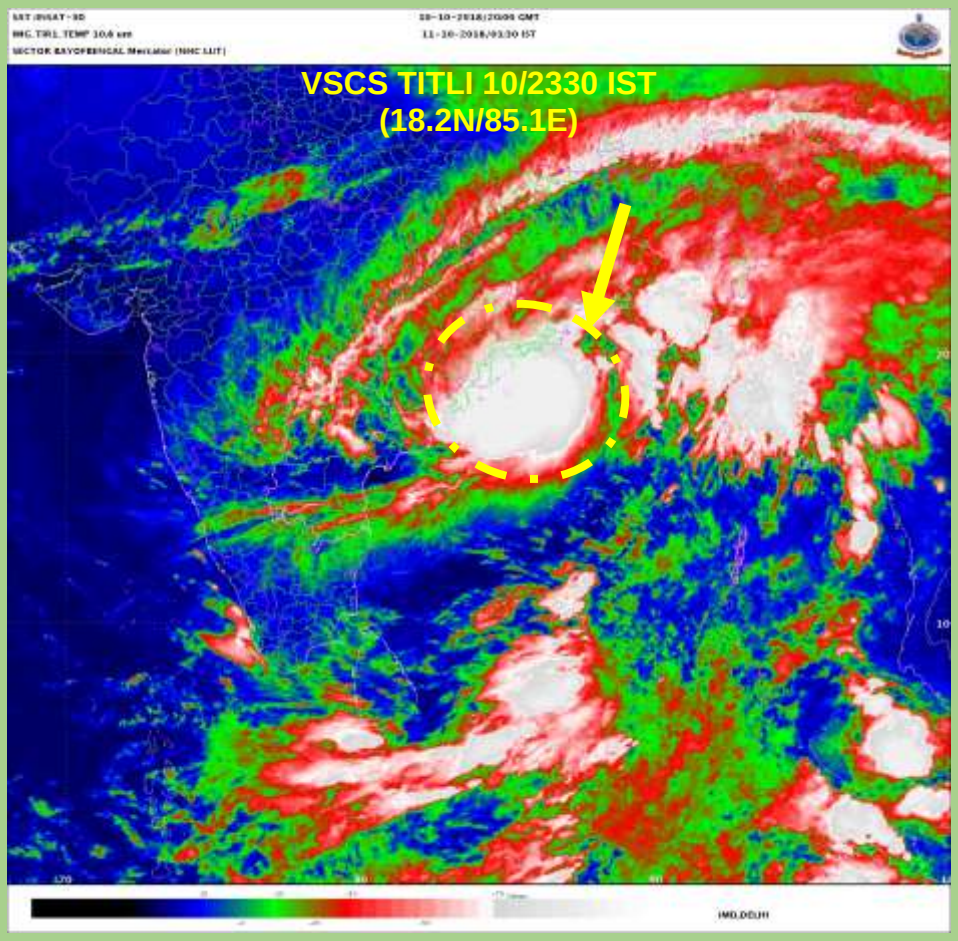
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Very Severe Cyclonic Storm, 'TITLI' over Eastcentral Bay of Bengal (08–13 October 2018): A Report



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

Cyclone Warning Division

India Meteorological Department

New Delhi

January 2019

Very Severe Cyclonic Storm "Titli" over Eastcentral Bay of Bengal (08-13 October 2018)

1. Introduction

The Very Severe Cyclonic Storm (VSCS) Titli originated from a low pressure area (LPA) which formed over southeast Bay of Bengal (BoB) and adjoining north Andaman Sea in the morning (0830 IST) of 7th October. It lay as a well marked low pressure area (WML) over the same region in the same evening (1730 IST). Under favourable environmental conditions, it concentrated into a Depression (D) over eastcentral BoB in the morning (0830 IST) of 8th October. Moving nearly west-northwestwards, it intensified into a deep depression (DD) over eastcentral BoB in the mid-night (2330 IST) of 8th October and further into a cyclonic storm (CS) **"Titli**" around noon (1130 IST) of 9th October. It then moved northwestwards and intensified, into a severe cyclonic storm (SCS) in the early hours (0230 IST) of 10th . It then moved north-northwestwards and further intensified into a very severe cyclonic storm (VSCS) around noon (1130 IST) of 10th. It crossed north Andhra Pradesh and south Odisha coasts near Palasa (18.8^0N/84.5^0E) to the southwest of Gopalpur during 0430-0530 IST of 11th as a VSCS with the wind speed of 140-150 gusting to 165 kmph. Moving further west-northwestwards, it weakened into an SCS around noon (1130 IST) of 11th and a CS in the same evening (1730 IST). Under the influence of southwesterly winds at middle and upper tropospheric levels, the system recurved northeastwards from 11th evening. It weakened into a DD over south Odisha in the mid-night (2330 IST) of 11th. It further weakened into a D in the afternoon (1430 IST) of 12th, into a WML over Gangetic West Bengal and adjoining Bangladesh & north BoB in the early hours (0530 IST) of 13th and into an LPA over the same region in the morning (0830 IST) of 13th.

The salient features of the system were as follows:

- Titli was the most destructive cyclonic storm to strike Indian coast during 2018.
- The genesis of VSCS, Titli over Bay of Bengal took place 45 hours after the genesis of VSCS, Luban over Arabian Sea. It was one of the rarest of rare events that simultaneously two VSCSs developed over Arabian Sea and Bay of Bengal.
- Considering the data during satellite era (1961 onwards), 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 system exhibited rapid intensification during 10th Oct with increase in maximum sustained wind speed from 50 knots at 0230 IST to 80 knots at 1200 UTC.

- The peak maximum sustained surface wind speed (MSW) of the cyclone was 140-150 kmph gusting to 165 kmph (80 knots) during 1200 UTC of 10th to 0000 UTC of 11th Oct. The lowest estimated central pressure was 972 hPa 1200 UTC of 10th to 0000 UTC of 11th Oct.
- The VSCS crossed north Andhra Pradesh and south Odisha coast near Palasa (Srikakulam district) to the southwest of Gopalpur with the same intensity during 0430-0530 IST of 11th Oct. 2018.
- The system maintained the cyclonic storm intensity for 15 hours even after landfall during 0000 UTC to 1500 UTC of 11th.
- The life period (D to D) of the system was 117 hours (4 days & 21 hours) against long period average (LPA) (1990-2013) of 114 hours for VSCS category over Bay of Bengal during post monsoon season.
- It moved slower, as the 12 hour average translational speed of the cyclone was 12.1 kmph against LPA (1990-2013) of 14.3 kmph for VSCS category over north Indian Ocean (Fig.2).
- The Velocity Flux, Accumulated Cyclone Energy (ACE) and Power Dissipation Index (PDI) were 6.25 X10^2 knots, 3.85 X 10^4 knots^2 and 2.55 X10^6 knots^3 respectively.
- The track and intensity of VSCS, Titli was largely analogous to that of the VSCS over the Bay of Bengal during 15-19 Oct. 1999, which crossed Odisha coast with a wind speed of 98 knots (180 kmph) in the early morning of 18th October 1999 and recurved northeastwards across Odisha. While Titli recurved after landfall, the VSCS of October 1999 recurved during the landfall period.
- While there was loss of about 198 human lives due to VSCS of 1999, it is about 89 due to VSCS Titli and associated floods in 2018.

Brief life history, characteristic features and associated weather along with performance of NWP and operational forecast of IMD are presented and discussed in following sections. The observed track of the system during **08-13 October** is presented in **Fig.1** The best track parameters of the system are presented in Table 1.

2. Monitoring of VSCS, 'TITLI'

The cyclone was monitored & predicted continuously by India Meteorological Department (IMD) prior to it's genesis as low pressure area over BoB from 5th October onwards. The system was monitored mainly with satellite observations from INSAT 3D and 3DR, SCAT Sat, polar orbiting satellites, scatterometer observations, Doppler Weather Radar (DWR) Visakhapatnam and Gopalpur 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 WMO/ESCAP Panel member countries including Bangladesh, Myanmar, Sri Lanka, National & State Disaster Management Agencies, general public and media since inception of the system over BOB.

3. Brief life history

3.1. Genesis

At 0300 UTC, the Madden Julian Oscillation (MJO) index lay in phase 1 with amplitude more than 1. Considering the environmental conditions, the sea surface temperature (SST) was 29-30^{0}C over most parts of eastcentral Bay of Bengal (BoB) and Andaman Sea becoming 30-31^{0}C over westcentral and northwest BoB. The tropical cyclone heat potential (TCHP) was about 60-80 KJ/cm^2 over major parts of south & central BoB becoming less than 40 KJ/cm^2 over north BoB. Low level relative vorticity was about 70 x10^{-5} sec^{-1} over Andaman Sea. The vorticity zone was extending upto 500 hPa level. The lower level convergence was about 10 x10^{-5}sec^{-1} over north Andaman Sea. The upper level divergence was about 10 x 10^{-5} sec^{-1} over north Andaman Sea. The vertical wind shear was low to moderate (5-15 kt) over south & central BoB and adjoining Andaman Sea. The animation of total precipitable water imageries (TPW) indicated the warm and moist air advection to the core of the system. The upper tropospheric ridge ran along 16^{0}N. The middle and upper tropospheric winds were southeasterly indicating northwestward movement of the system. Under these conditions and under the influence of a cyclonic circulation over north Andaman Sea and adjoining southeast BoB, an **LPA** formed over southeast BoB and adjoining north Andaman Sea at 0300 UTC of 7th October, 2018. Similar favourable conditions continued and the LPA over southeast BoB and adjoining north Andaman Sea lay as a WML over the same region at 0900 UTC of 7th October.

At 0300 UTC of 8th, the MJO lay in phase 1 with amplitude more than 1. The genesis potential parameter (GPP) indicated potential zone of cyclogenesis developing over eastcentral BoB on 8th. Similar sea conditions prevailed. The low level relative vorticity was about 70 x10^{-5} sec^{-1} over Andaman Sea. Extending upto 500 hPa level. The lower level convergence increased and was about 20 x10^{-5}sec^{-1} over eastcentral BoB to the northeast of system centre. The upper level divergence also increased significantly and was about 30 x10^{-5}sec^{-1} over eastcentral BoB. The vertical wind shear was low to moderate (5-15 kt) over south & central BoB and adjoining Andaman Sea. The animation of total precipitable water imageries indicated the warm and moist air advection to the core of the system. The upper tropospheric ridge ran along 16^{0}N. The middle and upper tropospheric winds were southeasterly indicating northwestward movement of the system. Under these circumstances the WML over southeast and adjoining eastcentral BoB concentrated into a **depression** over eastcentral BoB near 14.0°N/88.8°E.

3.2. Intensification and movement

At 1800 UTC of 8th, similar MJO and sea conditions prevailed. The low level relative vorticity increased becoming about 100 x10^{-5}sec^{-1} to the west of the system center and extended upto 500 hpa level. The lower level convergence was about 10 x10^{-5}sec^{-1} around the system centre. The upper level divergence was about 20 x 10^{-5} sec^{-1} around the system center. The vertical wind shear was low to moderate (10-15 kt) around the system center. Warm and moist air advection was taking place into the core of the system. The upper tropospheric ridge ran along 16^{0}N. The middle and upper tropospheric winds were southeasterly indicating northwestward movement of

the system. Under these conditions, the depression over eastcentral BoB moved further west-northwestwards and intensified into a **deep depression** (DD) near latitude 14.5°N/87.6°E.

At 0600 UTC of 9th, similar MJO conditions prevailed. The SST increased and was about 30-31^{0}C over westcentral BoB. THE TCHP was

The GPP indicated intensification of potential zone for intensification over westcentral BoB on 10th. The low level relative vorticity increased and was about 150 x10^{-5} sec^{-1} to the west of the system center and extended upto 500 hPa level. The lower level convergence increased and was about 20 x10^{-5} sec^{-1} around the system centre. The upper level divergence also increased and was about 30 x10^{-5} sec^{-1} around the system center. The vertical wind shear was low to moderate (10-15 kt) to the northwest of 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 ran along 16^{0}N. The middle and upper tropospheric winds were southeasterly indicating northwestward movement of the system. Under these conditions the DD over westcentral BoB moved west-northwestwards and intensified into a **cyclonic storm** (CS) 'Titli' over westcentral BoB near 14.8°N/86.7°E.

At 2100 UTC of 9th, the MJO was in phase 1 with amplitude greater than 1. The SST increased and was about 30-31^{0}C over westcentral BoB. The TCHP was 60-80 KJ/cm^2 over major parts of south & central BoB. The low level relative vorticity now increased and was about 250 x10^{-5} sec^{-1} around the system extending upto 200 hpa level. The lower level convergence was about 20 x10^{-5} sec^{-1} around the system centre. The upper level divergence was about 30 x10^{-5} sec^{-1} around the system center. The vertical wind shear was low to moderate (10-15 kt) to the northwest of the system centre. The animation of total precipitable water imageries indicated the warm and moist air advection to the core of the system. The upper tropospheric ridge ran along 16^{0}N. The middle and upper tropospheric winds were southeasterly indicating northwestward movement of the system. Under these conditions the CS 'Titli' over westcentral BoB intensified into a **severe cyclonic storm** (SCS) near latitude 15.7°N/85.8°E

At 0600 UTC of 10th, similar MJO and sea conditions prevailed. The low level relative vorticity was about 250 x10^{-5} sec^{-1} around the system extending upto 200 hpa level. The lower level convergence increased and was about 30 x10^{-5} sec^{-1} around the system centre. The upper level divergence increased and was about 40 x10^{-5} sec^{-1} around the system center. The vertical wind shear was low (05-10 kt) to the northwest of the system centre. The animation of total precipitable water imageries indicated the warm and moist air advection to the core of the system. The upper tropospheric ridge ran along 18^{0}N. The middle and upper tropospheric winds were southeasterly indicating northwestward movement of the system. Under these conditions the SCS 'Titli' over westcentral BoB intensified into a **very severe cyclonic storm** (VSCS) near latitude 17.0°N/85.6°E. favourable conditions continued and the system further intensified gradually reaching peak intensity of 80 kts at 1200 UTC of 10th near 17.5°N/85.3°E. The system maintained its peak intensity till 2100 UTC of same day and crossed north Andhra Pradesh and south

Odisha coasts near 18.8^0N/84.5^0E during 2300 UTC of 10th and 0000 UTC of 11th with peak intensity. Thereafter, the system started weakening but maintained it's intensity of VSCS for next 6 hours because of low vertical wind shear.

At 0600 UTC of 11th, MJO lay in phase 2 with amplitude more than 1. The low level relative vorticity was about 250 $x10^{-5}$ sec^{-1} around the system extending upto 200 hpa level. The lower level convergence decreased and was about 10-15 $x10^{-5}$ sec^{-1} around the system centre. The upper level divergence decreased and was about 20 $x10^{-5}$ sec^{-1} around the system center. The vertical wind shear was low (05 kt) around and to the east of the system centre. There was cold and dry air advection to the core of the system from northwest. The upper tropospheric ridge ran along 20^0N. The middle and upper tropospheric winds were southwesterly indicating northeastward movement of the system. Under these conditions the VSCS 'Titli' over south Odisha weakened into an **SCS** over south Odisha near 19.3^0N/83.8^0E.

Thereafter, due to land interactions, cold and dry air advection into the core of system and gradual decrease in the intensity of environmental parameters favourable for cyclogenesis, the system weakened gradually into a CS at 1200 UTC of 11th near 19.9^0N/83.7^0E, a **DD** at 1800 UTC of 11th near 20.3^0N/84.3^0E. From 1500 UTC of 11th, the system exhibited northeastwards movement under the influence of southwesterly middle and upper tropospheric winds and the ridge was located at 18^0N. Even after landfall for 15 hours the system maintained cyclonic storm intensity (≥34 kts) over land. Thereafter, it weakened into a **D** at 0900 UTC of 12th near 20.9^0N/85.5^0E over Odisha and into a **WML** at 0000 UTC of 13th over Gangetic West Bengal and adjoining Bangladesh & north BoB and into an **LPA** over the same region at 0300 UTC of 13th.

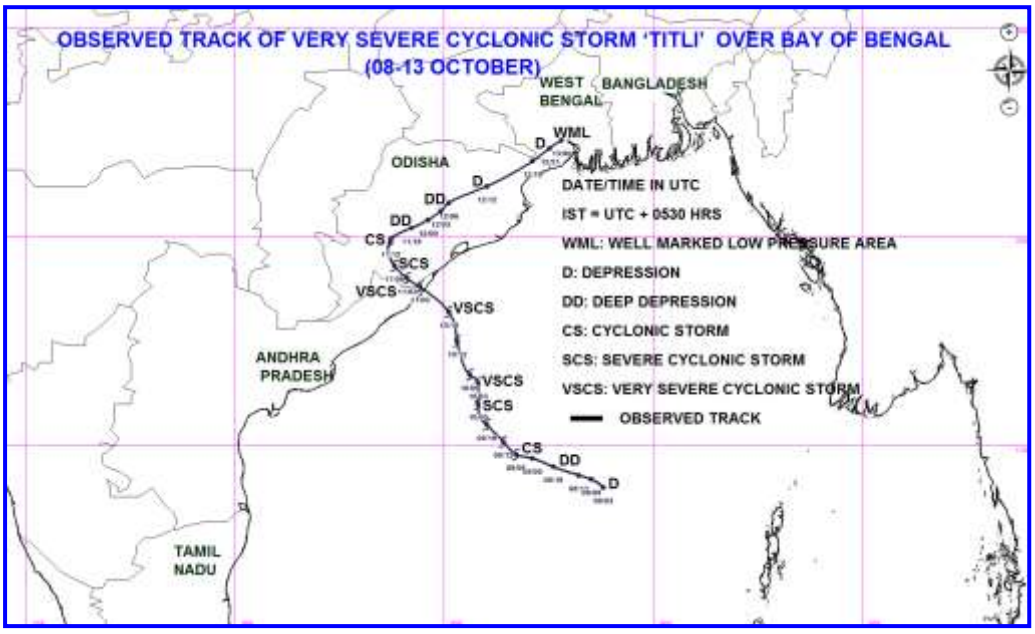


Fig.1 Observed track of VSCS TITLI (08- 13 October, 2018) over eastcentral Bay of Bengal.

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm, 'Titli' over eastcentral Bay of Bengal during 08-13 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
08/10/2018	0300	14.0	88.8	1.5	1002	25	3	**D**
	0600	14.0	88.8	1.5	1002	25	4	D
	1200	14.3	88.2	1.5	1002	25	4	D
	1800	14.5	87.6	2.0	1000	30	5	**DD**
09/10/2018	0000	14.7	87.1	2.0	1000	30	5	DD
	0300	14.7	86.9	2.0	999	30	6	DD
	0600	14.8	86.7	2.5	998	35	7	**CS**
	0900	14.9	86.6	2.5	997	35	7	CS
	1200	15.1	86.4	2.5	996	40	8	CS
	1500	15.3	86.2	2.5	995	40	9	CS
	1800	15.5	86.0	3.0	996	45	10	CS
	2100	15.7	85.8	3.0	994	50	12	**SCS**
10/10/2018	0000	16.0	85.8	3.5	990	55	16	SCS
	0300	16.5	85.8	3.5	988	60	18	SCS
	0600	17.0	85.6	4.0	982	70	24	**VSCS**
	0900	17.3	85.4	4.5	976	75	28	VSCS
	1200	17.5	85.3	4.5	972	80	32	VSCS
	1500	17.7	85.2	4.5	972	80	32	VSCS
	1800	18.2	85.1	4.5	972	80	32	VSCS
	2100	18.6	84.7	4.5	972	80	32	VSCS
		Crossed north Andhra Pradesh and south Odisha coasts near 18.8^{0}N/84.5^{0}E during 2300 UTC of 10th and -0000 UTC of 11th						
11/10/2018	0000	18.8	84.4	-	972	80	32	VSCS
	0300	19.0	84.1	-	985	65	21	VSCS
	0600	19.3	83.8	-	988	60	18	**SCS**
	0900	19.6	83.8	-	994	50	12	SCS
	1200	19.9	83.7	-	996	45	10	**CS**
	1500	20.1	84.0	-	998	40	8	CS
	1800	20.3	84.3	-	999	30	6	**DD**
12/10/2018	0000	20.5	84.7	-	1000	30	6	DD
	0300	20.6	84.9	-	1001	30	5	DD
	0600	20.8	85.2	-	1001	30	5	DD
	0900	20.9	85.5	-	1002	25	4	**D**
	1200	21.2	86.1	-	1002	25	4	D
	1800	21.9	87.2	-	1003	25	4	D
	2100	22.1	87.5	-	1004	20	3	D
13/10/2018	0000	**Weakened into a well-marked low pressure area over Gangetic West Bengal and adjoining Bangladesh and North Bay of Bengal.**						

The total precipitable water imageries (TPW) during 9th-12th October are presented in **Fig.2**. These imageries indicate continuous warm and moist air advection from the southeast sector into the system till 11th. From 11th afternoon onwards, the warm moist air advection into the core decreased significantly and cold & dry air advection into the core started increasing from northwest.

