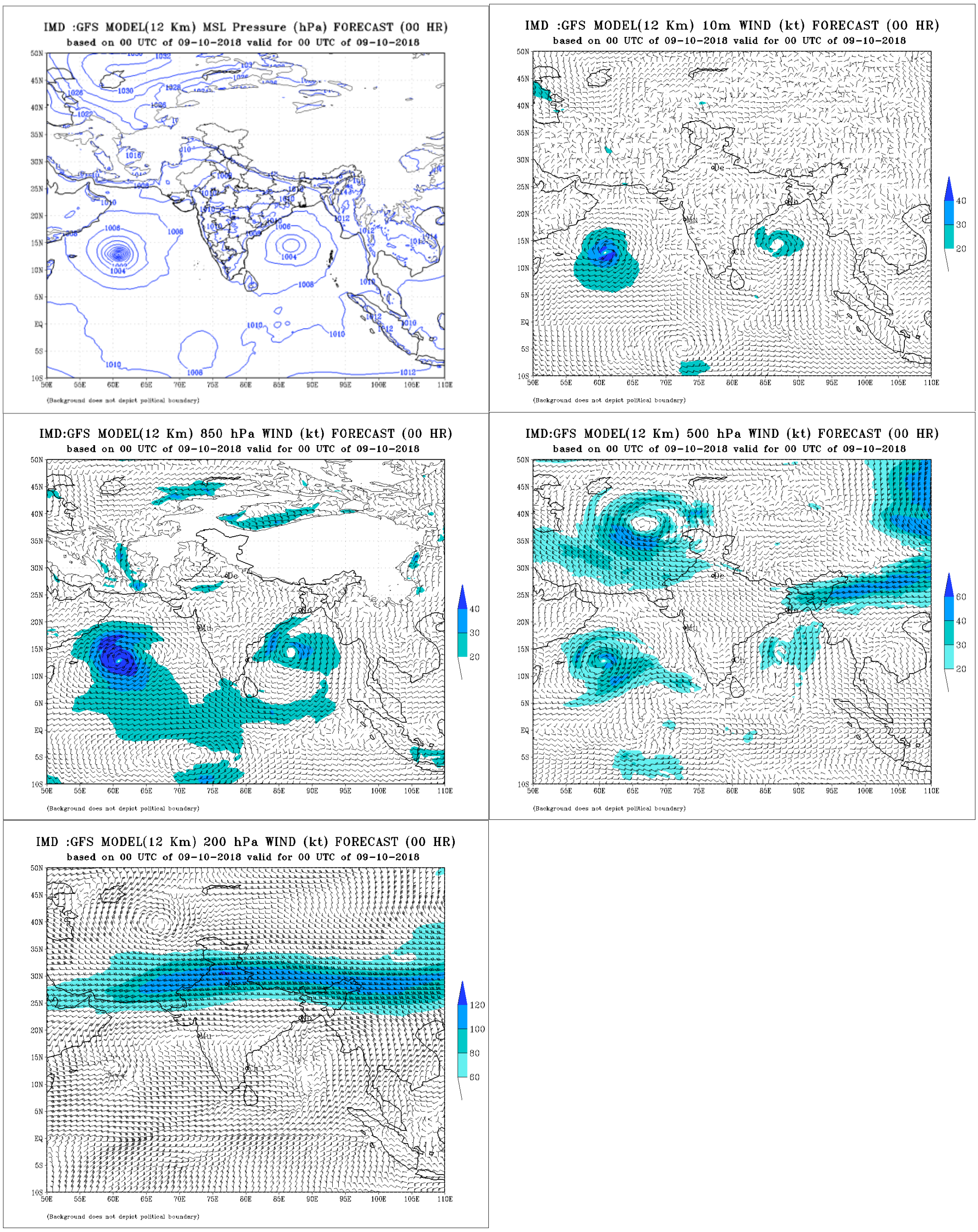


Fig.7 (iv): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 9th October 2018.

Analysis based on 0000 UTC of 10th Oct. indicated further intensification into VSCS and movement towards Yemen coast.

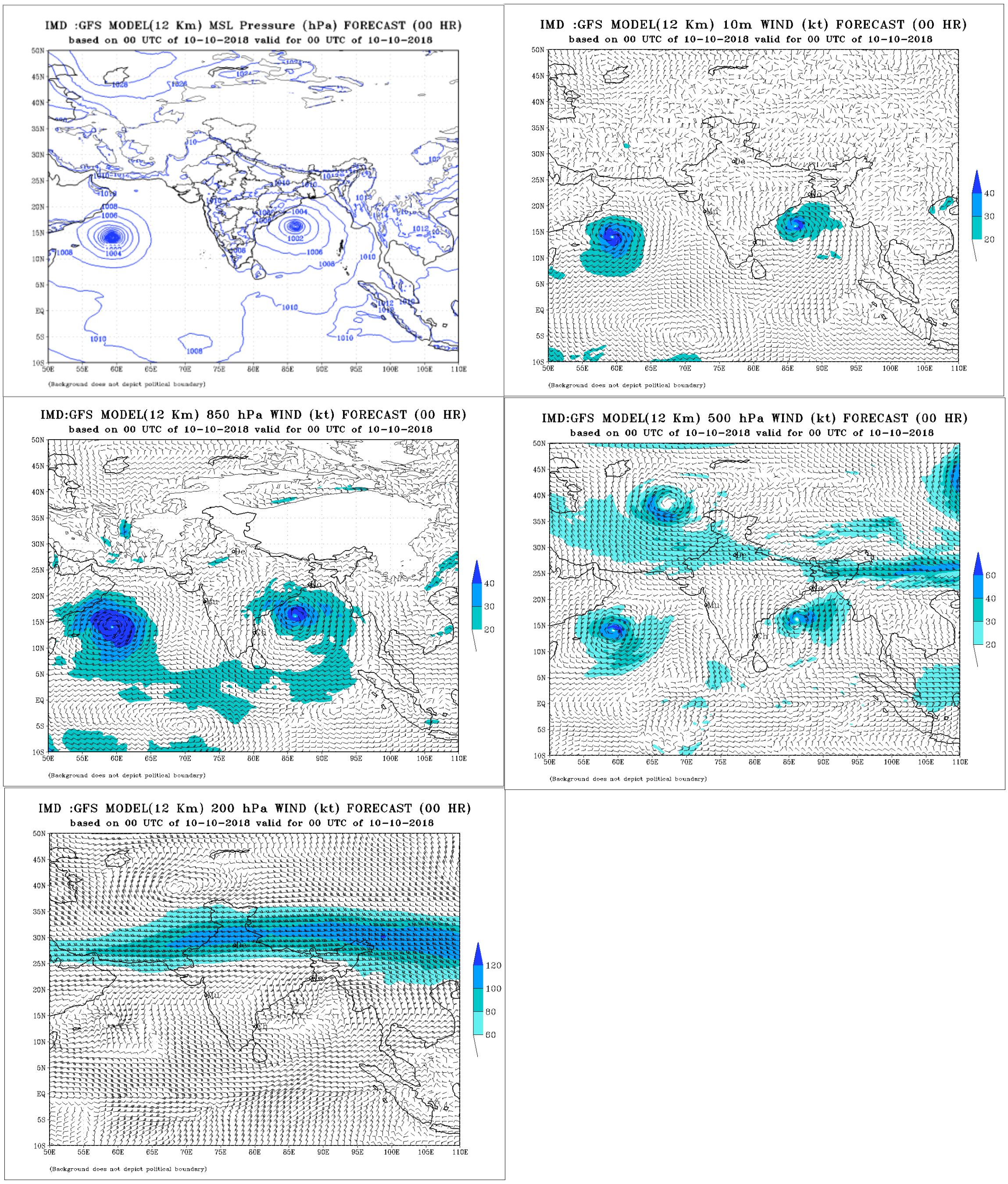


Fig.7(v): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 10th October 2018.

The initial conditions based on 0000 UTC of 11th indicated the system maintaining the intensity of VSCS.

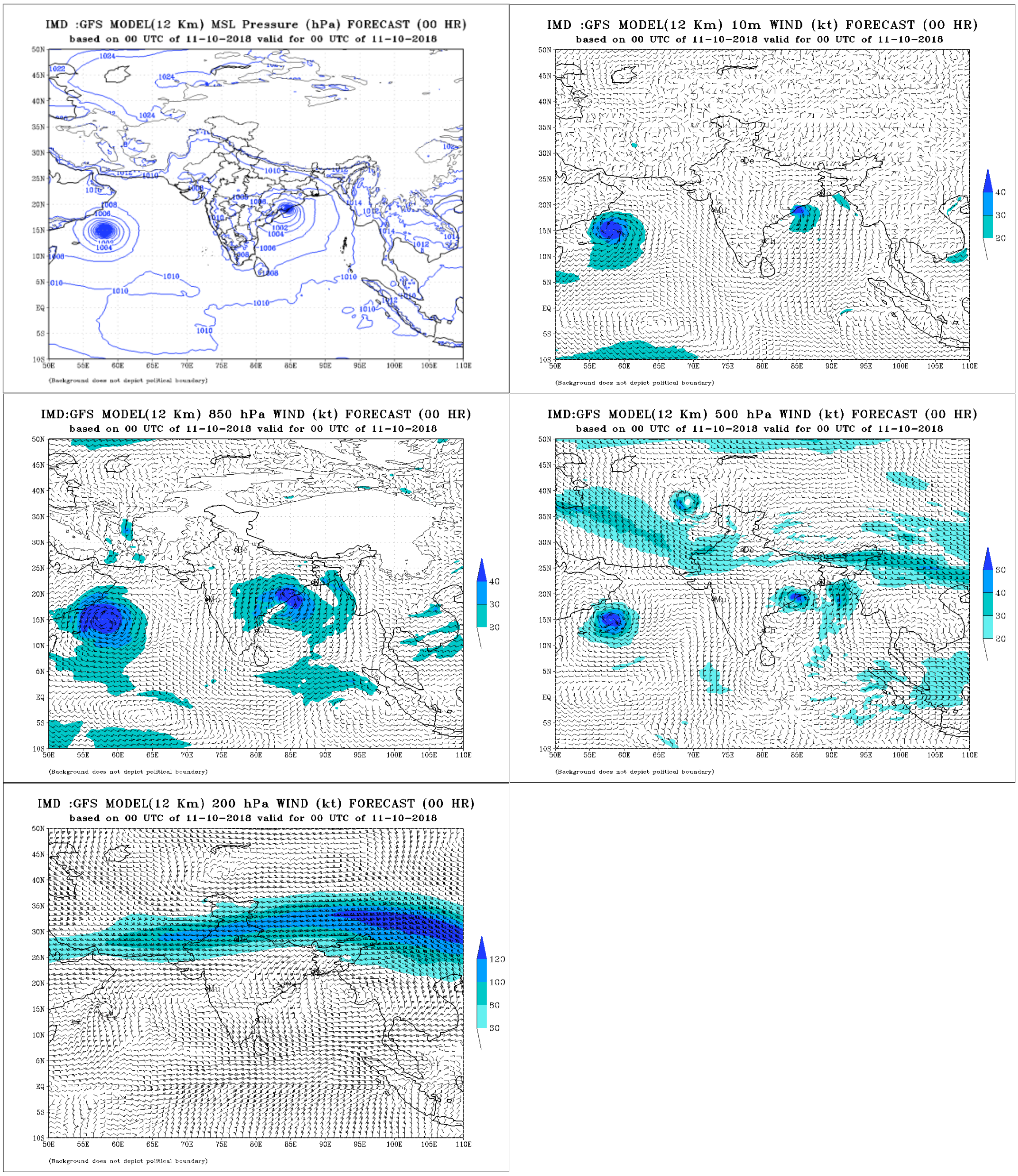


Fig.7(vi): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 11th October 2018.

The initial conditions based on 0000 UTC of 12th indicated the system maintaining the intensity of VSCS, but with slightly weakening trend.

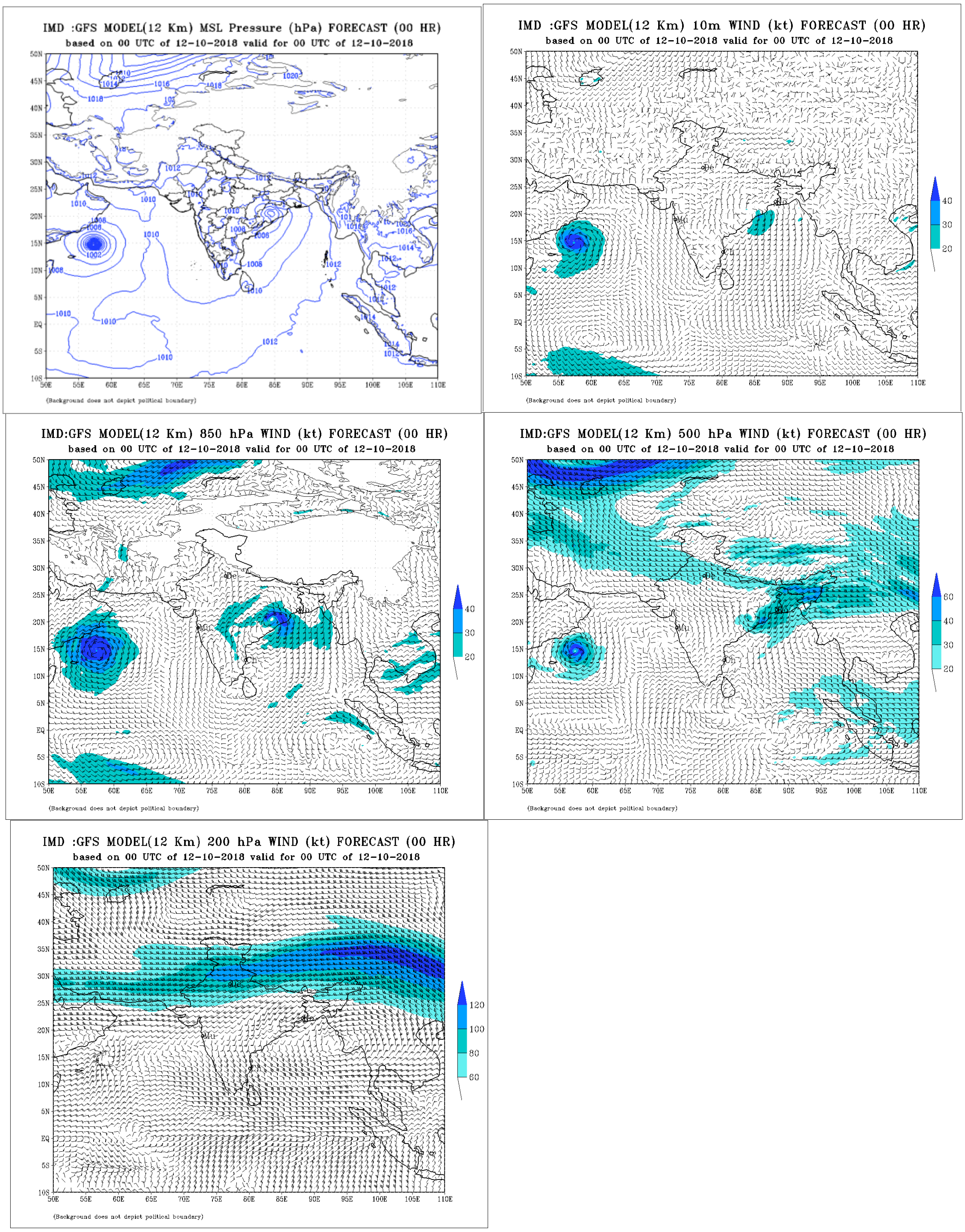


Fig.7 (vii): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 12th October 2018.

The initial conditions based on 0000 UTC of 13th indicated weakening of the system into SCS.

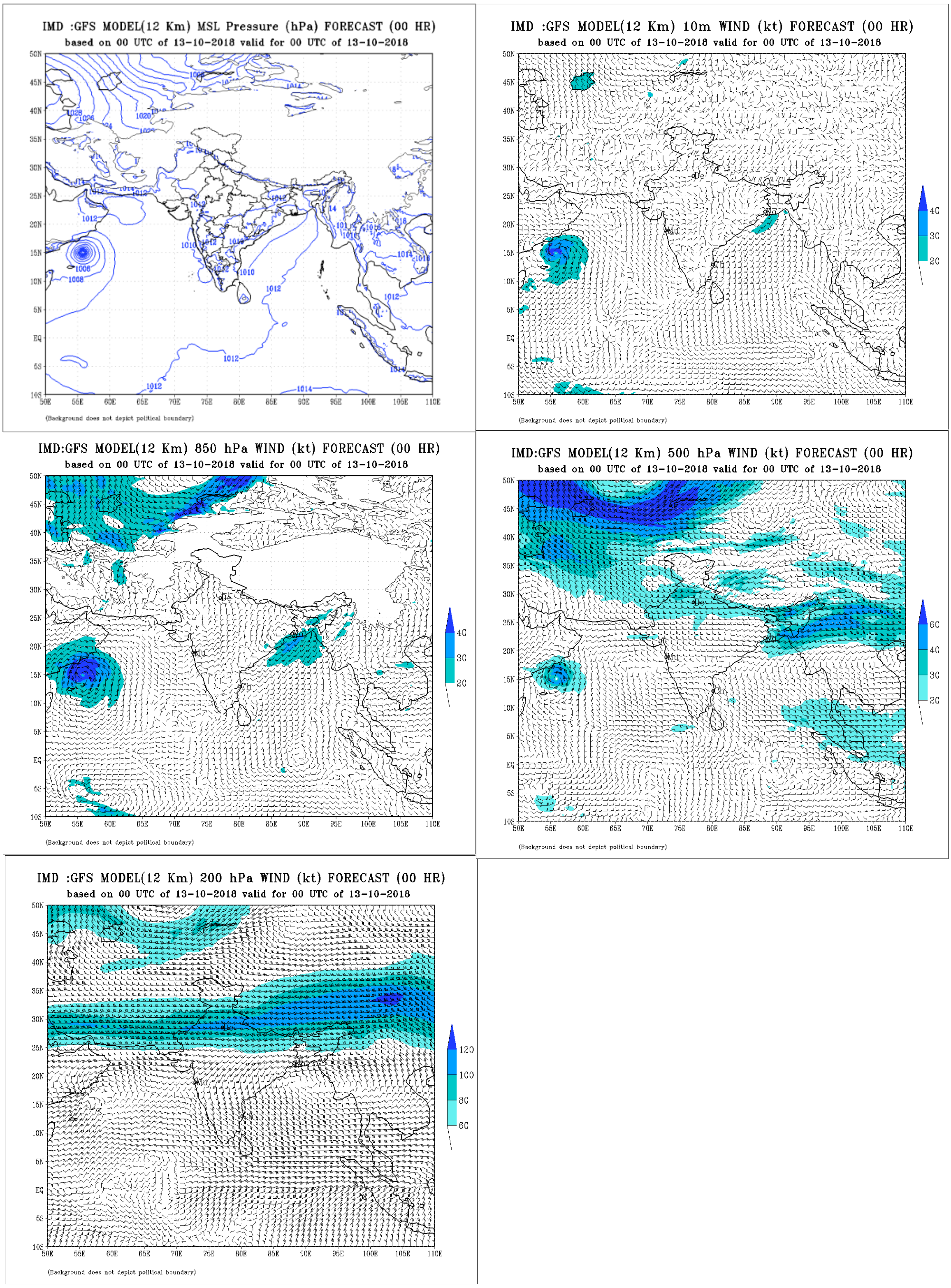


Fig.7(viii): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 13th October 2018.

