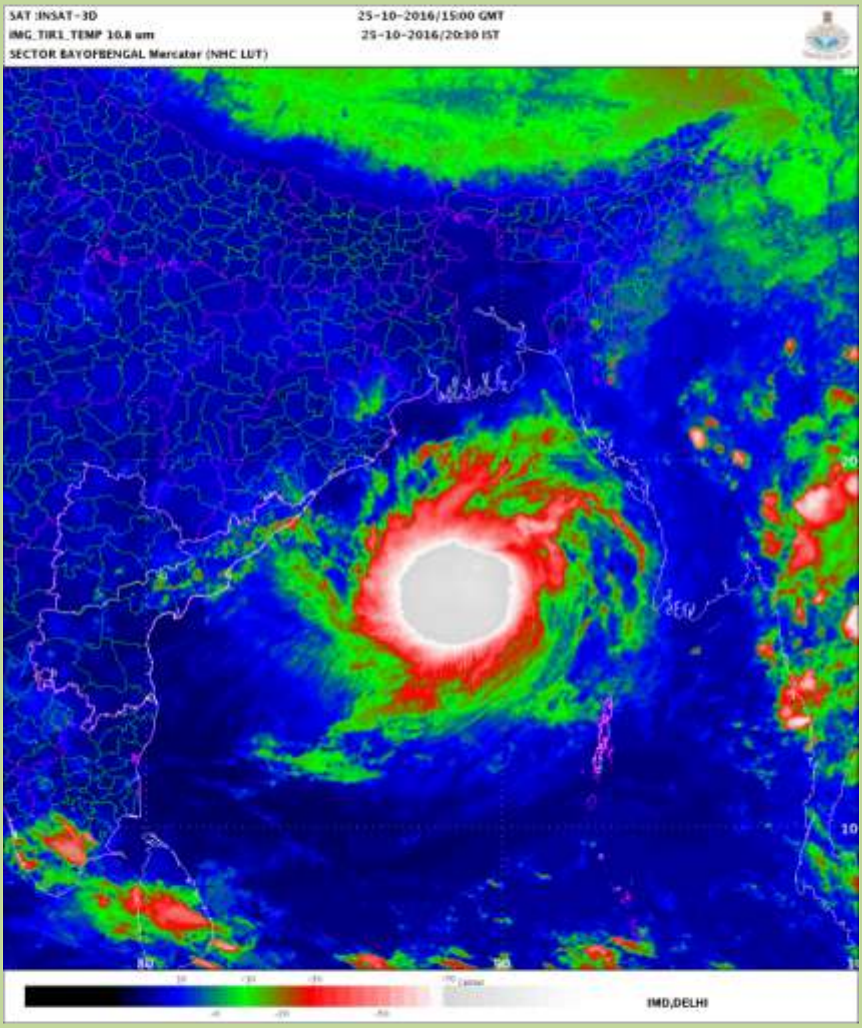
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Cyclonic Storm,'Kyant' over the Bay of Bengal (21-28 Oct 2016): A Report



INSAT-3D enhanced colored IR imagery based on 0600 UTC of 21st October

Cyclone Warning Division

India Meteorological Department

New Delhi

January 2017

Cyclonic Storm 'Kyant' over the BoB
(21-28 October 2016)

1. Introduction

The Cyclonic Storm (CS) Kyant developed on 21st October with the formation of a depression (D) over eastcentral BoB (BOB). Initially, it moved east-northeastwards towards Myanmar coast and steadily intensified into a deep depression (DD) on 23rd morning. Thereafter, it changed its direction of movement and recurved west-northwestwards. It intensified into a CS in the morning of 25th over eastcentral BOB. Thereafter, it again changed its direction of movement and moved west-southwestwards towards westcentral BOB off Andhra Pradesh coast. It maintained its intensity till midnight of 26th and thereafter weakened gradually becoming DD in the early hours 27th and D in the same evening. It weakened into a well marked low pressure area over westcentral BOB off Andhra Pradesh coast in the morning of 28th. Unique features of the system were:

- ❖ The track followed by the system was rare in nature as it experienced two recurvatures during its life period. First recurvature occurred in the evening of 23rd before the intensification of system into CS and the other occurred in the afternoon of 25th during the weakening phase.
- ❖ The recurvature was anticlockwise against the normal clockwise recurvature over the BOB. The last such recurvature over the BOB occurred in case of VSCS Madi (December, 2013).
- ❖ It was one of the longest track in recent years with life period of 7 days.
- ❖ While the rate of intensification was slow and steady taking about 4 days to become CS from the stage of depression, the rate of weakening was rapid as it reduced to a well marked low pressure area from the CS stage within 30 hours.
- ❖ The system weakened over the sea due to entrainment of dry and cold air from northwest India in association with anticyclonic circulation lying to the northwest of the system centre in middle and upper troposphere. The weakening occurred inspite of favourable (low-moderate) vertical wind shear over the storm region.
- ❖ The cyclone was monitored & predicted continuously since its inception by India Meteorological Department (IMD). At the genesis stage, the system was monitored mainly with satellite observations. Various national and international NWP 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.
- ❖ Though the system was moving towards Myanmar, no landfall over Myanmar was predicted by IMD.
- ❖ No Cyclone Alert/Warning was issued for any coastal state of India.

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.

2. Monitoring of CS,'Kyant'

The cyclone was monitored & predicted continuously since its inception by IMD. The observed track of the cyclone over BoB during 21st to 28th October 2016 is presented in Fig.1. The best track parameters of the systems are presented in Table 1**.**

At the genesis stage, the system was monitored mainly with satellite observations. Various national and international NWP models and dynamical-statistical models including IMD's and NCMRWF's global and meso-scale models, dynamical statistical models for genesis and intensity 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.

3. Brief life history

3.1. Genesis

A low pressure area formed over East-central BoB and neighbourhood at 0300 UTC on 19th October. It became .well marked low pressure are over eastcentral BoB and adjoining southeast BoB at 0300 UTC on 20th. It concentrated into a Depression at 0000 UTC on 21st over central and adjoining southeast BoB near latitude 13.5^{0}N and longitude 88.5^{0}E.

3.2. Intensification and Movement

Initially, it moved east-northeastwards towards Myanmar coast and steadily intensified into a deep depression (DD) on 23rd morning and lay centered at 0300 UTC of 23rd October over eastcentral BoB near latitude 15.5^{0}N and longitude 93.0^{0}E. It remained practically stationary at 1200 UTC of 23rd. It then recurved gradually in anti-clockwise direction and lay centered at 0300 UTC of 24th over eastcentral BoB near latitude 16.4^{0}N and longitude 93.2^{0}E. It then moved west-northwestwards and lay centered at 1200 UTC of 24th October near latitude 16.7^{0}N and longitude 92.7^{0}E. It further moved west-northwestwards and intensified into a Cyclonic Storm 'KYANT' and lay centered at 0300 UTC of 25th near latitude 17.0^{0}N and latitude 91.2^{0}E. It again recurved, moved west-southwestwards and lay centered at 1200 UTC of 25th over eastcentral BoB near latitude 16.8^{0}N and longitude 90.5^{0}E. It moved further west-southwestwards weakened into a DD and lay centered at 0000 UTC of 27th over westcentral BoB near latitude 15.7^{0}N and longitude 85.5^{0}E about 400 km south of Gopalpur. It moved further west-southwestwards and weakened into a Depression and lay centered at 1200 UTC of 27th over westcentral BoB near latitude 15.5^{0}N and longitude 83.5^{0}E. Continuing to move west-southwestwards, it weakened into a well marked low pressure area over westcentral BoB off Andhra Pradesh coast at 0000 UTC of 28th October.

The best track parameters associated with the system are presented in Table 1.

Table 1 Best track positions and other parameters of the Cyclonic Storm, 'KYANT' over the BoB during 21-28 October, 2016

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
21/10/2016	0000	13.5/88.5	1.5	1003	25	3	**D**
	0300	13.6/88.8	1.5	1003	25	3	D
	0600	13.7/89.3	1.5	1003	25	3	D
	1200	13.9/89.8	1.5	1003	25	3	D
	1800	13.9/89.9	1.5	1003	25	3	D
22/10/2016	0000	13.9/90.0	1.5	1002	25	4	D
	0300	14.0/90.5	1.5	1002	25	4	D
	0600	14.5/91.3	1.5	1002	25	4	D
	1200	14.9/92.0	1.5	1002	25	4	D
	1800	15.2/92.5	1.5	1002	25	4	D
23/10/2016	0000	15.5/93.0	1.5	1002	25	4	**D**
	0300	15.5/93.0	2.0	1000	30	5	**DD**
	0600	15.5/93.0	2.0	1000	30	5	DD
	1200	15.7/93.1	2.0	1000	30	5	DD
	1800	16.0/93.2	2.0	1000	30	5	DD
24/10/2016	0000	16.4/93.2	2.0	1000	30	5	DD
	0300	16.4/93.2	2.0	1000	30	5	DD
	0600	16.5/93.1	2.0	1000	30	5	DD
	1200	16.7/92.7	2.0	1000	30	5	DD
	1800	16.8/92.3	2.0	1000	30	5	DD
25/10/2016	0000	16.9/91.7	2.0	1000	30	5	**DD**
	0300	17.0/91.2	2.5	998	35	6	**CS**
	0600	17.0/90.9	2.5	998	35	6	CS
	0900	16.8/90.6	2.5	998	35	6	CS
	1200	16.9/90.5	2.5	998	35	6	CS
	1500	16.7/90.2	2.5	998	35	6	CS
	1800	16.7/89.8	2.5	998	35	6	CS
	2100	16.5/89.6	2.5	997	35	7	CS
26/10/2016	0000	16.6/89.0	2.5	996	40	8	CS
	0300	16.6/88.5	2.5	996	40	8	CS
	0600	16.5/88.0	2.5	996	40	8	CS
	0900	16.4/87.5	2.5	996	40	8	CS
	1200	16.3/87.0	2.5	996	40	8	CS
	1500	16.2/86.6	2.5	997	40	7	CS
	1800	16.1/86.4	2.5	998	35	6	**CS**
	2100	15.9/85.9	2.0	1000	30	5	**DD**
27/10/2016	0000	15.7/85.5	2.0	1002	30	5	DD
	0300	15.6/85.0	2.0	1002	30	5	DD
	0600	15.6/84.5	2.0	1003	30	5	DD
	1200	15.5/83.5	1.5	1004	30	4	**D**
	1800	15.4/83.0	1.5	1004	25	3	D
28/10/2016	0000	Well Marked Low Pressure Area over westcentral BoB off Andhra Pradesh coast					

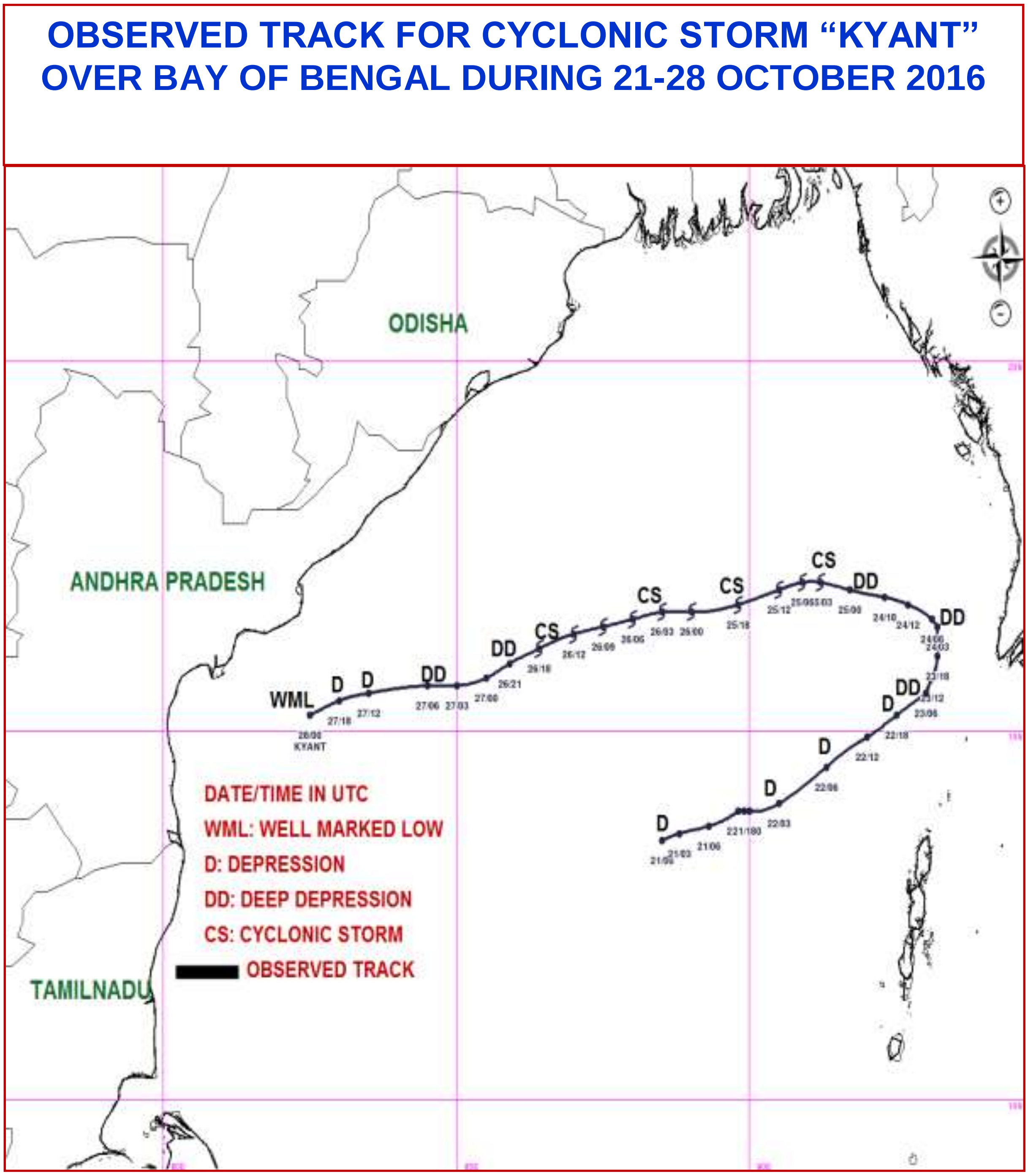


Fig.1: Observed track of CS Kyant during 21-28 October, 2016

The total perceptible water imageries (TPW) during 21st to 27th October 2016 are presented in Fig.2. It indicates that due to cross equatorial, flow warm and moist air continued to converge around the system centre till 25th. On 26th, it gradually decreased and it further decreased on 27th as the system moved west-southwestwards and came under the influence of the dry air incursion from the northwest in association with the anticyclone to the northwest of the system centre leading to weakening of the system over westcentral BoB.