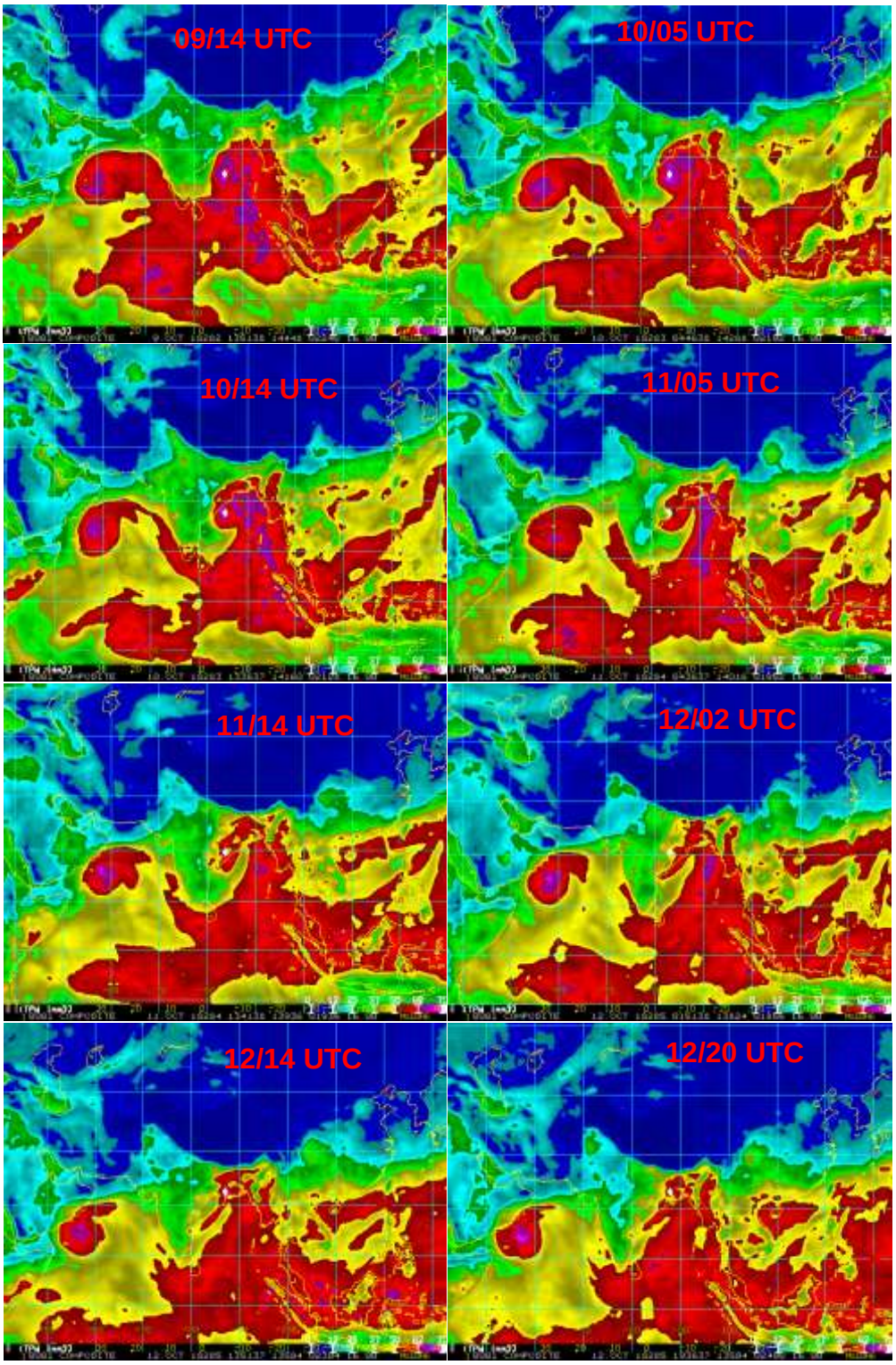


Fig. 2: Total Precipitable Water Imageries during 09-12 October, 2018

The mean wind shear and wind speed in middle and deep layer around the system centre is presented in **Fig.3**. The wind shear between lower to upper tropospheric levels around the system centre increased from 5 to 15 kt from 0000 UTC of 9th to 0300 UTC of 11th. It then increased gradually to 2o kt till 0300 UTC of 12th. Thereafter, it increased significantly to 30 kts by 1200 UTC of 12th. The direction of wind shear between lower to upper tropospheric levels was nearly north-northeasterly upto 1200 UTC of 11th, it then became east-northeasterly. The wind shear between lower to middle tropospheric levels around the system was gradually increased from 2 to 10 kt from 0000 UTC of 9th to 0000 UTC of 10th, thereafter decreased to almost 2 kt around 0300 UTC of 11th and increased to 20 kt around 1200 UTC of 12th. For this layer, the direction of wind shear was northerly upto 1200 UTC of 10th, thereafter it gradually became east-northeasterly. Hence the direction as well as the speed of shear was favourable for intensification of the system.

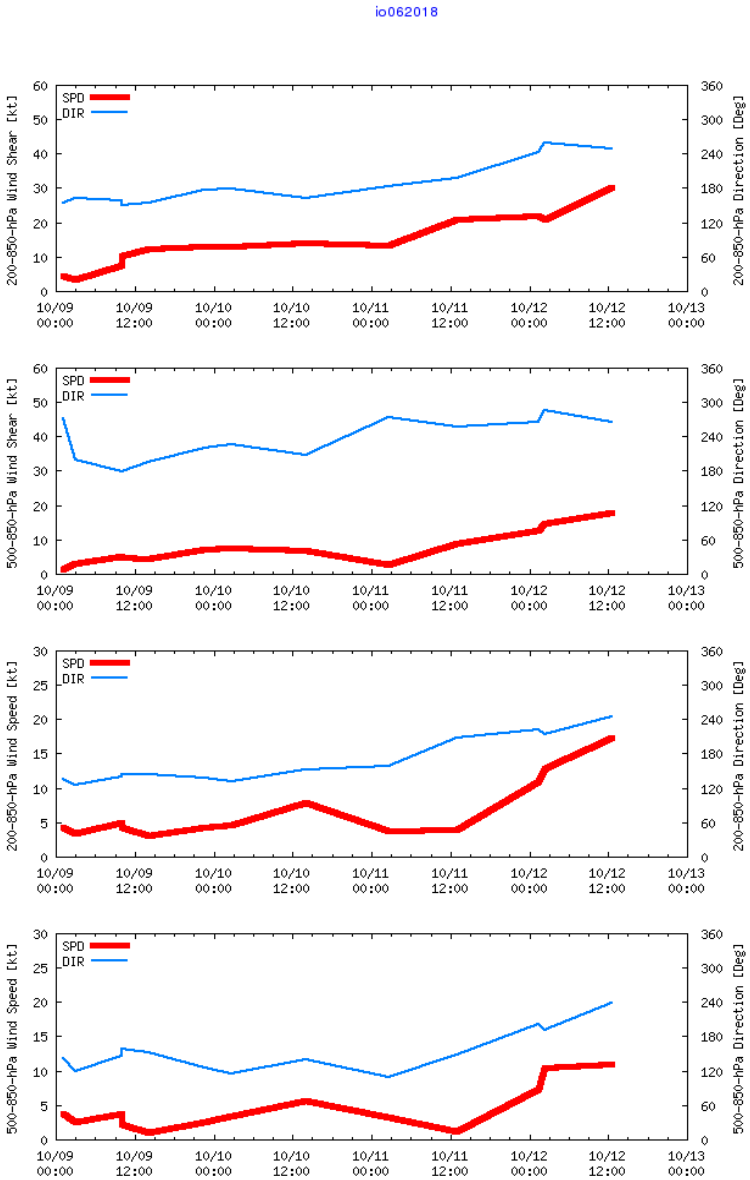


Fig.3 Wind shear and wind speed in the middle and deep layer around the system during 09nd to 13th October 2018.

3.3 Movement

From **Fig.3**, the mean deep layer winds between 200-850 hPa levels steered the system northwestwards till 0300 UTC of 11th with direction gradually becoming northeastwards from 1200 UTC of 11th onwards. The mean wind speed of deep layers was 5-7 knots upto 1200 UTC of 11th, thereafter it increased sharply becoming 13 knots by 1200 UTC of 12th. The six hourly movement of VSCS Titli is presented in **Fig.4 (a)**. The six hourly average translational speed of the cyclone was about 12.7 kmph and hence was slow moving in nature. The system had a track length of about 1450 km during its life period.

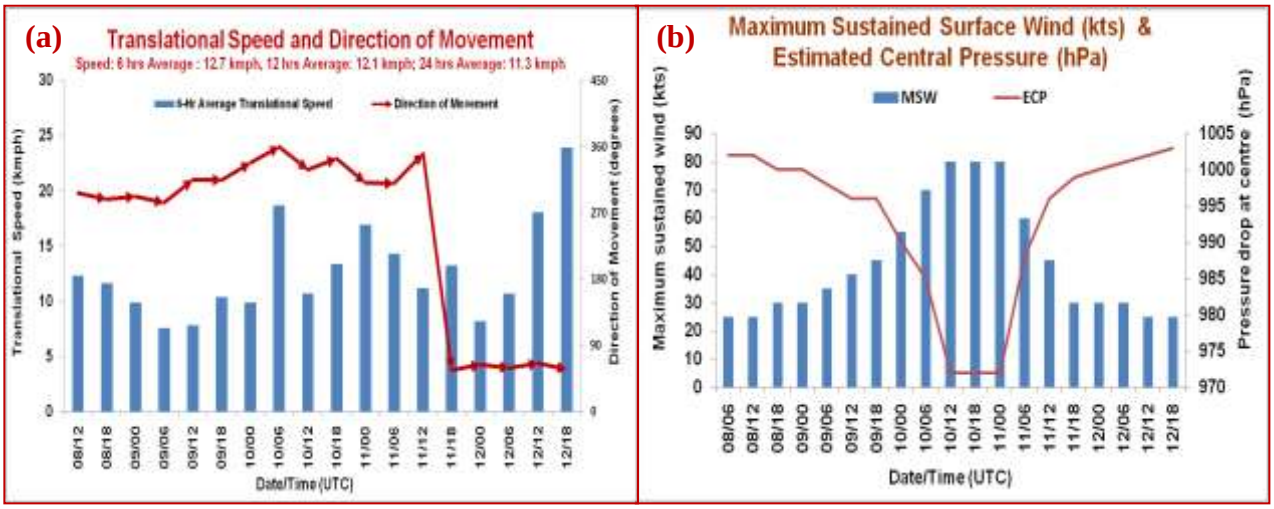


Fig. 4: (a) Translational speed & direction of movement and (b) Maximum sustained surface winds (kts) & Estimated Central Pressure

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

The lowest estimated central pressure and the maximum sustained wind speed are presented in **Fig.4 (b)**. The lowest estimated central pressure (ECP) had been 972 hPa during 1200 of 10th to 0000 UTC of 11th. The ECP gradually decreased from 1002 hPa at 0300 UTC of 8th to 996 hPa at 1200 UTC of 9th. Thereafter, there was sharp fall from 996 hPa at 1800 UTC of 9th to 972 hPa at 1200 UTC 10th. Thereafter, it remained constant at 972 hPa till 0000 UTC of 11th. Thereafter, there was sharp rise in ECP from 972 hPa (at 0000 UTC of 11th) to 996 hPa at 1200 UTC of 11th. Thereafter it increased gradually to 1003 hPa at 1800 UTC of 12th. Similarly, in the wind field it is seen that the maximum sustained surface wind speed (MSW) had been 80 kts during 1200 of 10th to 0000 UTC of 11th. The MSW gradually increased from 1002 hPa 25 kts at 0300 UTC of 8th to 40 kts at 1200 UTC of 9th. Thereafter, there was sharp rise from 45 kts at 1800 UTC of 9th to 80 kts at 1200 UTC 10th. Thereafter, it remained constant at 80 kts till 0000 UTC of 11th. Thereafter, there was sharp fall in MSW from 80 kts at 0000 UTC of 11th to 45 kts at 1200 UTC of 11th. Thereafter it decreased gradually to 25 kts at 1800 UTC of 12th. There was rapid intensification during 0000 UTC of 9th to 0000 UTC of 11th, when there was an increase in wind speed by 25 knots or more in past 24 hours.

5. 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.

5.1 INSAT-3D features

Typical INSAT-3D visible/IR imageries, enhanced colored imageries and cloud top brightness temperature imageries are presented in **Fig.5 (a-d)**.

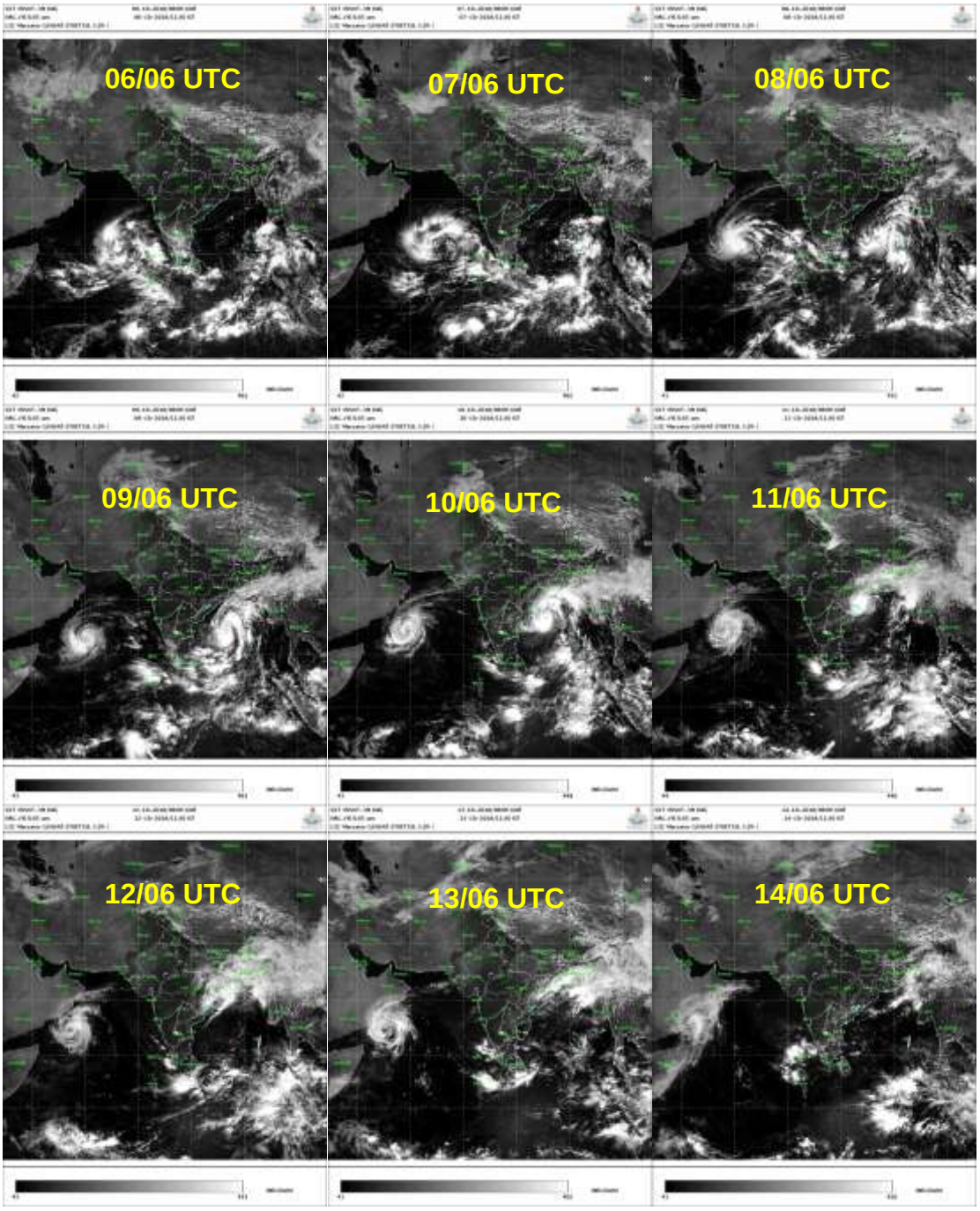


Fig. 5a: INSAT-3D visible imageries during life cycle of VSCS Titli (08-13 October, 2018)

At 0300 UTC of 7th, the intensity of the system was T 1.0. Broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 9.0°N & 16.0° N and longitude 88.0°E & 97.0°E. At 0900 UTC of 7th, the intensity of the system was T 1.0. Broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 9.0° N & 17.0° N and longitude 88.0° E & 96.0° E. At 0300 UTC of 8th, there was organization of cloud mass and the system was assigned intensity as T 1.5. Broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 13.2° N & 17.0° N and longitude 87.0°E & 95.0°E.

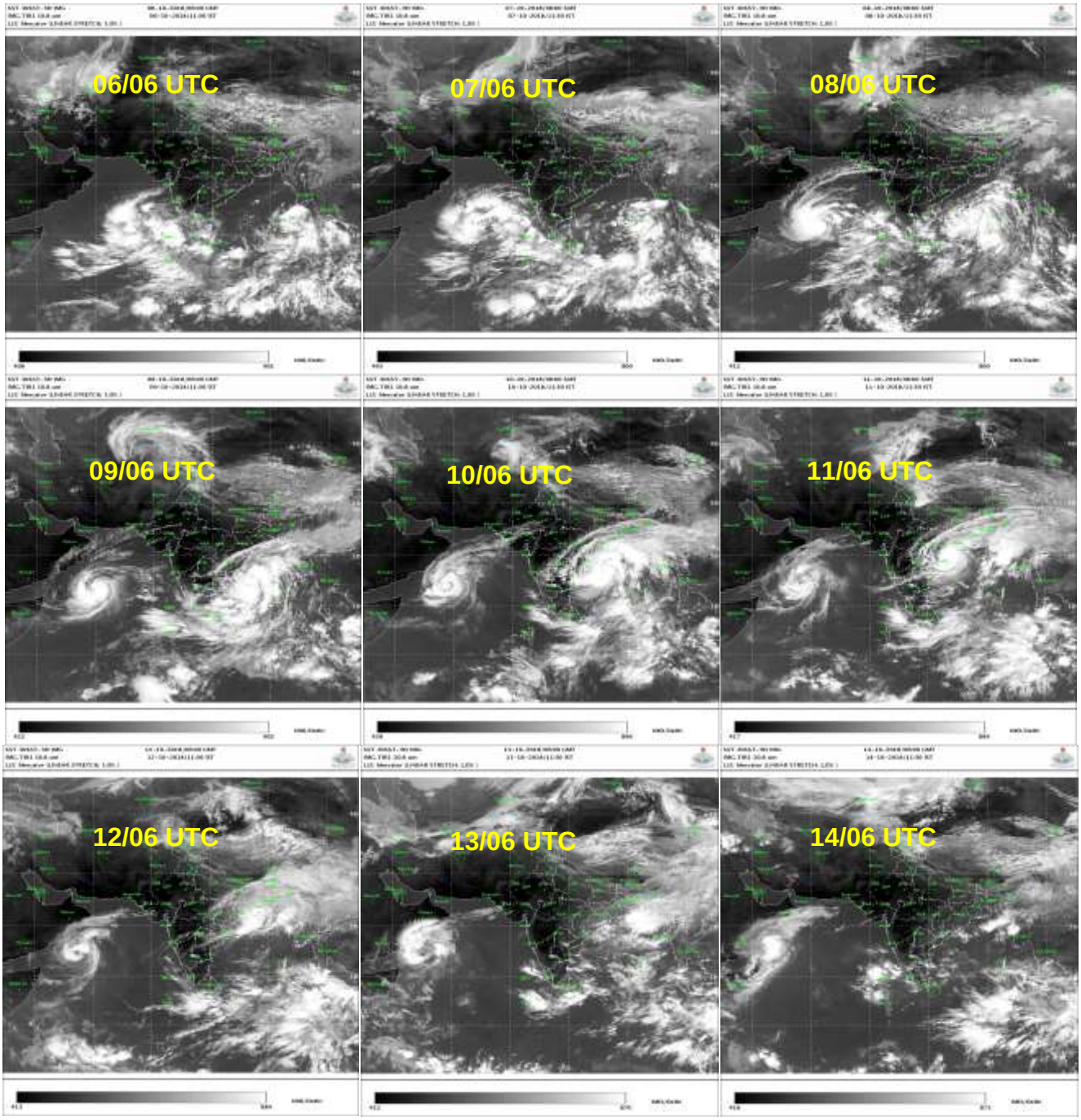


Fig. 5b: INSAT-3D IR imageries during life cycle of VSCS Titli (08-13 October, 2018)

At 1800 UTC of 8th, intensity of the system was T 2.0. Broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 6.0°N & 20.5°N and longitude 83.5°E & 96.5°E. At 0600 UTC of 9th, intensity of the system was T 2.0. Broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 10.0°N & 18.0°N and longitude 83.0°E & 90.0°E. At 0000 UTC of 10th, intensity of the system was T 3.5. Broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 13.5°N & 21.0°N and longitude 81.5°E & 90.0°E. The ragged eye developed at 0300 UTC of 10th October with a diameter of about 25 km. Gradually, it became a clear eye at 1200 UTC of 10th with eye diameter decreasing to 18 km.