The initial conditions based on 0000 UTC of 14th indicated further weakening of the system into CS.

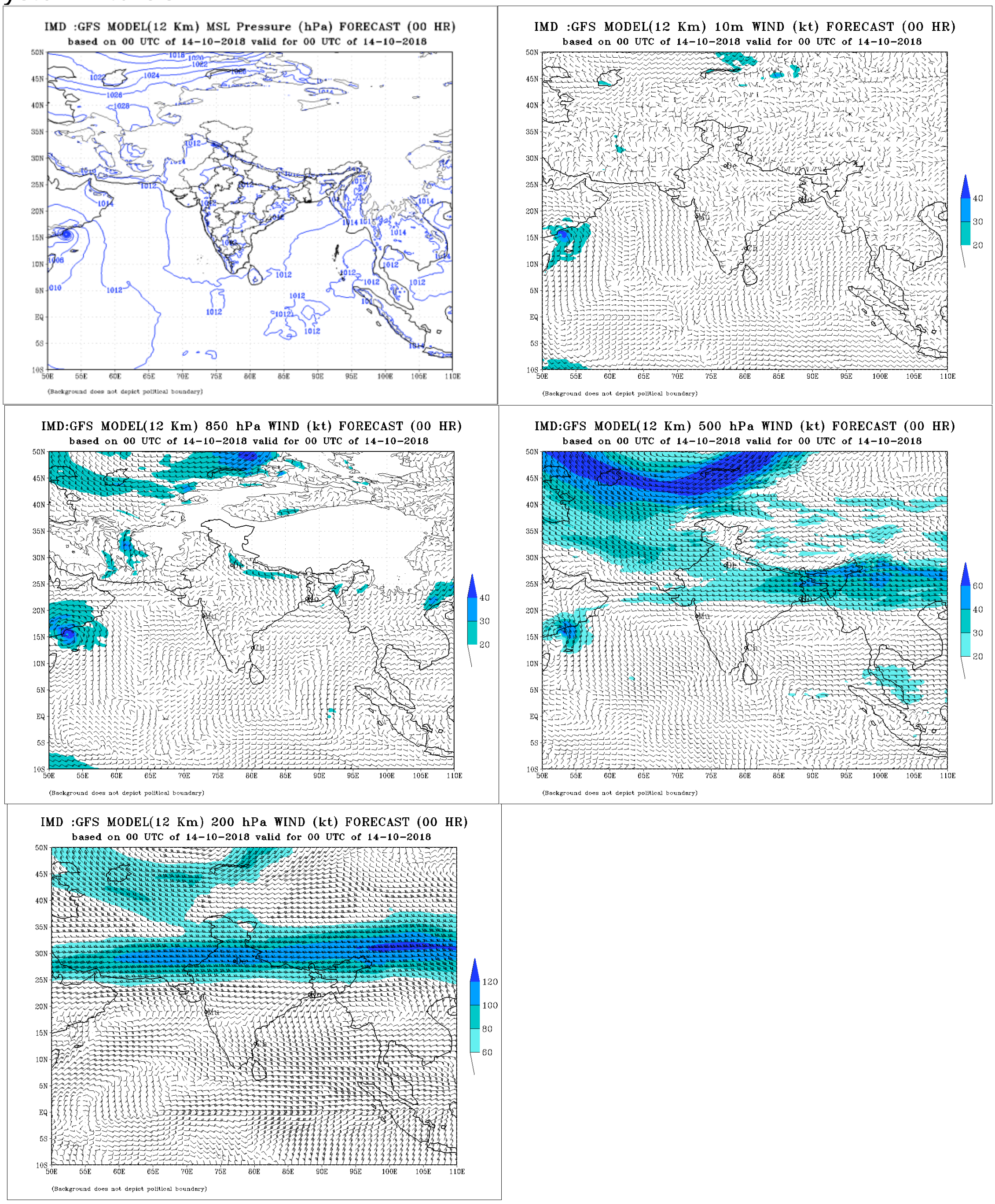


Fig.7(ix): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 14th October 2018.

The initial conditions based on 0000 UTC of 15th indicated weakening of the system over Yemen and adjoining Gulf of Aden.

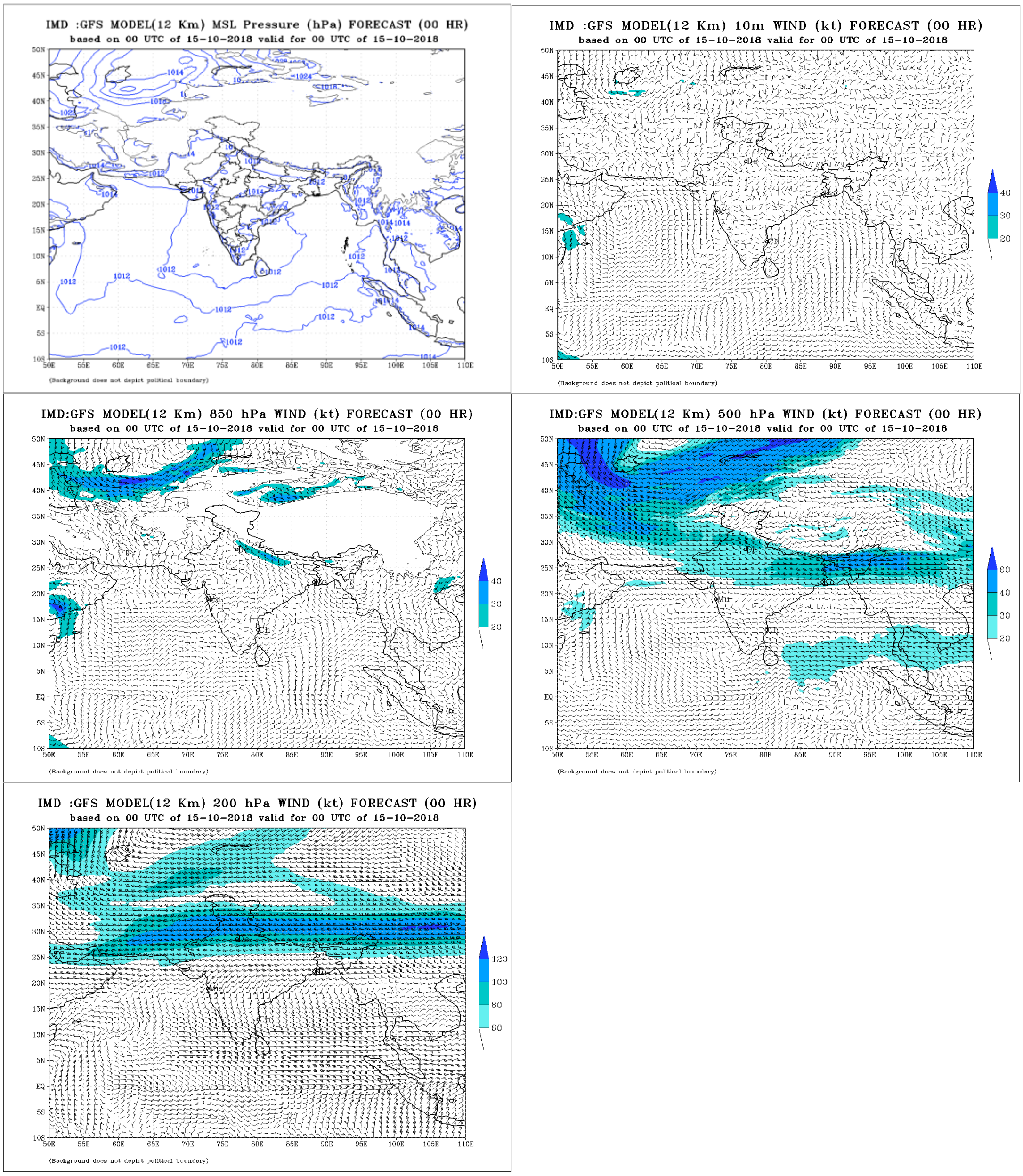


Fig.7(x): IMD GFS (T1534) mean sea level pressure (MSLP) and winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 15th October 2018.

Hence to conclude, to a large extent IMD GFS could simulate the genesis, intensification, movement and weakening of the system. However, during landfall it predicted west-southwestward movement against actual northwestward movement of the system.

5.1. Thermodynamical features based on HWRF model for weakening of the system before landfall.

The diagnostic products from IMD HWRF Model are presented in Fig. 8 (i-iii). The SST forecast based on 0000 UTC of 10th upto 96 hours is presented in Fig. 8 (i). The 96 hr. forecast indicated weakening of SST on 14th near Yemen coast.

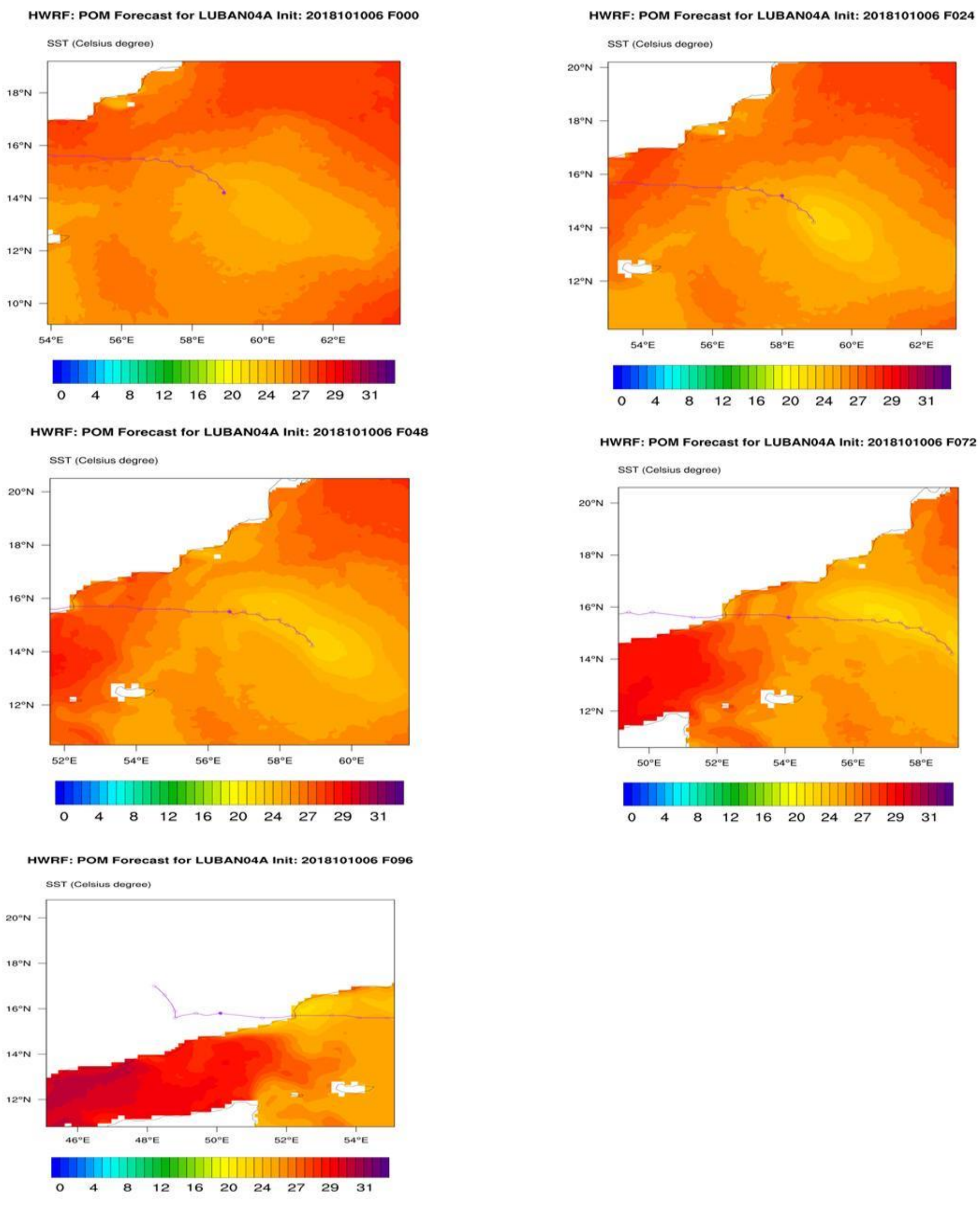


Fig 8 (i): IMD HWRF forecast of SST for next 96 hours based on 0000 UTC of 10th October.

The wind shear between 200-850 hPa levels is presented in Fig.8 (ii). It indicated high wind shear towards Oman and adjoining Yemen coast on 13 and 14 Oct.

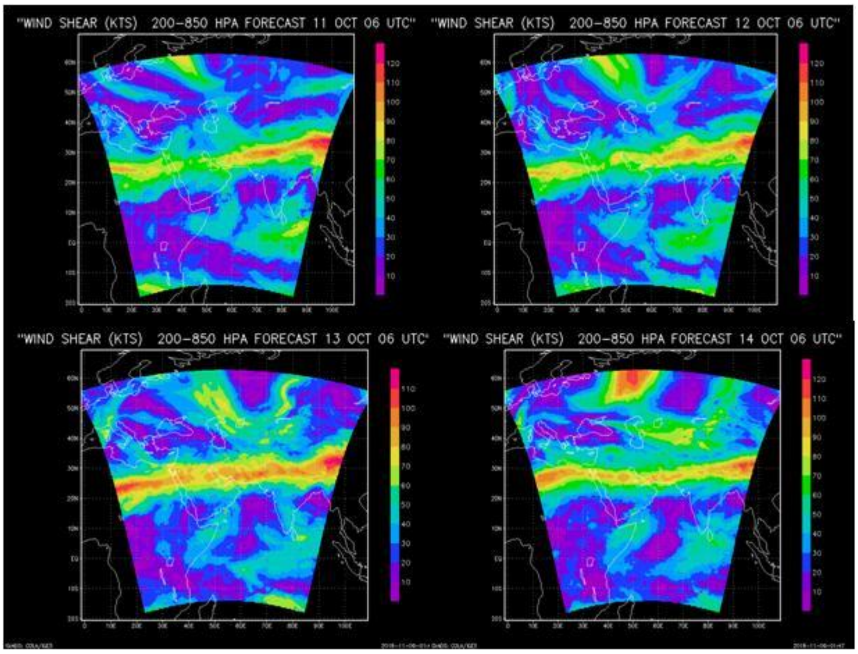


Fig 8(ii): IMD HWRF forecast of wind shear for next 96 hours based on 0000 UTC of 10th October.

The relative humidity at 500 hPa level is presented in Fig 8(iii). The humidity pattern in middle and upper indicated weakening of the system on 13th and 14th.