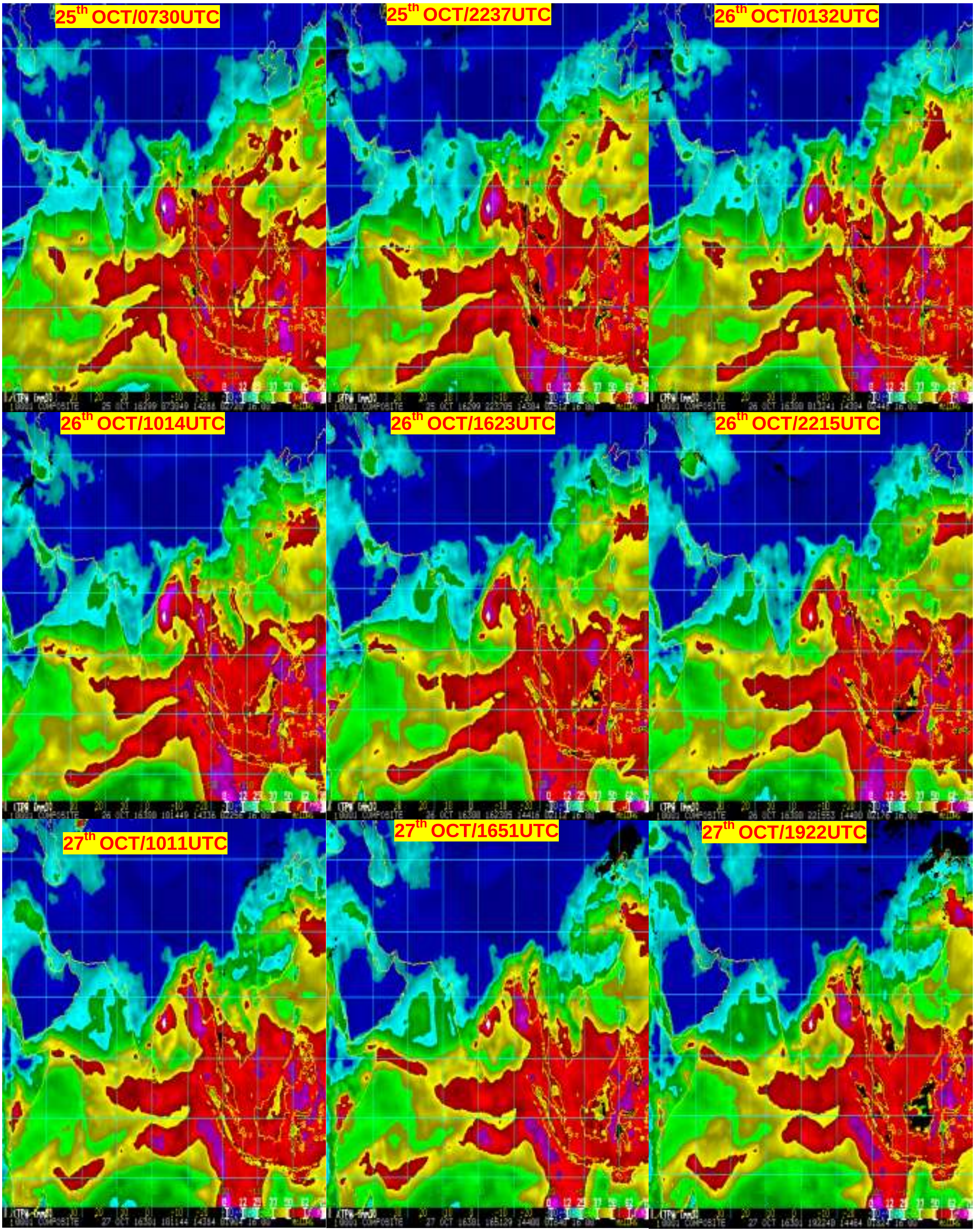


Fig.2 Total precipitable water (TPW) imageries during 25th to 27th October 2016

12 hourly translational speed and direction of movement are presented in Fig.3. The system followed a rare track. It experienced two recurvatures during its life period. Initially it moved northeastwards to east-northeastwards till 1800 UTC of 23rd. It experienced northwards recurvature from the evening of 23rd before the intensification of system into CS. From 0600 UTC of 24th, it moved west-northwestwards. It again experienced recurvature in track from 0600 UTC of 25th and moved southwestwards during the weakening phase.

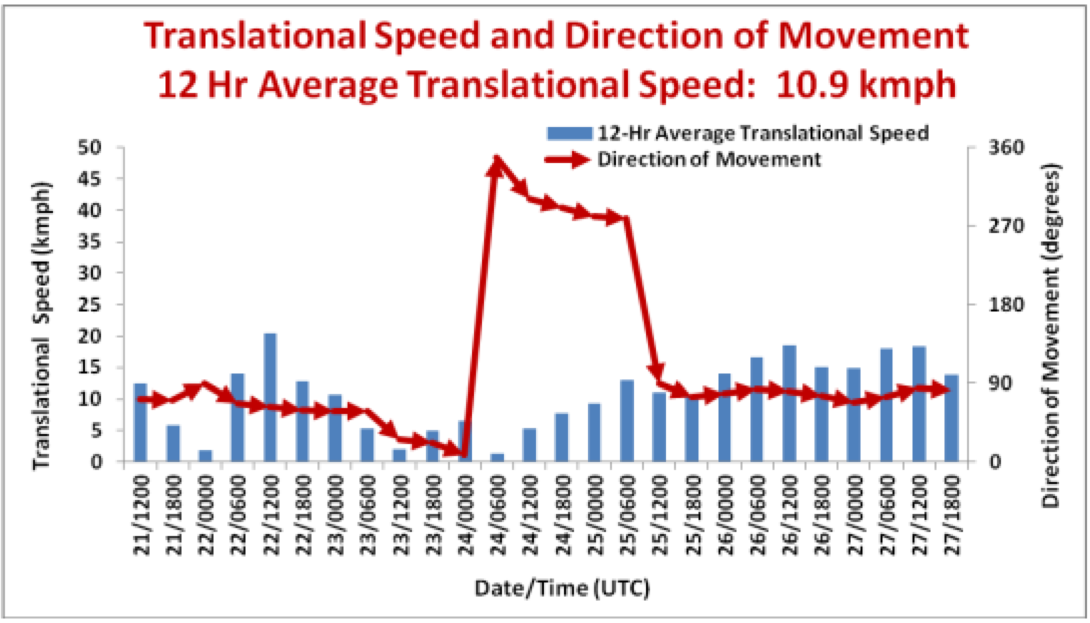


Fig.3 Twelve hourly average translational speed (kmph) and direction of movement in association with CS Kyant

The Wind shear and wind speed in the middle and deep layer around the system during 24th to 30th October, 2016 are presented in Fig. 4.

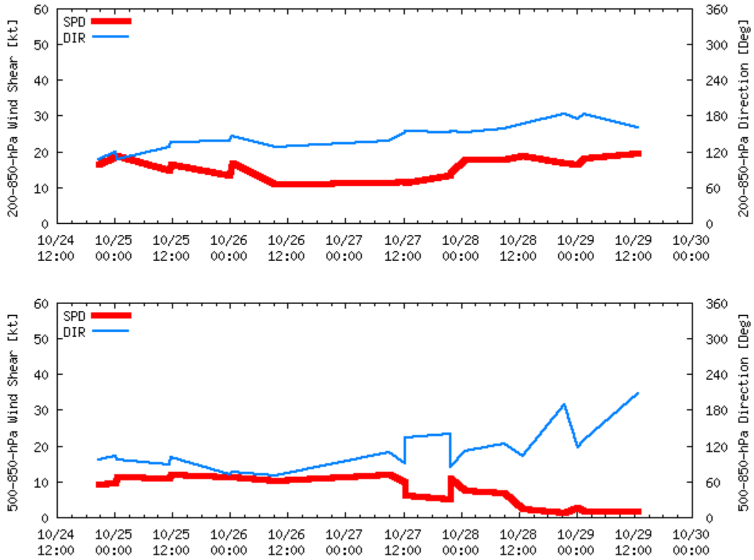


Fig.4: Wind shear and wind speed in the middle and deep layer around the system during 24th to 30th October, 2016.

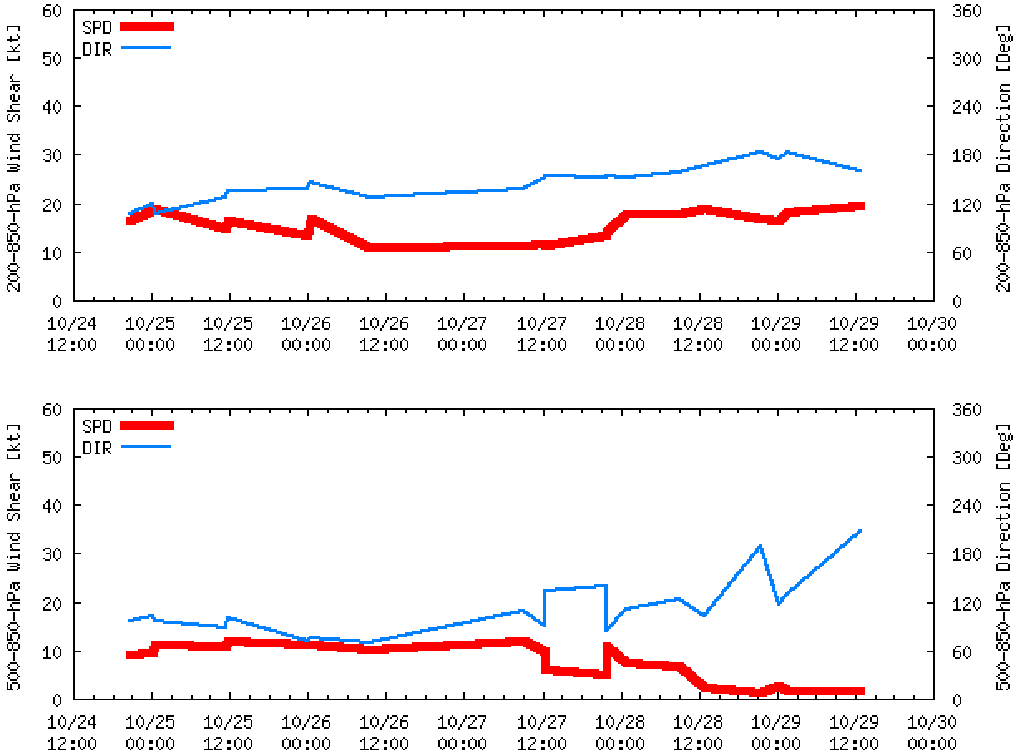


Fig.4 (contd): Wind shear and wind speed in the middle and deep layer around the system during 24th to 30th October, 2016.

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 Fig.5. The lowest estimated central pressure was 996 hPa. The estimated maximum sustained surface wind speed (MSW) was 40 knots during 0000 UTC of 26th to 1500 UTC of 26th October. The system weakened over the sea due to entrainment of dry and cold air from northwest India in association with anticyclonic circulation lying to the northwest of the system centre in middle and upper troposphere. The weakening occurred inspite of favourable (low-moderate) vertical wind shear over the storm region.

There was no rapid intensification of the system as it intensified from depression to cyclonic storm in about 96 hours. However, it weakened rapidly from CS to well marked low pressure area in 30 hours.

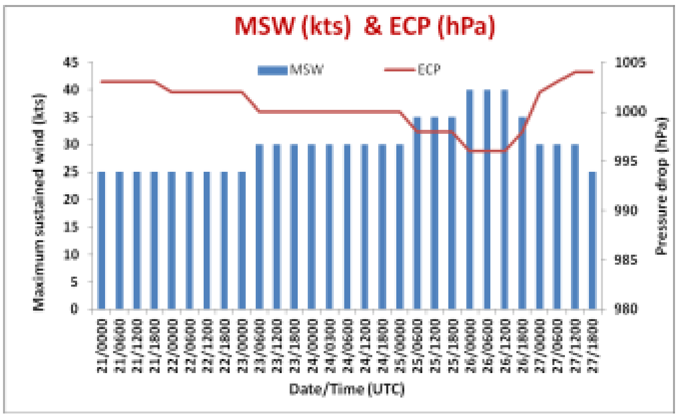


Fig.5 Lowest estimated central pressure and the maximum sustained wind speed

3.4. Structure

Sectorwise wind distribution imageries from CIRA around the system centre are presented in Fig.6a-6b. It depicts that maximum winds were observed in northwest and northeast sector.