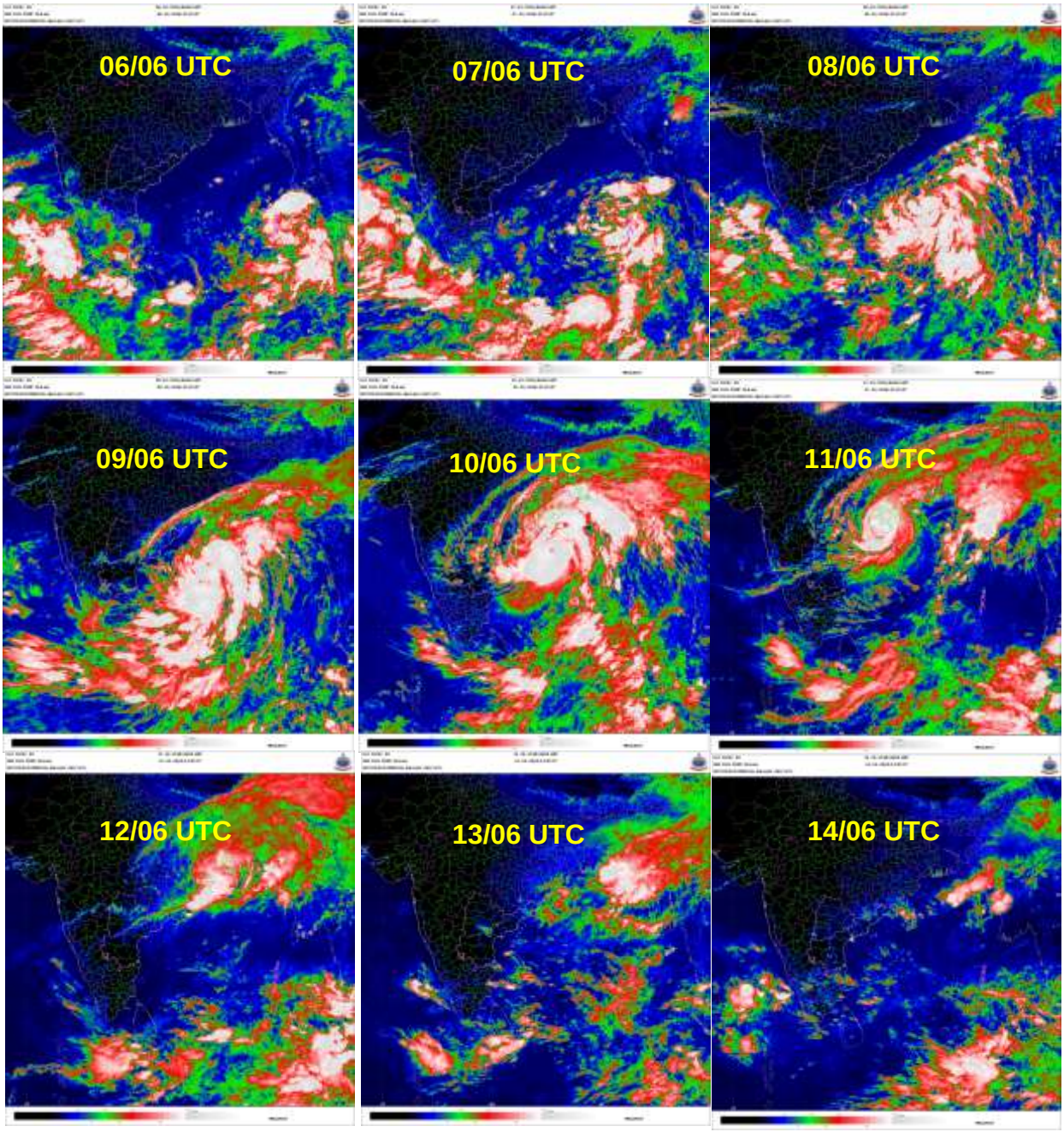


Fig. 5c: INSAT-3D enhanced colored imageries during life cycle of VSCS Titli (08-13 October, 2018)

Eye disappeared around 1500 UTC and reappeared at 1600 UTC of 10th. Thereafter, eye was visible till 0100 UTC of 11th. At the time of landfall eye diameter was around 24 km with eye temperature of -320C. The eye region was the warmest during 0900 to 1200 UTC of 10th with temperature of -140C. According to satellite imagery and eye characteristics, the intensity may be maximum during 0900-1200 UTC of 10th with the smallest and warmest eye. At 0600 UTC of 11th, broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 16.0°N & 21.0°N, west of longitude 87.0°E. At 1800 UTC of 11th, broken low and medium clouds with embedded intense to very intense convection lay over area between latitude 16.0°N & 22.0°N, west of longitude 87.0°E. At 0900 UTC of 12th, broken low and medium clouds with embedded intense to very intense convection lay over Odisha and neighbourhood between latitude 19.0^{0}N & 22.5^{0}N and longitude 82.5E & 87.0E.

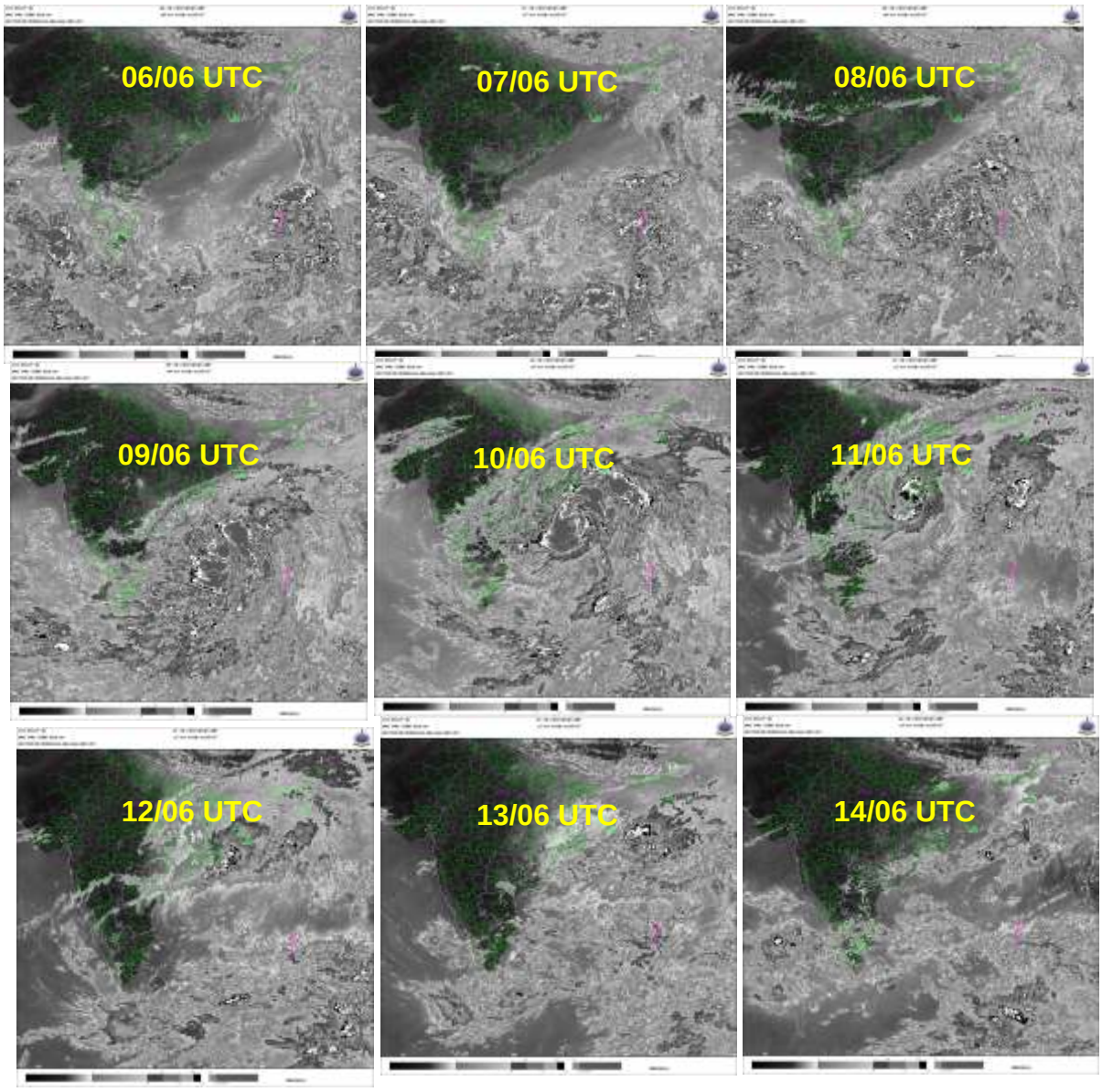


Fig. 5d: INSAT-3D cloud top brightness imageries during life cycle of VSCS Titli (08-13 October, 2018)

5.3. 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 Titli are presented in **Fig. 5(e).**

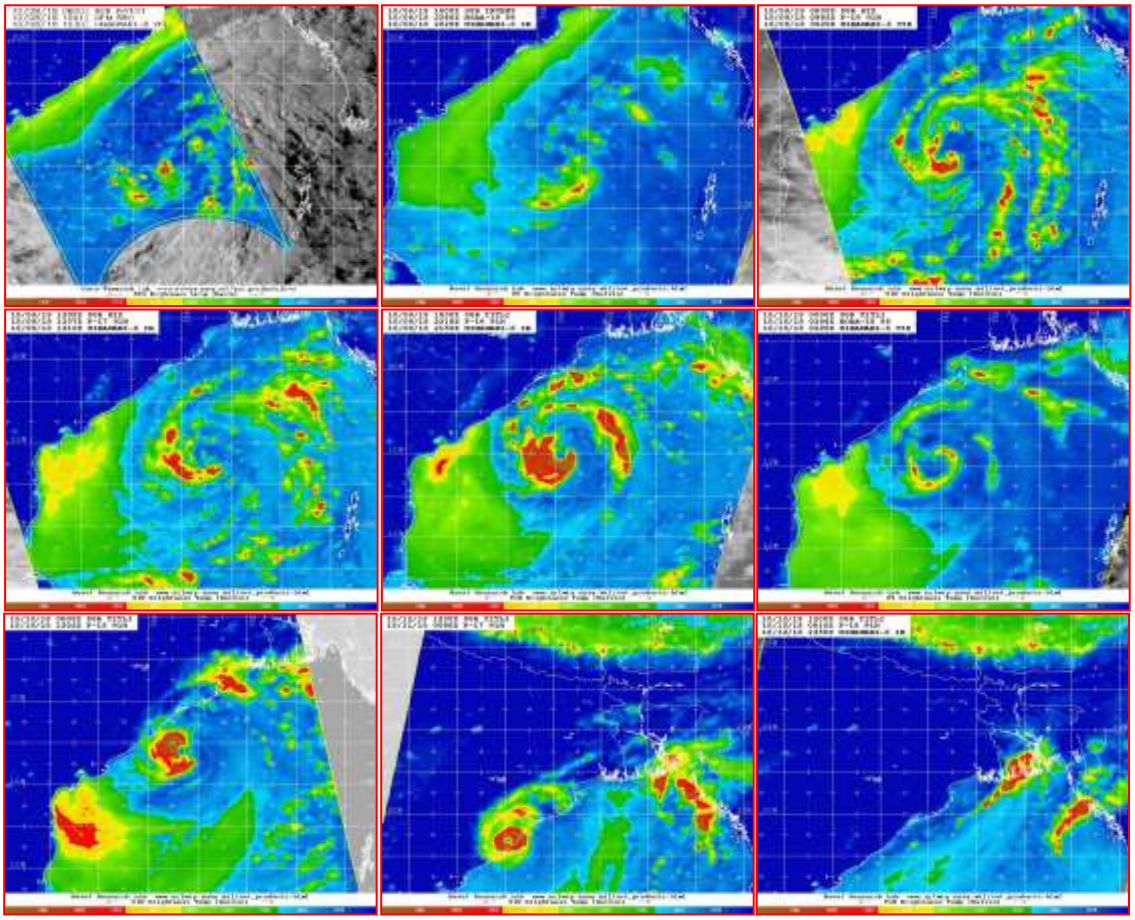


Fig. 5e: Microwave imageries during life cycle of VSCS Titli (08-13 October, 2018)

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. 5(f).

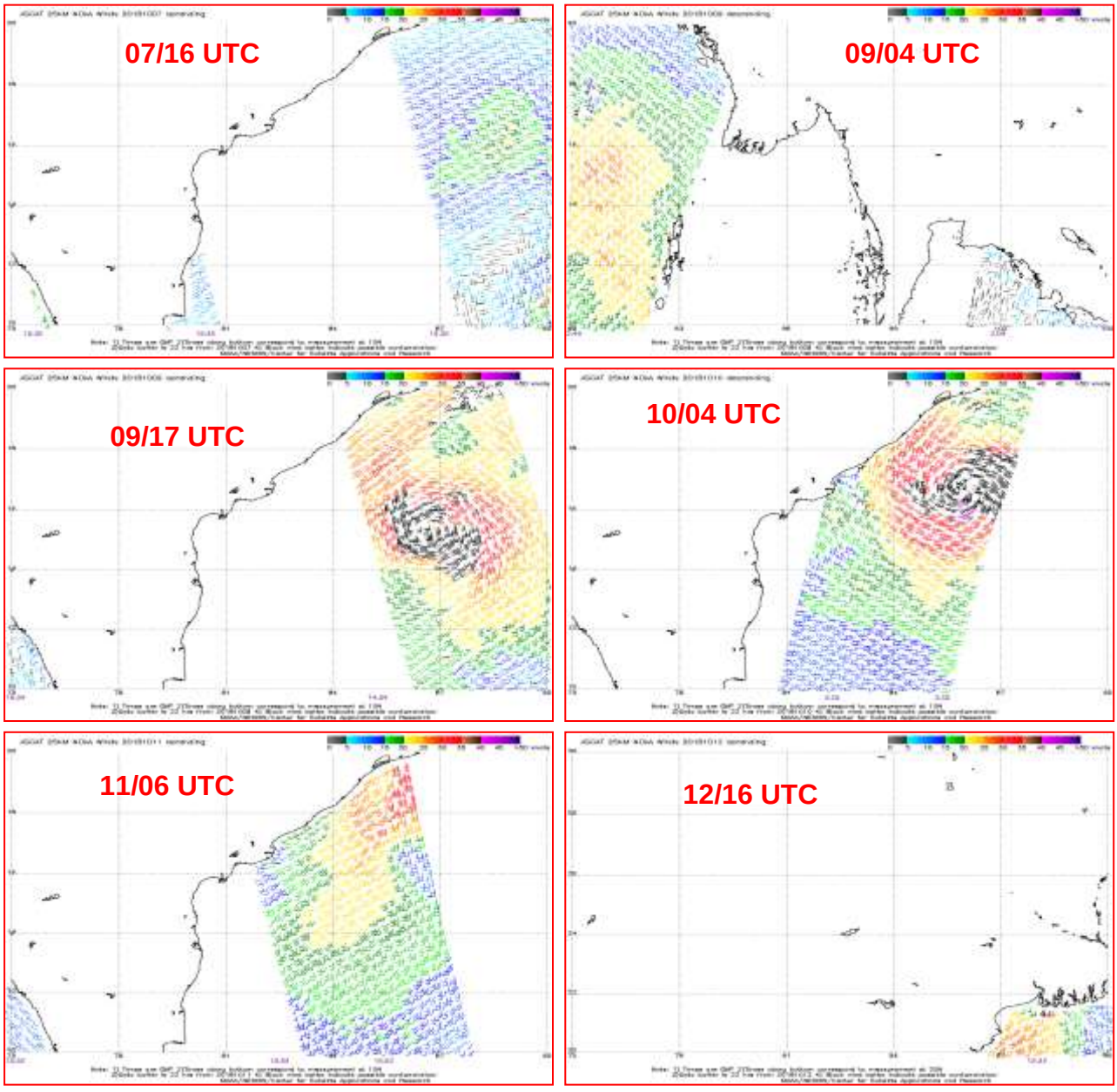


Fig. 5(f): ASCAT (Met-Op B) imageries during life cycle of VSCS Titli (08-13 October, 2018)

Typical imageries from polar satellite, SCATSAT are presented in Fig.5 (g). SCATSAT passes are available twice a day at around 0300 UTC and 1500 UTC at http://mosdac.gov.in/scorpio/SCATSAT_Data. These imageries helped in determination of centre to a good extent. Intensity estimates beyond 60 kts cannot be done with the help of these imageries. The matching index MI>0.6 represents cyclogenesis. The M.I. during 8th to 11th indicated cyclogenesis. However, the imageries on 4th and 6th also indicated MI>0.6, which was a false alarm.

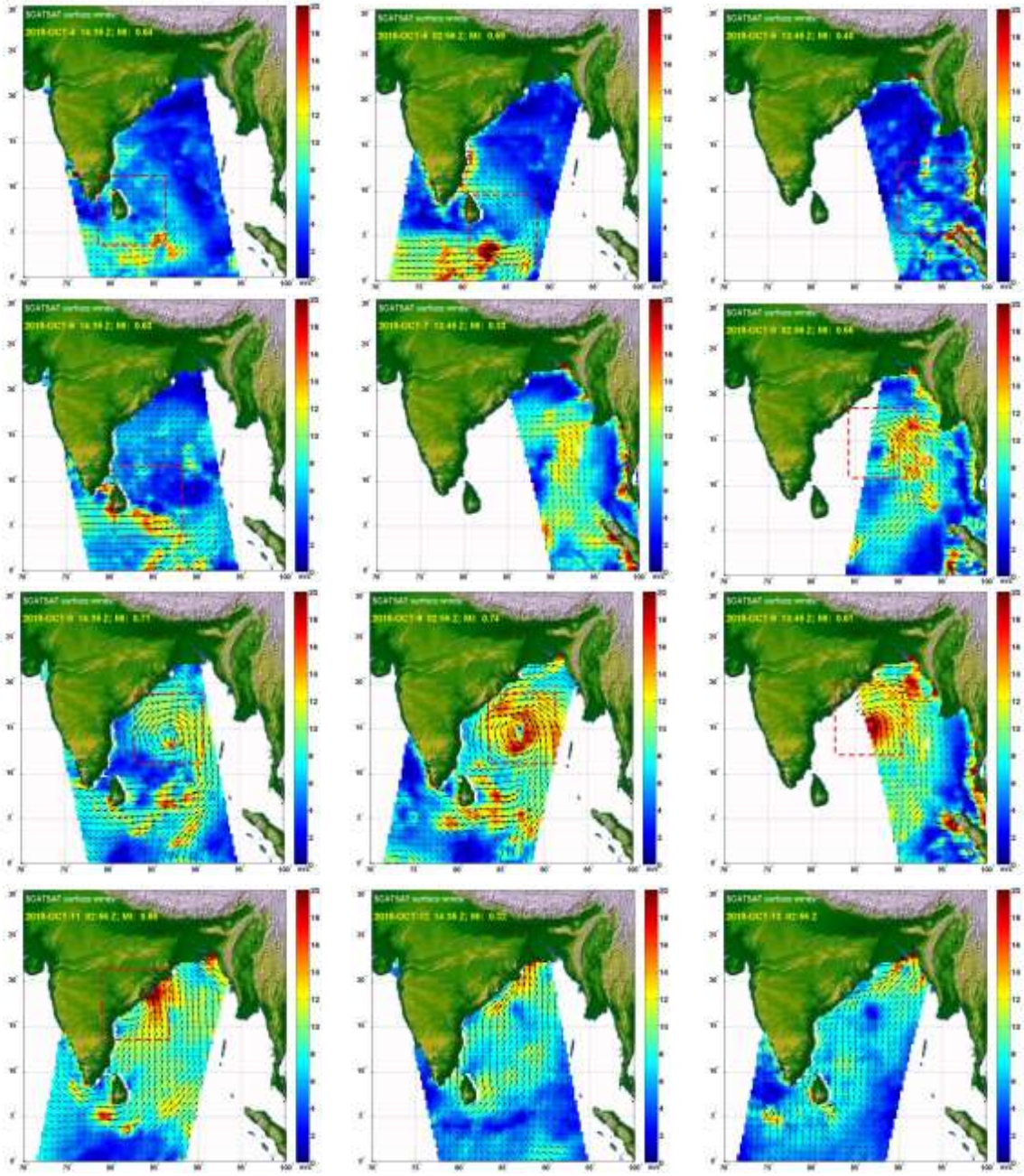


Fig. 5(g): SCAT SAT imageries during life cycle of VSCS Titli (08-13 October, 2018)

5.2. Radar Imageries:

The system came under Radar surveillance from the morning of 10th . Eye was visible in DWR Visakhapatnam since 0830 UTC of 10th. Diameter of eye was in the range 40-50 km during 0830 UTC to 2130 UTC of 10th. Thereafter, it started decreasing from 2200 UTC of 10th, becoming the least about 12km around 0100 UTC of 11th. The eye closed at 0200 UTC of 11th. As per observations from DWR Gopalpur, eye was not visible from 0300 UTC of 11th . After landfall, the system was captured by DWR Gopalpur till it's weakening. Typical radar imageries from DWR Visakhapatnam and Gopalpur are presented in **Fig. 5 (h-i)**.