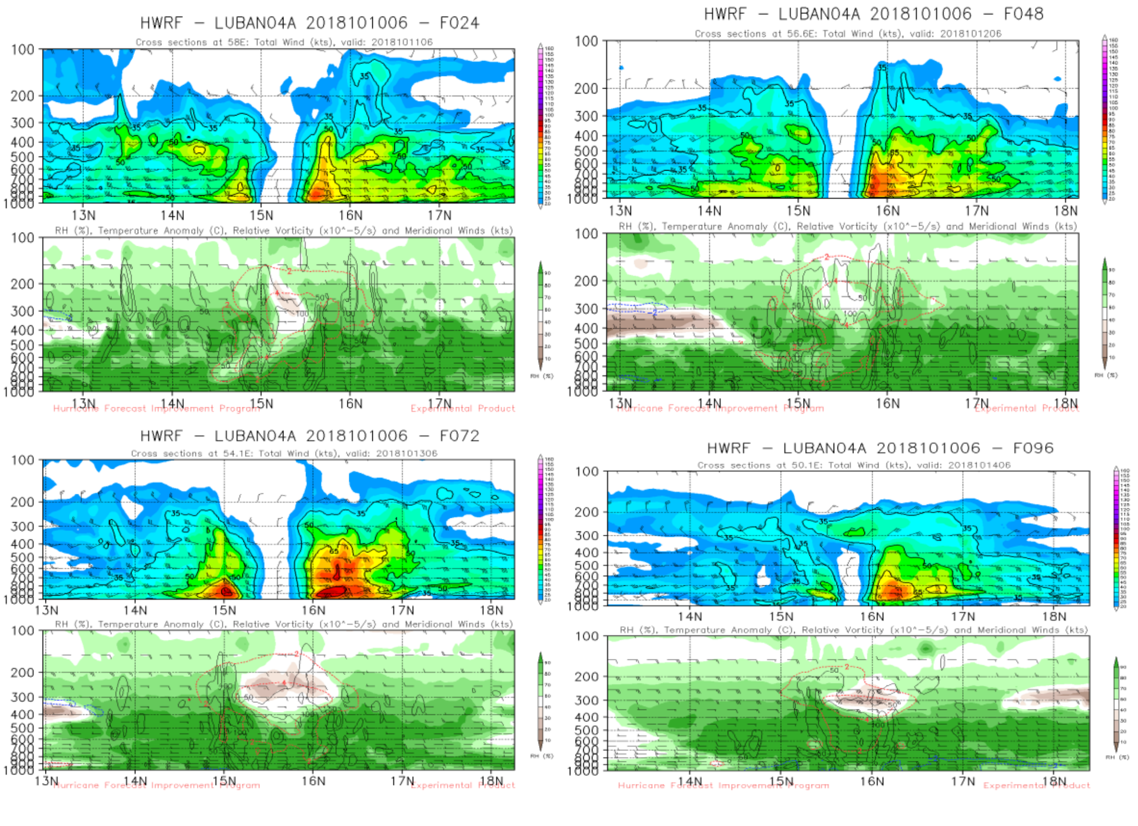


Fig 8(iii): IMD HWRF forecast of wind, relative humidity and temperature for next 96 hours based on 0000 UTC of 10th October.

6. Realized Weather:

6.1 Rainfall:

IMD-NCMRWF merged rainfall plots (Fig.9) indicate that the system caused heavy to very rainfall (8-16cm) over coastal areas of south Oman at a few places on 13th, 4-8 cm rainfall over coastal areas of Yemen on 14th and over interior parts of Yemen and Saudi Arabia on 15th.

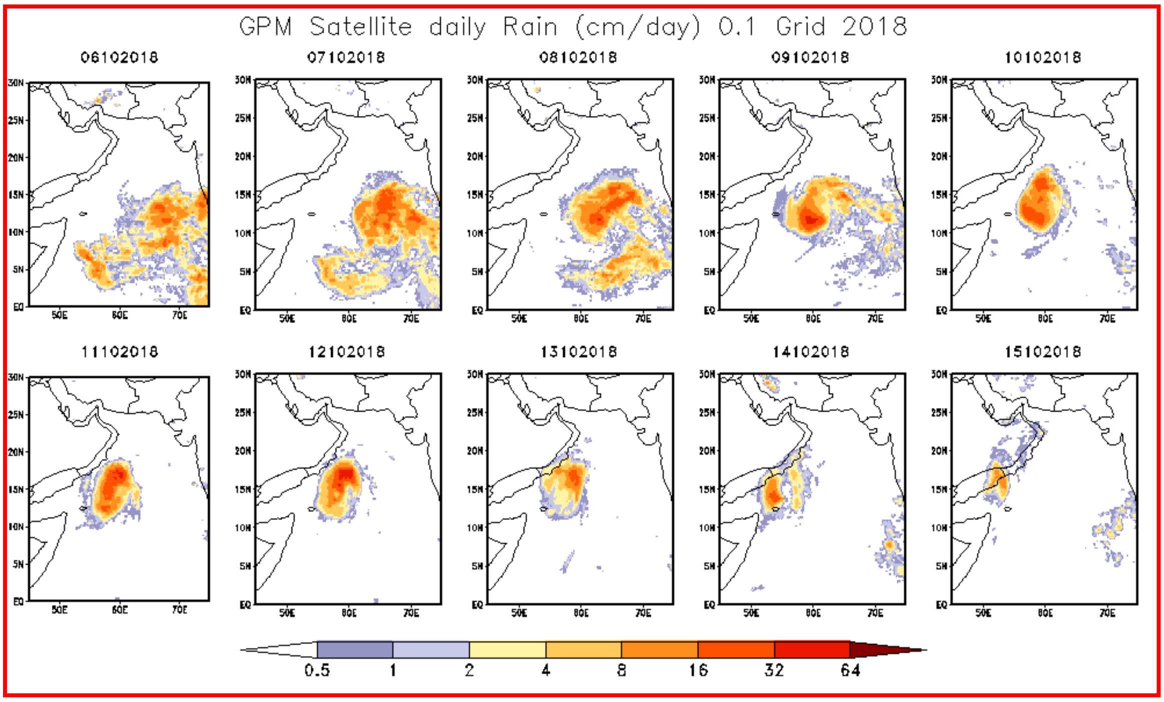


Fig.9: IMD-NCMRWF GPM merged gauge rainfall during 06-15 October and 7 days average rainfall (cm/day)

Realised weather over Yemen:

Al- Ghaidah (41398) : Rainfall (290mm), Wind 50kt.(45 gusting to 55kt),
Muklla (41443): Rainfall (56.5mm), Wind 20kt.
Socotra (41494): Rainfall (40mm), Wind 26kt.

Realised weather over Oman:
The highest amount of rainfall in Dhofar during 4pm on October 13 to 8am on October 14 was recorded in Dalkout (14.5 cm) followed by Salalah (13.8 cm), Rakhiout (13.3 cm), Mirbat (3.8 cm), Shaleem and Al Halaniyat Island (3.2 cm), Sadah (2.4 cm), Taqah (1.3 cm), Thumrait (1.1 cm) and Al Mazyouna (1.0 cm). The highest amount of rainfall recorded in Al Wusta was 1.1 cm in the Wilayat of Al Jaser, 9.0 cm in Mahout and 6.0 cm in Haima.

7. Damage due to VSCS Luban

Damage over India:

No casualties were reported from any Indian state due to VSCS, Luban.

Damage over Oman and Yemen: 14 persons lost their lives in Yemen due to floods in association with VSCS Luban. A few damage photographs are shown in Fig.10.

Fig.10. Flooding in Qishn district in Al Mahrah Governorate and damaged houses in Al Masilah district in Al Mahrah Governorate (Source: https://reliefweb.int/sites/reliefweb.int/files/resources/Cyclone%20Luabn%20Flash%20Update%203.pdf)

8. Performance of operational NWP models

IMD operationally runs a regional models, WRF for short-range prediction and one Global model T1534 for medium range prediction (10 days). The WRF-VAR model is run at the horizontal resolution of 27 km, 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25^0S to 45^0 N long 40^0 E to 120^0 E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 12 km. The boundary conditions are updated at every six hours interval. IMD also runs operationally, the cyclone specific Hurricane Weather Research & Forecast (HWRF) model (resolution 18 km, 6 km and 2 km) for cyclone track & intensity prediction in case of cyclone situation in the north Indian Ocean.

Global models are also run at NCMRWF. These include GFS and unified model adapted from UK Meteorological Office. NCUM (N768/L70) model features a horizontal resolution of 17km and 70 vertical levels. It uses 4D-Var assimilation and features no cyclone initialization/relocation. NCUM is a grid point model which has a Non-hydrostatic dynamics with a deep atmosphere suitable for all scales. NCMRWF Ensemble Prediction System (NEPS) is a global medium range probabilistic forecasting system adapted from UK MET Office. The configuration consists of 220 four cycles of assimilation corresponding to 00Z, 06Z, 12Z 18Z and 10-day forecasts are made using the 00Z initial condition. The N400L70 forecast model consists of 800x600 grid points on the horizontal surface and has 70 vertical levels. Horizontal resolution of the model is approximately 33 km in the mid-latitudes. The 10 day control forecast run starts with N768L70 analysis of the deterministic assimilation forecast system and 44 ensemble members start from different perturbed initial conditions consistent with the uncertainty in initial conditions. The initial perturbations are generated using Ensemble Transform Kalman Filter (ETKF) method.

In addition to the above NWP models, IMD also run operationally dynamical statistical models. The dynamical statistical models have been developed for (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and I Predicting decay in intensity after the landfall. Genesis potential parameter (GPP) is used for predicting potential of cyclogenesis (T3.0) and forecast for potential cyclogenesis zone. The multi-model ensemble (MME) for predicting the track (at 12h interval up to 120h) of tropical cyclones for the Indian Seas is developed applying multiple linear regression technique using the member models IMD-GFS, IMD-WRF, GFS (NCEP), ECMWF and JMA. The SCIP model is used for 12 hourly intensity predictions up to 72-h and a rapid intensification index (RII) is developed and implemented for the probability forecast of rapid intensification (RI). Decay model is used for prediction of intensity after landfall.

IMD also makes use of NWP products prepared by some other operational NWP Centres like, ECMWF (European Centre for Medium Range Weather Forecasting), GFS (NCEP), UKMO (UKMet), JMA (Japan Meteorological Agency). Ensemble prediction system (EPS) has been implemented at the NWP Division of the IMD HQ for operational forecasting of cyclones.

In this report performance of the individual models, MME forecasts, SCIP, GPP, RII and Decay model for cyclone MEKUNU are presented and discussed.

8.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for VSCS Luban

Fig.11 shows the predicted zone of cyclogenesis based on 0000 UTC of 2-7 Oct. for 7th Oct.

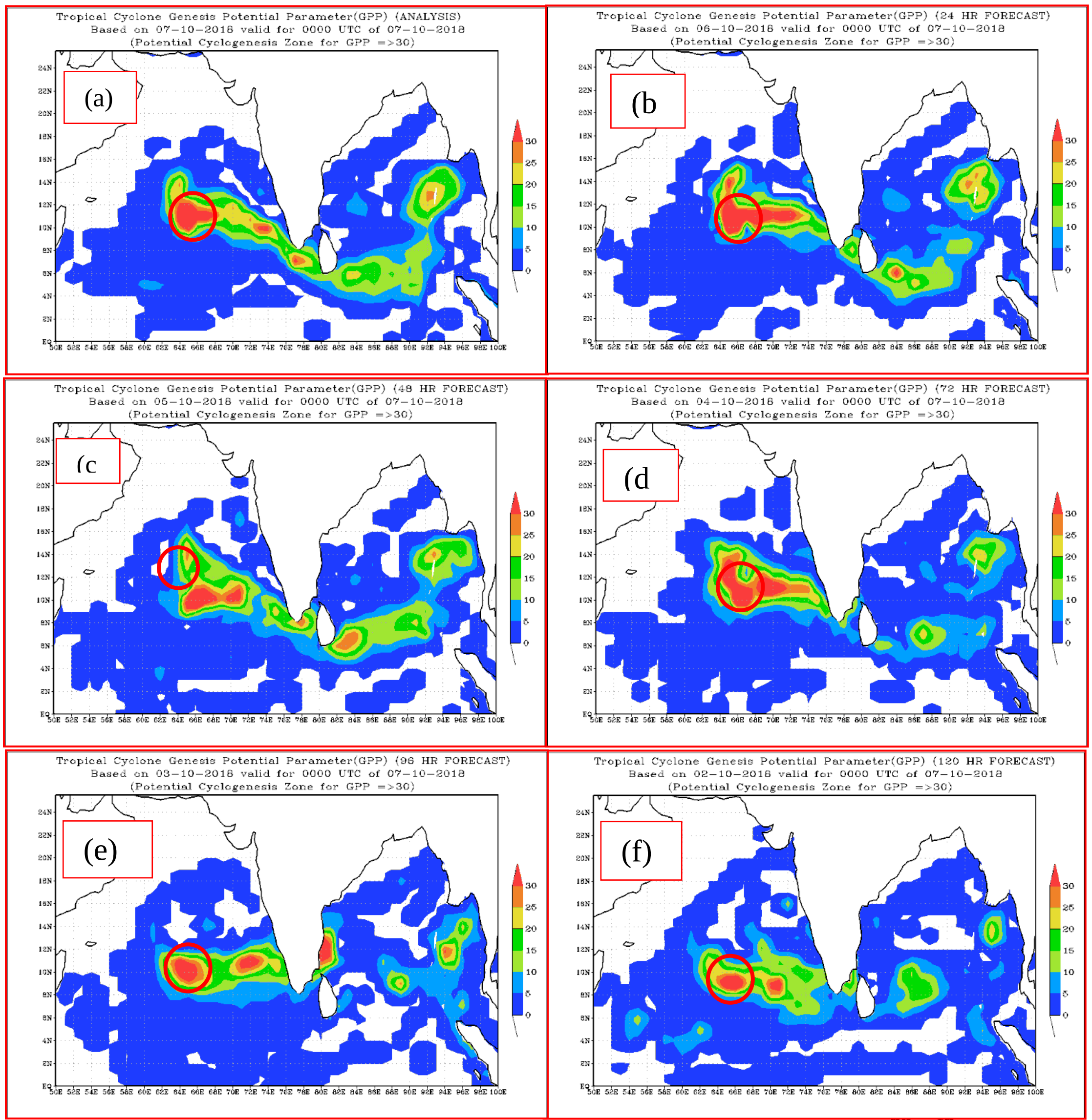


Fig.11(a-f): Predicted zone of cyclogenesis based on 0000 UTC of 2nd-7th October for 7th October.

The model could predict cyclogenesis zone correctly and consistently about 72 hours in advance. At the same time it was indicating a false potential zone for cyclogenesis over south BoB 48 & 72 hours in advance.

The potential of intensification (into cyclone) of a low pressure system at the early stages (T No. 1.0, 1.5, 2.0) of development was also predicted. Conditions for developed system is average GPP ≥ 8.0 and the forecasts of GPP (Fig. 12) showed potential to intensify into a cyclone at early stages of development (T.No. 1.0, 1.5, 2.0).

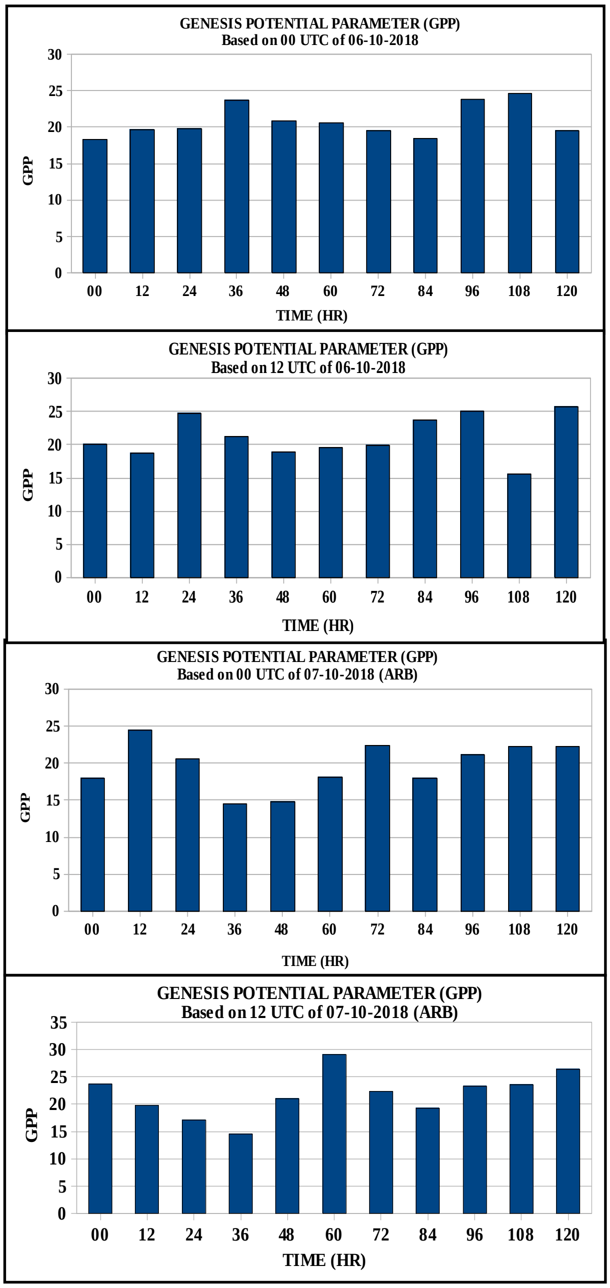


Fig. 12: Area average analysis and forecasts of GPP based on 0000 & 1200 UTC of 6th & 7th October, 2018

8.2 Track prediction by NWP models

The track prediction by indivdual NWP models and multi-model ensemble technique are presented in Fig.13. Based on 0000 UTC of 7th Oct. the models were in agreement for northwestward movement towards Oman and adjoining Yemen coast.