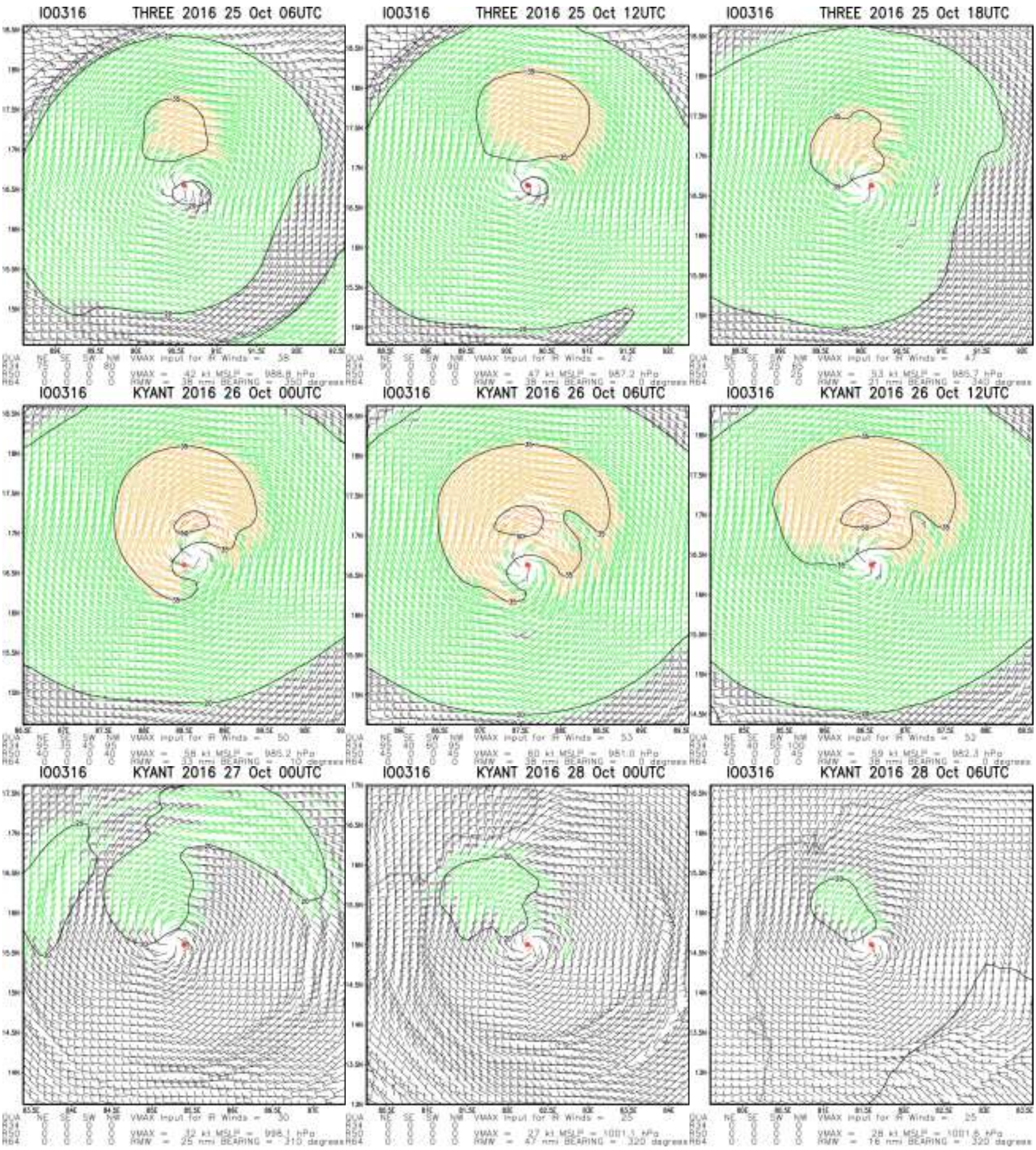


Fig. 6a: Typical imageries of wind distribution around cyclone Kyant from CIRA

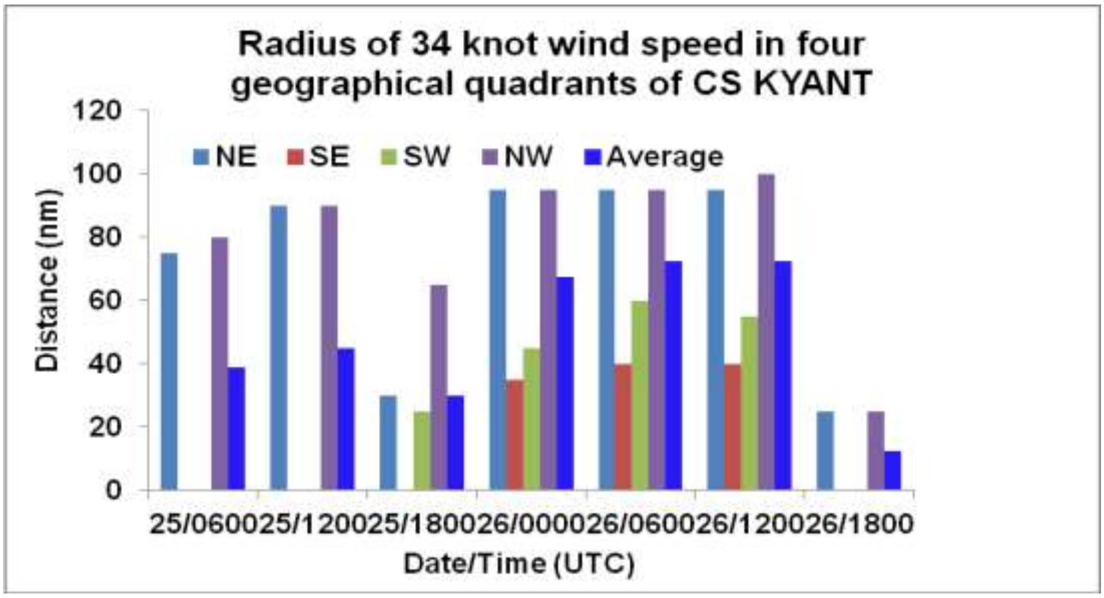


Fig.6b Sectorwise wind distribution of CS, Kyant.

Sectorwise wind distribution of CS Kyant (Fig. 6b) indicates that the size increased gradually becoming maximum on 26th forenoon. The system maintained its size till the evening of 26th and then it decreased sharply from 26th midnight.

4. Climatological aspects

Considering the area of genesis (+/- 2^0 around the genesis point), the cliamtological tracks of the TCs during 1891-2015 are presented in Fig.7. It indicates that climatologically, about one third of the cyclonic disturbances developing over this region moved westwards/northwestwards and crossed Andhra Pradesh/ north Tamil Nadu coast whereas two third moved towards Bangladesh/Myanmar coasts.

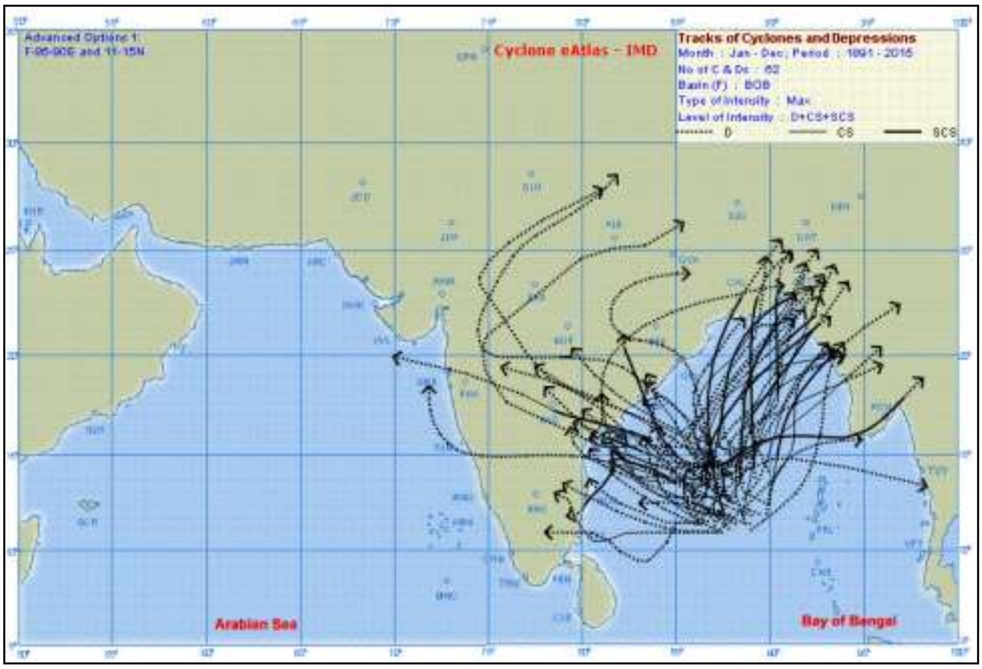


Fig7. Climatological tracks of TCs forming within +/- 2^0 around the genesis point during 1891-2015.

5. Features observed through Satellite

Satellite monitoring of the system was mainly done by using half hourly Kalpana-1 and INSAT-3D imageries. Satellite imageries of international geostationary satellites Meteosat-7 & MTSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered for monitoring the system. Typical satellite imageries are presented in Fig.8.

5.1 INSAT-3D features

At 0000 UTC of 21st October, the intensity of the system was T 1.5. Associated broken low and medium clouds embedded with intense to very intense convection lie over central and adjoining south BoB around the system centre. The lowest cloud top temperature (CTT) was about -75^{0}C. At 0300 UTC of 22nd, the convection showed shear pattern. The convective clouds were sheared towards southwest. Intensity of the system was T 1.5. Associated broken low and medium clouds embedded with intense to very intense convection lie over BoB between 12.0^{0}N to 17.0^{0}N and longitude 84.5^{0}E to 90.5^{0}E. The lowest CTT was about -80^0 C. At 0300 UTC of 23rd, the convective clouds were sheared towards west. The intensity of the system was T 2.0. Associated broken low and medium clouds embedded with intense to very intense convection lie over BoB between 12.0^{0}N to 17.0^{0}N and longitude 83.5^{0}E to 92.0^{0}E. The lowest CTT was about -85^0 C. At 0300 UTC of 24th, the convective clouds were sheared towards west. Intensity of the system was T 2.0. Associated broken low/medium clouds with embedded intense to very intense convectioin lie over BoB between latitude 14.0^{0}N to 20.5^{0}N and longitude 86.5^{0}E to 93.0^{0}E and the lowest CTT was about -80^0 C. At 0300 UTC of 25th, the convective clouds were organised in CDO pattern. Intensity of the system was T 2.5. Broken low and medium clouds with embedded intense to very intense convectioin lie over BoB between latitude 13.0^{0}N to 19.8^{0}N and longitude 86.5^{0}E to 94.0^{0}E. The lowest CTT was about -90^0 C. At 0300 UTC of 26th, the convective clouds were organised in CDO pattern. The intensity of the system was T 2.5. Broken low and medium clouds with embedded intense to very intense convectioin lie over BoB between latitude 14.0^{0}N to 20.0^{0}N and longitude 85.0^{0}E to 90.0^{0}E. The lowest cloud top temperature CTT was about -90^0 C. At 1800 UTC of 26th, the intensity of the system was T 2.5. Broken low and medium clouds with embedded moderate to intense convectioin lie over BoB between latitude 13.5^{0}N to 20.0^{0}N and longitude 82.0^{0}E to 88.0^{0}E. The lowest CTT was about -70^0 C. At 2100 UTC of 26th, the intensity of the system was T 2.0. Associated broken low and medium clouds with embedded moderate to intense convectioin lie over BoB between latitude 13.5^{0}N to 19.5^{0}N and west of longitude 87.0^{0}E. The lowest CTT was about -85^0 C. At 0000 UTC of 28th, the intensity of the system was T 1.0 the convection continued to show disorganization and also there was reduction in depth of convection. Scattered low and medium clouds with embedded moderate to intense convectioin lie over BoB between latitude 13.0^{0}N to 16.0^{0}N and longitude 81.0^0 E to longitude 83.5^{0}E. The lowest CTT was about -64^{0}C.

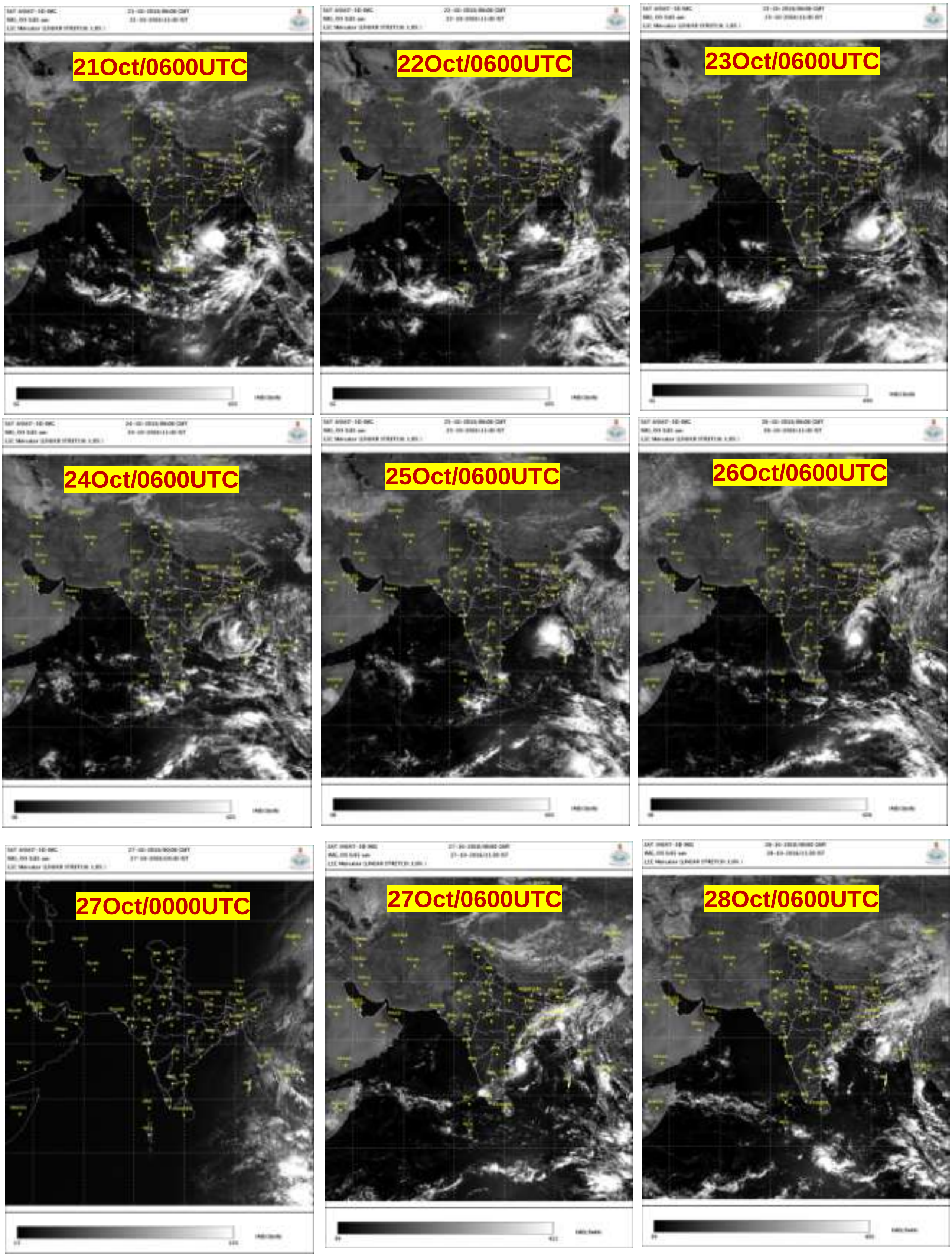


Fig.8a: INSAT-3D Visible imageries of CS Kyant based on 0600 UTC of 21-28 Oct. 2016