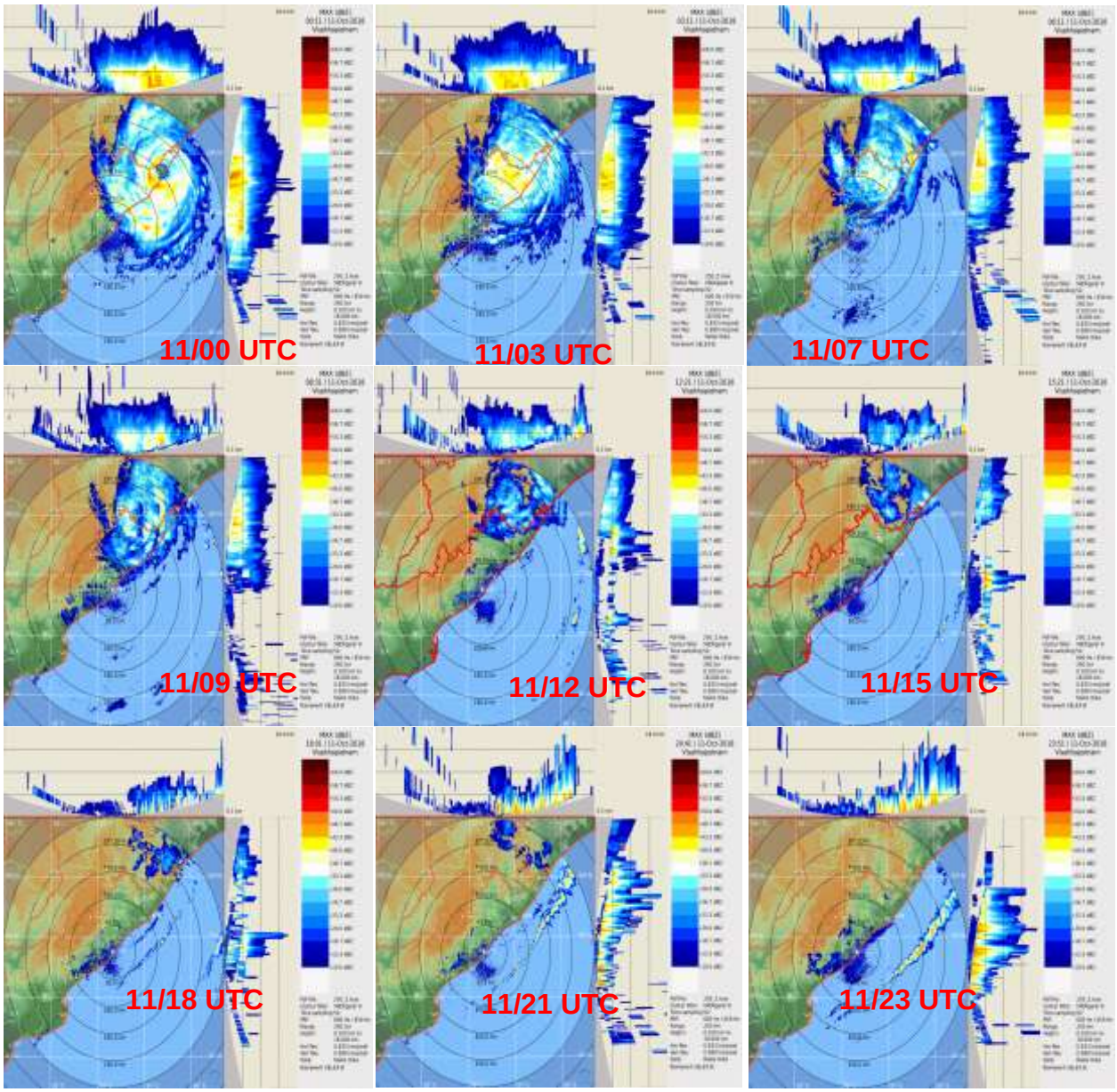


Fig. 5 (h): Max reflectivity imageries from DWR Visakhapatnam for VSCS Titli prior to landfall

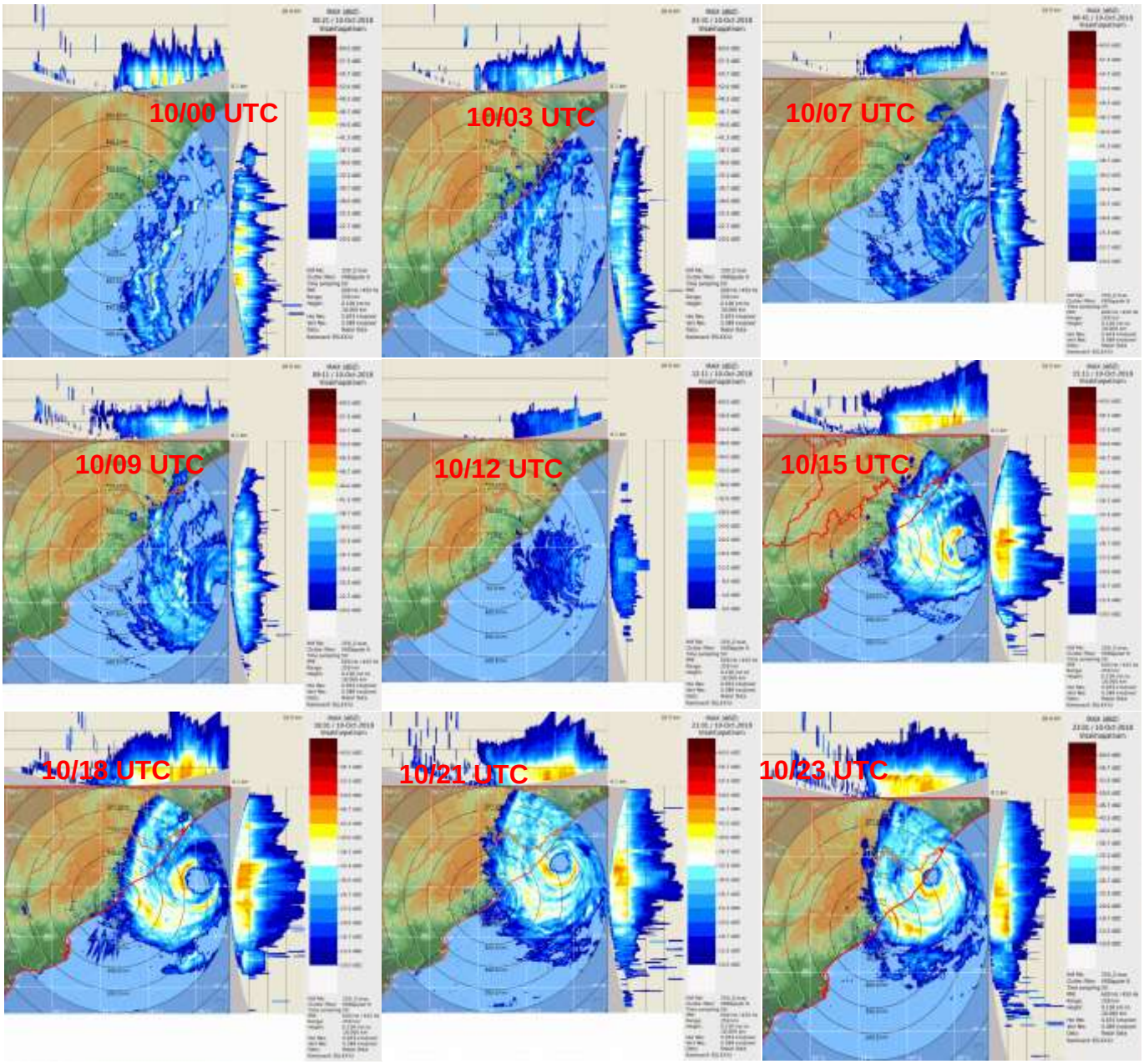


Fig. 5 (i): Max reflectivity imageries from DWR Gopalpur for VSCS Titli after landfall

6. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 7th to 13th October are presented in Fig.6. GFS (T1534). Based on 0000 UTC observations of 7th, the model could not pick up the signatures of low pressure area over southeast Bob and adjoining Andaman Sea. It indicated a cyclonic circulation over southwest BoB at 10 m level.

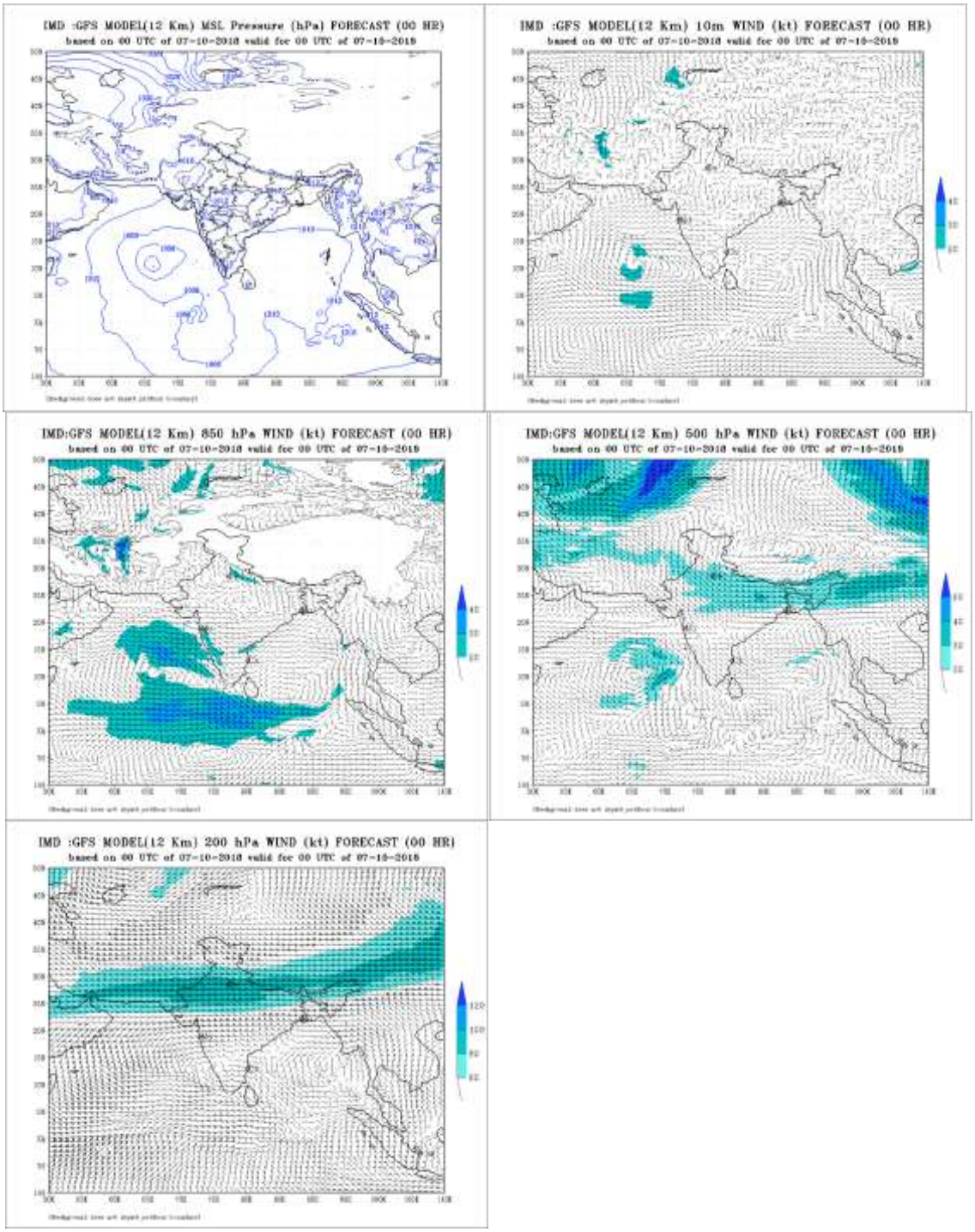


Fig. 6 (a): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 7th October

Analysis based on 0000 UTC of 8th October, indicated an LPA over eastcentral BoB Vertically the system extended upto 500 hPa level.

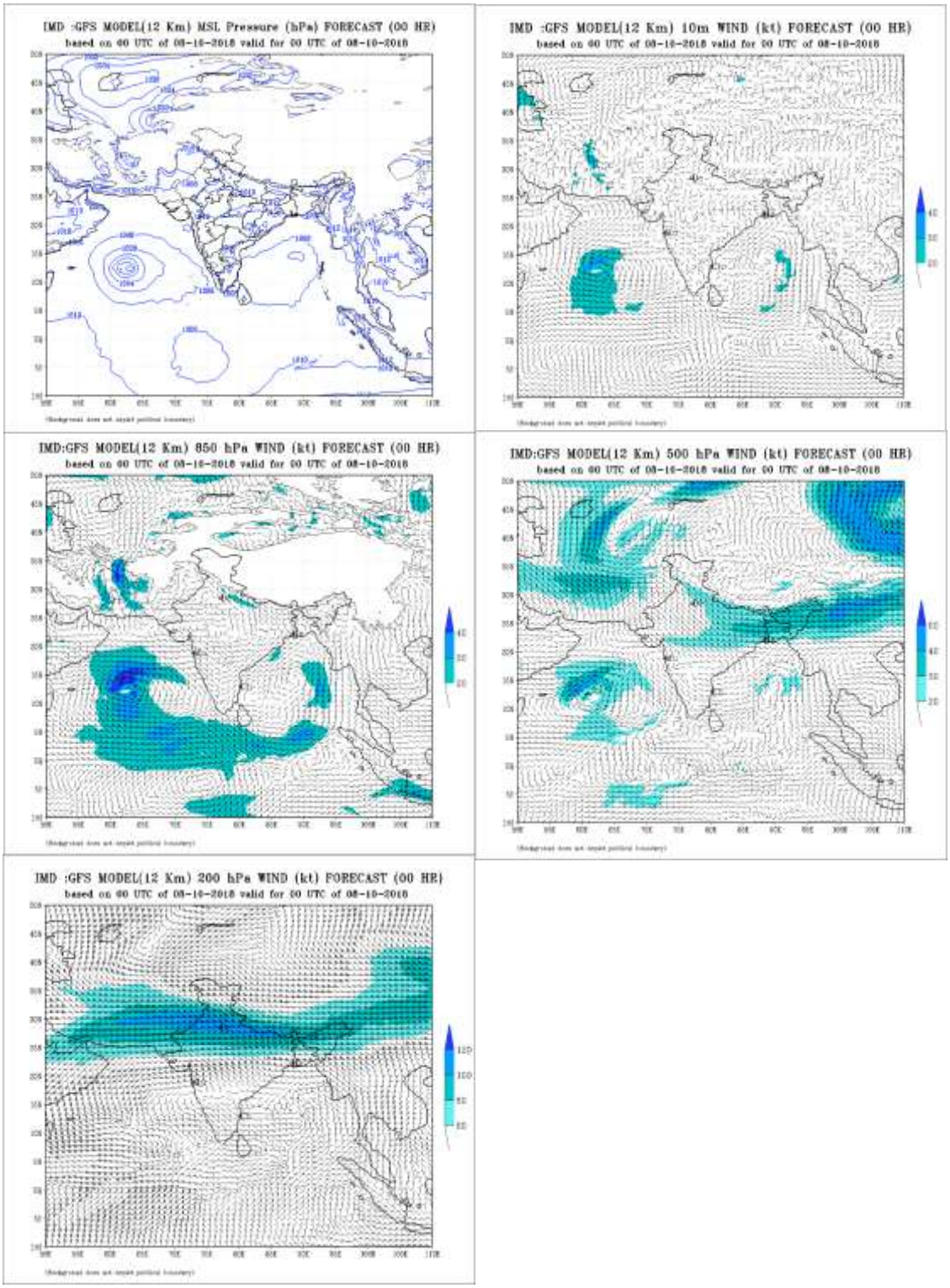


Fig. 6 (b): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 8th October

Analysis based on 0000 UTC of 9th October indicated a DD over eastcentral BoB. The circulation extended upto 500 hpa levels. The position and intensity was correctly picked up by the model.

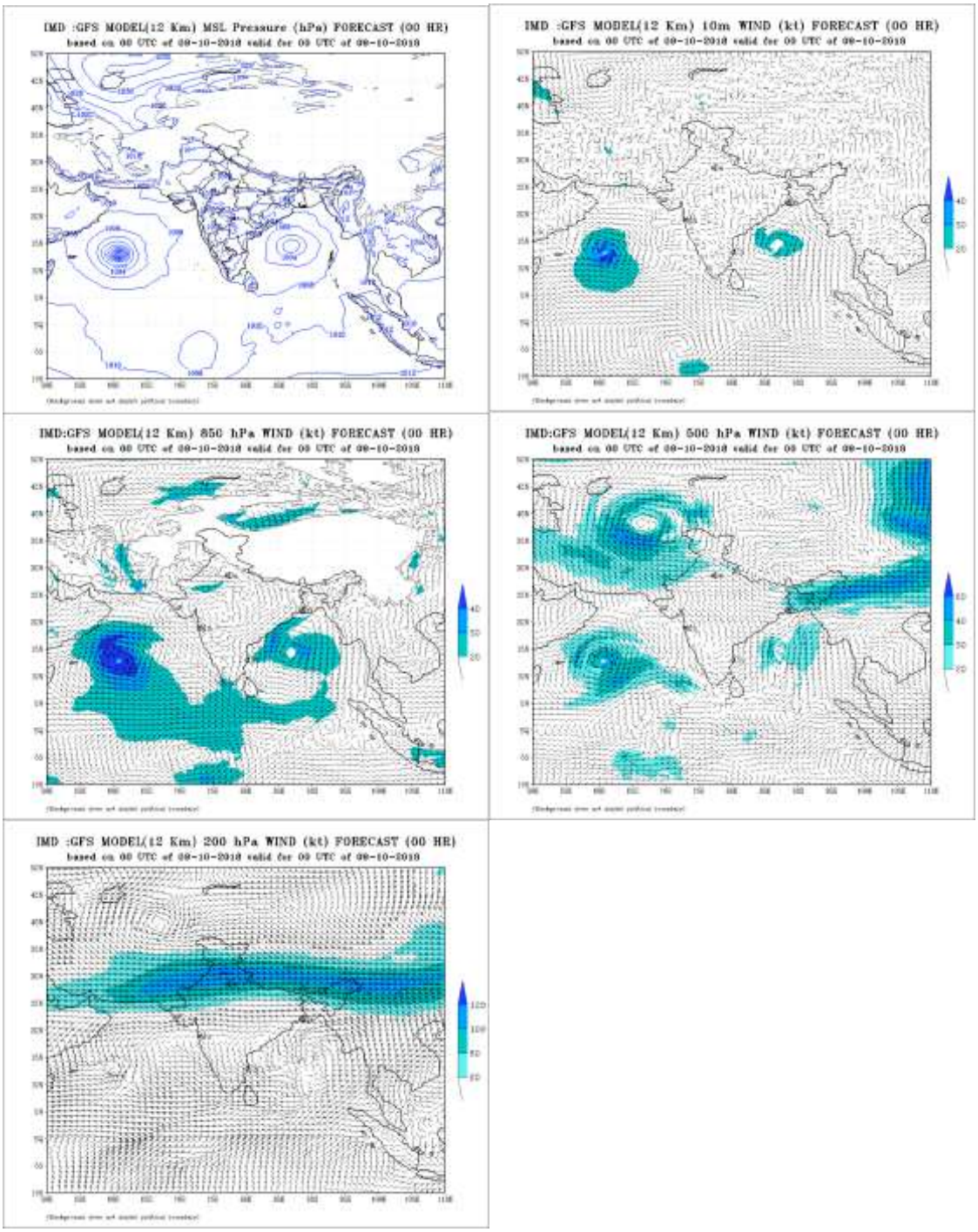


Fig. 6 (c): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 9th October

Initial conditions based on 0000 UTC of 10th October indicated intensification of the system into an SCS and the system lay over westcentral BoB. Vertically the circulation extended upto 500 hPa levels. The intensity and location was correctly picked by the model.