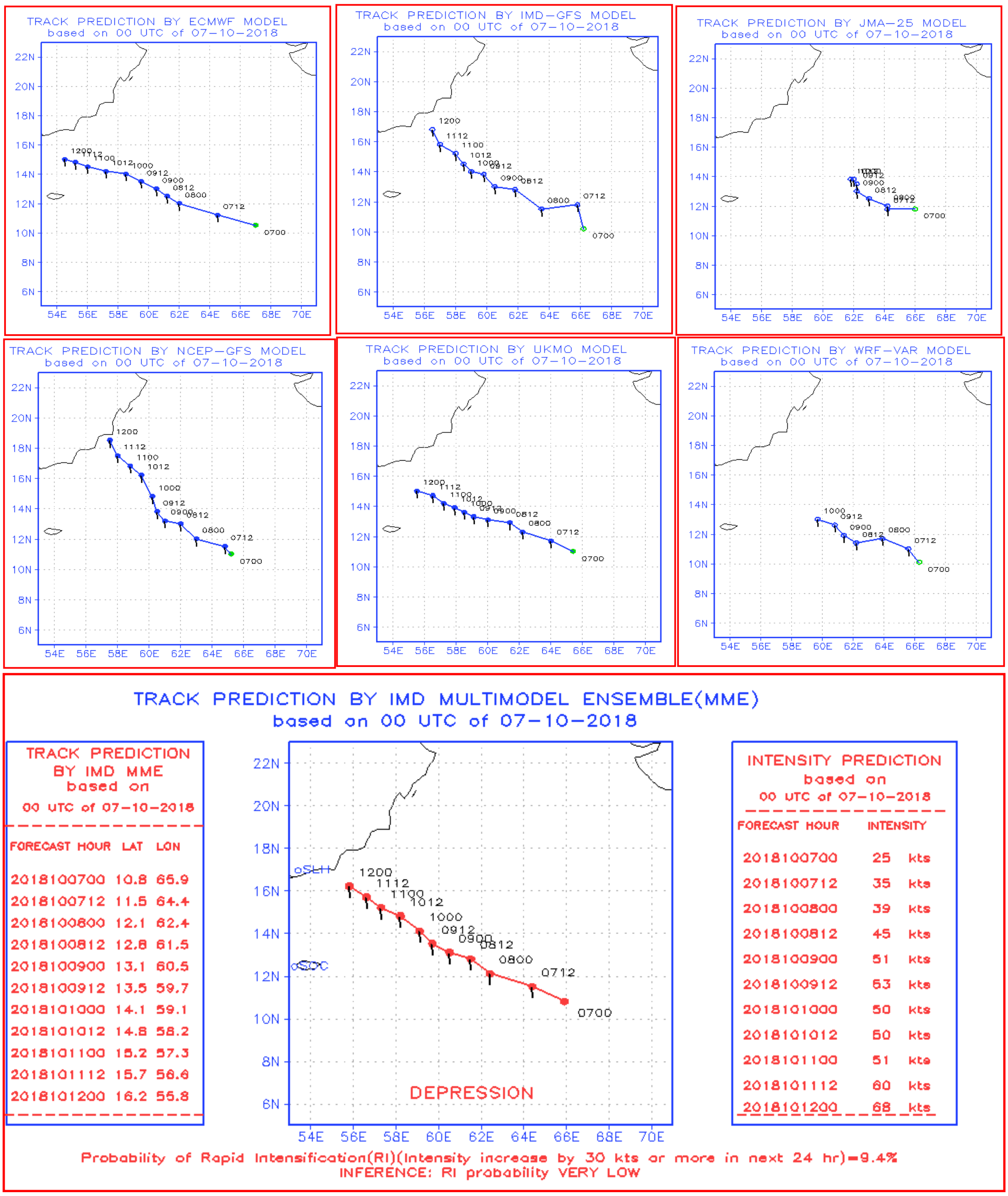


Fig.13(a). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 7th Oct. 2018

Based on 0000 UTC of 8th Oct. the models were large difference in track forecastby the models. IMD GFS and NCEP GFS indicated landfall over south Oman during 1200-1800 UTC of 12th Oct.

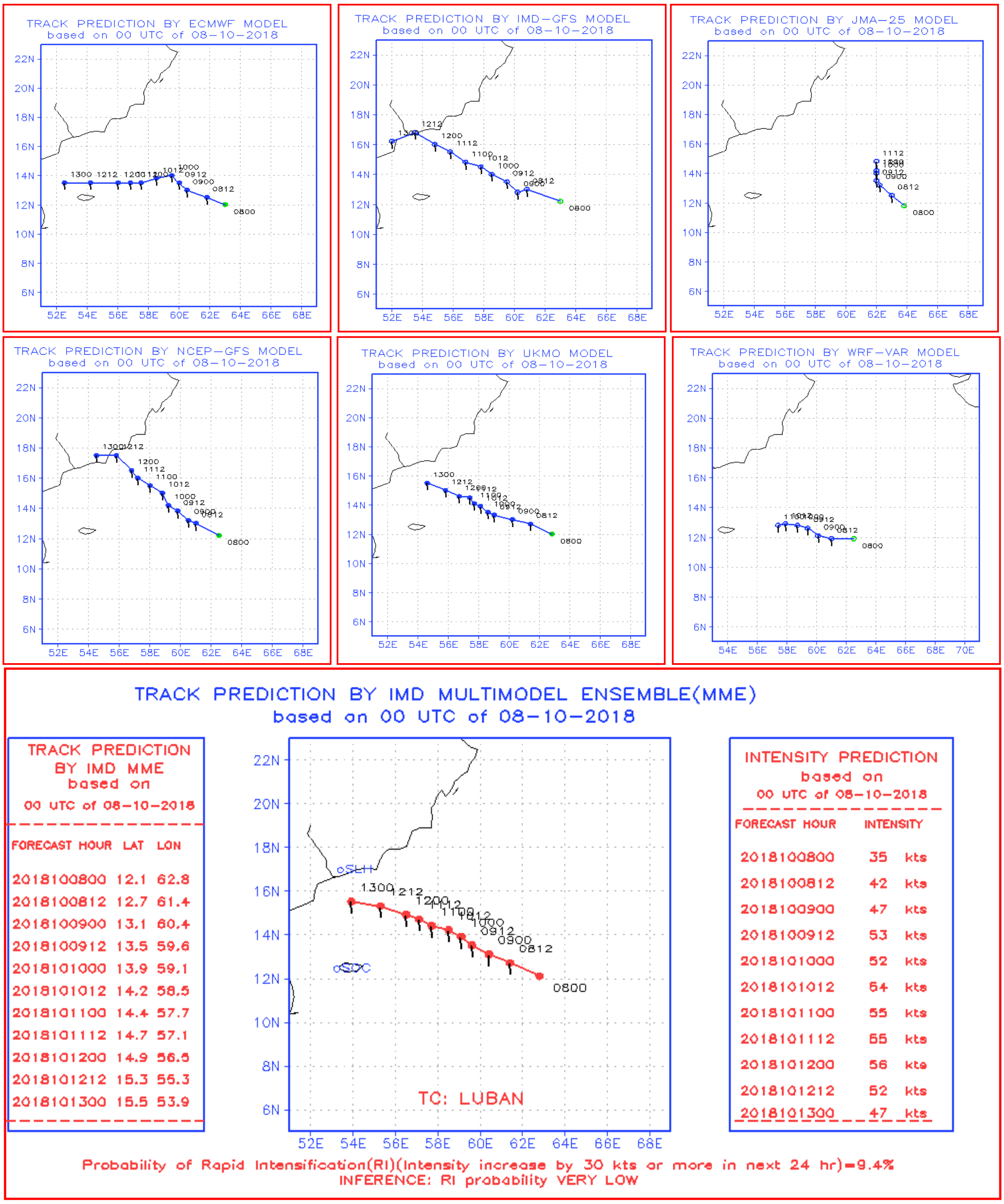


Fig.13(b). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 8th Oct. 2018

Based on 0000 UTC of 9th Oct. the models were in agreement again for northwestward movement towards Oman and adjoining Yemen coast. However, ECMWF indicated movement towards Gulf of Aden. IMD GFS, NCEP GFS, UKMO and MME indicated landfall near Yemen and adjoining Oman coast.

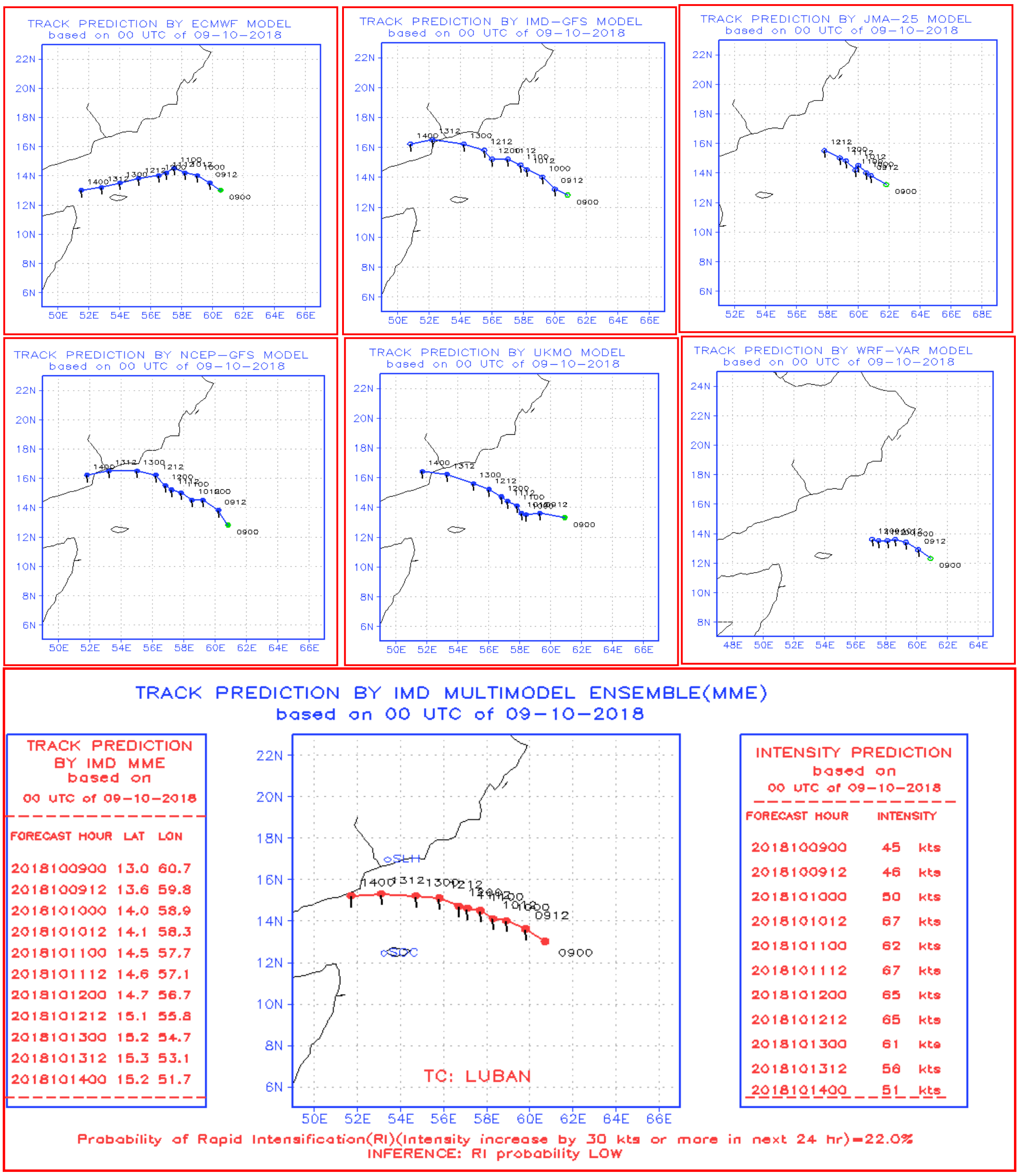


Fig.13(c). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 9th Oct. 2018

Based on 0000 UTC of 10th Oct. the models were in agreement again for northwestward movement towards Oman and adjoining Yemen coast. However, ECMWF indicated movement towards Gulf of Aden. IMD GFS, NCEP GFS, UKMO and MME indicated landfall near Yemen and adjoining Oman coast.

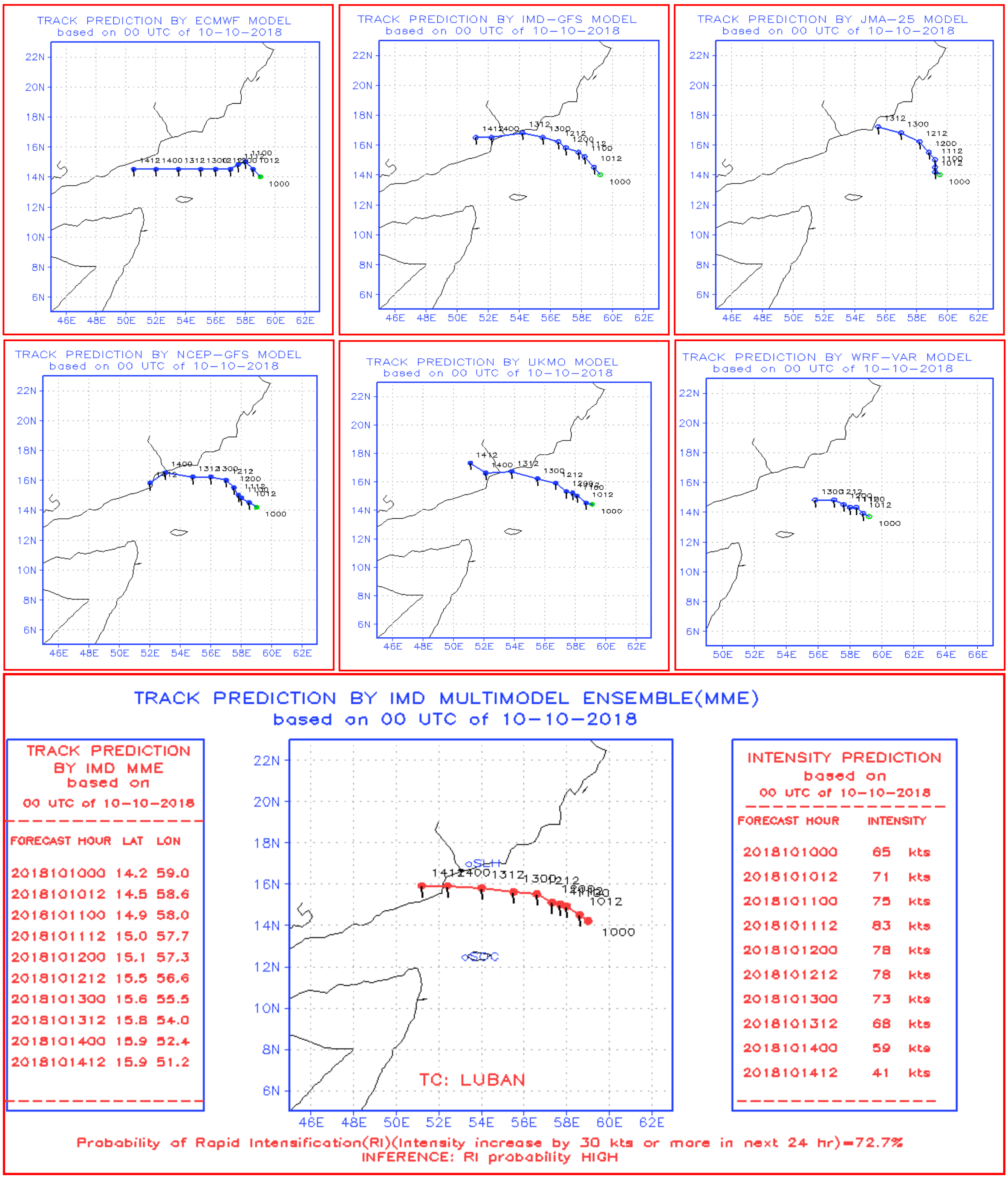


Fig.13(d). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 10th Oct. 2018

Based on 0000 UTC of 11th Oct. the models were in agreement again for northwestward movement towards Oman and adjoining Yemen coast. However, ECMWF indicated movement towards Gulf of Aden. IMD GFS, NCEP GFS, UKMO and MME indicated landfall near Yemen and adjoining Oman coast.The ECMWF, NCEP GFS indicated west-southwestward movement on 14th and MME from 1200 UTC of 14th.

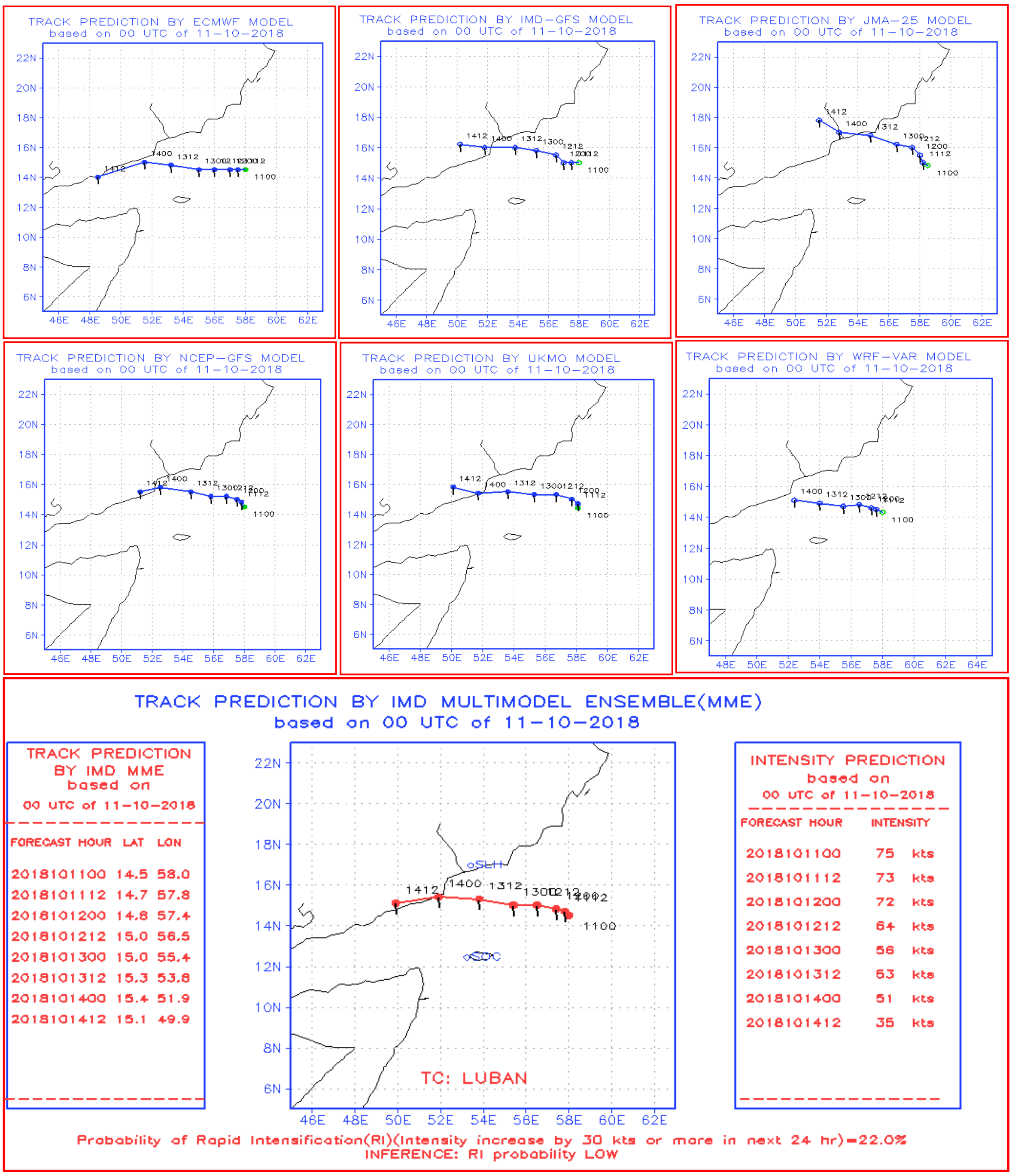


Fig.13(e). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 11th Oct. 2018

Based on 0000 UTC of 12th Oct. the models were in agreement again for northwestward movement towards Oman and adjoining Yemen coast. However, ECMWF, NCEP GFS and MME indicated movement towards Gulf of Aden skirting Yemen coast. IMD GFS, NCEP GFS, UKMO indicated landfall near Yemen coast.