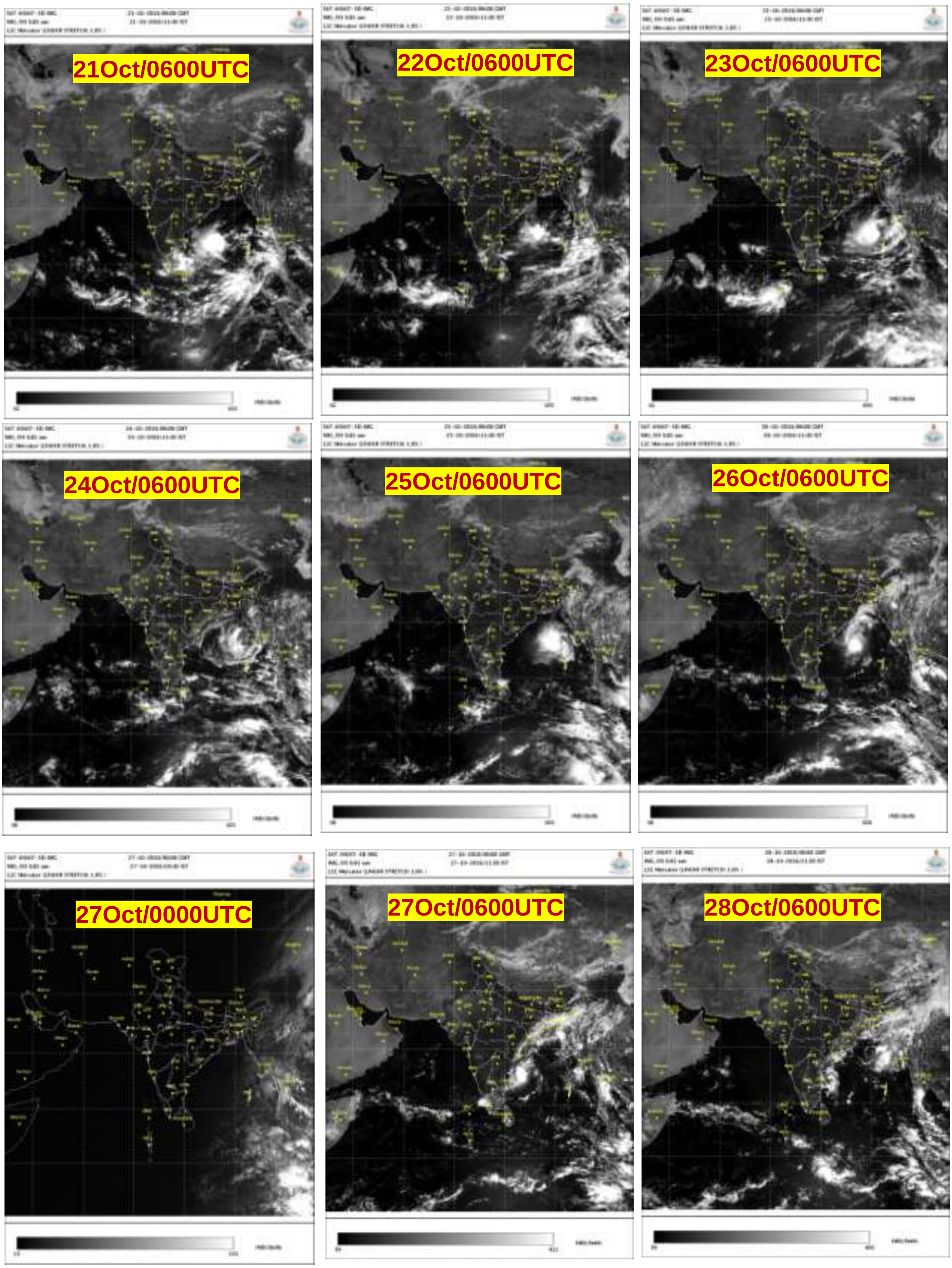


Fig.8b. INSAT-3D IR imageries of CS, Kyant based on 0600 UTC of 21-28 Oct. 2016

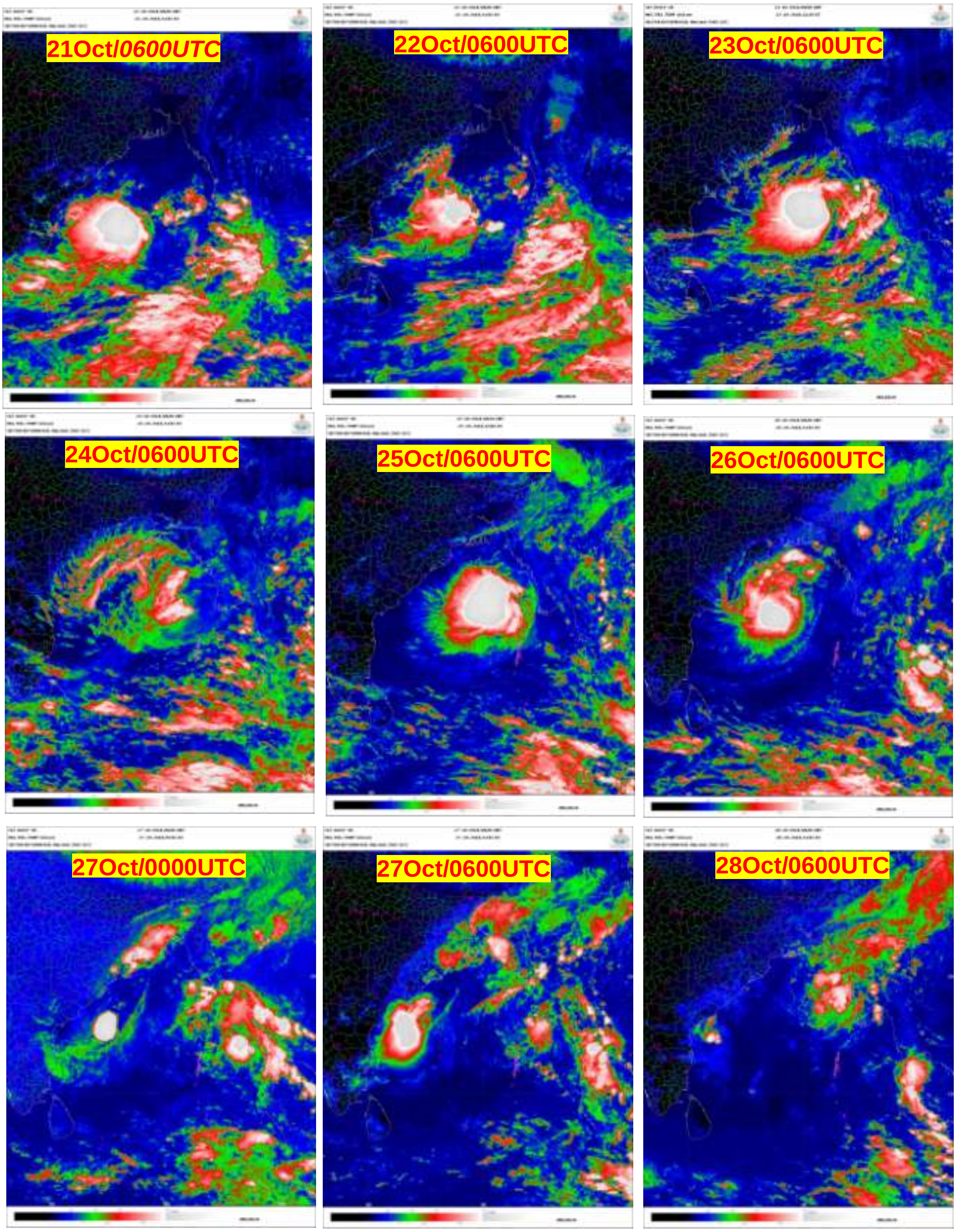


Fig.8c. Enhanced colored IR imageries of CS, Kyant based on 0600 UTC of 21-28 Oct. 2016

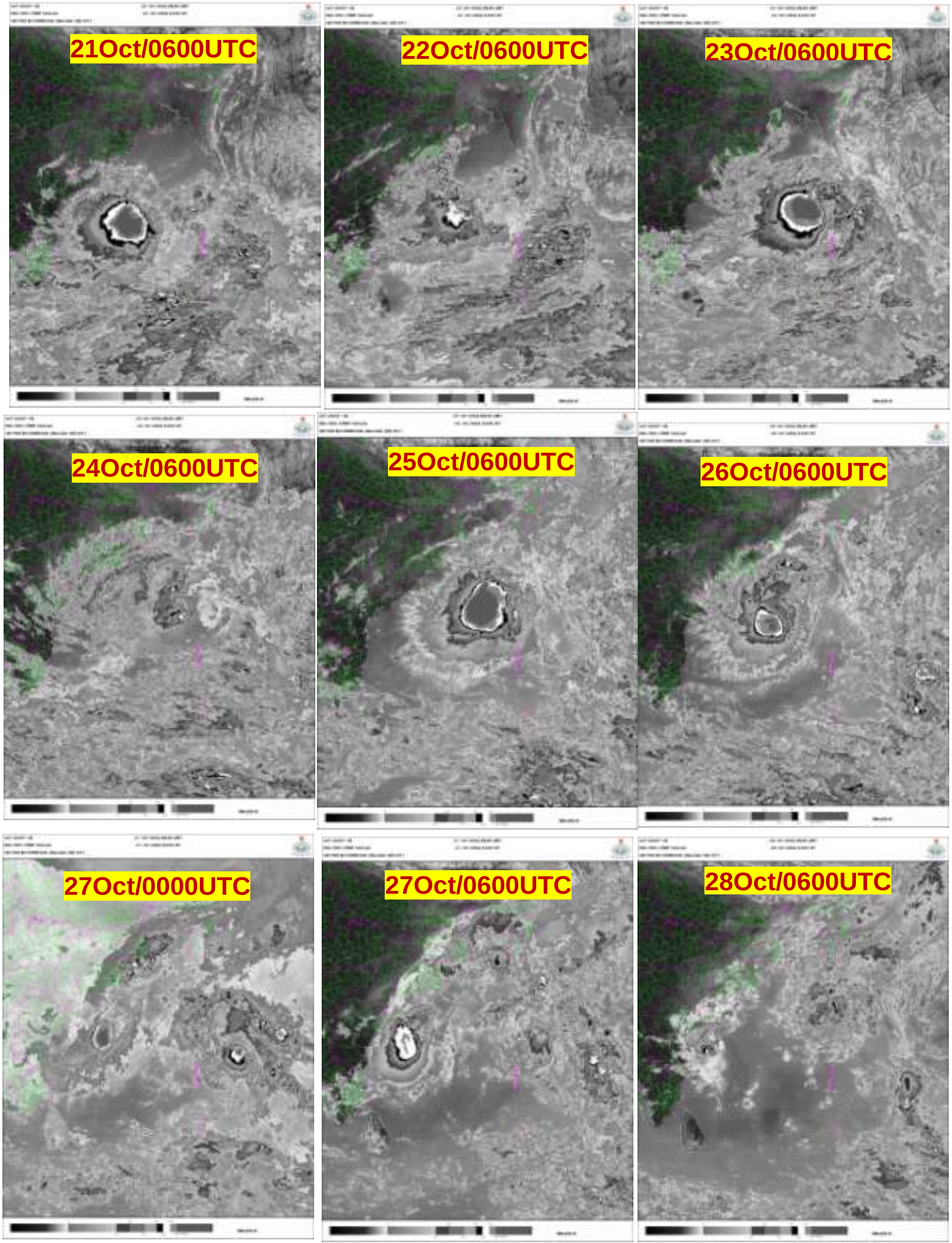


Fig.8d. Cloud top brightness temperature imageries of CS, Kyant based on 0600 UTC of 21-28 Oct. 2016

5.2 Microwave features

The microwave imageries of the CS Kyant covering its life period from 21st - 28th Oct 2016 are presented in Fig.8e. These imageries helped in understanding the internal structure of the system and better estimation of location of the system. It could indicate the region of intense convection and hence the rainfall. The microwave imageries indicate that the convection was concentrated in the southwest sector till morning of 22nd. Thereafter, it shifted to northwest sector with increase in spatial spread from afternoon of 22nd. It got more organised from 23rd October with convection concentrating in southwest and northwest sector. Similar conditions continued till 25th morning. Convection got organised with appearance of curved convective band pattern from 22nd. It gradually became more organized and showed central dense overcast (CDO) pattern on 25th evening. Thereafter, from 26th onwards, the convection started disorganising and the system weakened into a well marked low pressure area in the early morning of 28th October.

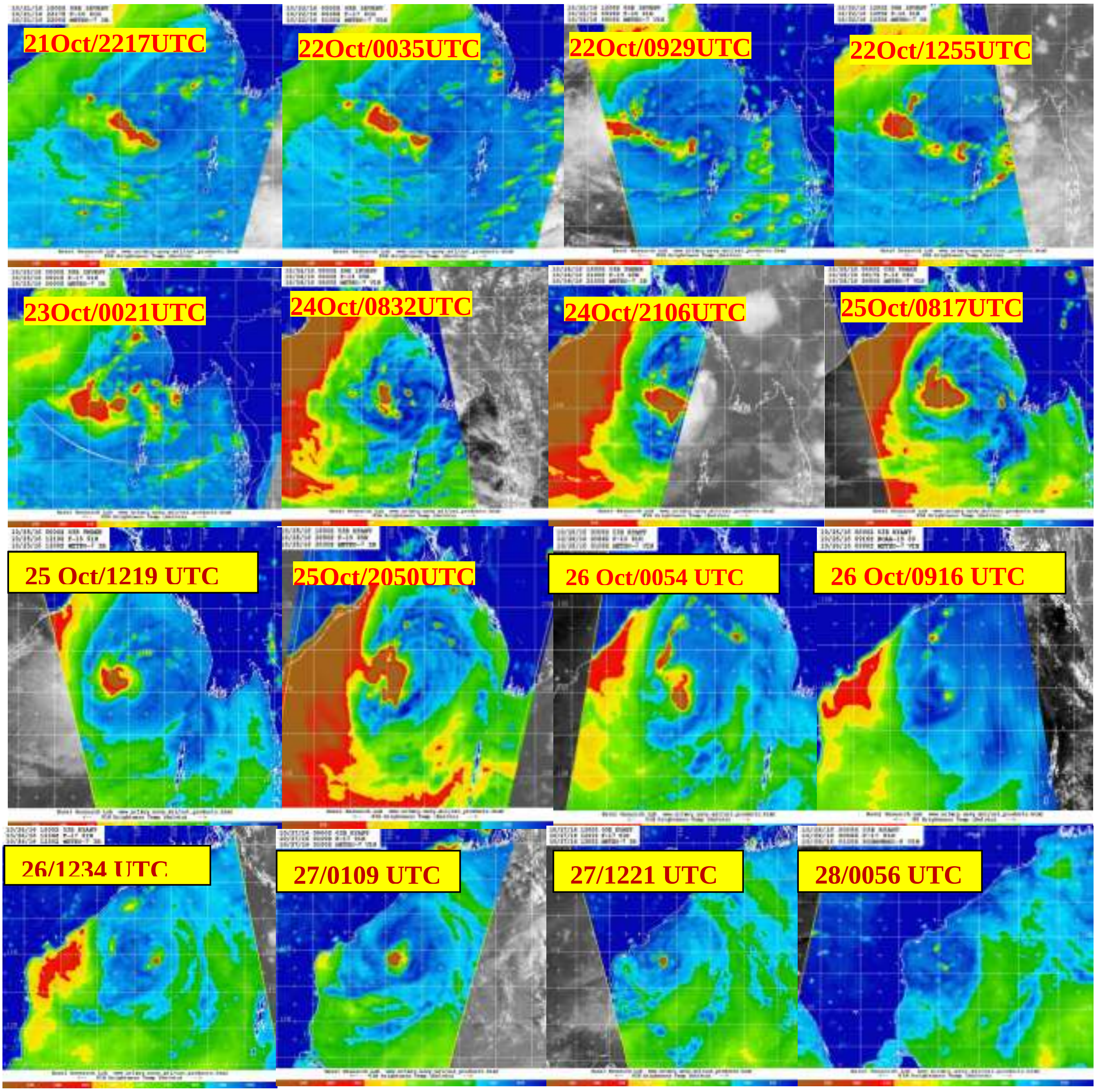


Fig.8e. Microwave imageries of CS, Kyant based during 21st to 28th October 2016

6. Dynamical features

IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels are presented in Fig.9. At 0000 UTC of 21st October, the system was centered near 13.5^{0}N/88.5^{0}E. IMD-GFS analysis field of MSLP indicated development of depression over eastcentral BoB near 14.5^{0}N/89.5^{0}E. Winds at 850 hPa levels showed cross equatorial inflow of warm moist air from southeast sector into the system. Winds at 200 hPa levels indicated ridge running along 21.0^{0}N in association with anticyclonic circulation lying to the northeast of system centre. However, the system was steered east-northeastwards under the influence of lower to middle level winds.