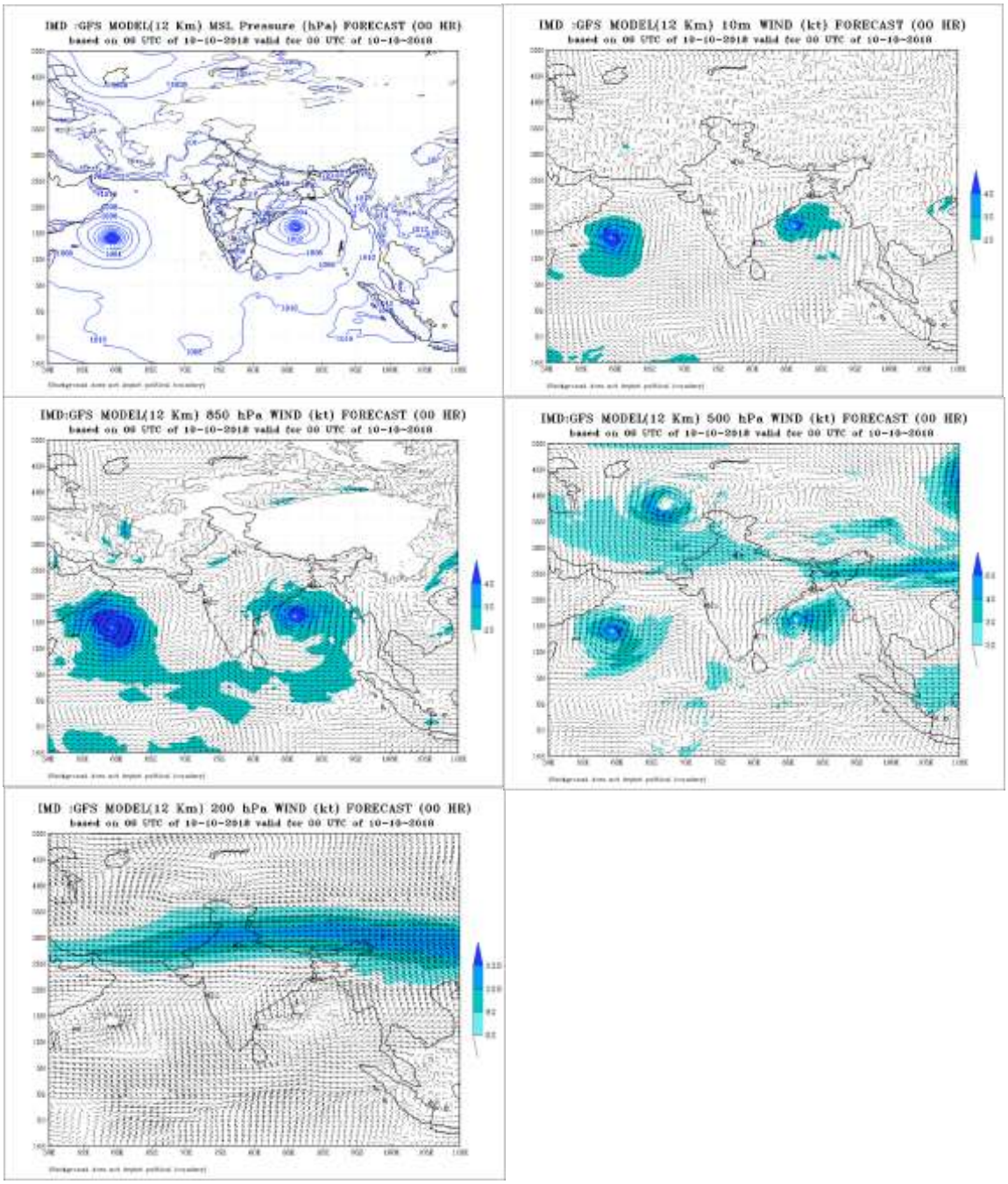


Fig. 6 (d): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 10th October

Analysis based on 0000 UTC of 11th October indicated the system crossing north Andhra Pradesh and adjoining south Odisha coasts as a VSCS prior to 0000 UTC of 11th. The model could pick up landfall point, time and intensity correctly.

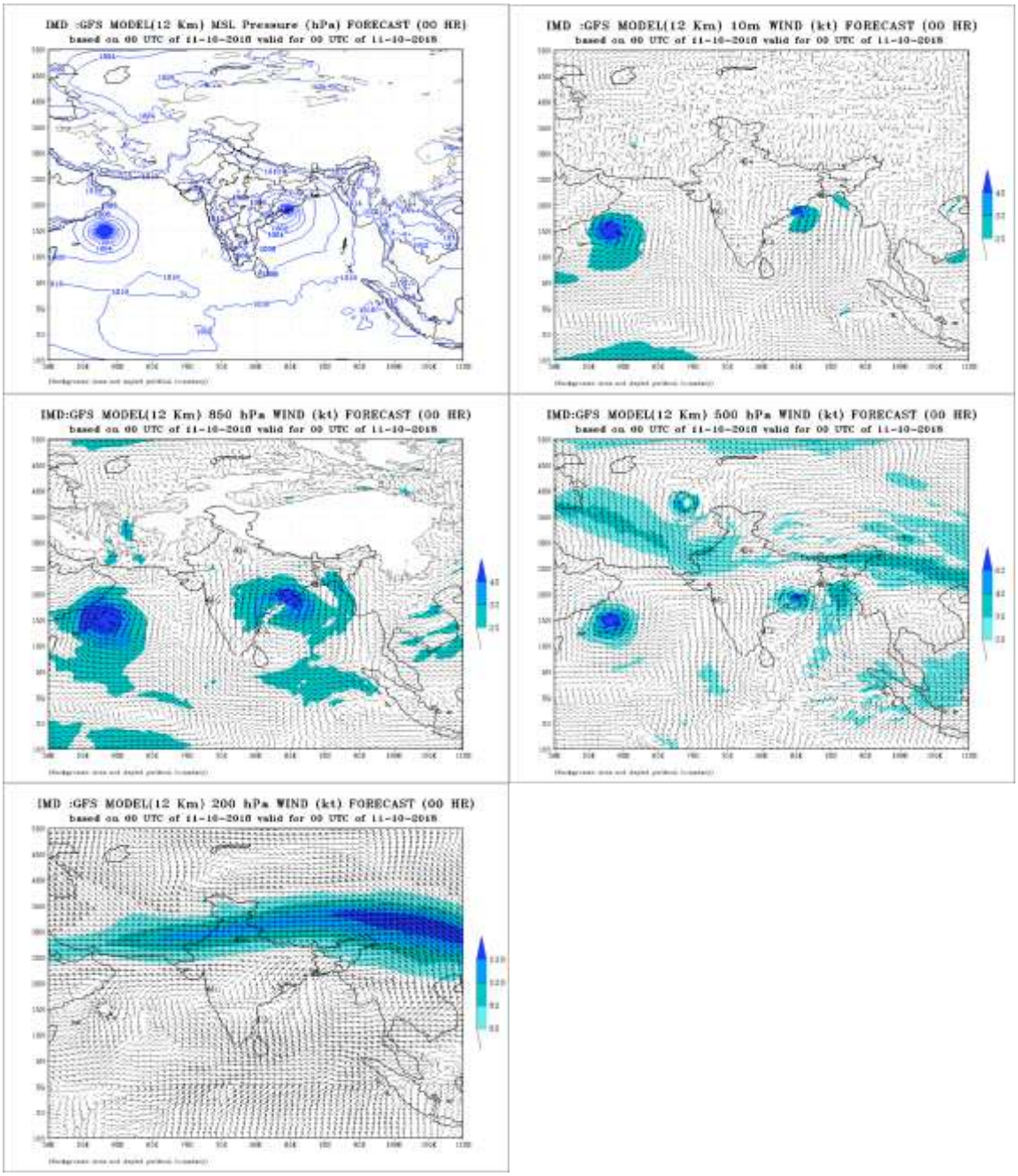


Fig. 6 (e): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 11th October

The initial conditions based on 0000 UTC of 12th indicated weakening of the system into a deep depression over south Odisha. The model picked up the intensity and location intensity correctly.

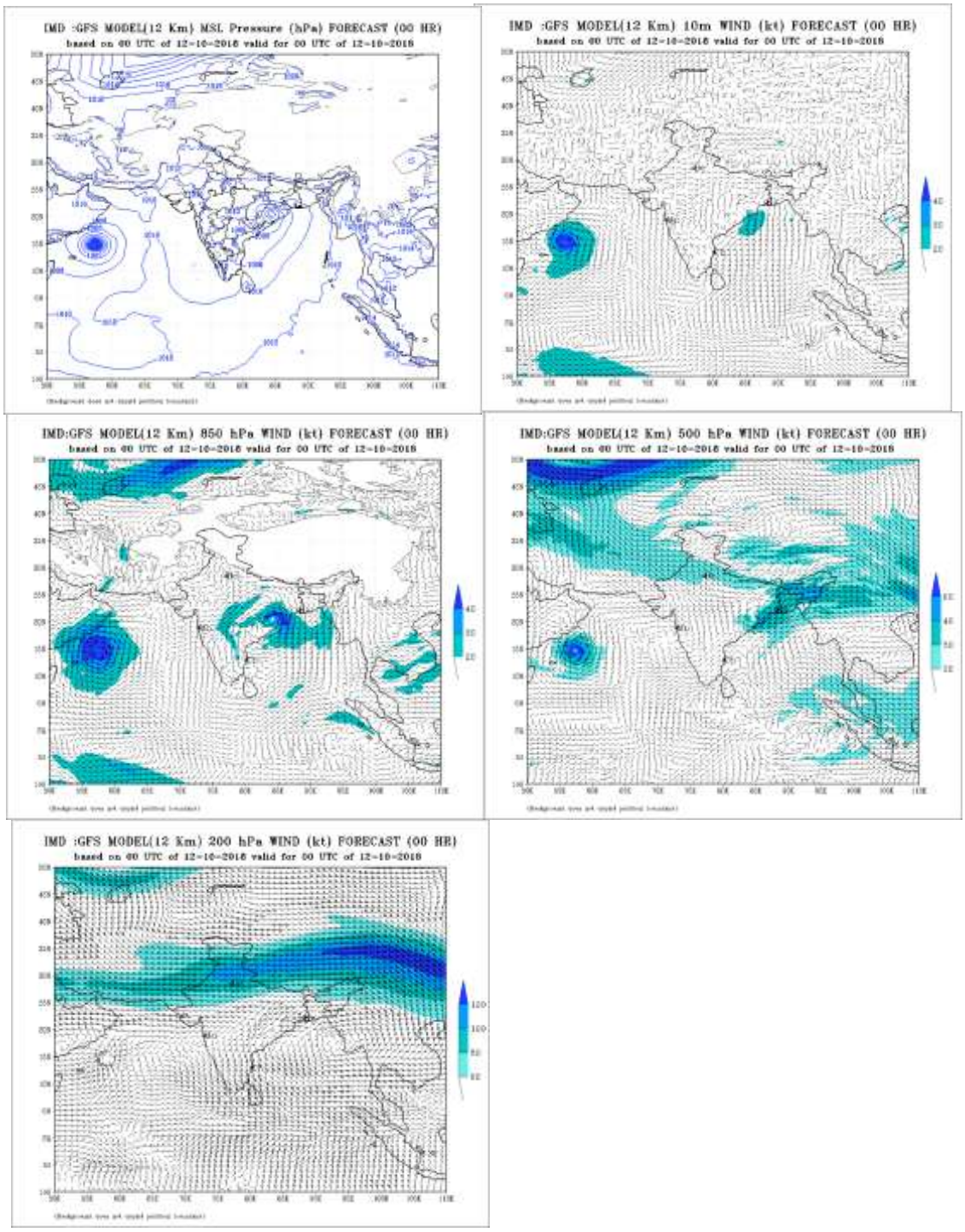


Fig. 6 (f): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 12th October

Based on initial conditions of 0000 UTC of 13th, the model indicated cyclonic circulation over Gangetic West Bengal and adjoining north BoB. At 0000 UTC of 13th, the system weakened into a WML over Gangetic West Bengal and adjoining Bangladesh & north BoB. Thus IMD GFS could predict the track, intensity and landfall of the system correctly.

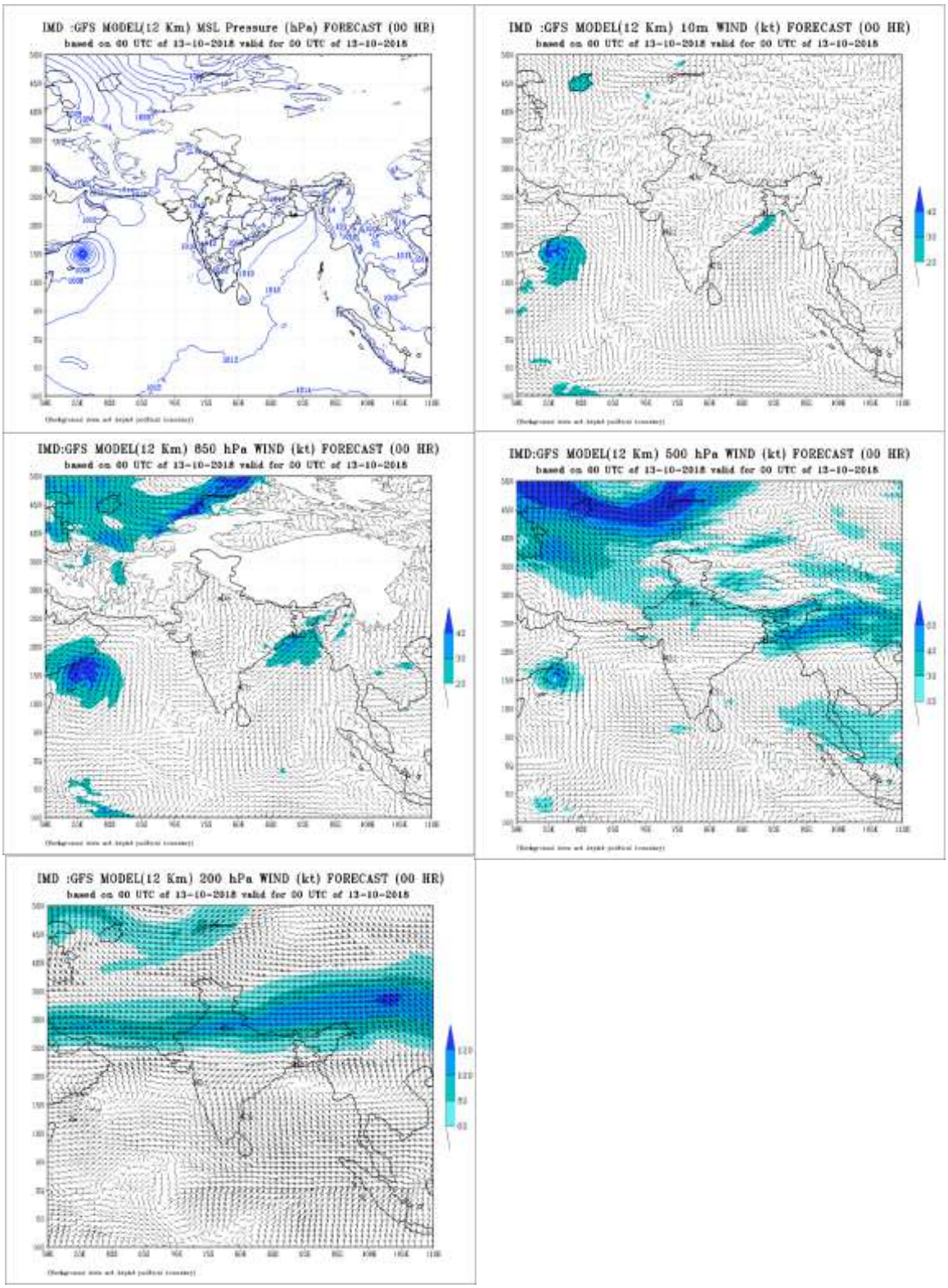


Fig. 6 (g): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 13th October

7. Realized Weather:

7.1 Rainfall:

NCMRWF GPM merged gauge rainfall data is depicted in **Fig 7**. It indicates the occurrence of extremely heavy rainfall over Oman and adjoining Yemen due to this cyclone." With following text:

Rainfall associated with VSCS titli based on IMD-NCMRWF GPM merged gauge rainfall data is depicted in **Fig 7**.

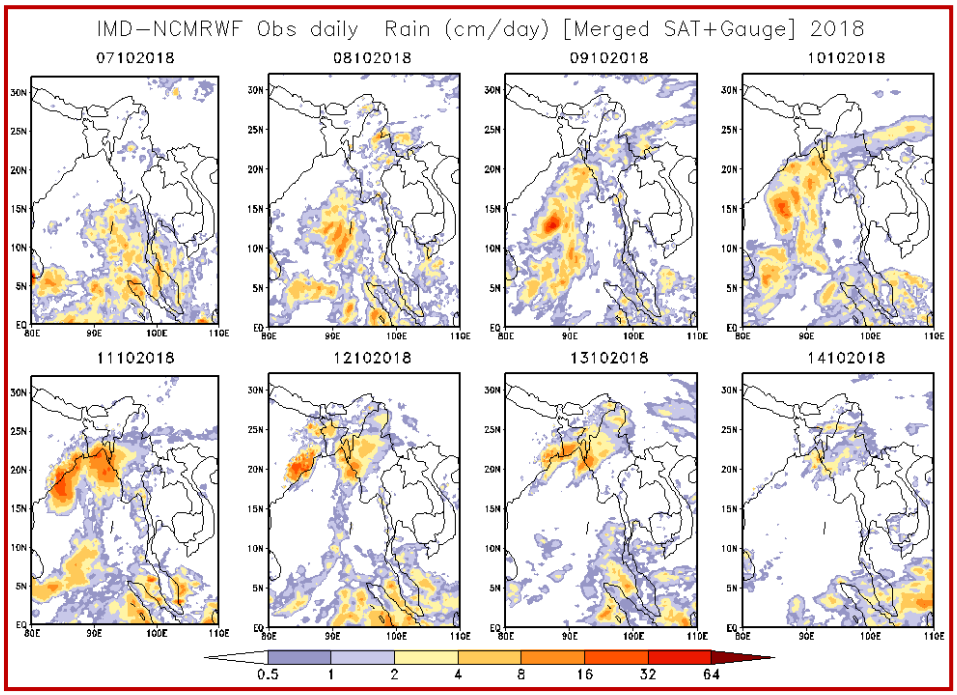


Fig.7: IMD-NCMRWF GPM merged gauge rainfall during 07th October– 13th October and 7 days average rainfall (cm/day)

It indicates that the system caused rainfall at most places with heavy to very rainfall at isolated places over southeast BoB and adjoining north Andaman Sea on 7th, heavy to very rainfall at a few places over southeast BoB on 8th, heavy rainfall at most places over southwest BoB upto northeast BoB with extremely heavy falls at isolated places over eastcentral BoB on 9th & 10th, rainfall at most places with heavy to very heavy rainfall at many places over coastal Odisha, Gangetic west Bengal and adjoining north BoB upto Assam with extremely heavy falls at isolated places over coastal Odisha on 11th, heavy to very falls at a few places with extremely heavy falls over coastal Odisha & heavy to very falls at most places over Assam on 12th and heavy to very falls at many places over Gangetic West Bengal upto Assam, Meghalaya, Manipur, Mizoram on 13th. The rainfall was higher in the right forward sector of the cyclone during and after the landfall.

Realized 24 hrs accumulated rainfall (≥7cm) ending at 0830 hrs IST of date during the life cycle of the system is presented below:

11th October

Odisha:- Mahendragarh-23, R.Udaigiri & Mohana-22 each, Purushottampur-21, Rajghat-17, Nuagada -16, Aska-15, Bhograi, Digapahandi, Balikuda-14 each, Chhatrapur, Ranpur, Raghunathpur & Sorada-13 each, Kendrapara, Nilgiri, Nh5 Gobindpur, Balasore, Kantapada-12 each, Kaptipada, Soro, Marsaghai , Chandikhol , Paradeep & Binjharpur -11 each, Alipingal, Jagatsinghpur Aws, Basudevpur, Gop, Korei & Gopalpur-10 each, Tikabali, Bhanjnagar, Jaipur, Kujanga , Madhabarida, Odagaon , Betanati , Remuna , Belaguntha , Tirtol , Pattamundai, Bhadrak, Niali -9 each, Raikia , Kakatpur, Nimpara, G Udayagiri , Puri, Nischintakoili , Pipili, Astaranga , Tangi, Jaleswar-8 each, Banpur, Jagannath Prasad , Krishnaprasad, Narsinghpur, Balimundali, Derabis , Banki , Akhuapada, Salepur , Bari , Balipatna , Jajpur, Bhubaneswar , Nayagarh, Jenapur, Garadapur -7 each,

Gangetic West Bengal:- Digha-14, Contai-10,

Coastal Andhra Pradesh: Itchpuram-24, Tekkali-23 and Palasa-20 and Kalingapatnam-9.

12th October

Coastal Andhra Pradesh: Pathapatnam-14, Veeraghattam, Ichchapuram, Kurupam-11 each, Tekkali-10, Balajipeta-9, Mandasa, Komarada & Sompeta & Palakonda-8 each, Palasa & Jiyyamma Valasa-7 each,

Odisha: G Udayagiri-35, Kantapada-32, Raikia & Banki-28, Mohana-24, Sorada, Phiringia-23 each, Ranpur-22, Baliguda-21, Harabhanga, K Nuagaon, Phulbani, Daspalla-20 each, Puri, Satyabadi, Tigiria, Baripada, Jagatsinghpur & Niali-19 each, Bolagarh-18, Jaipur, Gania & Banpur-17 each, Tikarpara, Athgarh & Nimpara-16 each, Odagaon, Narsinghpur, Bhanjnagar, Barmul, R.Udaigiri, Nayagarh, Jajpur & Balipatna-15 each, Tangi, Kotagarh, Krishnaprasad, Garadapur & Cuttack-14 each, Salepur, Alipingal & Mahanga-13 each, Parjang, Madhabarida, Talcher, Jagannath Prasad, Gop, Ambadola, Kashinagar, Pipili & Kendrapara-12 each, Gudari, Balimundali, Mundali, Korei, Samakhunta, Marsaghai, Hindol, Madanpur & Rampur-11 each, Lanjigarh, Binjharpur, Nilgiri, Dhenkanal, Bari, Sukinda, Khandapara, Kotraguda, Tirtol, Danagadi, Gunupur, Derabis & Bhubaneswar -10 each, Brahmagiri, Banarpal, Jenapur, Naraj, Bonth, Rajkishorenagar, Angul & Tihidi-9 each, Muniguda, Dhamnagar, Chandanpur, Akhuapada, Rajkanika, Berhampur, Kantamal, Bhadrak, Raghunathpur, Bhuban & Astaranga-8 each, Purushottampur, Chendipada, Chandikhol, Balikuda, Altuma Cwc, Harichandanpur, Khairamal, Athmalik, Narla, Boudhgarh, Rayagada, Bangiriposi, Soro, Sonepur, Bhawanipatna, Nawana, Pattamundai, Saintala, Chandbali, Ghatagaon, Kamakhyanagar, Anandpur & Basudevpur-7 each.