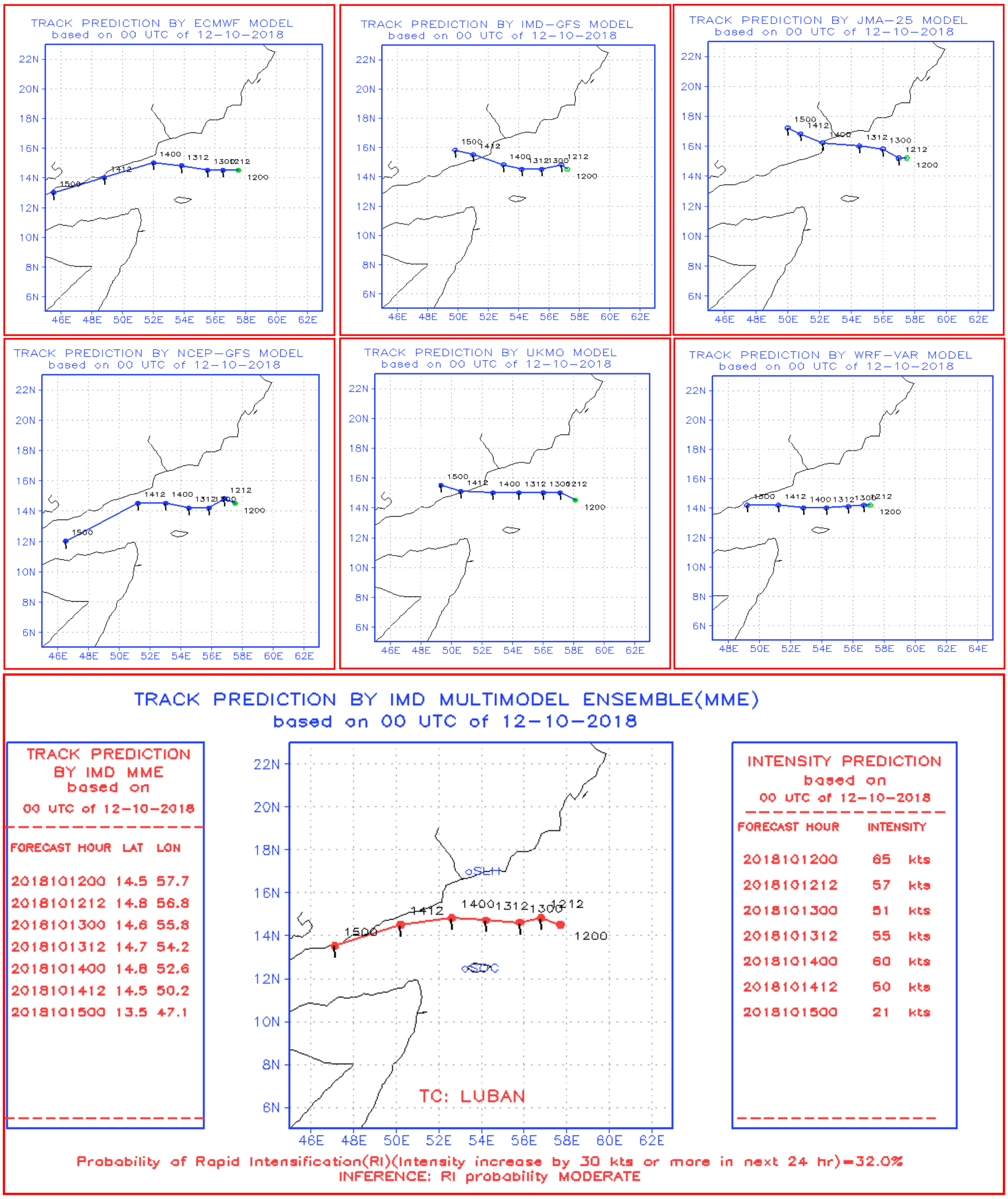


Fig.13(f). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 12th Oct. 2018

Based on 0000 UTC of 13th Oct. the models were in agreement for initial west-northwestward movement towards Yemen coast and then west-southwestward movement. However, ECMWF, NCEP GFS and MME indicated movement towards Gulf of Aden skirting Yemen coast. IMD GFS, JMA and UKMO indicated landfall near Yemen coast.

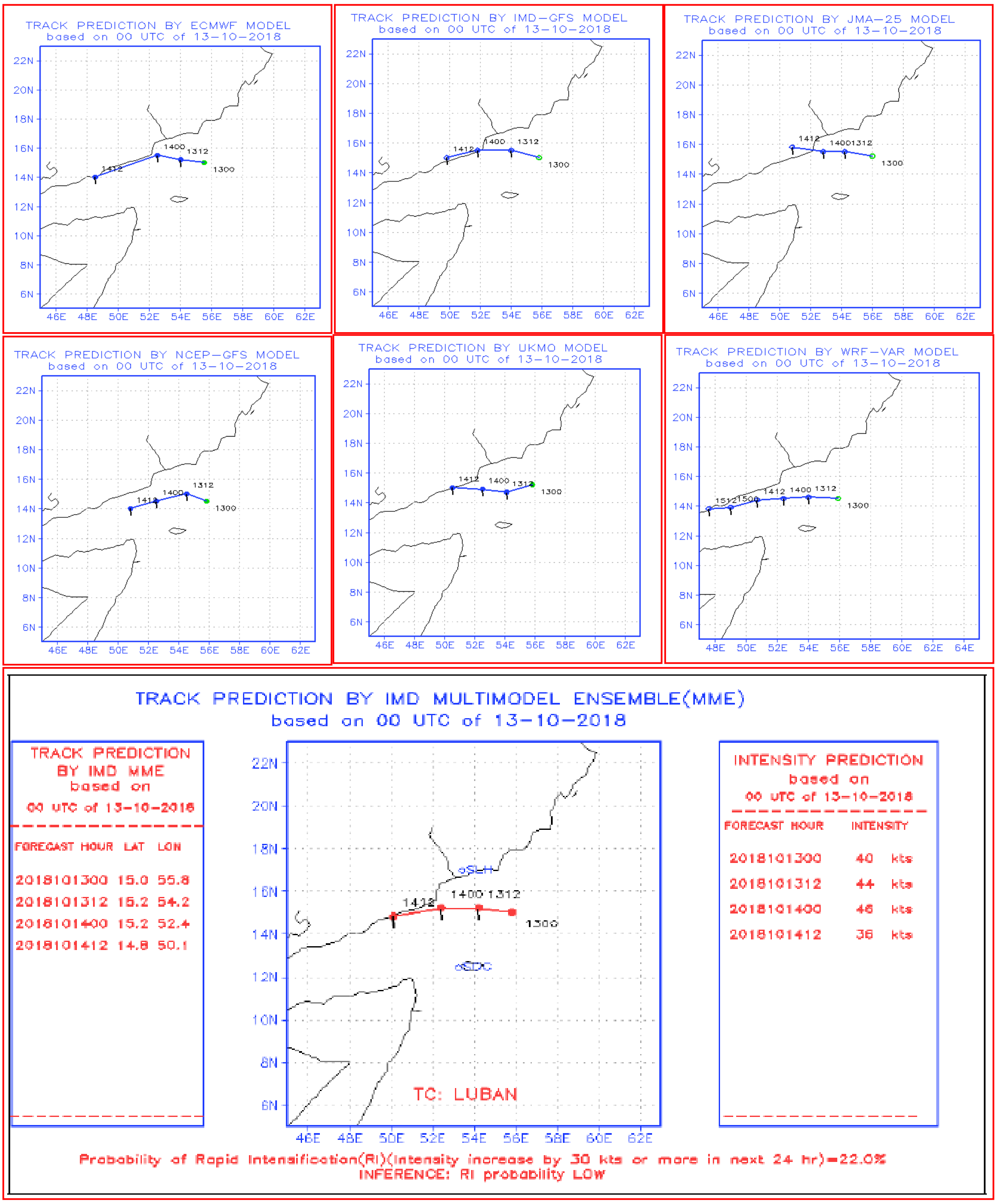


Fig.13(g). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 13th Oct. 2018

Based on 1200 UTC of 13th Oct. all the models except NCEP GFS indicated west-northwestward movement and landfall over Yemen. The NCEP GFS model showed west-southwestward movement towards Gulf of Aden.

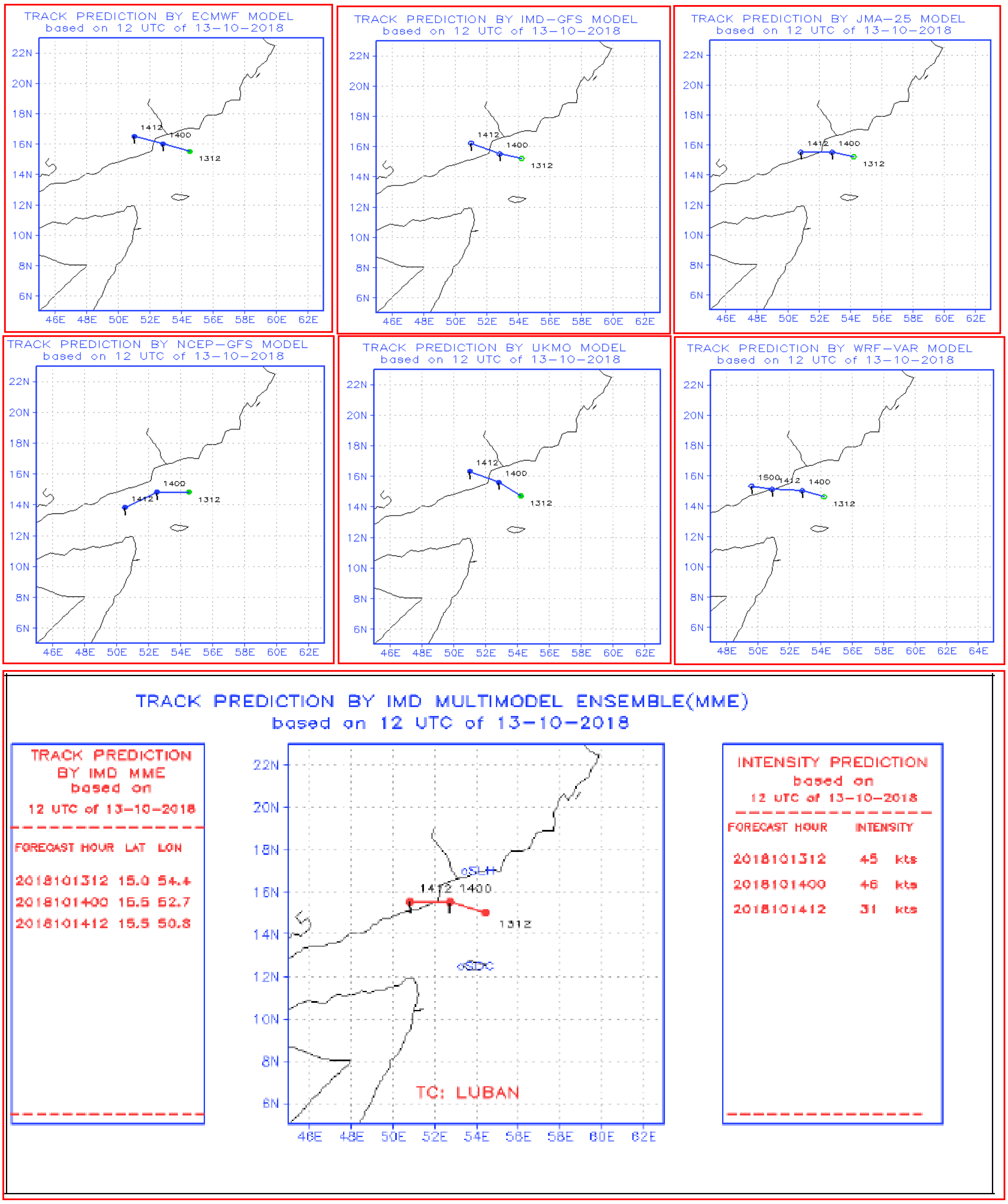
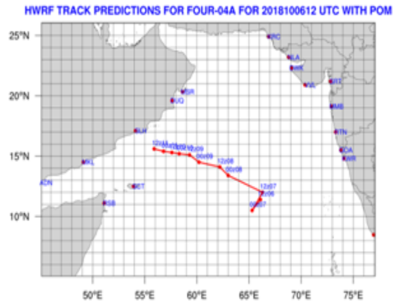
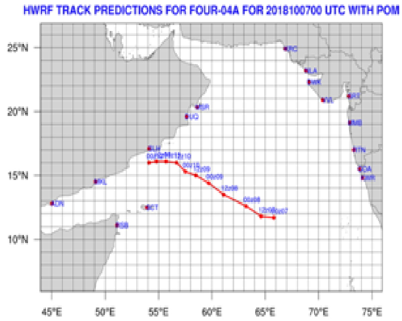


Fig.13 (h). Track prediction by indivdual NWP models and multi-model ensemble technique based on 0000 UTC of 7th Oct. 2018

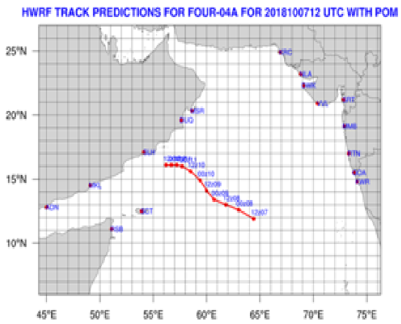
The track and intensity prediction by IMD-HWRF model for VSCS, Luban is presented in Fig.14. It indicates that the model could predict the track reasonably well indicatinh northwestward movement towards Yemen and adjoining south Oman coast based on 1200 UTC of 6th and 00 and 12 UTC of 7th. However, based on 00 UTC of 8th, it indicated west-southwestward movement towards Gulf of Aden after 72 hrs.



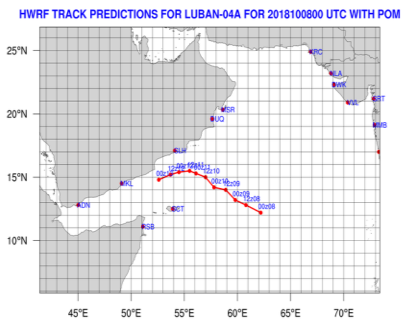
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
12z06	11.4	66.1	1004	26.
00z07	10.5	65.3	999.	45.
12z07	12.0	66.3	996.	43.
00z08	13.4	63.0	995.	53.
12z08	14.1	62.2	989.	48.
00z09	14.5	60.2	986.	60.
12z09	15.1	59.3	980.	52.
00z10	15.2	58.3	967.	69.
12z10	15.3	57.6	958.	85.
00z11	15.4	56.8	960.	86.
12z11	15.6	55.9	964.	76.



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z07	11.7	65.8	1002	27
12z07	11.8	64.6	994.	36
00z08	12.6	63.2	992.	40
12z08	13.5	61.1	984.	57
00z09	14.4	59.7	985.	45
12z09	15.0	58.5	980.	49
00z10	15.3	57.5	977.	54
12z10	16.0	56.7	968.	64
00z11	16.1	55.7	972.	64
12z11	16.1	54.8	973.	63
00z12	16.0	54.1	975.	66

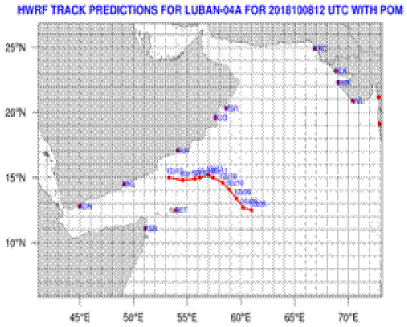


Dt/Hr.	Lat.	Lon.	MSLP	Vmax
12z07	11.9	64.4	1001	26.
00z08	12.6	63.0	992.	36.
12z08	13.0	61.8	984.	46.
00z09	13.4	60.7	982.	47.
12z09	14.1	60.0	972.	51.
00z10	14.9	59.4	964.	56.
12z10	15.6	58.5	955.	65.
00z11	16.0	57.7	958.	72.
12z11	16.1	57.2	963.	66.
00z12	16.1	56.7	966.	65.
12z12	16.1	56.2	972.	58.