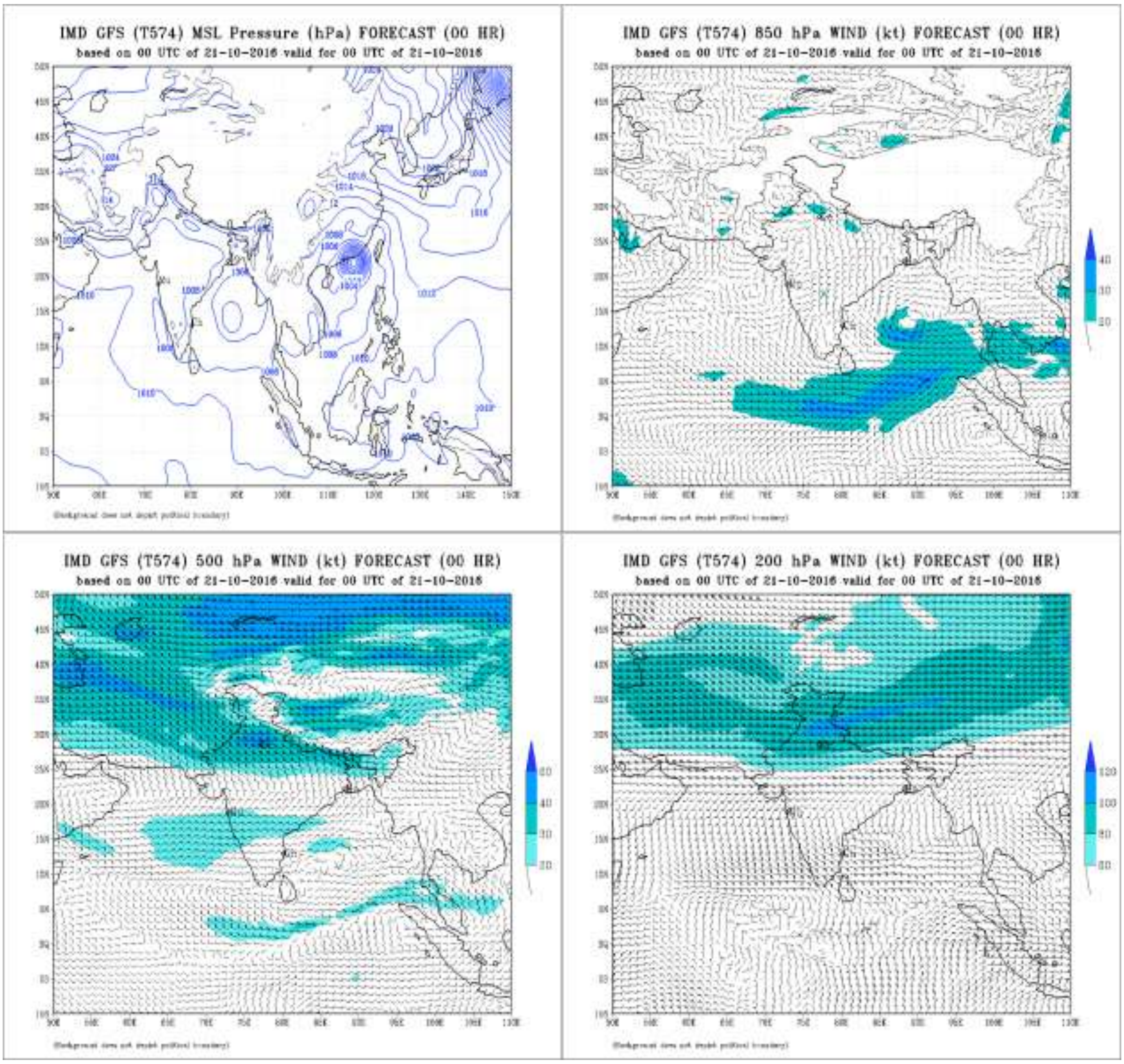


Fig. 9 (a): IMD GFS MSLP and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 21st Oct 2016

At 0000 UTC of 22nd October, the system was centered near 13.9^{0}N/90.0^{0}E. IMD-GFS analysis field of MSLP indicated depression over eastcentral BoB near 15.0^{0}N/90.0^{0}E. Winds at 850 hPa levels showed cross equatorial inflow of warm moist air from southeast sector into the system. Winds at 200 hPa levels indicated ridge running along 19.0^{0}N in association with anticyclonic circulation lying to the northeast of system centre. Middle and lower level winds showed steering of system northeastwards towards Myanmar coast.

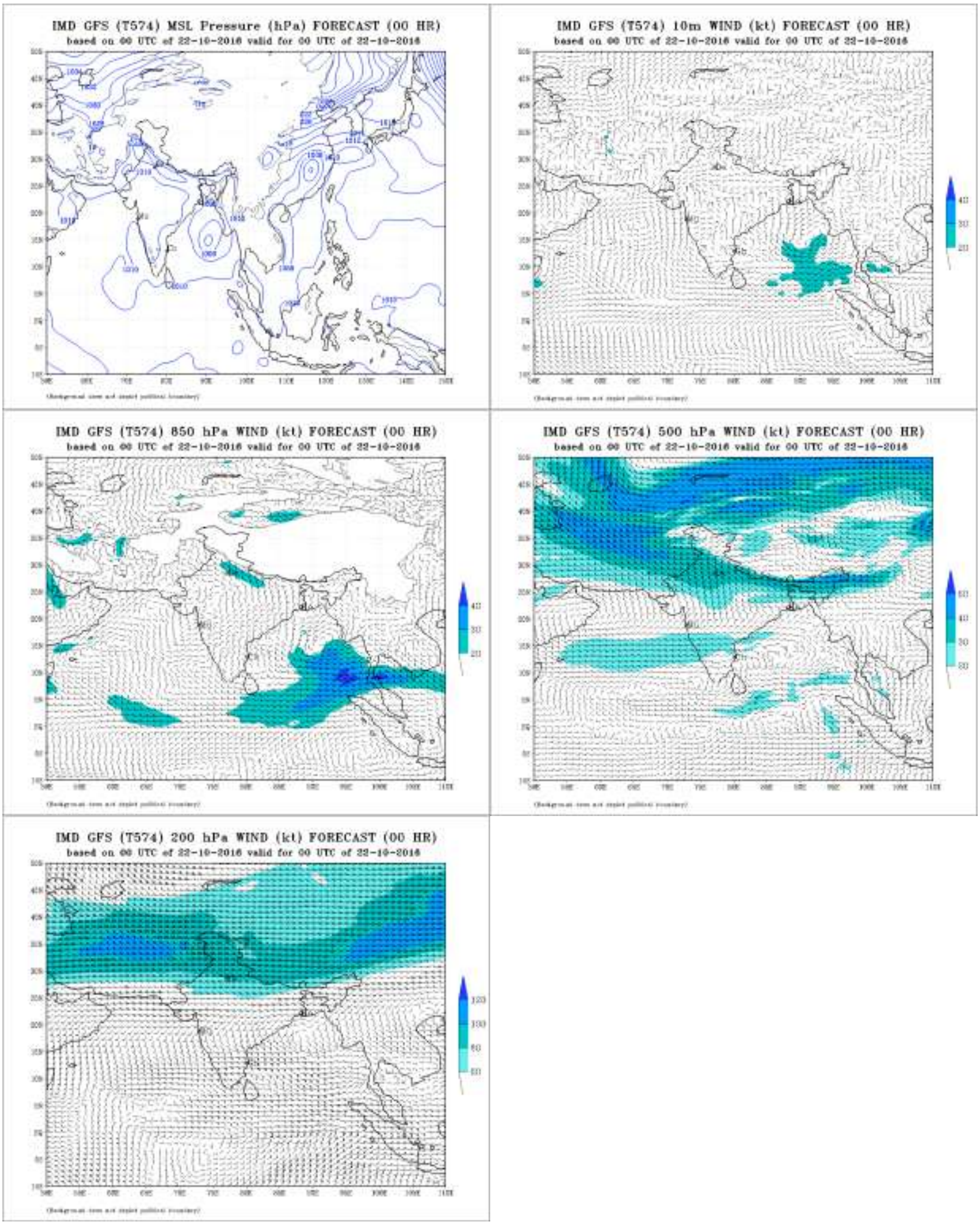


Fig. 9 (b): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based

At 0000 UTC of 23rd October, the system was centered near 15.5^0N/93.0^0E. IMD-GFS analysis field of MSLP indicated intensification of system into a deep depression over eastcentral BoB near 15.5^0N/93.0^0E. Winds at 850 hPa levels showed cross equatorial inflow of warm moist air from southeast sector into the system. Circulation was extending upto 500 hPa levels. Winds at 200 hPa levels indicated ridge running along 19.0^0N in association with anticyclonic circulation lying over Myanmar coast. Middle and lower level winds showed steering of system northeastwards and then northwards.

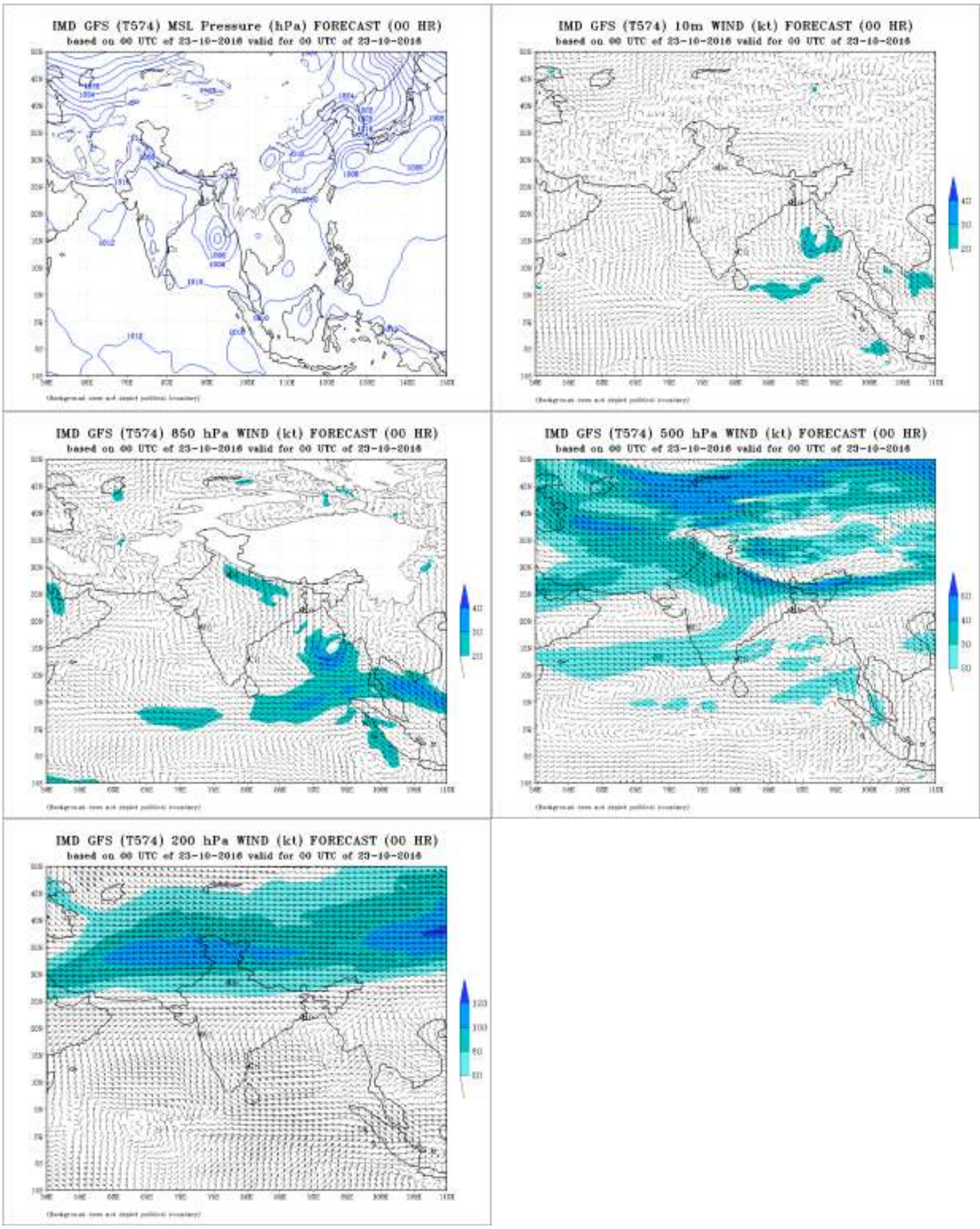


Fig. 9 (c): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 23rd Oct 2016

At 0000 UTC of 24th October, the system as DD was centered near 16.4^{0}N/93.2^{0}E. IMD-GFS MSLP analysis field showed signs of slight weakening of the system against the intensification into DD and it was located near 16.0^{0}N/92.0^{0}E. Wind field at 850 and 500 hPa levels showed similar features. As the system intensified, the steering level changed from lower-middle levels to middle-upper levels. Thus the system commenced to be steered by middle and upper level winds and hence started moving northwestwards from 24th.