Gangetic West Bengal:

Murarai-7.

Assam, Meghalaya, Mizoram and Tripura:

Moderate rainfall upto 5 cm at many places

13th October

Assam & Meghalaya: Karimganj and B P Ghat-8 each,

Nagaland, Manipur, Mizoram & Tripura: Serchip-8,

Gangetic West Bengal: Digha-15, Contai-13, Kalaikunda-10,

Odisha:- Betanati Arg-16, Kaptipada, Rajghat & Bhograi-13 each, Danagadi, Dhamnagar, Balimundali, Tihidi & Bonth-11 each, Jaleswar & Remuna -10 each, Thakurmunda & Karanjia-9 each, Jajpur, Samakhunta, Bangiriposi, Mahanga,

Anandpur, Bari & Balasore, NH5 Gobindpur & Chandanpur-8 each, Baripada, Nilgiri, Udala, Sukinda, Ghatagaon, Jamsolaghat-7 each

14th October

Assam & Meghalaya: Cherrapunji-9, Cherrapunji (RKM)-8,

8. Damage due to VSCS Titli

As per report by media and post cyclone survey team, IMD about 77 people lost their lives in Odisha and 8 deaths were reported from Andhra Pradesh due to VSCS Titli. Typical damage photographs are presented in Fig.8.

Fig. 8 (a): Uprooted Peepal Tree at Khajuru, Andhra Pradesh

Fig.8(b): Uprooted Palm Tree at Khajuru, Andhra Pradesh

Fig. 8 (c): Uprooted coconut trees in Baruva village, AP

Fig.8 (d): Casuarina Jhau tree twisted and broken by gale wind in Baruva village, AP

9. 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 Titli are presented and discussed.

9.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for VSCS Titli

Fig. 9 shows the predicted zone of cyclogenesis based on 0000 UTC of 3rd to 8th October for 0000 UTC of 8th October.

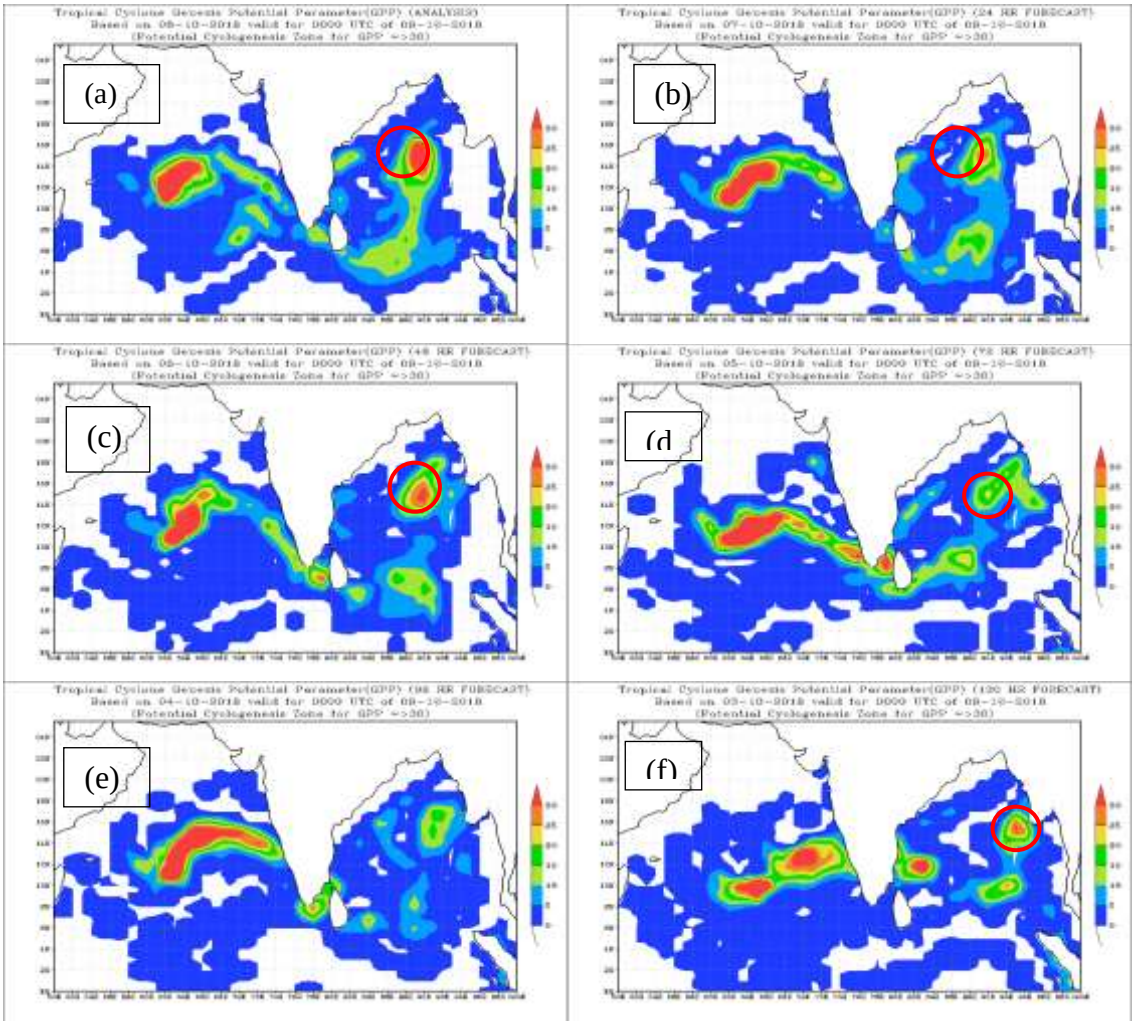


Fig. 9 (a-f): Predicted zone of cyclogenesis based on 0000 UTC of 3rd October (120 hours in advance) to 8th October (0 hours in advance) 2018.

The model could predict cyclogenesis zone correctly and consistently at 0000 UTC of 6th (48 hours in advance) and 0000 UTC of 3rd (120 hours in advance). At the same time it was indicating a false potential zone for cyclogenesis over southwest BoB (120 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 (i) Developed system: Threshold value of average GPP ≥ 8.0 and (ii) Non-developed system: Threshold value of GPP < 8.0. The area average analysis based on 0000 UTC of 7th indicated cyclogenesis during 1200 UTC of 7th to 1200 UTC of 8th with weakening trend thereafter. The analysis based on 1200 UTC of 7th indicated cyclogenesis till 1200 UTC of 8th with weakening till 1200 UTC of 9th and again cyclogenesis during 0000 UTC of 10th to 0000 UTC of 11th and no cyclogenesis

thereafter. Based on 0000 UTC of 8th, it indicated cyclogenesis with intensification for next 12 hours, weakening for next 24 hours followed by intensification during subsequent 24 hours and weakening thereafter. Based on 1200 UTC of 8th, it indicated cyclogenesis during 1200 of 8th to 0000 UTC of 10th with weakening on 1200 UTC of 10th followed by intensification till 0000 UTC of 11th and weakening thereafter. Based on 0000 UTC of 9th, it indicated cyclogenesis upto 0000 UTC of 11th but with weakening trend from 0000 UTC of 10th. Thus, during initial stages it picked up cyclogeneis and intensification correctly. But weakening of system around 10th and during landfall was not correctly predicted. The system never weakened in between and during landfall.

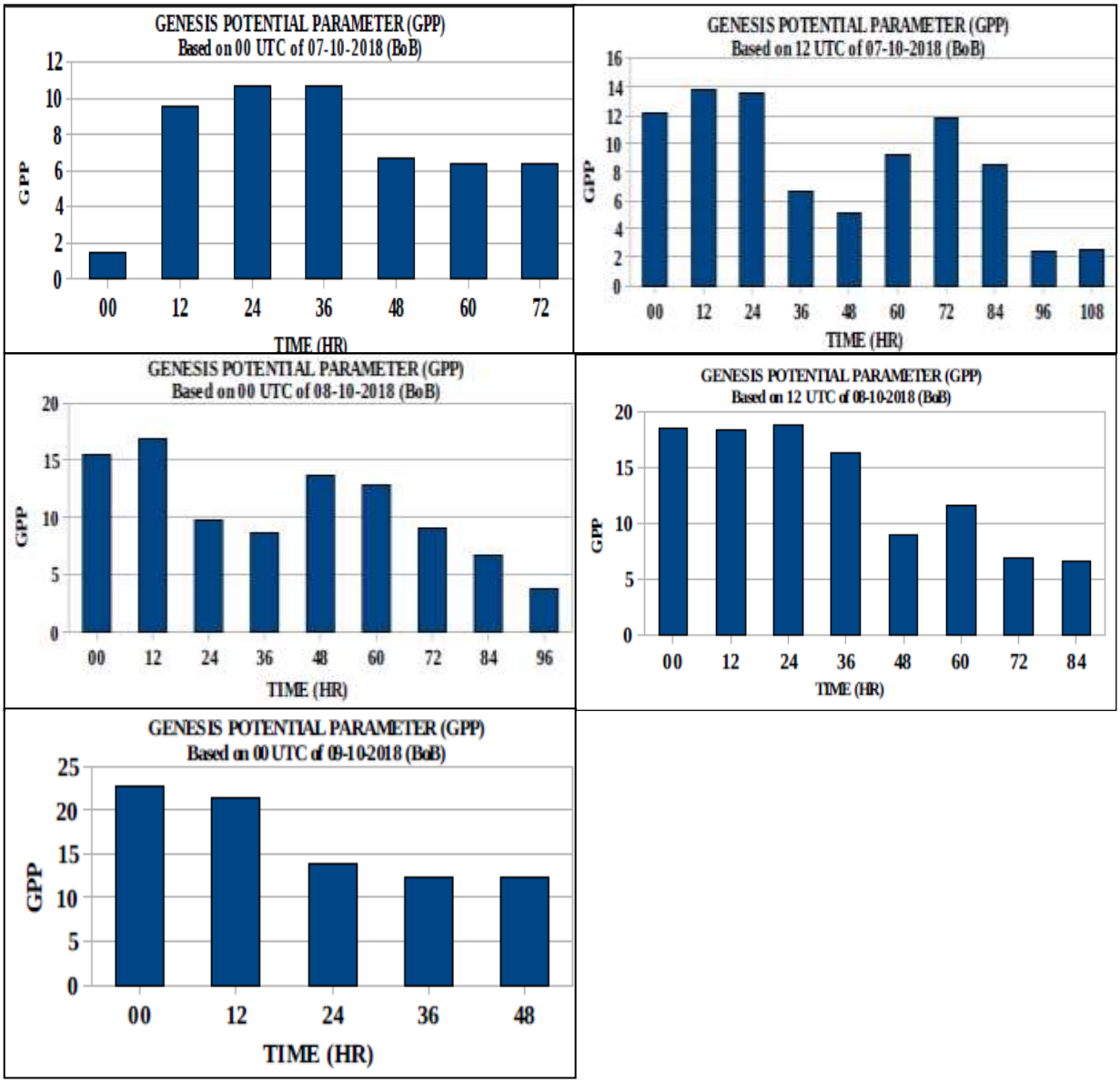


Fig. 10: Area average analysis and forecasts of GPP based on 0000 & 1200 UTC of 07st and 0000 UTC of 09nd October, 2018

9.2 Track prediction by NWP models

Track prediction by various NWP models is presented in Fig.11. Based on initial conditions of 0000 UTC of 9th October, all the models predicted northwestwards movement towards north Andhra Pradesh and adjoining south Odisha coasts. Most of the models were predicting landfall around noon of 11th. All models except WRF-VAR were predicting northeastwards recurvature after landfall.

Based on initial conditions of 0000 UTC of 10th October, all the models predicted northwestwards movement towards north Andhra Pradesh and adjoining south Odisha coasts. Most of the models were predicting landfall around 0000 UTC of 11th except WRF-VAR and NCEP GFS which were indicating landfall around 1200 UTC of 11th. All models were predicting northeastwards recurvature after landfall. IMD-MME and HWRF were correctly predicting intensity at the time of landfall around 80 kts. Both the models were also predicting rapid intensification during 0000 UTC of 10th to 11th and also rapid weakening after landfall.

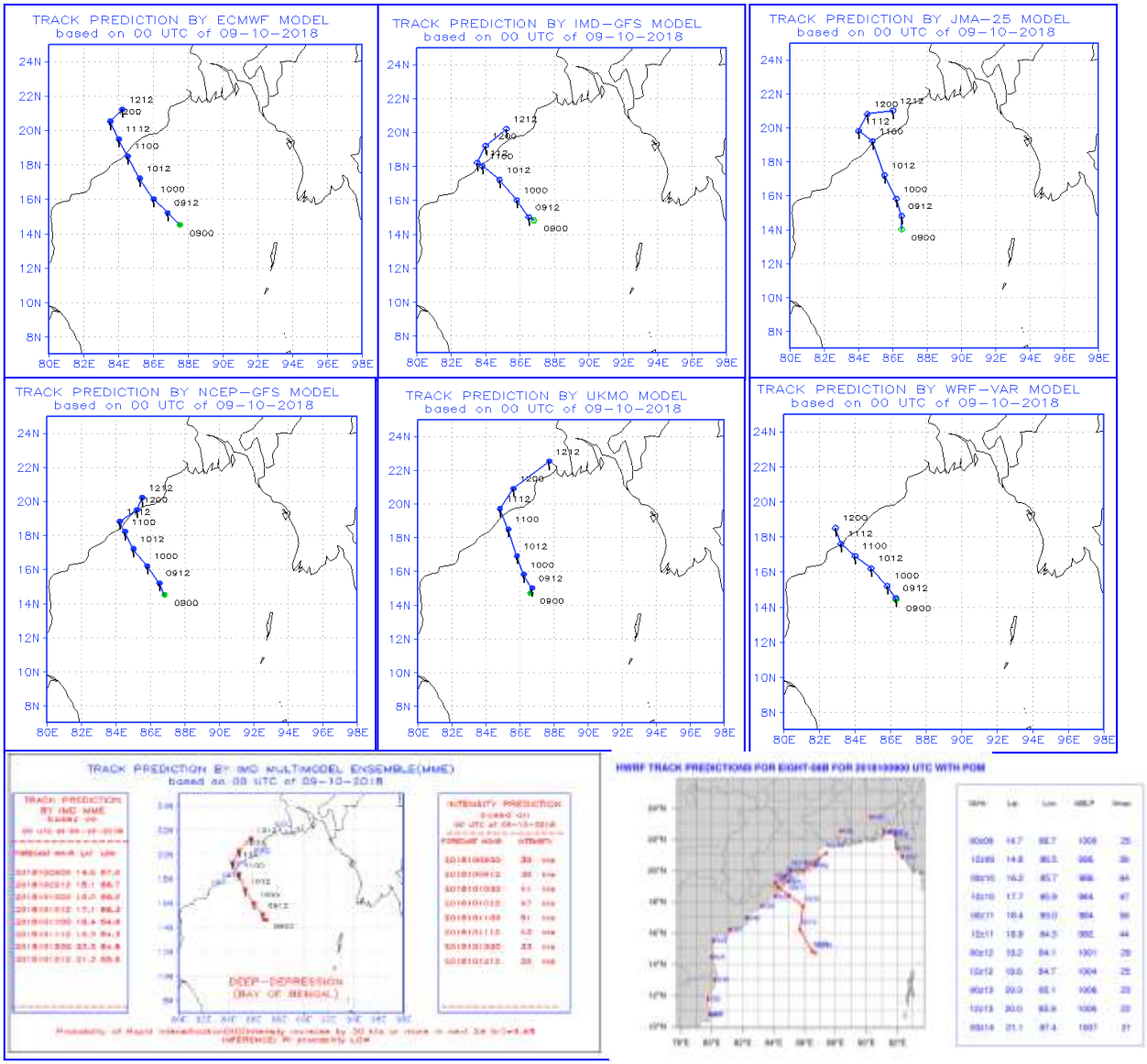


Fig. 11 (a): NWP model track forecast based on 0000 UTC of 9th October

Based on initial conditions of 0000 UTC of 10th October, all the models predicted northwestwards movement towards north Andhra Pradesh and adjoining south Odisha coasts. Most of the models were predicting landfall around 0000 UTC of 11th except WRF-VAR and NCEP GFS which were indicating landfall around 1200 UTC of 11th. All models were predicting northeastwards recurvature after landfall. IMD-MME and HWRF were correctly predicting intensity at the time of landfall around 80 kts. Both the models were also predicting rapid intensification during 0000 UTC of 10th to 11th and also rapid weakening after landfall.

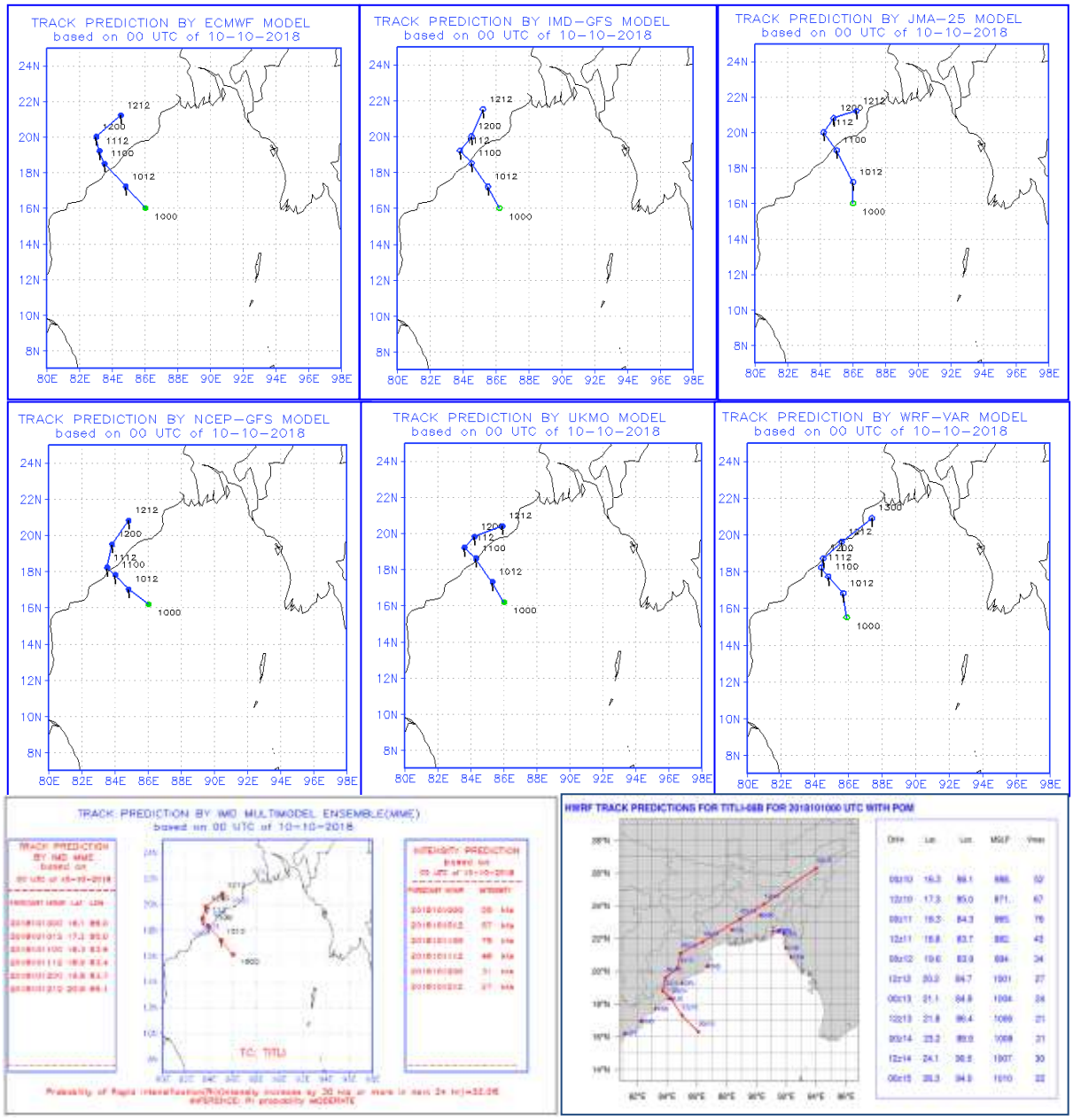


Fig. 11 (b): NWP model track forecast based on 0000 UTC of 10th October

9.3 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 errors for 24 hours lead period were the least by UKMO followed by IMD-GFS, IMD-MME, ECMWF and HWRF. For 48 hours lead period, the errors were the least by IMD-MME followed by ECMWF and IMD GFS. For 72 hours lead period, the errors were the least by JMA followed by IMD-MME. Overall the errors were the least by MME followed by JMA for various lead periods.