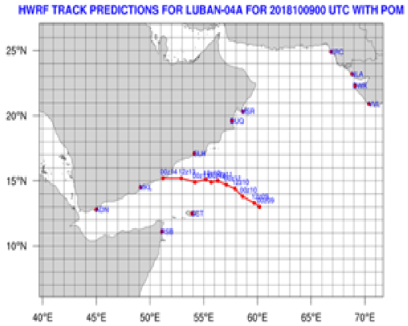


Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z08	12.2	62.2	999.	34
12z08	12.8	60.8	986.	51
00z09	13.2	59.8	986.	50
12z09	14.0	58.9	983.	54
00z10	14.2	57.8	978.	49
12z10	15.0	57.0	969.	66
00z11	15.3	56.1	965.	71
12z11	15.5	55.5	967.	70
00z12	15.4	54.5	975.	61
12z12	15.2	53.7	978.	62
00z13	14.8	52.6	982.	56

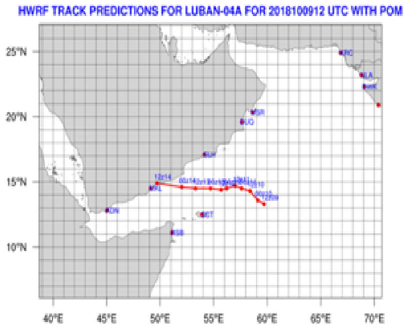
Fig.14. Track and intensity prediction by IMD-HWRF model for VSCS Luban



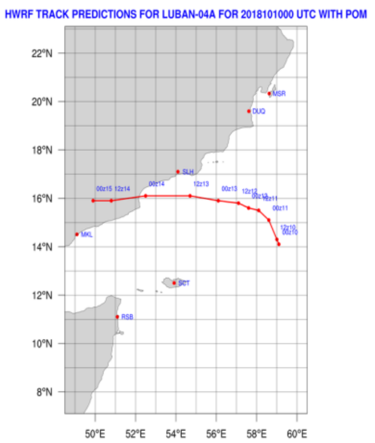
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
12z08	12.5	61.0	994.	42.
00z09	12.7	60.2	990.	48.
12z09	13.4	59.6	985.	51.
00z10	14.1	58.9	980.	51.
12z10	14.6	58.3	972.	64.
00z11	15.0	57.4	966.	72.
12z11	15.2	57.0	961.	78.
00z12	15.0	56.2	969.	69.
12z12	14.9	55.7	971.	67.
00z13	14.8	54.6	972.	70.
12z13	15.0	53.3	971.	74.



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z09	13.0	60.2	992.	42
12z09	13.3	59.7	985.	56
00z10	13.8	58.6	986.	44
12z10	14.4	57.9	980.	53
00z11	14.7	57.1	973.	65
12z11	15.0	56.3	966.	73
00z12	14.9	55.7	973.	69
12z12	15.1	55.2	979.	58
00z13	14.9	54.2	985.	51
12z13	15.2	52.9	983.	61
00z14	15.2	51.2	989.	56



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
12z09	13.3	59.7	988.	55.
00z10	13.6	59.1	990.	44.
12z10	14.3	58.4	988.	45.
00z11	14.5	57.6	979.	59.
12z11	14.7	57.0	970.	69.
00z12	14.5	56.2	973.	68.
12z12	14.4	55.7	976.	63.
00z13	14.5	54.7	981.	58.
12z13	14.5	53.3	981.	63.
00z14	14.6	52.0	980.	65.
12z14	14.9	49.7	985.	62.



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z10	14.1	59.1	983.	63
12z10	14.3	59.0	978.	49
00z11	15.1	58.6	979.	53
12z11	15.5	58.1	975.	60
00z12	15.6	57.6	976.	60
12z12	15.8	57.1	979.	56
00z13	15.9	56.1	983.	54
12z13	16.1	54.7	980.	62
00z14	16.1	52.5	984.	57
12z14	15.9	50.8	991.	51
00z15	15.9	49.9	996.	41

Fig.14 (contd). Track and intensity prediction by IMD-HWRF model for VSCS Luban

Based on 12 UTC of 8th, 00 and 12 UTC of 9th, it indicated initial northwestward movement and then nearly westward movement making landfall over Yemen coast near 15 deg. N. The predication based on 00UTC of 10th showed similar track but landfall near 16 deg. N. Similar track forecast continued based on initial condition of 12UTC of 10th and 00UTC of 11th but with landfall between 15 and 16 deg. N.

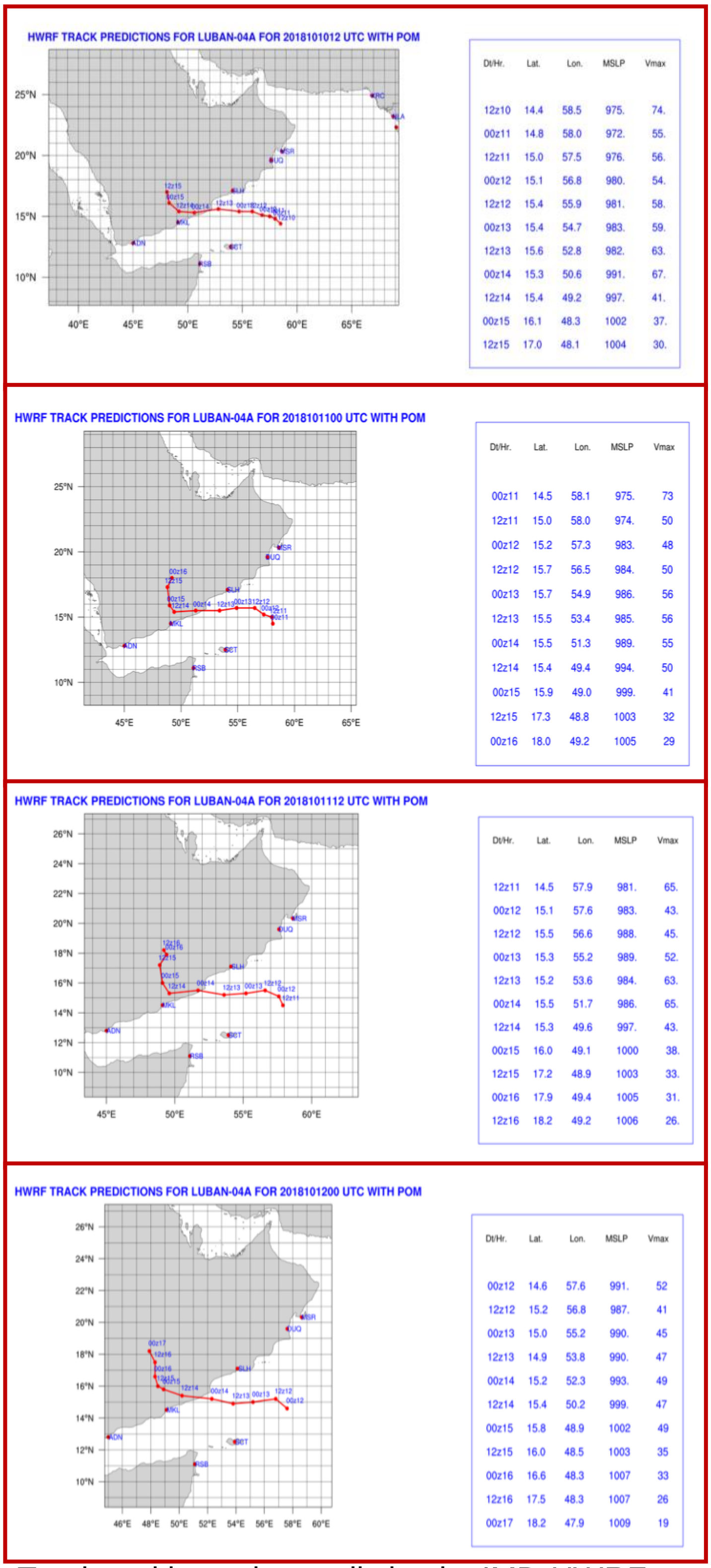
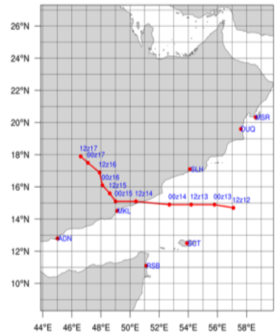


Fig.14 (contd). Track and intensity prediction by IMD-HWRF model for VSCS Luban

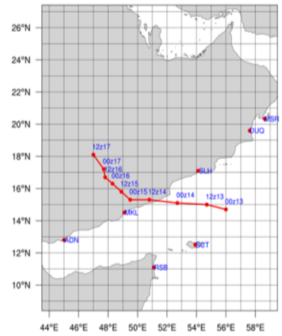
The west-northwestward movement just before landfall between 15 and 16 deg. N was predicted based on initial condition of 12 UTC of 11th and 00 UTC of 12th. However again based on initial condition of 12 UTC of 12th and 00 UTC of 13th, the landfall was predicted near 15 deg. N. The northwestward movement of the system was predicted based on 12 UTC of 13th making landfall near 15.7 deg. N.

HWRF TRACK PREDICTIONS FOR LUBAN-04A FOR 2018101212 UTC WITH POM



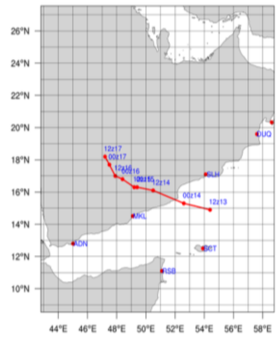
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
12z12	14.7	57.1	993.	49.
00z13	14.9	55.8	987.	44.
12z13	14.9	54.2	988.	52.
00z14	14.9	52.7	988.	57.
12z14	15.1	50.4	992.	59.
00z15	15.1	49.0	997.	49.
12z15	15.6	48.6	1000	39.
00z16	16.1	48.1	1005	38.
12z16	16.9	47.9	1007	30.
00z17	17.5	47.1	1008	19.
12z17	17.9	46.6	1008	17.

HWRF TRACK PREDICTIONS FOR LUBAN-04A FOR 2018101300 UTC WITH POM



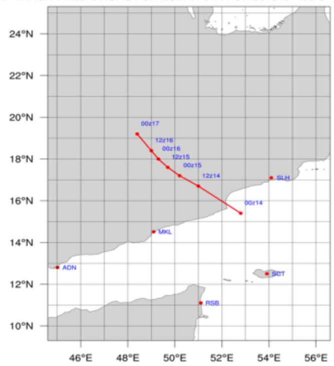
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z13	14.7	56.0	999.	42
12z13	15.0	54.7	992.	51
00z14	15.1	52.7	994.	50
12z14	15.3	50.8	997.	63
00z15	15.3	49.5	1002	51
12z15	15.8	48.9	1002	42
00z16	16.3	48.3	1006	35
12z16	16.7	47.8	1006	27
00z17	17.2	47.7	1007	25
12z17	18.1	47.0	1007	20

HWRF TRACK PREDICTIONS FOR LUBAN-04A FOR 2018101312 UTC WITH POM



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
12z13	14.9	54.4	989.	44
00z14	15.3	52.6	996.	48
12z14	16.1	50.5	997.	43
00z15	16.3	49.4	1000	41
12z15	16.3	49.2	1002	34
00z16	16.8	48.4	1004	34
12z16	17.0	47.9	1005	28
00z17	17.7	47.5	1007	19
12z17	18.2	47.2	1007	18

HWRF TRACK PREDICTIONS FOR LUBAN-04A FOR 2018101400 UTC WITH POM



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z14	15.4	52.8	999.	35
12z14	16.7	51.0	1002	37
00z15	17.2	50.2	1002	31
12z15	17.6	49.7	1003	30
00z16	18.0	49.3	1006	28
12z16	18.4	49.0	1007	21
00z17	19.2	48.4	1008	18

Fig.14 (contd). Track and intensity prediction by IMD-HWRF model for VSCS Luban

Composite forecast tracks based on initial conditions of 0000, 0600 & 1200 UTC during 12 UTC of 7th to 00 UTC of 14th Oct. are presented in Fig. 15.

It indicates that most of the track forecasts indicated landfall to the south of the actual landfall point.

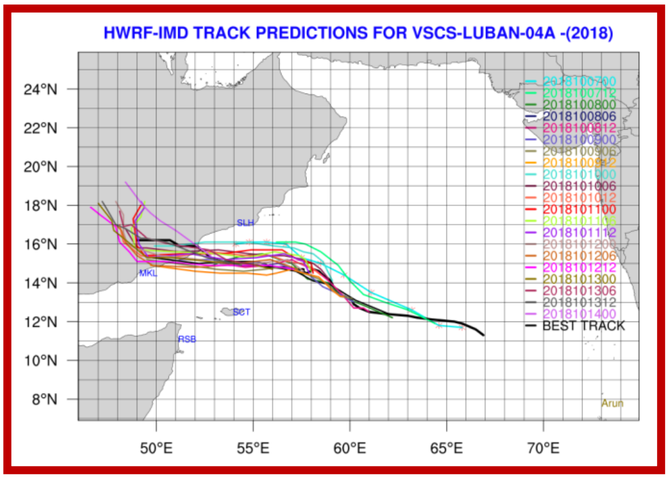


Fig. 15: Observed and forecast tracks by IMD HWRF model based on initial conditions during 1200 UTC of 7th to 0000 UTC of 14th October 2018.

8.3. Track and intensity forecast errors by various NWP Models

The average track forecast errors (Direct Position Error) in km at different lead period (hr) of various models are presented in Table 2. From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast error was minimum for MME followed by ECMWF and UKMO models for 24 and 48 hr forecasts. For 72 hr forecasts, it minimum and similar for both MME and UKMO model. The error was minimum for UKMO model followed by MME for 96 and 120 hr forecasts.

Table-2. Average track forecast errors (Direct Position Error (DPE)) in km (Number of forecasts verified is given in the parentheses)

Lead time	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
IMD-GFS	60(15)	70(15)	75(14)	105(13)	114(12)	141(12)	173(10)	213(9)	264(8)	306(7)
IMD-WRF	77(15)	92(15)	117(14)	138(13)	150(12)	147(12)	-	-	-	-
JMA	90(15)	119(15)	157(14)	189(13)	218(12)	240(12)	284(10)	-	-	-
NCEP-GFS	46(15)	70(15)	83(14)	100(13)	104(13)	160(12)	158(10)	247(9)	248(8)	371(70
UKMO	44(15)	50(15)	71(14)	71(13)	84(13)	98(12)	106(10)	122(9)	150(8)	204(7)
ECMWF	55(15)	50(15)	81(14)	70(13)	115(13)	166(12)	191(10)	218(9)	270(8)	338(7)
IMD-HWRF	51(30)	75(30)	86(28)	118(26)	148(24)	168(22)	188(20)	197(18)	205(16)	265(14)
IMD-MME	36(15)	42(15)	58(14)	54(13)	66(12)	99(12)	107(10)	145(9)	156(8)	232(7)
NCUM	-	60 (14)	-	125(17)	-	148(17)	-	186(17)	-	285(14)
NEPS	-	56(14)	-	97(14)	-	138)13)	-	171(10)	-	245(9)

The landfall point and time forecast errors of the models are presented in Table 3 and 4 respectively. Either the landfall could not be predicted or the error was high in case of most of the models. Even the MME could not predict the landfall for most of the lead periods. Among the individual models, the 24 hr landfall point forecast error was minimum in case of HWRF model.

Table-3. Landfall point forecast errors (km) of NWP Models at different lead time (hour)

Lead time →	18H	30H	42H	54H	66H	78H	90H	102H	114H	126H
Based on	**13 October 12z**	**13 October 00z**	**12 October 12z**	**12 October 00z**	**11 October 12z**	**11 October 00z**	**10 October 12z**	**10 October 00z**	**09 October 12z**	**09 October 00z**
IMD-GFS	11	35	145	74	22	22	44	178	101	148
IMD-WRF	145	527	-	-	-	-	-	-	-	-
JMA	35	35	11	44	44	234	252	-	-	-
NCEP-GFS	-	-	-	-	25	0	15	24	11	67
UKMO	11	203	145	164	35	40	33	165	84	67
ECMWF	35	454	100	174	454	372	-	-	-	-
IMD-HWRF	31	0	187	241	55	35	22	16	99	176
IMD-MME	40	-	-	-	40	55	-	11	-	-

Table-4. Landfall time forecast errors (hour) at different lead time (hr)
('+' indicates delay landfall, '-' indicates early landfall)

Lead time →	18H	30H	42H	54H	66H	78H	90H	102H	114H	126H
Based on	**13 October 12z**	**13 October 00z**	**12 October 12z**	**12 October 00z**	**11 October 12z**	**11 October 00z**	**10 October 12z**	**10 October 00z**	**09 October 12z**	**09 October 00z**
IMD-GFS	-1	-8	+1	+3	-7	-8	-10	-15	-18	-20
IMD-WRF	+6	+18	-	-	-	-	-	-	-	-
JMA	-1	-1	-4	-6	-6	-13	-18	-	-	-
NCEP-GFS	-	-	-	-	+1	-3	-6	-6	-13	-10
UKMO	-2	+6	+1	+4	-6	-8	-6	-15	-15	-11
ECMWF	-2	+6	-3	-	0	+6	+6	-	-	-
IMD-HWRF	0	-3	+3	+6	-6	-12	-12	-12	0	0
IMD-MME	-1	-	-	-	-4	-6	-	-5	-	-

-

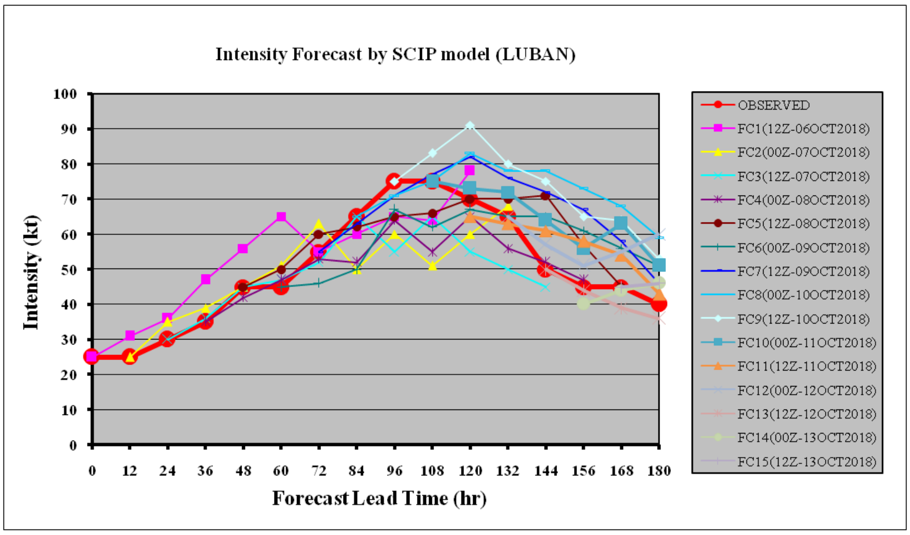


Fig.16. Intensity prediction by SCIP model of IMD

The intensity prediction by IMD SCIP model based on initial conditions of 0000 & 1200 UTC during 6th to 13 Oct. 2018 is presented in Fig. 16. Overall, SCIP underestimated intensity of the system during intensification stage and overestimated the intensity during weakening stage. The average absolute errors (AAE) and Root Mean Square errors (RMSE) are presented in Table 5 and that of HWRF model in Table 6. On comparison, the error is higher in case of HWRF model for all time scales. The error in SCIP model was also higher (more than 15 knots) for 72 and 96 hr forecasts.