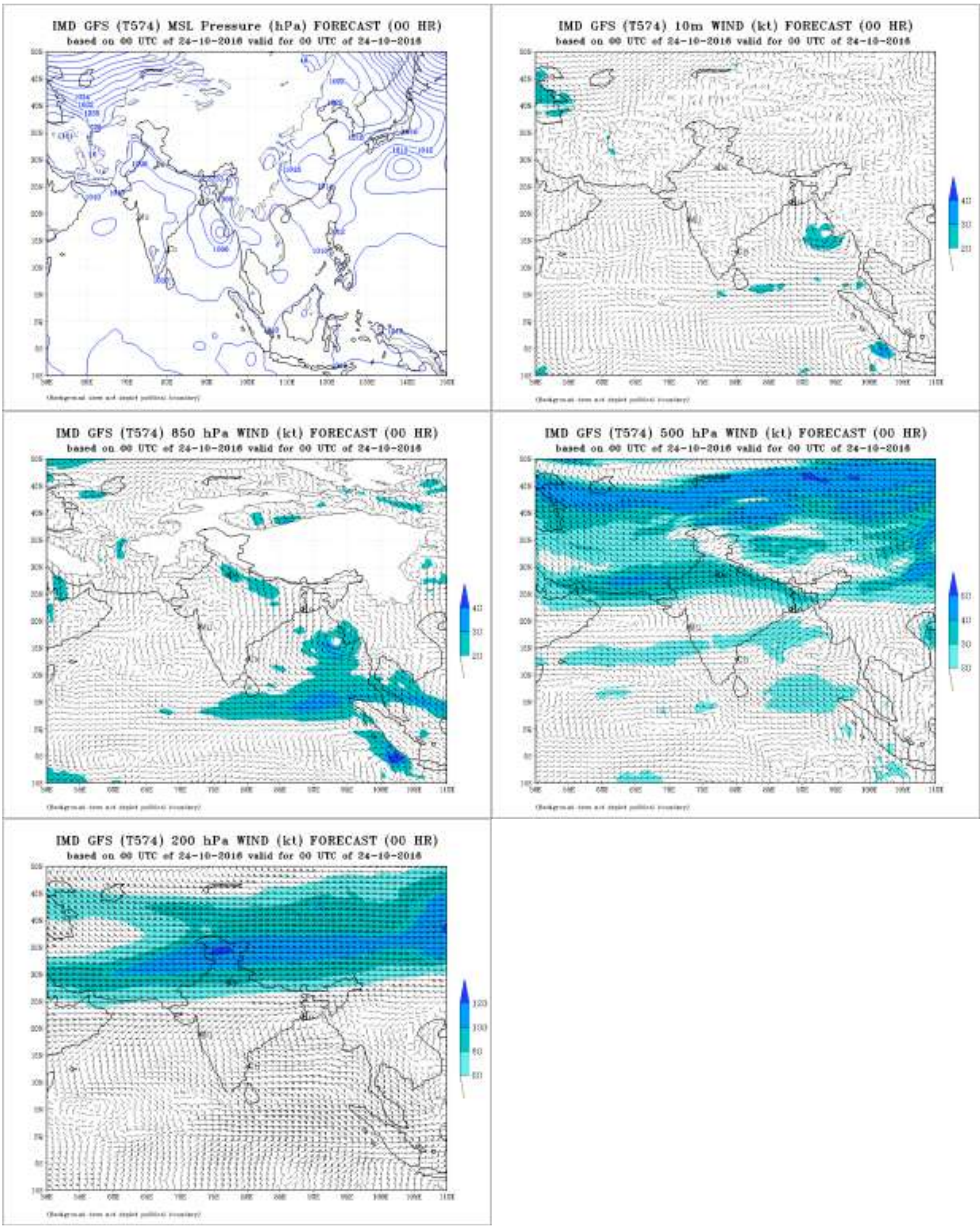


Fig.9 (d): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 24th Oct 2016

At 0000 UTC of 25th October, the system further intensified into CS and was centered near 16.9^{0}N/91.7^{0}E. On the other hand, IMD-GFS MSLP analysis field showed no further intensification of the system and it was located near 16.0^{0}N/91.0^{0}E. Wind field at 850 and 500 hPa levels showed similar features. Thus the system continued to be steered by middle and upper level winds and hence moved west-northwestwards on 25th.

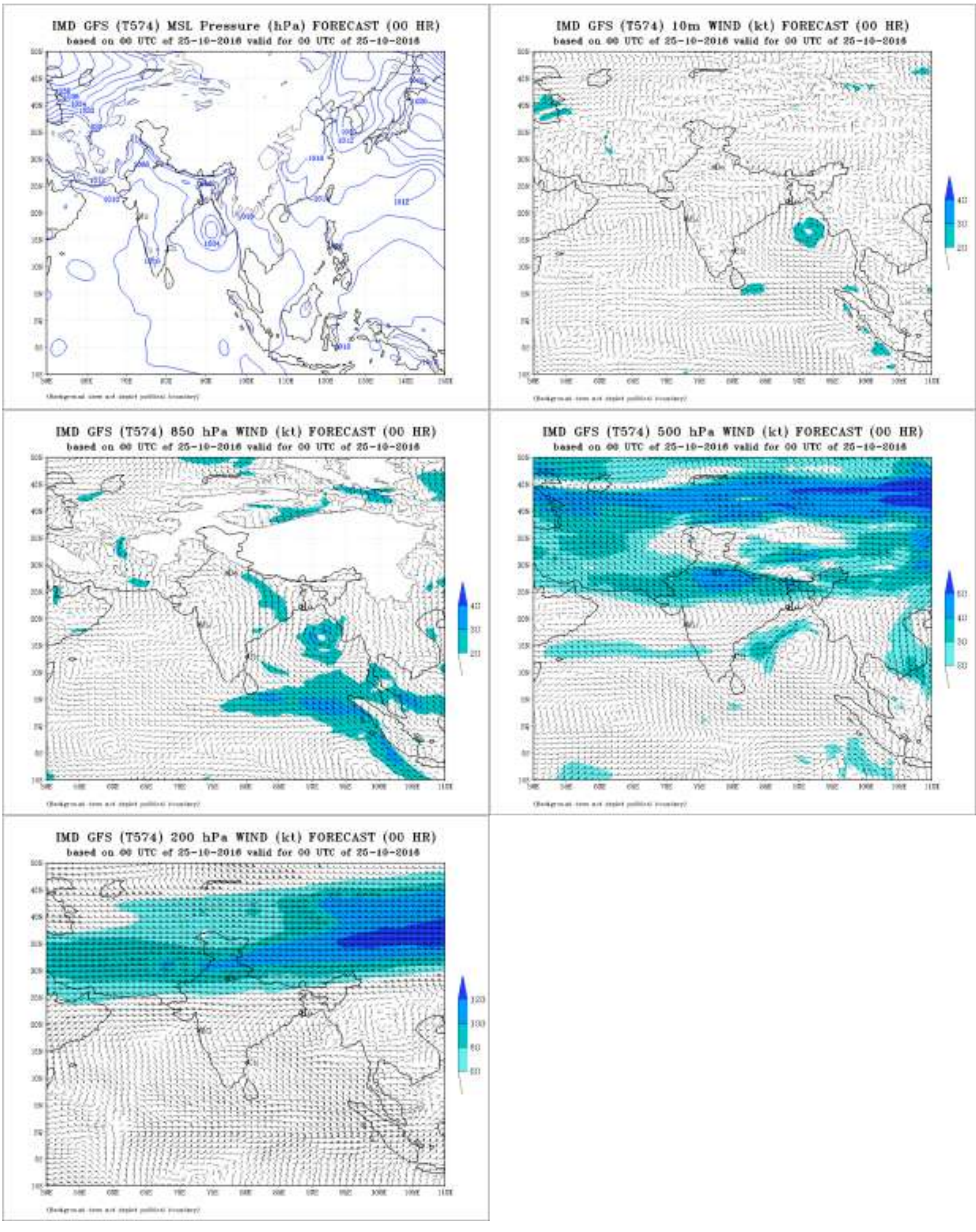


Fig. 9 (e): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 25th Oct 2016

At 0000 UTC of 26th October, the system as cyclonic storm was centered near 16.6°N/89.0°E. IMD-GFS MSLP analysis field showed intensification of the system into cyclonic storm near 17.0°N/89.0°E showing west-northwestwards movement. Wind field at 850, 500 and 200 hPa levels showed similar features. The model could not capture west-southwestward movement. Actually anticyclonic circulation at middle levels was lying to the northwest of system centre which steered the system west-southwestwards.

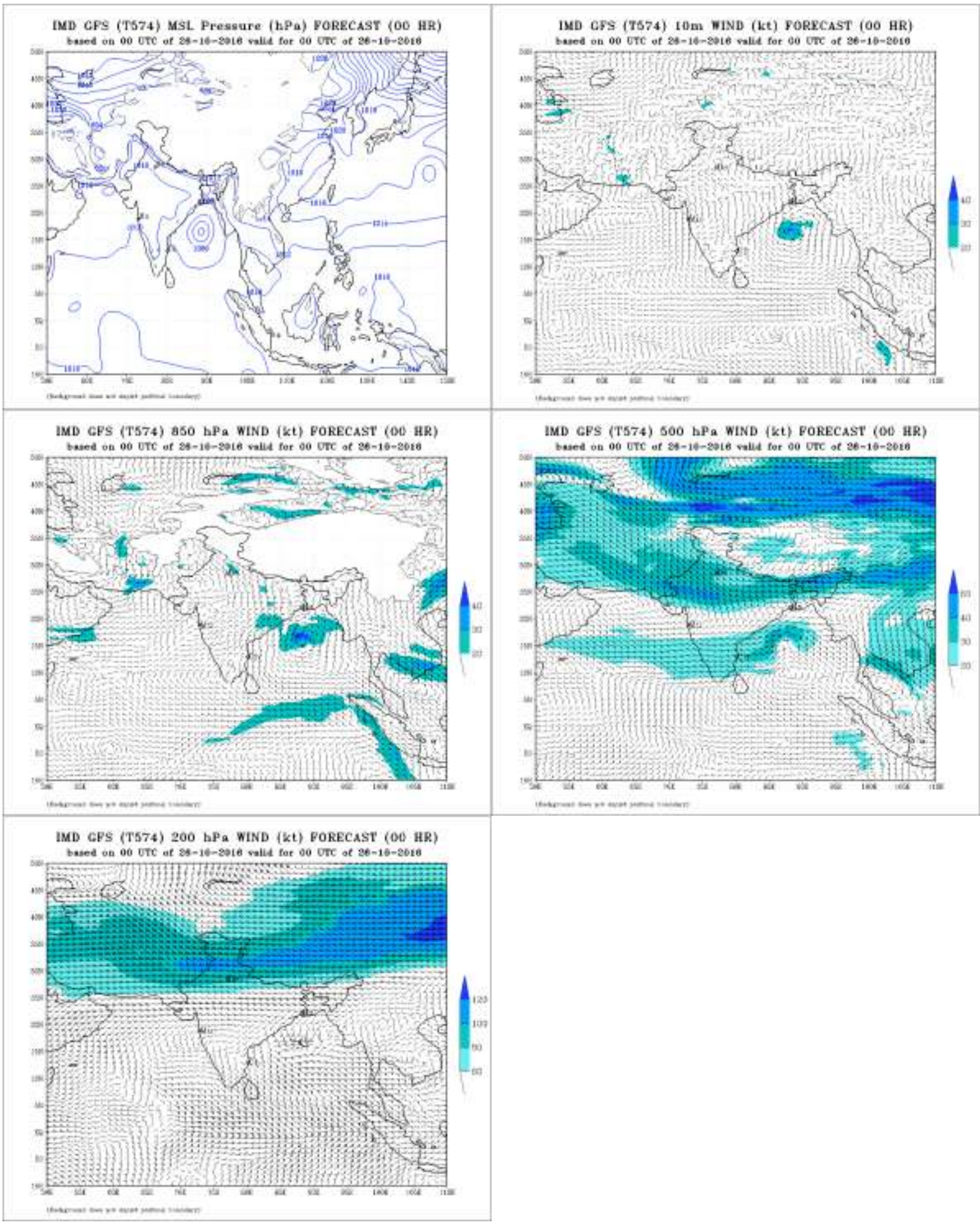


Fig. 9 (f): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 26th Oct 2016

At 0000 UTC of 27th October, the system which weakened into a DD at 2100 UTC of 26th October 2017 was centered near 15.7^{0}N/85.5^{0}E. IMD-GFS MSLP analysis field showed weakening of the system into a low pressure area near 15.5^{0}N/85.0^{0}E showing west-southwestwards movement. The wind fields showed a feeble circulation extending upto 850 hPa only.