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
IMD-GFS	31(5)	45(5)	63(5)	77(5)	97(4)	129(3)	130(2)	76(1)
IMD-WRF	103(5)	119(5)	161(5)	197(5)	208(4)	227(3)	-	-
JMA	71(5)	80(5)	55(5)	86(5)	43(4)	37(3)	50(2)	-
NCEP-GFS	44(5)	80(5)	90(5)	93(5)	108(4)	128(3)	133(2)	-
UKMO	34(5)	36(5)	63(5)	90(5)	85(4)	134(3)	178(2)	122(1)
ECMWF	48(5)	56(5)	56(5)	83(5)	99(4)	131(3)	124(2)	119(1)
IMD-HWRF	42(9)	58(9)	84(9)	119(8)	168(6)	230(4)	210(2)	-
IMD-MME	35(5)	48(5)	60(5)	74(5)	74(4)	57(3)	46(2)	122(1)

( ): Number of forecasts verified; -: No forecast issued

Landfall point and time forecast errors are presented in Table 3 and 4. For 24 hours lead period, the landfall point error was within 50 km for IMD-GFS, IMD-WRF, JMA, UKMO followed by HWRF and MME. For 48 hours lead period errors were the least by MME followed by HWRF, ECMWF and NCEP GFS. Overall it can be seen that model errors were significantly less for all lead periods except IMD WRF.

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

Forecast Lead Time (hour) →	12 hr	24 hr	36 hr	48 hr	60 hr
Based on	**10 / 12z**	**10 / 00z**	**09 / 12z**	**09 / 00z**	**08 / 12z**
IMD-GFS	0	35	79	115	35
IMD-WRF	191	25	22	199	238
JMA	46	46	46	61	-
NCEP	35	131	99	49	92
UKMO	0	39	61	61	39
ECMWF	0	92	55	35	49
HWRF	33	69	45	22	-
IMD-MME	15	77	39	10	22

Landfall time error for all lead periods by IMD-MME, IMD-HWRF, IMD GFS, JMA and ECMWF were significantly less. Models could very well predict the landfall time of the system.

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

Forecast Lead Time (hour) →	12 hr	24 hr	36 hr	48 hr	60 hr
Based on	**10 October 12z**	**10 October 00z**	**09 October 12z**	**09 October 00z**	**08 October 12z**
IMD-GFS	0	0	0	0	-1
IMD-WRF	+24	+24	+1	+12	+12
JMA	0	+1	+1	0	-
NCEP	+1	+10	+12	+6	+12
UKMO	-2	0	+12	+9	0
ECMWF	+4	-2	+5	+1	+3
HWRF	0	0	+3	+6	-
IMD-MME	0	0	+6	+6	0

Landfall Time Error: Landfall Forecast Time- Actual Landfall Time
- : No forecast issued

9.3.1. Intensity prediction by SCIP Model

The composite intensity track prediction by IMD SCIP model based on initial conditions of 0000 & 1200 UTC during 8th - 10th October is presented in Fig. 12. Overall, SCIP underestimated the intensity of the system including the peak intensity.

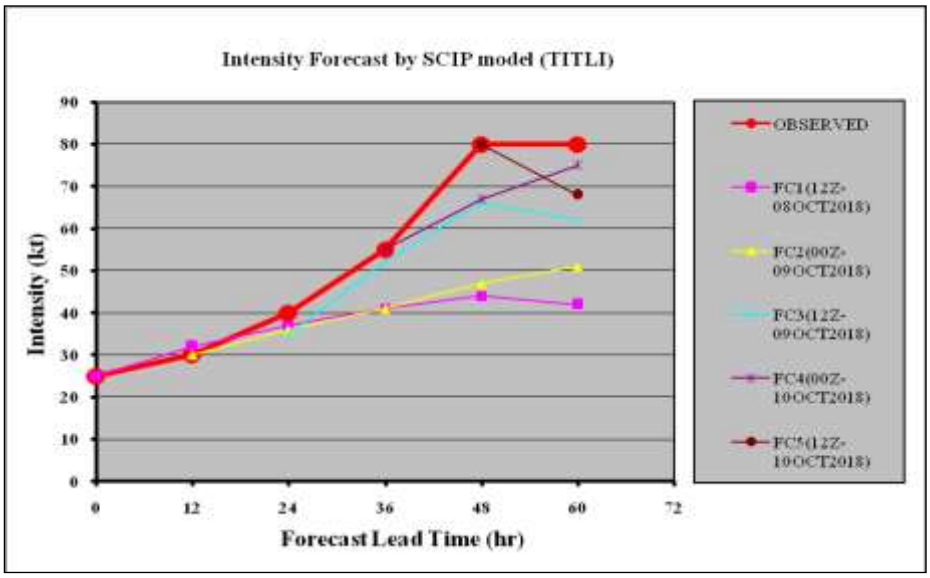


Fig.12: Intensity prediction by SCIP Model

The absolute and root mean square errors in intensity forecast by IMD SCIP and IMD HWRF are presented in Table 5. The intensity forecast errors by HWRF were significantly less as compared to IMD-SCIP for all lead periods. The comparative analysis of intensity predicted by IMD-SCIP and observed intensity is presented in Fig.13. It can be seen that IMD-SCIP overall underestimated the intensity of the model.

Table-5 Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of SCIP model and HWRF model

Lead Time→	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr
IMD-SCIP (AAE)	6.8(5)	9.0(4)	21.7(3)	32.5(2)	38.0(1)		
HWRF (AAE)	7.5 (9)	7.4 (9)	9.3 (9)	8.6 (8)	2.1 (6)	2.2 (4)	2.1 (2)
IMD-SCIP (RMSE)	8.3	10.3	23.2	32.7	38.0		
HWRF (RMSE)	8.7	10.2	10.3	10.3	2.4	2.6	2.8

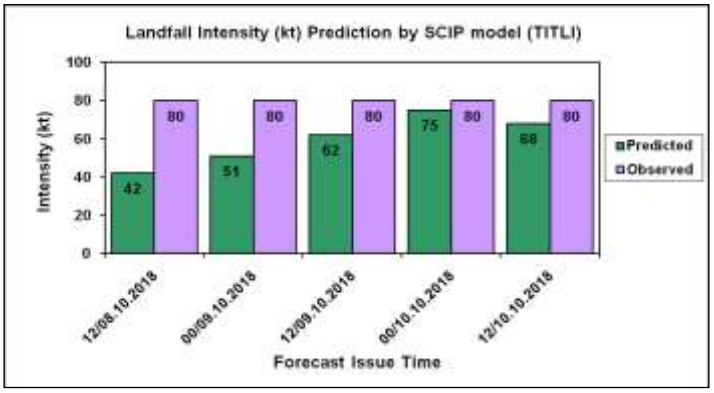


Fig. 13: **Comparative analysis of intensity predicted by IMD-SCIP and observed intensity**

Decay after landfall

Based on 0000 UTC of 11th, the decay model predicted more rapid decay as compared to actual decay in intensity of the system. However, the update based on 0600 UTC of 11th could correctly predict the decrease in intensity after landfall. Comparative analysis of intensity forecast by Decay Model based on 00 & 06 UTC of 11th October and actual intensity is presented in Fig. 14.

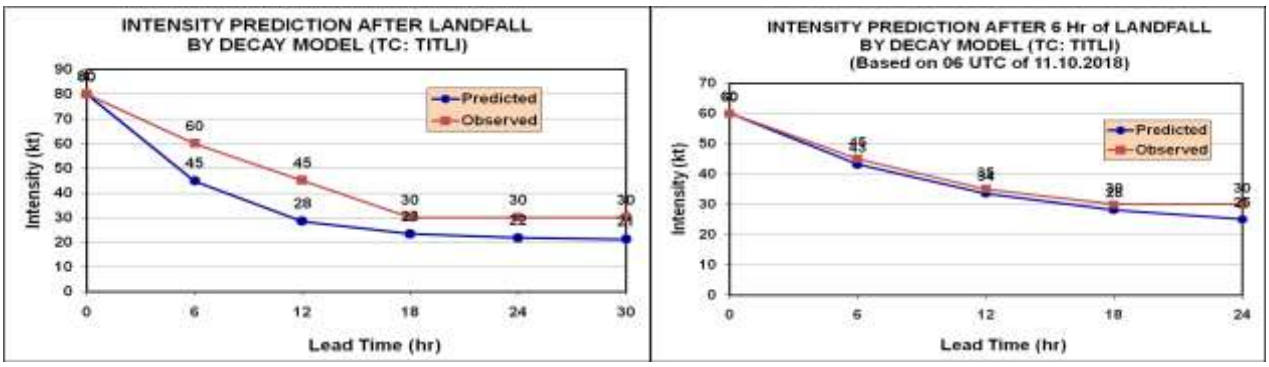


Fig. 14: Intensity prediction after landfall based on 00 & 06 UTC of 11th compared to actual intensity.

9.4. Heavy rainfall forecast by HWRF model

The forecast rainfall swaths by HWRF model are presented in **Fig.15**. HWRF could successfully predict occurrence of rainfall along the predicted track even after the landfall of system. It also predicted the rainfall upto north eastern parts of the country.

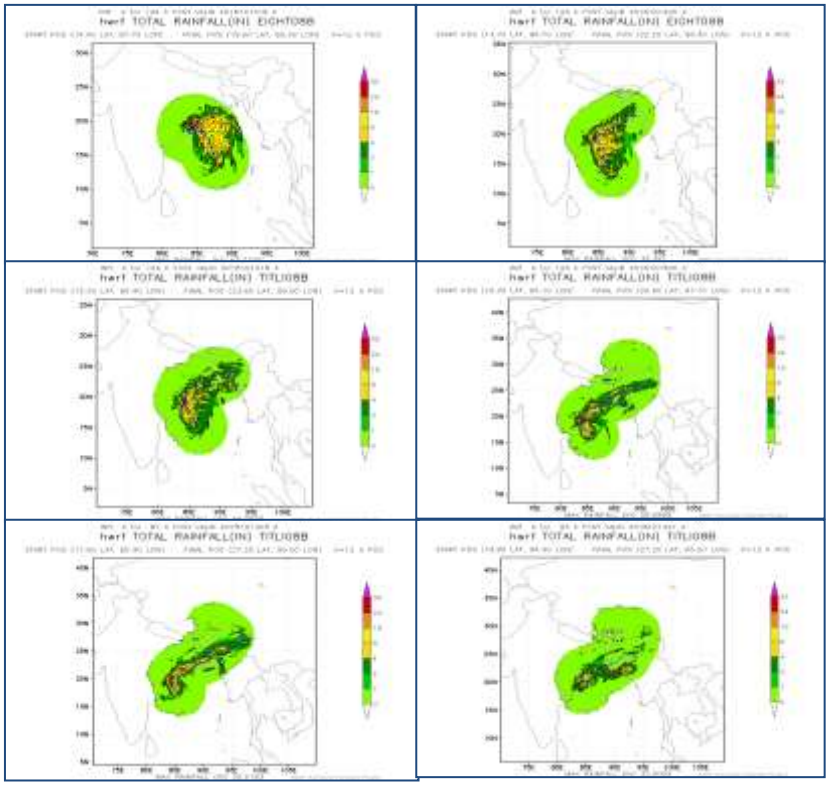


Fig.15: Heavy rainfall forecast by HWRF based on initial conditions of 00 & 12 UTC of 8th-11th October, 2018.

9.4. Storm surge forecast

IMD predicts storm surge forecast based on guidance from Advance Circulation (ADCIRC) model and Indian Institute of Delhi Model.

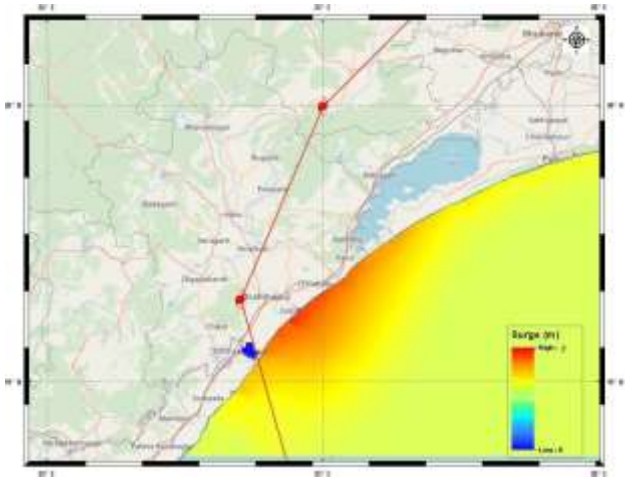


Fig. 16: Storm Surge Forecast issued by ADCIRC Model based on 1800 UTC of 10th October, 2018

IMD predicted storm surge of height of about 1.0 meter above astronomical tide to inundate low lying areas of Srikakulam district of Andhra Pradesh; Ganjam, Khurda & Puri districts of Odisha at the time of landfall. Gopalpur Port (Odisha) reported tide height of 0.85m and Palasa (Andhra Pradesh) reported tide height of about 1meter on 11th at the time of landfall. Storm surge forecast by ADCIRC Model based on 1800 UTC observations of 10th October is presented in **Fig.16**.

10. Operational Forecast Performance

10.1. Genesis Forecast

- First information about formation of low pressure area (LPA) over south Bay of Bengal and neighbourhood around 8th was issued in Press Release dated the 5th October at 1310 IST (about 45 hours in advance of formation of LPA). LPA formed at 0300 UTC of 7th.
- In the Press Release issued on 7th (based on 0300 UTC, issued at 1330 IST), it was mentioned that, the LPA would become well marked low pressure area (WML) during next 12 hours and concentrate into a Depression during subsequent 24 hours (about 9 hours in advance of formation of WML and 24 hours in advance of formation of depression). WML formed at 1200 UTC of 7th over southeast BoB and adjoining north Andaman Sea and depression formed over eastcentral BoB at 0300 UTC of 8th.

10.2. Landfall Forecast

- First information about that the system would cross Odisha and adjoining north Andhra Pradesh coasts between Gopalpur and Kalingapatnam around 11th morning was given in the bulletin issued at 0900 hrs IST of 9th October (about 43 hours prior to landfall). The system crossed north Andhra Pradesh and south Odisha coasts near Palasa (18.8^{0}N/84.5^{0}E) to the southwest of Gopalpur during 0430-0530 IST of 11th.
- The landfall point was further specified in the bulletin issued at 2030 hrs IST of 10th October that the system would cross Odisha and adjoining north Andhra Pradesh coasts close to Gopalpur around 11th morning (about 9 hours in advance). Typical observed and forecast track is presented in **Fig. 17**.

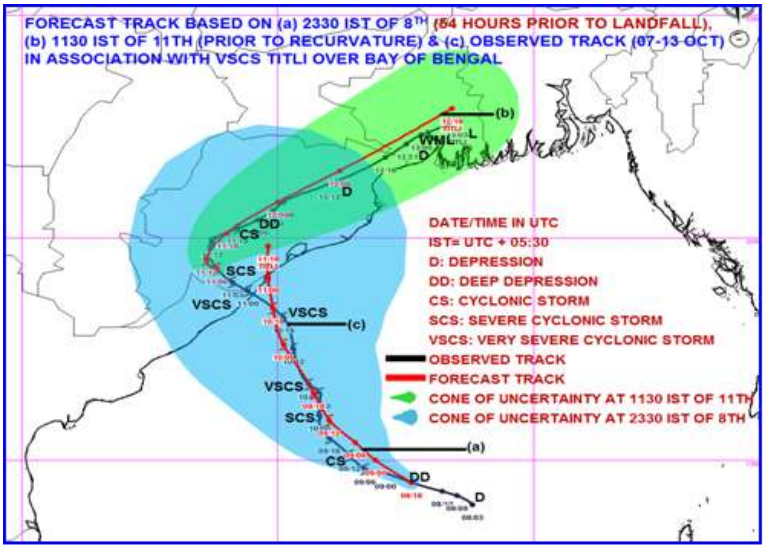


Fig.17: Observed track of VSCS Tiltli and forecast based on 1800 UTC of 8th and 0600 UTC of 11th (prior to recurvature)

- The landfall point forecast errors were about 15.6, 15.6 and 46.7 km for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 115.4 km respectively. The landfall time forecast errors were about 5.0, 3.0 and 3.5 hours for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 3.6, 5.4 and 4.6 hours respectively. The landfall point error was significantly less than long period average (LPA) of past five years for all lead periods (**Fig.18**) and **Table 6**.

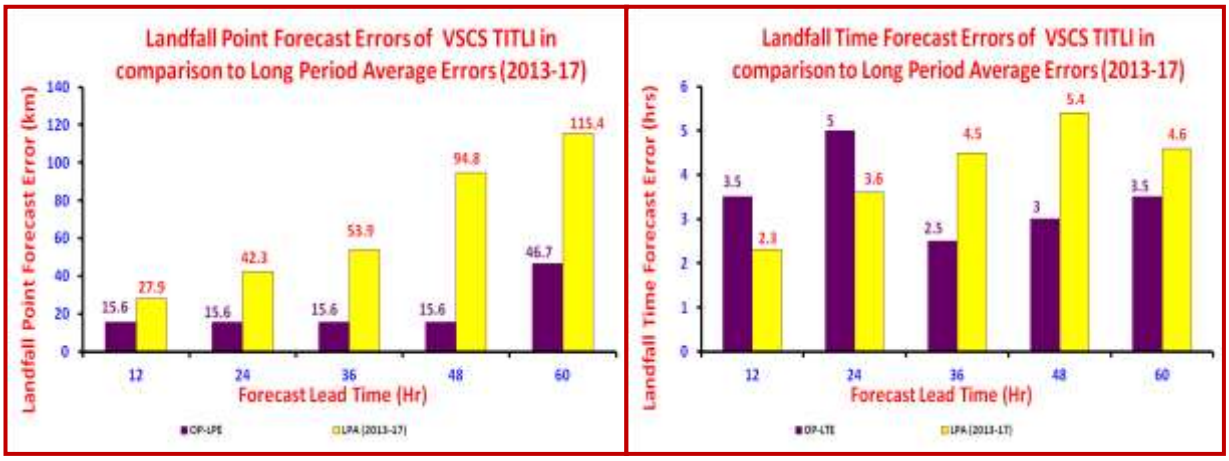


Fig.18: Landfall Point (km) and Time (hrs) Errors for VSCS Titli

Table 6: Landfall Point (km) and Time Error (hrs) in association with VSCS Titli

Lead Period (hrs)	Base Time	Landfall Point (^{0}N/^{0}E)		Landfall Time (hours)		Operational Error		LPA error (2013-17)	
		Forecast	Actual	Forecast	Actual	LPE (km)	LTE (hours)	LPE (km)	LTE (hours)
12	10/12	18.9/84.6	18.8/84.5	11/0300	10/2330	15.6	3.5	27.9	2.3
24	10/00	18.9/84.6	18.8/84.5	11/0430	10/2330	15.6	5.0	42.3	3.6
36	09/12	18.9/84.6	18.8/84.5	11/0230	10/2330	15.6	2.5	53.9	4.5
48	09/00	18.9/84.6	18.8/84.5	11/0250	10/2330	15.6	3.0	94.8	5.4
60	08/12	19.1/84.7	18.8/84.5	11/0300	10/2330	46.7	3.5	115.4	4.6

LPE: Landfall Point Error, LTE: Landfall Time Error, LPA: Long Period Average,
LPE= Forecast Landfall Point-Actual Landfall Point,
LTE= Forecast Landfall Time-Actual Landfall Time

10.3. Track Forecast

- First information that the system will move towards Odisha & adjoining north Andhra Pradesh Coasts from 8th onwards for next 72 hours was issued in Press Release dated the 5th October at 1310 IST (about 45 hours in advance of formation of LPA and 140 hours prior to landfall).
- In the first Bulletin issued on 8th, it was mentioned that the system would move northwestwards towards Odisha and adjoining north Andhra Pradesh coasts during next 72 hours.

- First information about the northeastwards recurvature of system towards Gangetic West Bengal across coastal Odisha from 12th morning was given in the bulletin issued at 1130 IST 9th October (about 60 hours in advance, recurvature started at 1500 UTC of 11th).
- The track forecast errors were about 98, 114 and 113 km for 24, 48 and 72 hrs lead period against past five year (2013-17) average errors of 93, 144 and 201 km respectively. For all the lead periods beyond 36 hours, the track forecast errors were less than the past five years average. For 12 & 24 hours lead period, it was comparable to past five years average (**Fig.19**) **(Table 7)**.