Table-5 Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of SCIP model (Number of forecasts verified is given in the parentheses)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
IMD-SCIP (AAE)	4.2(15)	6.6(14)	7.5(13)	12.2(12)	11.9(11)	13.5(10)	12.6(9)	15.9(8)	9.6(7)	4.8(6)
IMD-SCIP (RMSE)	4.9	8.6	9.2	13.4	14.5	16.7	14.2	16.6	10.4	6.1

Table-6 Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of HWRF model (Number of forecasts verified is given in the parentheses)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
HWRF (AAE)	11.1(30)	10.8(30)	11.4(28)	10.4(26)	11.5(24)	11.0(22)	10.9(20)	12.2(18)	13.6(16)	15.6(14)
HWRF (RMSE)	13.8	13.6	13.7	13.3	13.5	12.9	12.9	13.4	15.9	17.9

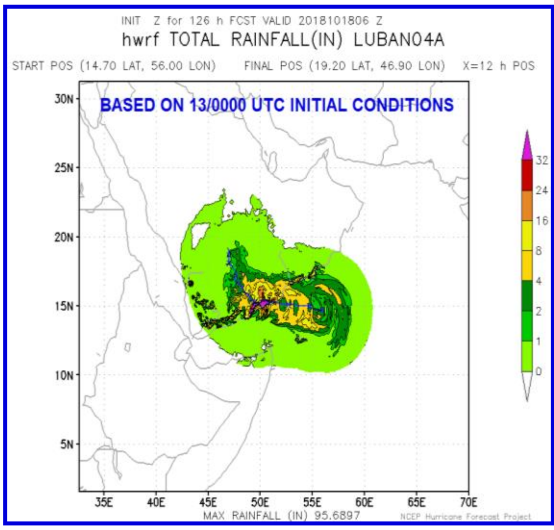
The probability of rapid intensification (RI) index by MME is shown in Table 7. Rapid intensification occurred during 0600 UTC of 9th to 0600 UTC of 10th Oct. as shown in Table 1 with increase in wind speed from 45 knots to 75 knots. However, the RI index couldn’t predict RI of the system based on 0000 UTC of 09th, as it indicated low probability (22% probability). Though it predicted rapid intensification based on 0000 UTC of 10th with probability of 72%, there was change in intensity by 10 knots only during 0000UTC of 10th to 0000 UTC of 11th Oct.

Table 7: Probability of Rapid intensification (RI) by RI Model

Forecast based on	Probability of RI predicted	Probability of RI	Intensity changes(kt) in 24hrs
0000UTC/07.10.2018	09.4 %	Very low	+10
0000UTC/08.10.2018	09.4 %	Very low	+10
0000UTC/09.10.2018	22.0 %	Low	+20
0000UTC/10.10.2018	72.7 %	High	+10
0000UTC/11.10.2018	22.0 %	Low	-10
0000UTC/12.10.2018	32.0 %	Moderate	-20
0000UTC/13.10.2018	22.0 %	Low	-05

8.4. Heavy rainfall forecast by HWRF model

The forecast rainfall swaths by HWRF model are presented in **Fig.17**. HWRF could successfully predict occurrence of rainfall along the predicted track even after the landfall of system. Based on 1200 UTC of 24th, the expected rainfall during 1200 UTC of 24th to 1200 UTC of 28th May is about 8-16 inches (20-40cm) over coastal areas of south Oman and southeast Yemen. It may be 20-25 inches (50-60 cm) at some places in south coastal Oman. Over interior areas of Oman, it may be around 8-10 inches (20-25 cm) during 1200 UTC of 24th to 1200 UTC of 28th May. As per the available rainfall reports from media at Oman, extremely heavy rainfall of the order of 30 cm was recorded on the day of landfall over Salalah.



Heavy Rainfall Guidance:

(i) Yemen: Based on initial conditions of 13/00 UTC, HWRF model predicts, the cumulative rainfall during the period of next 5 days (0000 UTC of 13th - 0000 UTC of 18th October) is likely to be more than 30 inches along coastal areas of Yemen around the point of landfall between longitude 48^{0}E & 51^{0}E. The intensity of rainfall gradually decreases towards interior Yemen becoming 16 - 30 inches in the right forward sector.

(ii) Oman: Rainfall is expected to be 8-16 inches in some pockets in the area around Salalah in south Oman.

Fig.17: Heavy rainfall forecast by HWRF based on initial conditions of 0000 UTC of 13th October, 2018

8.5. Storm surge forecast

IMD predicts storm surge forecast based on guidance from Advance Circulation (ADCIRC) model and Indian Institute of Delhi Model. IMD predicted expected storm surge of 1 metre above astronomical tide at the time of landfall based on initial condition of 11^{th}. It was further revised as 0.5 metre above the astronomical tide based on 0000 UTC of 13^{th} Oct. Storm surge forecast by ADCIRC Model based on 0000 UTC observations of 13^{th} Oct. 2018 is presented in **Fig.18**.

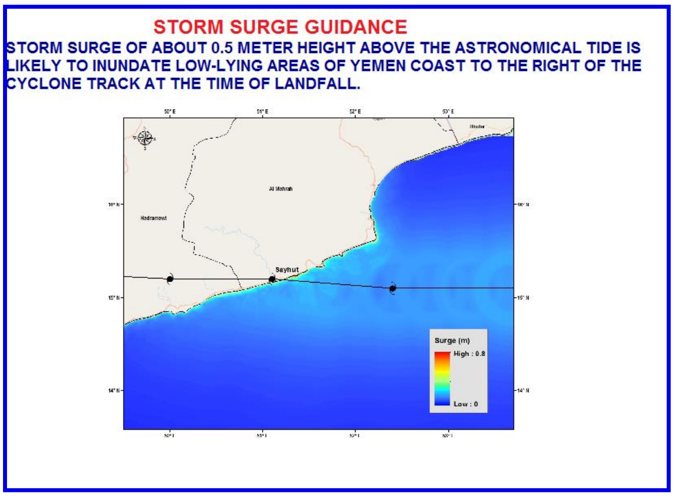


Fig.18: Typical Storm Surge guidance from INCOIS based on 0000 UTC of 13^{th} October 2018.

9. Operational Forecast Performance

9.1. Genesis Forecast

- First information about formation of low pressure area (LPA) over southeast AS around 5^{th} was issued in Tropical weather outlook dated the 3^{rd} October at 0600 UTC (about 45 hours in advance of formation of LPA). The LPA formed over southeast AS & neighbourhood at 0300 UTC of 5^{th} October. In the same bulletin, it was also forecast that the LPA would concentrate into a depression by 7^{th} October (about 69 hours in advance of formation of D). Depression formed over southeast & adjoining eastcentral AS in the afternoon (0900 UTC) of 6^{th} October.

9.2. Landfall Forecast

- First information that the system crossing Yemen and adjoining Oman coasts around 1200 UTC of 13^{th} was near 15.2^{0}N/51.4^{0}E was issued in the Tropical Cyclone Advisory issued at 1600 UTC of 8^{th} October (about 5 days and 15 hours prior to landfall). The system crossed coast near 15.8^{0}N/52.2^{0}E between 0530-0600 UTC of 14^{th}.
- The advisory was further updated in the Tropical Cyclone Advisory issued at 0600 UTC of 12^{th} October that the system would cross Yemen coast between Riyan (Mukalla) and Al-Ghaidah (Yemen) close to 15^{0}N around noon (0600-0900 UTC) of 14^{th}. Typical observed and forecast track is presented in **Fig.19**.
- The landfall forecast errors are presented in Table 8.

- The landfall point forecast errors were about 172.2, 103.8 and 103.8 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 122.1 km respectively. The landfall time forecast errors were about 1.0, 1.0 and 1.0 hours for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 3.6, 5.4 and 3.8 hours respectively. The landfall point error was significantly less than long period average (LPA) of past five years for all lead periods (**Fig.20**)

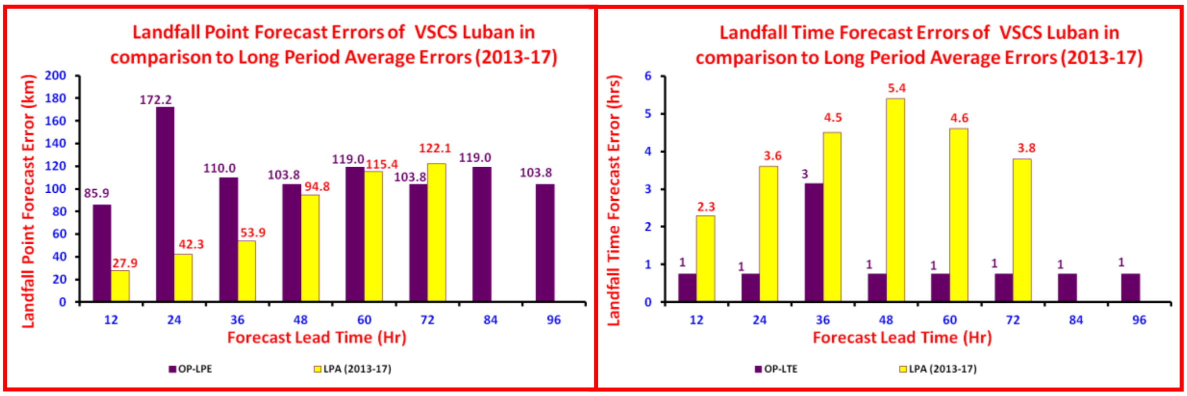


Fig.20. Landfall Point (km) and Time (hrs) Errors for VSCS Luban

Table 8: Landfall Point & Time Forecast Errors of VSCS, Luban

LPE: Landfall Point Error, LTE: Landfall Time Error, LPA: Long Period Average,

Lead Period (hrs)	Base Time (UTC)	Landfall Point				Landfall Time (UTC)		Operational Error		LPA error (2013-17)	
		Forecast		Actual		Fore-cast	Actual	LPE (km)	LTE (hrs)	LPE (km)	LTE (hrs)
		Lat(^{0}N)	Long(^{0}N)	Lat(^{0}N)	Long(^{0}N)						
12	13/18	15.3	51.6	15.8	52.2	14/0500	14/0545	85.9	1	27.9	2.3
24	13/06	15.1	50.8	15.8	52.2	14/0630	14/0545	172.2	1	42.3	3.6
36	12/18	15.2	51.4	15.8	52.2	14/0900	14/0545	110.0	3	53.9	4.5
48	12/06	15.3	51.4	15.8	52.2	14/0630	14/0545	103.8	1	94.8	5.4
60	11/18	15.2	51.3	15.8	52.2	14/0500	14/0545	119.0	1	115.4	4.6
72	11/06	15.3	51.4	15.8	52.2	14/0630	14/0545	103.8	1	122.1	3.8
84	10/18	15.2	51.3	15.8	52.2	14/0630	14/0545	119.0	1	-	-
96	10/06	15.3	51.4	15.8	52.2	14/0500	14/0545	103.8	1	-	-

LPE= Forecast Landfall Point-Actual Landfall Point,
LTE= Forecast Landfall Time-Actual Landfall Time

9.3. Track Forecast

- First information that the system will move northwestwards was issued at 0600 UTC 3rd October in the daily Tropical Weather Outlook even before the formation of the LPA over southeast AS (about 11days prior to landfall).
- The warning was further updated in the daily Tropical Weather Outlook issued at 0600 UTC of 4th, that the system would move northwestwards towards Oman coast (about 10days prior to landfall).

- In the first bulletin issued at 1200 UTC of 6th October, it was specifically mentioned that the system would move towards south Oman & adjoining Yemen coasts (about 7.5 days prior to landfall).

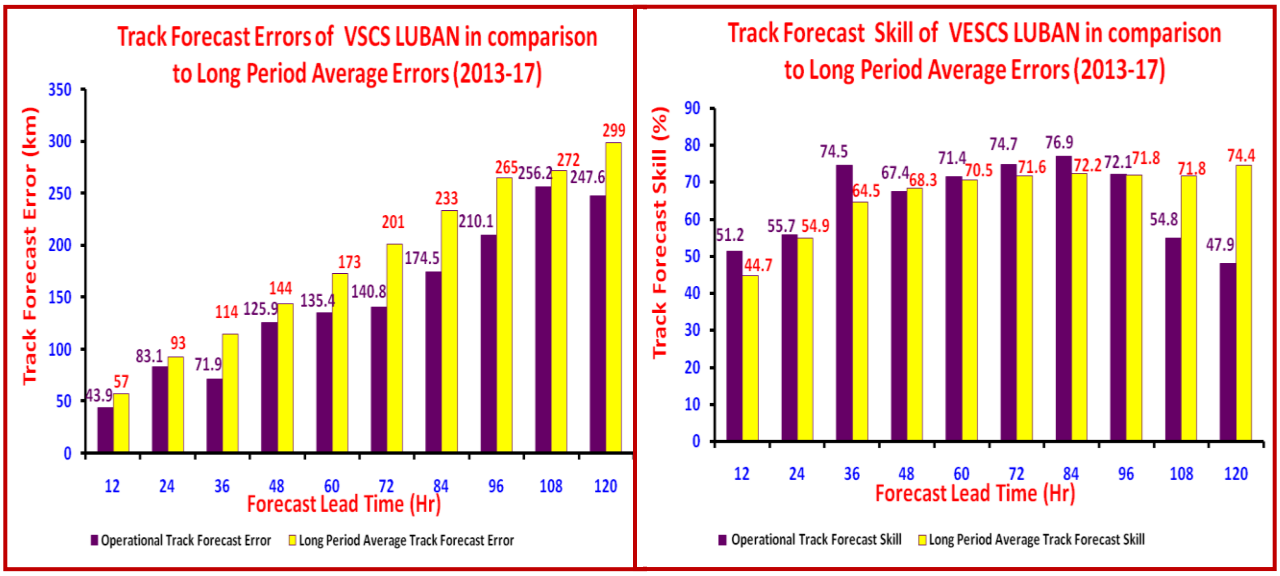


Fig.21: Track Forecast Errors and Skill for VSCS Luban

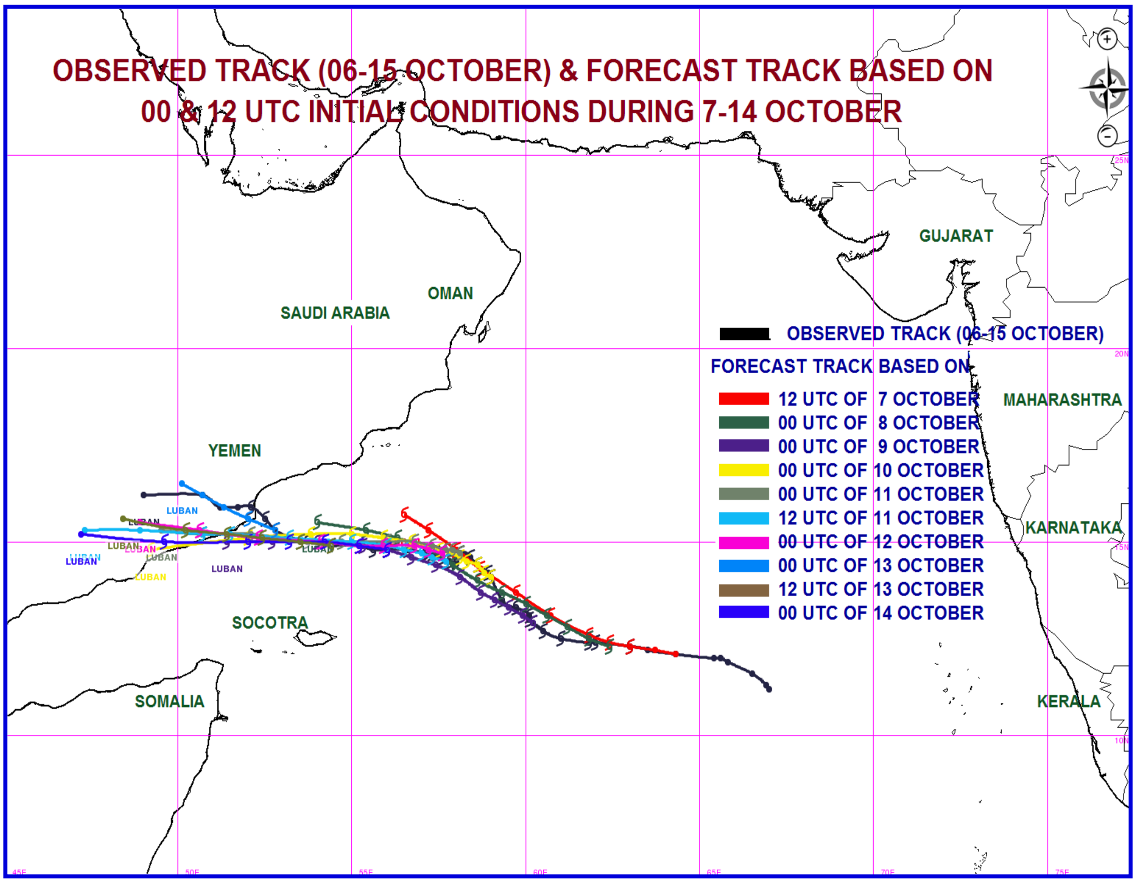


Fig.22: Observed track and forecast tracks for different lead periods

- The track forecast errors were about 83.1, 125.9 and 140.8 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 93, 144 and 201 km respectively. The track forecast skill was about 55.7, 67.4 and 74.7

km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 54.9, 68.3 and 71.6% respectively. The track forecast errors were significantly less than the past five years average for all lead period and the skill was comparable or even more than past five years average. The skill was less for lead periods beyond 108 hours. (**Fig.21, Table 9**).