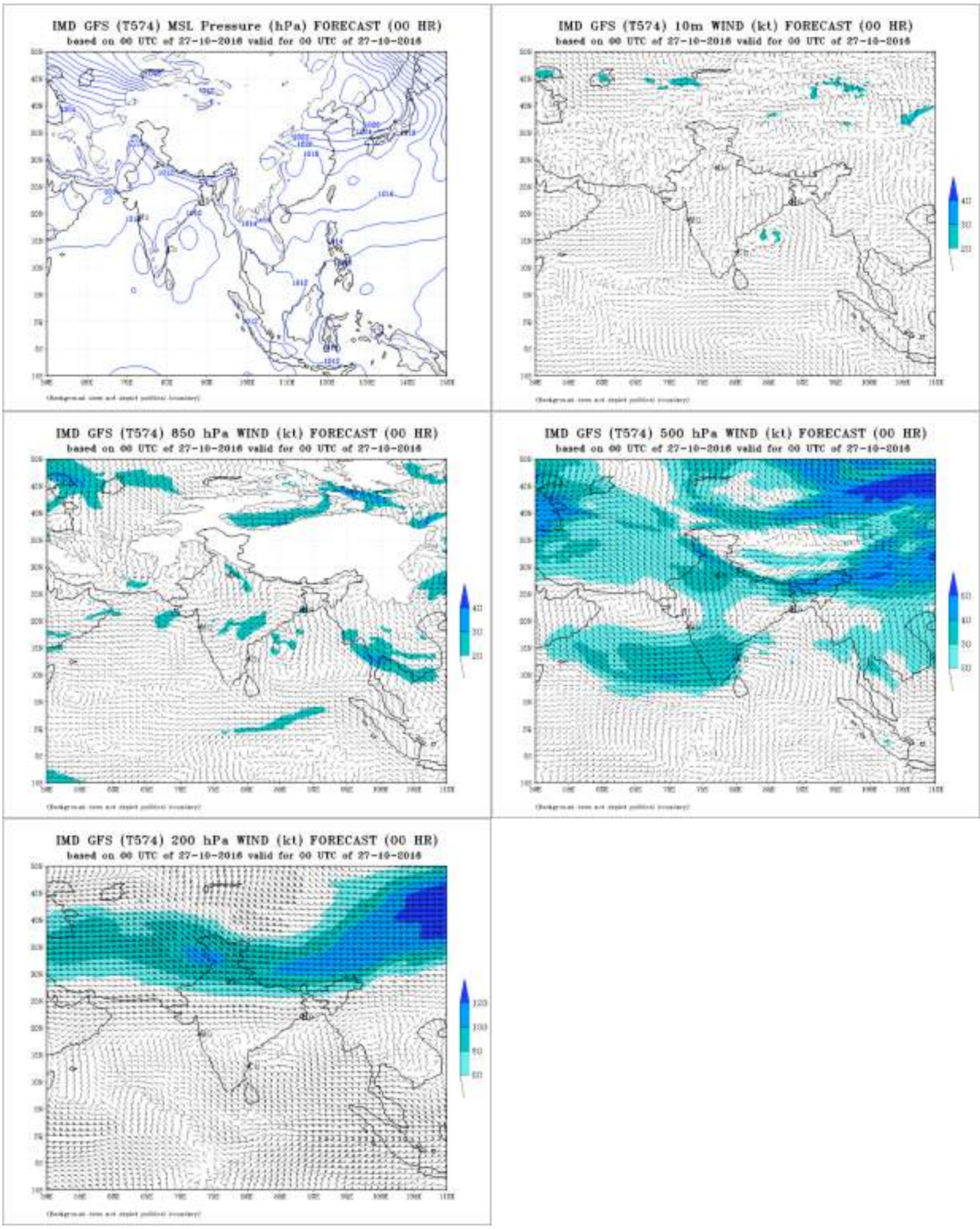


Fig. 9 (g): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 27th Oct 2016

At 0000 UTC of 28th October, the system lay as a well marked low over Westcentral Bay. IMD-GFS MSLP analysis field showed weakening of the system into a low pressure area near 12.5^0N/82.5^0E showing west-southwestwards movement. The wind fields showed a feeble circulation extending upto 850 hPa only and weakening of the system over southwest and adjoining westcentral BoB off north Tamilnadu and south Andhra Pradesh coasts.

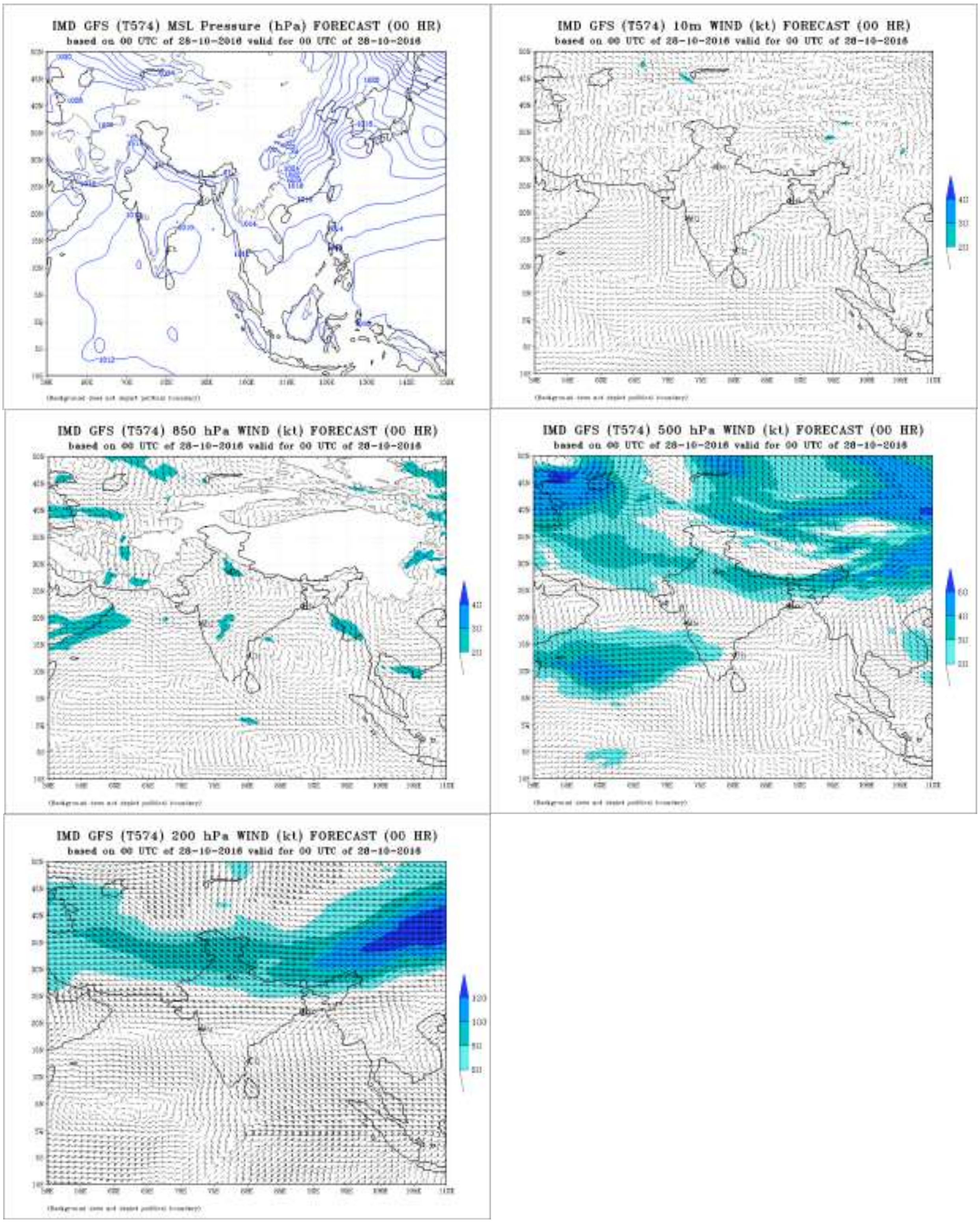


Fig. 9 (h): IMD GFS MSLP, 10 m wind and winds at 850, 500 and 200 hPa levels based on 0000 UTC of 28th Oct 2016

8. Realized Weather:

8.1 Rainfall:

Based on IMD-NCMRWF GPM merged gauge rainfall data, rainfall associated with the system is depicted in Fig 10. The system caused heavy to very rainfall over eastcentral BoB during. 21st-26th October. On 27th October it caused heavy rainfall over westcentral and adjoining eastcentral BoB. On 28th October, the system caused heavy rainfall over westcentral BoB off south Andhra Pradesh coast.

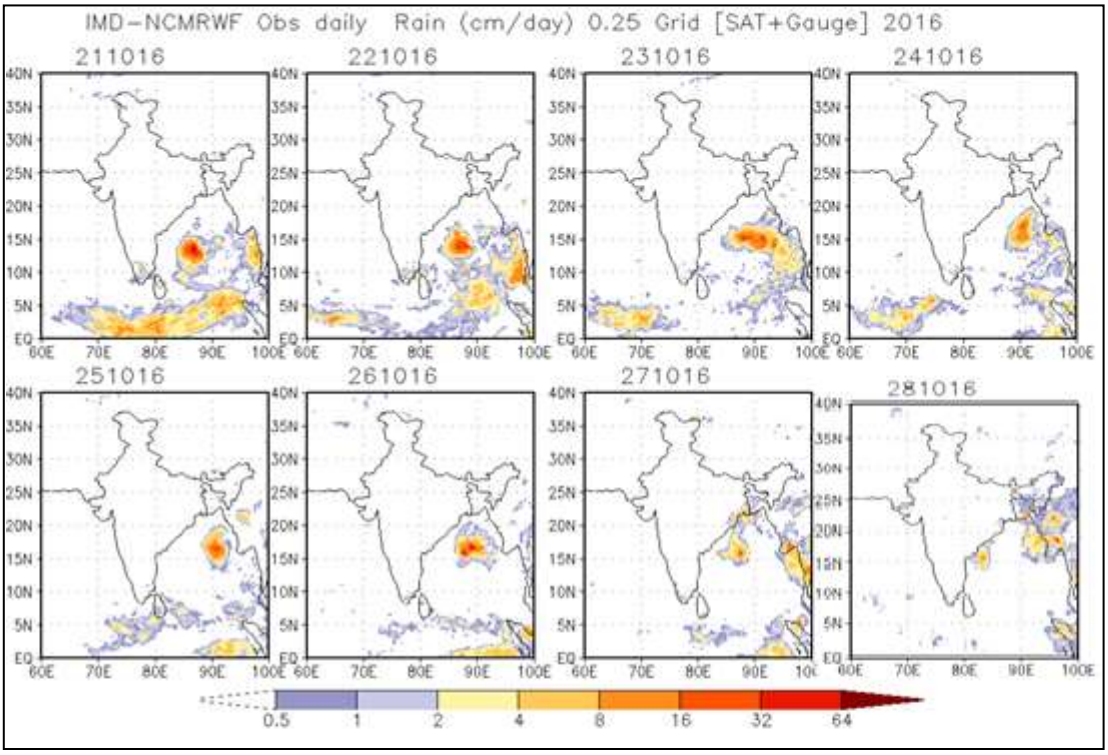


Fig. 10: IMD-NCMRWF GPM merged gauge rainfall during 21st-28th October.

9. Damage:

As cyclone Kyant weakened over sea, no damage was reported due to this system.

10. Performance of operational NWP models

IMD operationally runs a regional models, WRF for short-range prediction and one Global model T574L64 for medium range prediction (7 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^{o} S to 45^{o} N long 40^{o} E to 120^{o} E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 23 km. The boundary conditions are updated at every six hours interval.

Global models are also run at NCMRWF. These include GFS and unified model adapted from UK Meteorological Office. Apart from the observations that are used in the earlier system, the new observations assimilated at NCMRWF include (i) Precipitation rates from SSM/I and TRMM (ii) GPSRO occultation (iii) AIRS and AMSRE radiances (iv) MODIS winds. Additionally ASCAT ocean surface winds and INSAT-3D AMVs are also assimilated. 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. It has semi-implicit time integration with 3D semi-Lagrangian advection, terrain following height coordinates and high order advection. It features mass-flux for shallow convection with convective momentum transport, non-local mixing and entrainment for boundary layer. NCMRWF Ensemble Prediction System (NEPS) is a global medium range probabilistic forecasting system adapted from UK MET Office. The configuration consists of 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 midlatitudes. 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 (Bishop et al., 2001).

An important component common to both the deterministic and ensemble model is that they do not use any TC relocation in the analysis.

The Met Office bi-variate approach to tracking TCs is used in the real-time to track the location of the CS ‘Kyant’. This method is in contrast to the earlier operational National Centers for Environmental Prediction (NCEP) who use any or all of MSLP, 850 hPa and 700 hPa relative vorticity (RV) and geopotential height to track tropical cyclones (Marchok, 2002). The bi-variate method identifies TCs by examination of the 850RV field, but then fixes the TC centre to the nearest local MSLP minimum (Hamming,2015). Key advantage of the method is that it gives a strong signal of the approximate centre of the TC even for weak systems.

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), JMA (Japan Meteorological Agency). Hurricane WRF (HWRF) model and Ensemble prediction system (EPS) has been implemented at the NWP Division of the IMD HQ for operational forecasting of cyclones.

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

10.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for Kyant

Grid point analysis and forecasts of GPP could indicate the cyclogenesis zone over eastcentral BoB 120 hrs before its formation. Since all low pressure systems do not intensify into cyclones, it is important to identify 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. Conditions for: (i) Developed system: Threshold value of average GPP ≥ 30.0 and (ii) Non-developed system: Threshold value of GPP < 30.0. Figure 11 (a-e) show the predicted zone of cyclogenesis. From 19th onwards GPP indicated favourable conditions for cyclogenesis over eastcentral BoB.

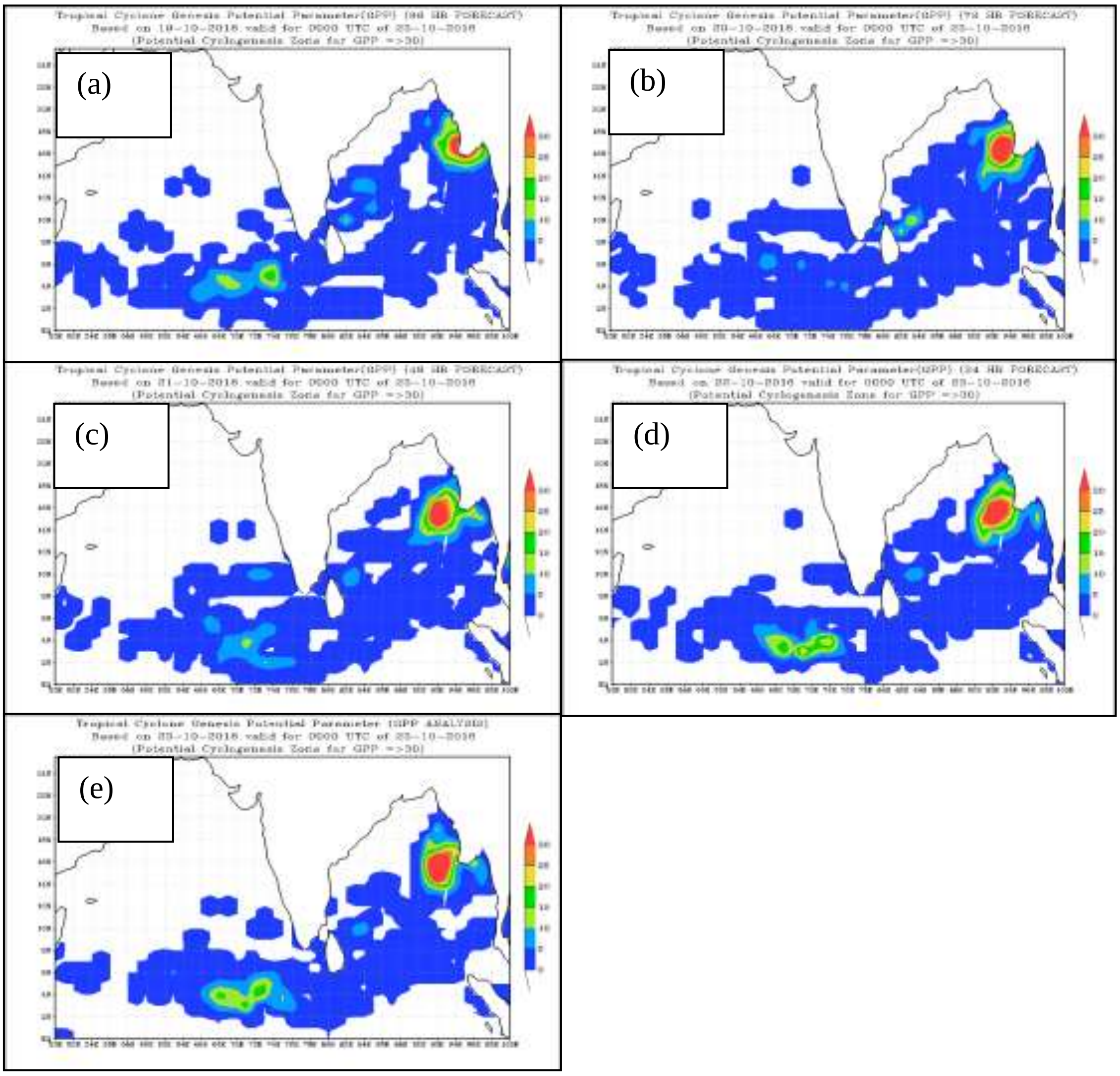


Fig. 11(a-e): Predicted zone of cyclogenesis.