Table 7: Average Track forecast error in association with VSCS Titli

Lead Period (hrs)	N	Average track forecast error (km)	Skill (%)	LPA (2013-17)	
				Track forecast error (km)	Skill (%)
12	15	58.9	42.4	57	44.7
24	13	98.4	48.9	93	54.9
36	11	103.9	57.0	114	64.5
48	9	114.4	47.3	144	68.3
60	7	109.7	42.9	173	70.5
72	5	113.0	29.9	201	71.6
84	1	140.9	42.7	233	72.2

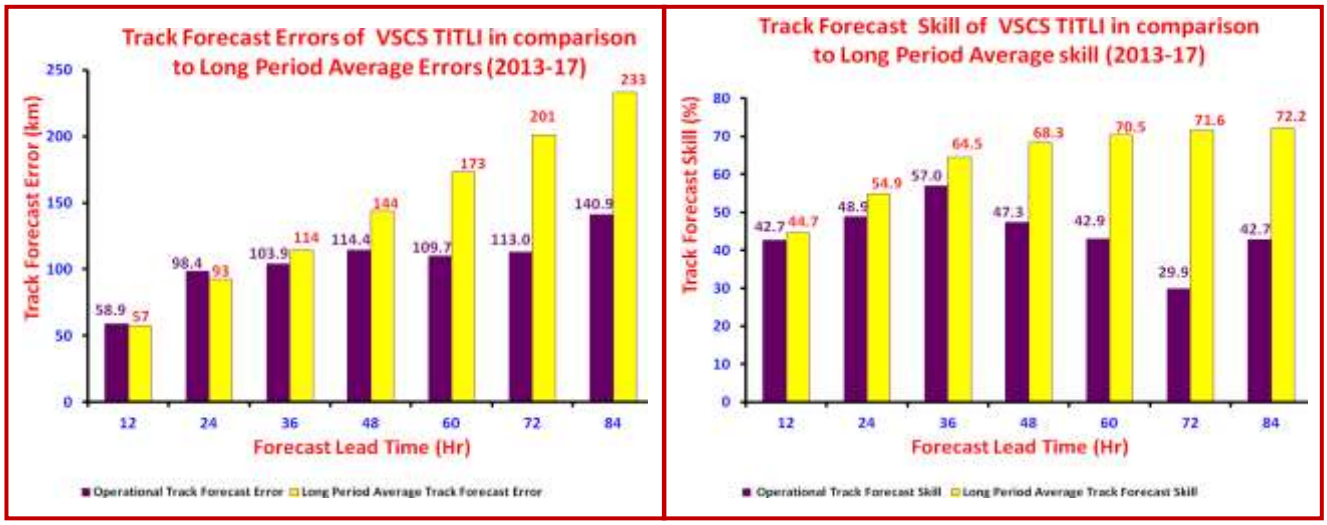


Fig.19: Track Forecast Errors and Skill for VSCS Titli

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

10.4. Intensity Forecast

- First information that the system would cross coast as a VSCS with maximum sustained wind speed of 140-150 kmph gusting to 165 kmph was issued at 0400 hours IST of 11th (about 5 hours prior to landfall).
- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 10.8, 10.3 and 2.0 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 69.7, 85.3 and 96.0% against the LPA of 37.1, 56.8 and 69.3% respectively (**Fig.20 and Table 8)**. For all lead periods, the errors in intensity forecast were significantly less and skill was significantly high.
- The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 12.6, 17.0 and 2.8 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 71.2, 79.8 and 94.9% against the LPA of 40.1, 60.0 and 73.0% respectively (**Fig.21 and Table 8)**. For all lead periods, the errors in intensity forecast were significantly less and skill was significantly high.

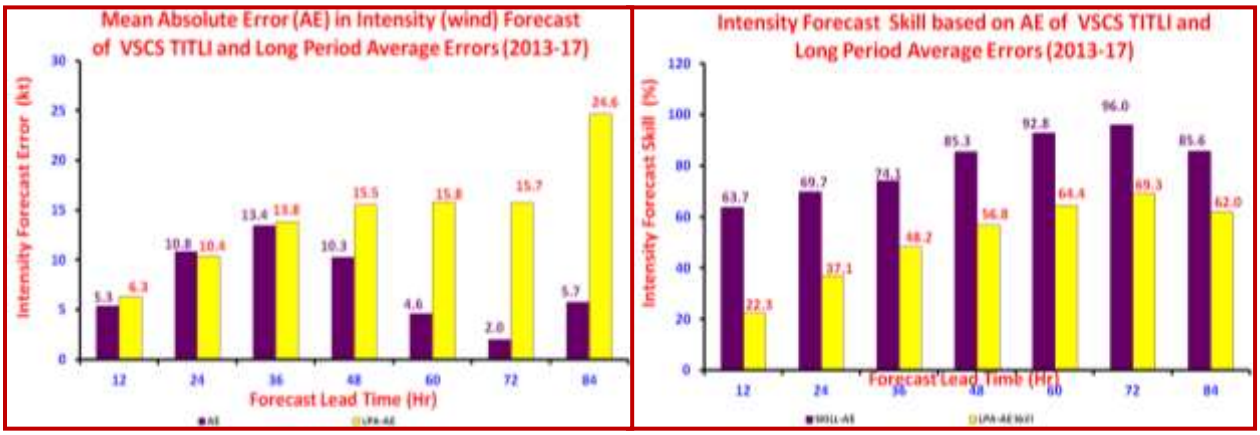


Fig. 20: Absolute errors (AE) of intensity forecast and skill for VSCS Titli

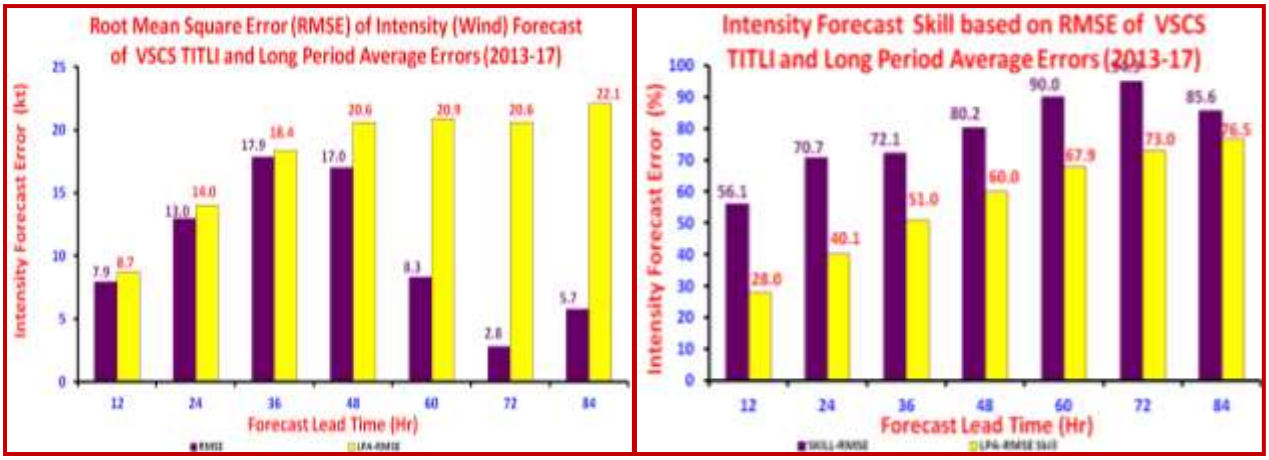


Fig.21: Root Mean Square Errors (RMSE) of intensity forecast and skill for VSCS Titli

Table 8: Average Intensity forecast error in association with VSCS Titli

Lead Period (hrs)	N	Average Intensity Error (kts)		Skill (%) in intensity forecast		LPA Intensity forecast Error (kts) (2013-17)		LPA Skill (%) in Intensity forecast (2013-17)	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	15	5.3	7.9	63.7	56.1	6.3	8.7	22.3	28.0
24	13	10.8	13.0	69.7	70.7	10.4	14.0	37.1	40.1
36	11	13.4	17.9	74.1	72.1	13.8	18.4	48.2	51.0
48	9	10.3	17.0	85.3	80.2	15.5	20.6	56.8	60.0
60	7	4.6	8.3	92.8	90.0	15.8	20.9	64.4	67.9
72	5	2.0	2.8	96.0	94.9	15.7	20.6	69.3	73.0
84	1	5.7	5.7	85.6	85.6	24.6	22.1	62.0	76.5

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

10.5. Verification of Adverse Weather associated with the system:

The verifications of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Table 9-11. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table – 9 Verification of Heavy Rainfall Forecast

Date/Base Time of observation (UTC)	24 hr Heavy rainfall warning ending at 0830 hrs IST of next day	Realised 24-hour heavy rainfall ending at 0300 UTC of date
08/10/2018 0300 UTC	**For 9th October**: Heavy rainfall (H) at isolated places over south coastal Odisha. **For 10th October** Heavy to very heavy rainfall (H-VH) at a few places and extremely heavy falls (Ex. H) at isolated places over coastal Odisha, heavy falls at isolated places over north coastal Andhra Pradesh (CAP) and H-VH falls at isolated places over Gangetic West Bengal (GWB). **For 11th October** H-VH at a few places and Ex.H falls at isolated places over coastal & adjoining interior Odisha, H at isolated places over north CAP and H-VH at isolated places over GWB. **For 12th October:** H at isolated places over north coastal Odisha	**10th October** Moderate rainfall occurred at a few places over coastal Odisha **11th October** **Odisha:-** Heavy to very heavy rainfall at a few places over coastal Odisha and extremely heavy rainfall at isolated places over south coastal Odisha **Gangetic West Bengal:-** Isolated

09/10/2018 0300 UTC	**For 9th October:** H at isolated places over south coastal Odisha and north CAP from evening/night and H at isolated places over Mizoram & Tripura. **For 10th October** H-VH at a few places and Ex.H falls at isolated places over coastal Odisha, H at isolated places over north coastal Andhra Pradesh (CAP), H-VH at isolated places over Gangetic West Bengal (GWB) and H at isolated places over Mizoram & Tripura.. **For 11th October** H-VH at a few places and Ex.H falls at isolated places over coastal & adjoining interior Odisha, H at isolated places over north CAP and H-VH at isolated places over GWB, H at isolated places over Assam & Meghalaya and H-VH falls at isolated places over Mizoram & Tripura. **For 12th October:** H at isolated places over north coastal Odisha, H-VH at isolated places over GWB, Assam & Meghalaya and Mizoram & Tripura.	heavy to very heavy rainfall over coastal districts **Coastal Andhra Pradesh:** Heavy to extremely heavy rainfall at a few places over Srikakulam district. **12th October** **Coastal Andhra Pradesh:** Heavy to extremely heavy rainfall at a few places over Srikakulam district. **Odisha:** Heavy to very heavy rainfall at a few places and extremely heavy rainfall at isolated places over south and north coastal Odisha **Gangetic West Bengal:** Heavy rainfall at isolated places over coastal districts **Assam, Meghalaya, Mizoram and Tripura**: Moderate rainfall upto 5 cm at many places **13th October** **Assam & Meghalaya:** Heavy rainfall at isolated places **Nagaland, Manipur, Mizoram & Tripura:** Heavy rainfall at isolated places **Gangetic West Bengal:** Heavy to very heavy rainfall
10/10/2018 0300 UTC	**For 10th October** H-VH at a few places and Ex.H at isolated places over coastal Odisha and isolated H over interior Odisha, H-VH falls at isolated places over north CAP & GWB. **For 11th October** H-VH at a few places and extremely heavy falls at isolated places over coastal Odisha and isolated H over interior Odisha, H-VH at isolated places over north CAP & GWB, H-VH at isolated places over Mizoram & Tripura. **For 12th October:** H falls at isolated places over north coastal Odisha, H-VH falls at isolated places over GWB, Assam & Meghalaya and Mizoram & Tripura. **For 13th October:** H at isolated places over Assam & Meghalaya and Mizoram & Tripura.	
11/10/2018 0300 UTC	**For 11th October** H-VH at a few places and Ex.H at isolated places over south Odisha, H-VH at isolated places over north CAP & GWB, Assam & Meghalaya and Mizoram & Tripura. **For 12th October:** H-VH at isolated places over Odisha, heavy to very heavy falls at a few places over GWB, H-VH and Ex.H falls at isolated places over Assam & Meghalaya and H-VH falls at isolated places over Mizoram & Tripura. **For 13th October:**	

	H falls at isolated places over GWB, H-VH and Ex.H at isolated places over Assam & Meghalaya and H-VH at isolated places Mizoram & Tripura.	at isolated places over coastal West Bengal **Odisha:-** Heavy to very heavy rainfall at isolated places over north Odisha. **14th October** **Assam & Meghalaya:** Heavy rainfall at isolated places over Meghalaya
12/10/2018 0300 UTC	**For 12th October:** H-VH and Ex.H at isolated places over north Odisha, H-VH at isolated places over GWB, Assam & Meghalaya and Mizoram, Tripura & Manipur **For 13th October:** H-VH at isolated places over GWB, Assam & Meghalaya and Mizoram, Tripura & Manipur	
13/10/2018 0300 UTC	H at isolated places very likely over south Assam, east Meghalaya, Mizoram, Tripura and Manipur during next 24 hours	

Table 10: Verification of Gale/Squally Wind Forecast issued by IMD

Date/ Time of observation (UTC)	Gale/ Squally wind Forecast for north Andhra Pradesh, Odisha and West Bengal	Realised wind speed
08/10/2018 0300 UTC	• Squally wind speed reaching 45-55 kmph gusting to 65 kmph is very likely to commence along & off along north Andhra Pradesh, Odisha and West Bengal coast from 9th afternoon. • It is very likely to increase gradually becoming 70-80 kmph gusting to 90 kmph from 10th October 2018 evening onwards along & off south Odisha & adjoining districts of north Andhra Pradesh coasts and 55-65 kmph gusting to 75 kmph along & off north Odisha, west Bengal and remaining districts of north Andhra Pradesh coasts.	• Gopalpur: Maximum wind speed of 126 kmph at 0430 hrs IST of 11th. • Gopalpur recorded 55 kmph wind speed at 1730 IST of 11th and 45 kmph at 0830 IST of 12th October. • Bhawanipatna(Kalahandi district) reported 52 kmph at 1730 IST of 11th. • Puri reported 59 kmph at 0530 IST of 12th. • Paradip reported 35
09/10/2018 0300 UTC	• Squally wind speed reaching 45-55 kmph gusting to 65 kmph is very likely to commence along & off along north Andhra Pradesh, Odisha and West Bengal coast from today, the 9th October night. • It is very likely to increase gradually becoming 80-90 kmph gusting to 100 kmph from 10th October 2018 evening onwards along & off south Odisha & adjoining districts of north Andhra Pradesh coasts and 55-65 kmph gusting to 75 kmph along & off north Odisha, west Bengal and remaining districts of north Andhra Pradesh coasts.	
10/10/2018 0300 UTC	• Gale wind speed reaching 60-70 kmph gusting to 80 kmph is very likely to commence along & off north Andhra Pradesh and Odisha coasts from today afternoon. • **It is very likely to increase gradually becoming 140-150 kmph gusting to 165 kmph from today, the 10th October 2018 night onwards along & off south Odisha & adjoining districts of north Andhra Pradesh coasts** and 70-80 kmph gusting to 90 kmph along & off north Odisha and remaining districts of north Andhra Pradesh coasts. • Squally winds speed reaching 50-60 kmph gusting 70 kmph is very likely to commence along & off West Bengal coast from today afternoon and gradually increase to 60-70 kmph gusting 80 kmph from today night onwards.	
11/10/2018	• **Gale wind speed reaching 90-100 kmph gusting to 115 kmph**	

0300 UTC	**very likely over Gajapati, Ganjam, Nayagarh Kandhamal & Raigada districts of Odisha during next three hours** and gradually decrease thereafter becoming squally wind speed of 50-60 kmph gusting to 70 kmph by evening. **Gale wind speed reaching 60-70 kmph gusting to 80 kmph very likely along & off south coastal Odisha during next three hours** and squally wind speed of 40-50 kmph gusting to 60 kmph likely during subsequent 18 hours. • Squally wind speed of 40-50 kmph gusting 60 kmph very likely along & off north Odisha and West Bengal coasts during next 24 hours. Squally wind speed of 30-40 kmph gusting to 50 kmph is very likely over adjoining districts of north interior Odisha from today afternoon for subsequent 12 hours.	kmph on 10th and 12th and 27 kmph on 11th • Estimated wind speed at the time of landfall : 140-150 kmph gusting to 165 kmph.
12/10/2018 0300 UTC	• Squally wind speed of 45-55 kmph gusting to 65 kmph very likely along & off Odisha and West Bengal and 35-45 kmph gusting to 55 kmph likely over adjoining areas of north interior Odisha during next 12 hours.	

Table 11: Verification of Storm Surge Forecast issued by IMD

Date/ Time(UTC)	Storm Surge Forecast	Recorded storm surge
09/10/2018 0600 UTC	Storm surge of height of about 0.5 m above astronomical tide is very likely inundate low lying areas of Srikakulam district of Andhra Pradesh; Ganjam, Khurda & Puri districts of Odisha at the time of landfall.	Gopalpur Port (Odisha) reported tide height of 0.85m and Palasa (Andhra Pradesh) reported tide height of about 1meter on 11th at the time of landfall.
10/10/2018 0300 UTC	Storm surge of height of about 1.0 meter above astronomical tide is very likely to inundate low lying areas of Srikakulam district of Andhra Pradesh; Ganjam, Khurda & Puri districts of Odisha at the time of landfall.	

10. Warning Services

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… +84 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 +48 hrs lead period.
- **Four stage Warning:** The precyclone watch was issued with the formation of depression in the first bulletin issued by IMD at 1200 hrs IST of 8th Oct. It was upgraded to cyclone alert in the bulletin issued at 0900 hrs IST of 09th Oct with the intensification of the depression into a deep depression. It was

further upgraded to cyclone warning in the bulletin issued at 1500 hrs IST of 9th Oct (38 hrs before landfall). The post-landfall outlook for the expected adverse weather in the interior districts due to the cyclone was issued at 1330 hrs IST of 10th (15 hrs before landfall).

- **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 concerned states along the east coast of India including Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Assam & Meghalaya, Manipur, Mizoram & Tripura. 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 related to heavy rain, gale/squally wind & storm surge were also presented in graphics alongwith colour codes in the website.
- **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, Kolkata and Cyclone warning centres at Bhubaneswar and Visakhapatnam to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** First warning for fishermen of the states of West Bengal, Odisha and Andhra Pradesh was issued at 1200 hrs IST of 7th 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.

Statistics of bulletins issued by RSMC New Delhi and Area Cyclone Warning Centre Kolkata and Cyclone Warning Centre Bhubaneswar in association with the VSCS Titli are given in **Table 12.**

Table 12 (a): Bulletins issued by RSMC New Delhi

S.N	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	37	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 Bulletins	10	• 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. • Put up on RSMC New Delhi website
3	Bulletin from DGM	8	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	43	1. IMD's website 2. WMO/ESCAP member countries and WMO through GTS and E-mail.
5	GMDSS Bulletins	16	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)	12	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 2220) To general public (1,11,998) to users registered with RSMC website from the states of Odisha, Andhra Pradesh, West

			Bengal and National level disaster managers.
8	Warnings through Social Media	Daily (4 times)	Cyclone Warnings were uploaded on Social networking sites (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	10	Disaster Managers, Media persons by email and uploaded on website
11	Press Briefings	Daily	Regular briefing daily

Table 12 (b): Bulletins issued by Area Cyclone Warning Centre (ACWC) Kolkata, Chennai (CHN) and Cyclone Warning Centre Bhubanaeswar (CWC BBN) and Visakhapatnam (CWC VZK)

S.No.	Type of Bulletins Number	No. of Bulletins issued				
		CWC BBN	ACWC Kolkata		CWC VZK	ACWC CHN
1.	Sea Area Bulletin	NIL	31		-	07
2	Coastal Weather Bulletin	28	WB Coast-20	A & N Coasts-20	16	07
3	Fishermen Warning	39	WB Coast - 27	A & N Coasts-08	24	13
4	Port Warning	28	WB - 15	A & N Islands - 07		07
5	Heavy Rainfall Warning	35	GWB- 3, SHWB & Sikkim- 1	A & N Islands-3		NIL
6	Wind Warning	27				NIL
7	Gale Wind Warning	14			3	NIL
8	Storm Surge Warning	16				NIL
9	Information & Warning issued to State Government and other Agencies (Special Bulletin)	38	WB- 21	A & N-05	13	05
10	Cyclone Alert/Cyclone Warning/ Cyclone Dewarning Message				1/12/1	
11	SMS/WhatsApp	1450/4800	2100		600	250
12	Press Release	04			2	

11. Summary

The very severe cyclonic storm (VSCS) Titli originated from a low pressure area (LPA) which developed over southeast BoB and adjoining north Andaman Sea in the morning of 7th October. It concentrated into a depression over eastcentral BoB in the morning of 8th October, deep depression (DD) in the same mid-night and further into a cyclonic storm (CS) **"Titli"** around noon of 9th October. It then moved northwestwards and intensified, into a severe cyclonic storm (SCS) in the early hours of 10th. It then moved north-northwestwards and further intensified into a very severe cyclonic storm (VSCS) around noon of 10th. It crossed north Andhra Pradesh and south Odisha coasts near Palasa (18.8^0N/84.5^0E) to the southwest of Gopalpur during 0430-0530 IST of 11th as a VSCS with the wind speed of 140-150 gusting to 165 kmph. It weakened into an SCS around noon of 11th and a CS in the same evening. The system recurved northeastwards from 11th evening. It weakened into a DD over south Odisha in the mid-night of 11th. It further weakened into a D in the afternoon of 12th and into a WML over Gangetic West Bengal and adjoining Bangladesh & north BoB in the early hours of 13th.

The system was monitored & predicted continuously by IMD prior to it's genesis as low pressure area over BoB from 5th October onwards till it's dissipation on 13th. It's genesis, movement, landfall, recurvature, intensity and associated adverse weather were well predicted by IMD. The landfall point forecast errors were about 15.6, 15.6 and 46.7 km for 24, 48 and 60 hrs lead period against past five year (2013-17) average errors of 42.3, 94.8 and 115.4 km respectively. The track forecast errors were about 98, 114 and 113 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 10.8, 10.3 and 2.0 knots against the LPA of 10.4, 15.5 and 15.7 knots respectively.

12. Acknowledgement:

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 Titli. 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, Kolkata, Cyclone Warning Centre (CWC) Bhubaneswar, Visakhapatnam, Meteorological Centre (MC) Tripura, Doppler Weather Radar Stations at Gopalpur & Visakhapatnam, 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.