- The track forecast based on 0000 & 1200 UTC during 7th-14th October and observed track during 6th -15th October is presented in **Fig. 22.** It indicates that for all lead periods track was well predicted. The observed and a typical forecast track with cone of uncertainty based 0000 UTC of 09th Oct. is presented in **Fig.23.**

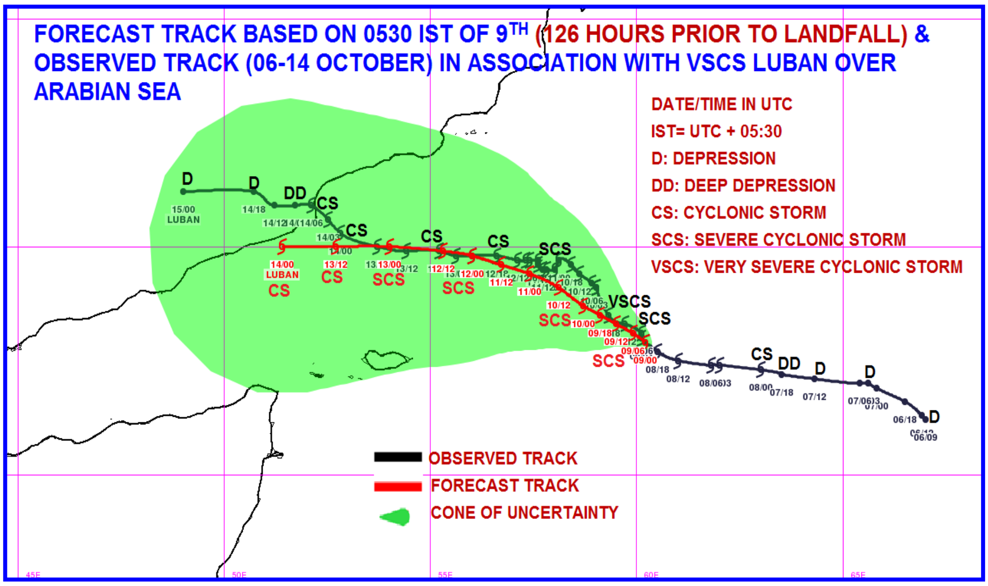


Fig.23: Observed track of VSCS Luban and forecast track based on 0000 UTC of 9th October

Table 9: Average Track forecast error in case of VSCS, Luban

Lead Period (hrs)	N	Average track forecast error (km)	Skill (%)	LPA (2013-17)	
				Track forecast error (km)	Skill (%)
12	27	43.9	51.2	57	44.7
24	26	83.1	55.7	93	54.9
36	24	71.9	74.5	114	64.5
48	22	125.9	67.4	144	68.3
60	20	135.4	71.4	173	70.5
72	18	140.8	74.7	201	71.6
84	16	174.5	76.9	233	72.2
96	13	210.1	72.1	265	71.8
108	11	256.2	54.8	272	71.8
120	7	247.6	47.9	299	74.4

N: No. of observations verified, LPA: Long Period Average (2013-17)

9.4. Intensity Forecast

- First information that the system would intensify into a cyclonic storm was given in the Tropical Weather issued at 0600 UTC of 3rd October (about 120 hrs in advance of intensification of system into a cyclonic storm on 0600 UTC of 9th).
- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 9.9, 13.5 and 16.2 knots against the LPA of 10.4, 15.5 and 15.7 knots respectively. The skill in intensity (wind) forecast based on AE for 24, 48 and 72 hrs lead period was 24.4, 46.5 and 59.0% against the LPA of 37.1, 56.8 and 69.3% respectively (**Fig.24, Table 10**).
- The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 12.1, 15.2 and 17.7 knots against the LPA of 14.0, 20.6 and 20.6 knots respectively. The skill in intensity (wind) forecast based on RMSE for 24, 48 and 72 hrs lead period was 28.4, 55.3 and 67.5% against the LPA of 40.1, 60.0 and 73.0% respectively **(Fig.25, Table 10**). For all lead periods, the RMSE in intensity forecast were significantly less as compared to past five years average.
- Typical wind distribution forecast product is presented in **Fig.26**.

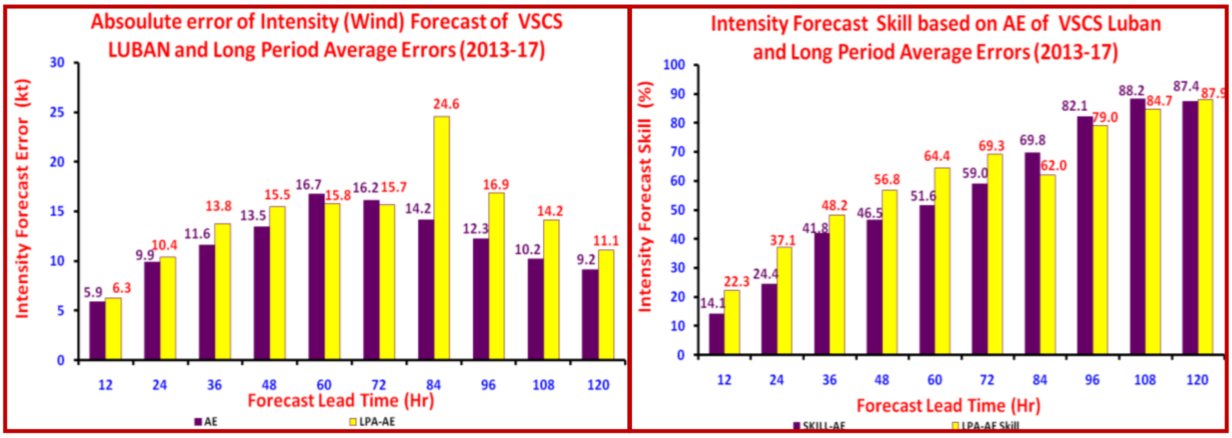


Fig.24: Absolute errors (AE) of intensity forecast and skill for VSCS Luban

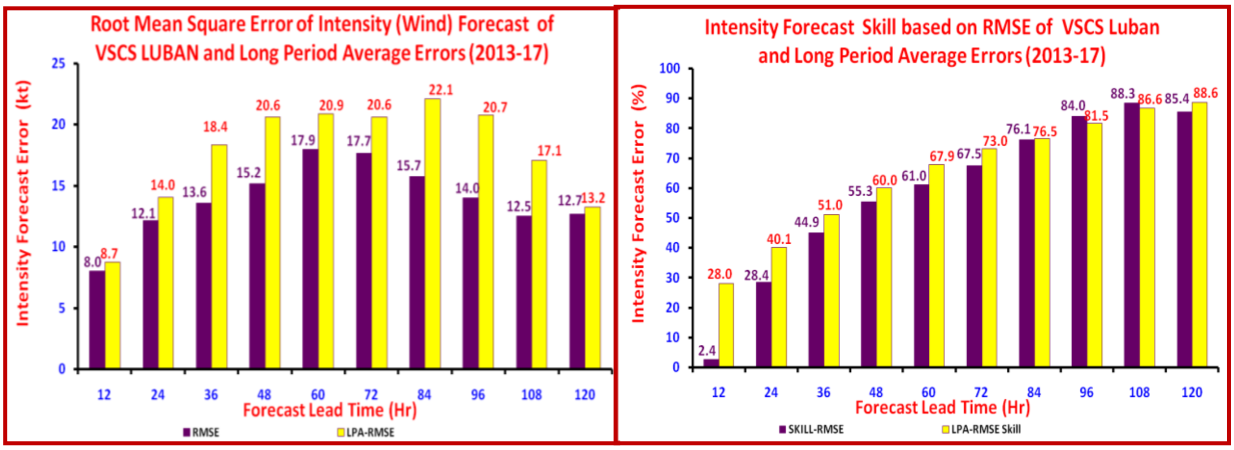


Fig.25: Root Mean Square Errors (RMSE) of intensity forecast and skill for VSCS Luban

Table 10: Average Intensity forecast error in association with VSCS Luban

Lead Period (hrs)	N	Average Intensity Error (kts)		Skill (%) in intensity forecast		LPA Intensity forecast Error (kts) (2013-17)		LPA Intensity forecast Skill (%) (2013-17)	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	27	5.9	8.0	61.4	66.9	6.3	8.7	22.3	28.0
24	26	9.9	12.1	74.9	78.4	10.4	14.0	37.1	40.1
36	24	11.6	13.6	71.6	74.5	13.8	18.4	48.2	51.0
48	22	13.5	15.2	56.7	63.1	15.5	20.6	56.8	60.0
60	20	16.7	17.9	65.9	72.4	15.8	20.9	64.4	67.9
72	18	16.2	17.7	71.7	78.3	15.7	20.6	69.3	73.0
84	16	14.2	15.7	90.3	90.8	24.6	22.1	62.0	76.5
96	13	12.3	14.0	83.8	82.9	16.9	20.7	79.0	81.5
108	11	10.2	12.5	86.4	86.7	14.2	17.1	84.7	86.6
120	7	9.2	12.7	87.4	85.4	11.1	13.2	87.9	88.6

N: No. of observations verified; AE: Absolute Error; RMSE: Root Mean Square Error, LPA: Long Period Average (2013-17).

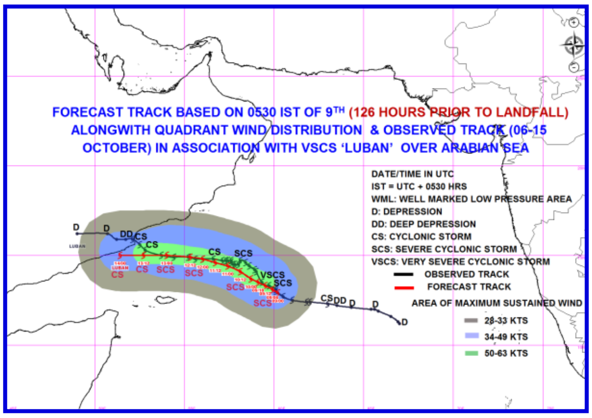


Fig. 26: Wind distribution graphics based on 0000 UTC of 9th October

10. Bulletins issued by IMD

10.1 Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track, intensity, and landfall forecast for +06, +12, +18, +24, +36 and +48… +120 hrs lead period till the system weakened into a low pressure area. The above forecasts were issued from the stage of depression onwards along with the cone of uncertainty in the track forecast five times a day and every three hours during the cyclone period. The hourly update was also provided prior to and during the landfall of the cyclone.
- **Cyclone structure forecast for shipping and coastal hazard management** The radius of maximum wind and radii of MSW ≥28 knots and

≥34 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36 and +120 hrs lead period.

- **Adverse weather warning bulletins:** The tropical cyclone forecasts alongwith expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update during cyclone period to the central, state and district level disaster management agencies including MHA NDRF, NDMA for all the states along west coast of India, Lakshadweep Islands and Daman & Diu and Dadar Nagar Haveli. The bulletin also contained the suggested action for disaster managers and general public in particular for fishermen. These bulletins were also issued to Defence including Indian Navy & Indian Air Force.
- **Warning graphics:** The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The adverse weather warnings were also presented in graphics alongwith colour codes in the website. Further the heavy rainfall guidance based on Hurricane Weather & Research Forecast Model (HWRF) run at IMD and storm surge guidance graphics from INCOIS AdCirc Model were also provided to WMO, Yemen & Oman. Typical examples are presented in **Fig.12 and Fig.13 respectively**.
- **Warning and advisory through social media:** Daily updates were uploaded on face book and tweeter regularly during the life period of the system.
- **Press release and press briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services division at New Delhi and bulletins for maritime interest were issued by Area cyclone warning centres of IMD at Chennai, Mumbai and Cyclone warning centres at Ahmedabad and Thiruvananthapuram to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** First warning for fishermen of the west coast of India and Lakshadweep Islands was issued at 1730 hrs IST (1200 UTC) of 6^{th} October.
- **Advisory for international Civil Aviation:** The Tropical Cyclone Advisory Centre (TCAC) bulletin for International Civil Aviation were issued every six hourly to all Meteorological Watch Offices in Asia Pacific region for issue of significant meteorological information (SIGMET). It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong.
- **Diagnostic and prognostic features of cyclone:** The prognostics and diagnostics of the systems were described in the RSMC bulletins and tropical cyclone advisory bulletins.

- **TC Vital:** Tropical cyclone vital parameters were prepared every six hour from deep depression stage onwards and provided to various NWP modeling groups in India for generation/relocation of vortex in the model so as to improve the track and intensity forecast by the numerical models

Statistics of bulletins issued by RSMC New Delhi in association with the VSCS Luban are given in **Table 10a.**

10.2. Bulletins issued by ACWCs and CWCs

The bulletins issued by ACWCs and CWCs are presented in **Table 10(b).**

Table 10(a): Bulletins issued by RSMC New Delhi

S. N	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	54	1. IMD's website, RSMC New Delhi website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Chief Secretary- Andhra Pradesh, Odisha, West Bengal, Mizoram, Tripura, Assam, Meghalaya and Manipur.
2	Hourly bulletin	4	1. IMD's website, RSMC website 2. WMO/ESCAP member countries through GTS and E-mail.
3	Bulletin from DGM	7	FAX and email to Cabinet Secretary, Principal Secretary to Prime Minister, Secretary Ministry of Home Affairs, Defence, Agriculture, Information & Broadcasting, Department of Sc. & Technology, NDMA, and Shipping & Surface Transport, Control Room Home Affairs, Director Indian Railways, Director General Doordarshan & All India Radio, Director General National Disaster Response Force and Chief Secretary- Andhra Pradesh, Odisha, West Bengal, Mizoram, Tripura, Assam, Meghalaya and Manipur.
4	RSMC Bulletin	65	3. IMD's website, RSMC website 4. WMO/ESCAP member countries through GTS and E-mail.
5	GMDSS Bulletins	59	1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)
6	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	29	1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website
7	Warnings through SMS	Daily	SMS to disaster managers at national level and concerned states (every time when there was change in intensity) (Total 2274)
8	Warnings	Daily	Cyclone Warnings were uploaded on Social networking sites

	through Social Media	(4 times)	(Face book and Tweeter) since inception to weakening of system (every time when there was change in intensity).
9	Message through Whatsapp	Daily (5 times)	Everyday based on observation of 00, 03, 06, 12, 18 UTC observations to central level disaster managers
10	Press Release	11	Disaster Managers, Media persons by email and uploaded on website
11	Press Briefing	Daily	Regular briefing daily

Table 10(b): Bulletins issued by ACWC Mumbai (ACWC MUM) and Meteorological Centre Thiruvananthapuram (MC TRV) in association with VSCS Luban

S.No.	Type of Bulletin	No. of Bulletins issued	
		ACWC MUM	MC TRV
1.	Sea Area Bulletins	32	00
2.	Coastal Weather Bulletins	14	20
3.	Fishermen Warnings issued	13	40
4.	Port Warnings	12	06
5.	Heavy Rainfall Warning	NIL	07
6.	Gale Wind Warning	NIL	Nil
7.	Information & Warning issued to State Government and other Agencies		62
8	Special Weather Bulletins		01
9.	SMS	99	641

11. Summary and Conclusion:

VSCS Luban originated from an LPA which formed over southeast AS and neighbourhood in the morning of 5th October. It crossed Yemen and adjoining Oman coast to the south of Al-Ghaida during 0530-0600 UTC of 14th October as a cyclonic storm with a wind speed of 70-80 kmph gusting to 90 kmph. The system was unique in the sense that during this period two very severe cyclonic storms developed over AS and BoB and cyclonic storm Luban had multiple recurvatures.

The landfall point forecast errors were about 172.2, 103.8 and 103.8 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 122.1 km respectively. The track forecast errors were about 83.1, 125.9 and 140.8 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 93, 144 and 201 km respectively. The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 9.9, 13.5 and 16.2 knots against the LPA of 10.4, 15.5 and 15.7 knots respectively.

12. Acknowledgements:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledges the contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of VSCS Luban. We in particular acknowledge contribution from WMO in dissemination of warnings and advisories to Oman & Yemen and Meteorological Centres at Oman & Yemen for their active co-ordination with RSMC New Delhi that helped minimise damage due to VSCS Luban over Yemen. We acknowledge the contribution of all sister organisations of Ministry of Earth Sciences including National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National

Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), research institutes including IIT Bhubaneswar, IIT Delhi and Space Application Centre, Indian Space Research Organisation (SAC-ISRO) for their valuable support. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai, Mumbai, Cyclone Warning Centre (CWC) Ahmedabad, Thiruvananthapuram, Meteorological Centre (MC) Goa, Bengaluru, Numerical Weather Prediction Division, Satellite and Radar Division, Surface & Upper air instruments Divisions, New Delhi and Information System and Services Division at IMD is also duly acknowledged.