Considering the Area average analysis of GPP, the condition for: (i) Developed system is GPP ≥ 8.0 and for (ii) Non-developed system is GPP < 8.0. The analysis and forecasts of GPP (Fig.12 (i-iv)) show that GPP indicated its potential to intensify into a cyclone at early stages of development (T.No. 1.0, 1.5, 2.0). However, area average analysis of GPP over estimated the cyclogenesis. It was showing GPP>8.0 from 20th onwards. Analysis based on 0000 UTC of 22nd showed favourable potential for cyclogenesis upto 1200 UTC of 25th and weakening thereafter. Analysis based on 0000 UTC of 23rd showed favourable potential for cyclogenesis upto 0000 UTC of 25th and weakening trend thereafter.

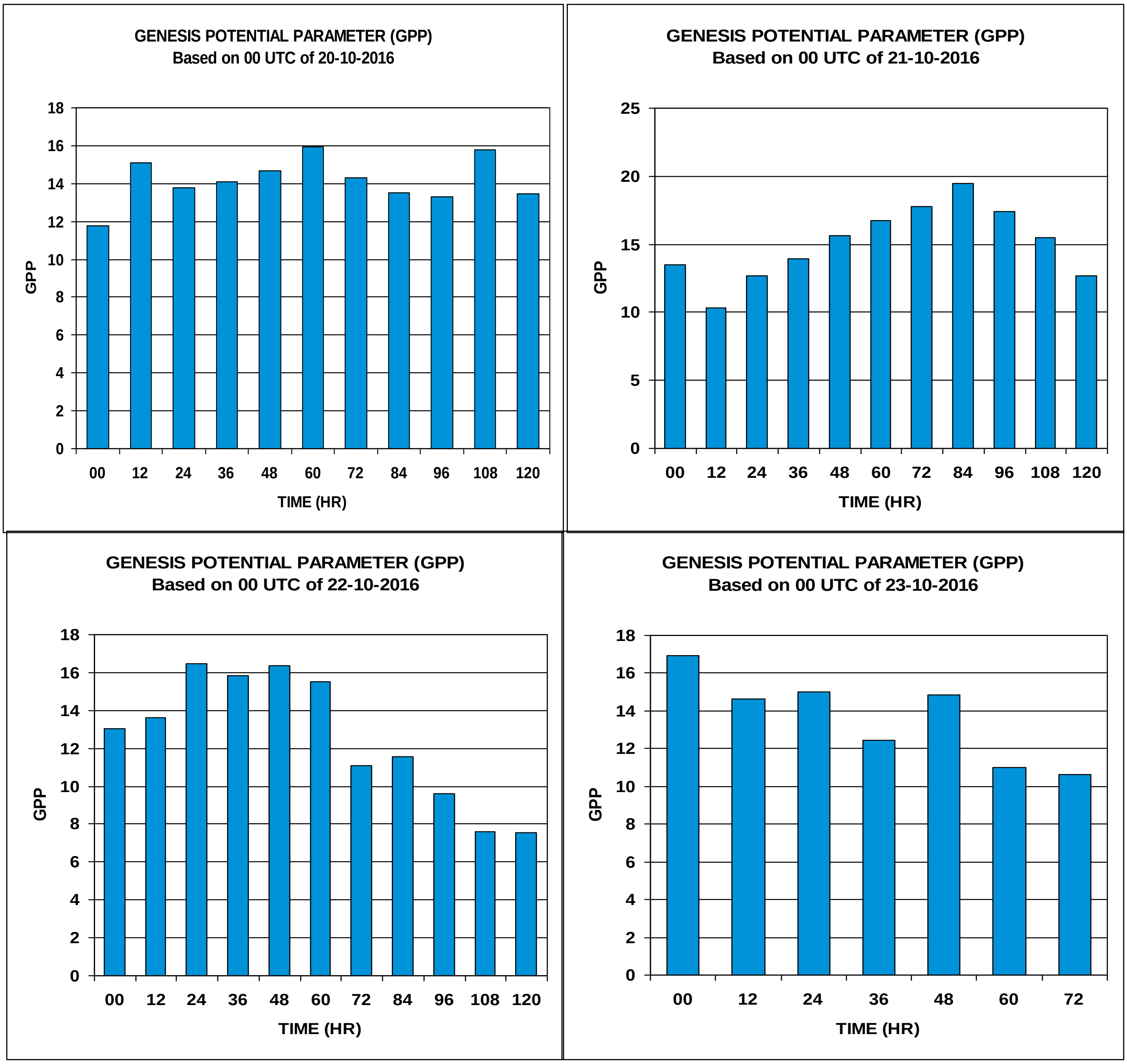


Fig. 12: Area average GPP analysis and forecasts based on 0000 UTC of 20th – 23rd October, 2016

10.2 Track prediction by NWP models

Track prediction by various NWP models is presented in Fig.13. Based on initial conditions of 0000 UTC of 21st, all the models were unanimously predicting anticlockwise recurving track and weakening over sea except WRF-VAR model which predicted northeastward movement with weakening over eastcentral BoB. Most of the models were predicting west-northwestwards recurvature from 23rd night. Only UKMO and NCUM predicted west-southwestwards recurvature from 25th afternoon onwards.

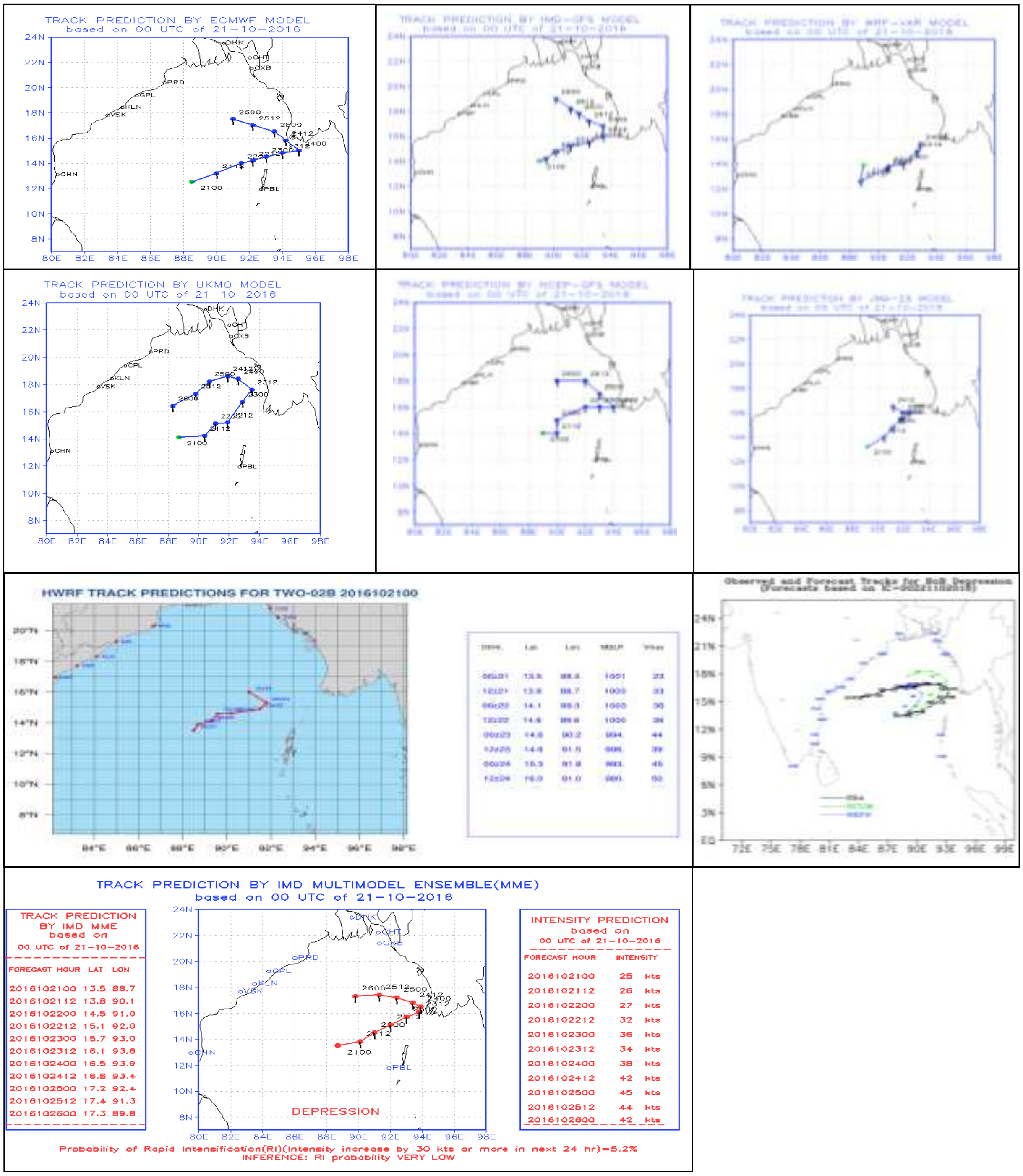


Fig.13(a) Track prediction by various NWP models based on 0000 UTC of 21st October, 2016.

Based on initial conditions of 0000 UTC of 22nd, all the models were unanimously predicting anticlockwise recurving track. However, IMD-GFS, NCEP-GFS and WRF-VAR were predicting landfall over Myanmar coast and re-emergence in eastcentral BoB with IMD-GFS showing second landfall over Bangladesh. HWRF predicted landfall over north Andhra Pradesh. Other models were predicting weakening over sea. There was large divergence in track prediction by various models. Only UKMO and NCUM predicted west-southwestwards recurvature from 25th afternoon onwards.

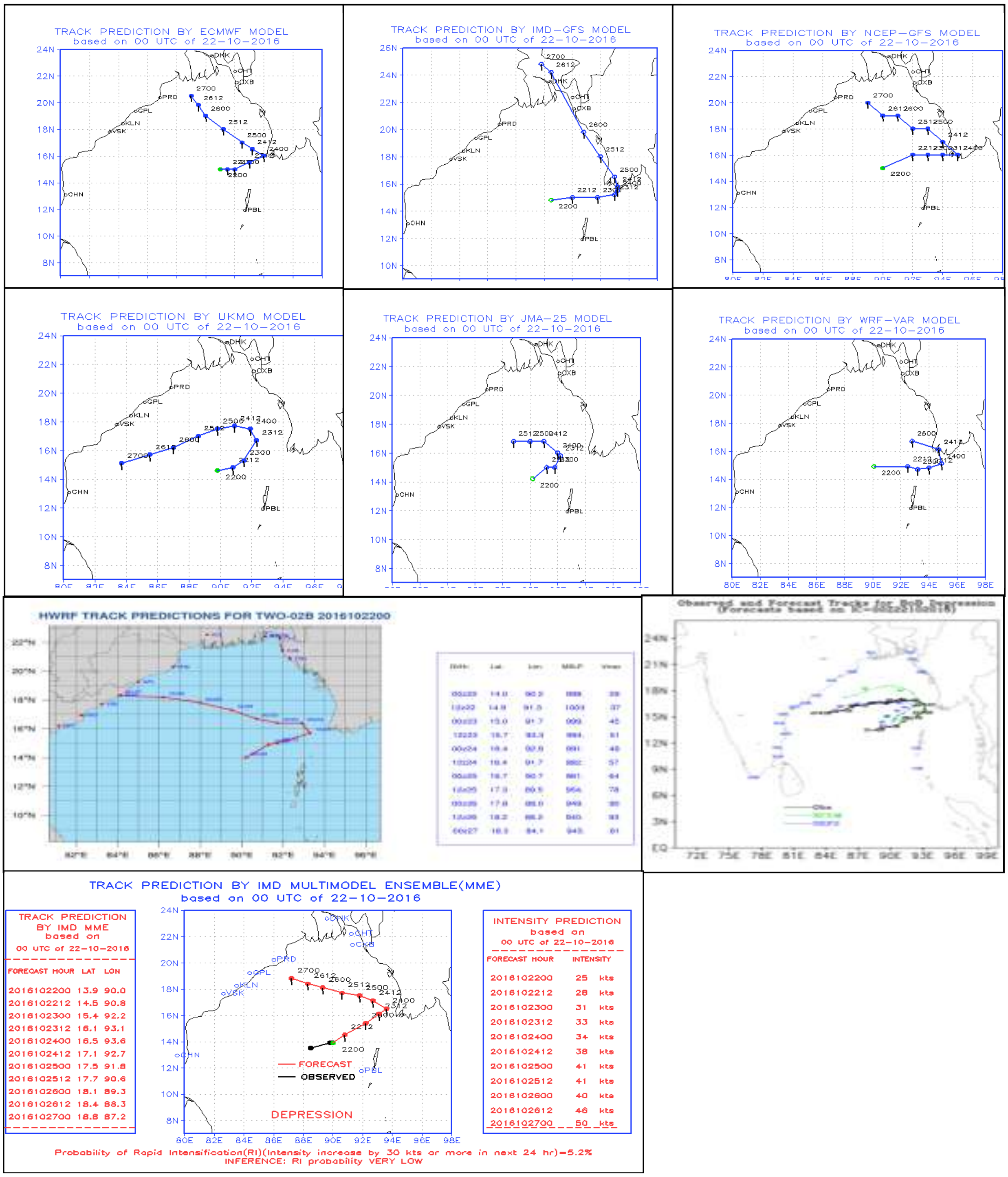


Fig.13 (b) Track prediction by various NWP models based on 0000 UTC of 22nd October, 2016.

Based on initial conditions of 0000 UTC of 23rd, only JMA, UKMO and NCUM were predicting weakening over westcentral BoB. The landfall point prediction by other models varied from Odisha and Bangladesh. There was large divergence in track prediction by various models. Only UKMO and NCUM predicted west-southwestwards recurvature from 25th night onwards.

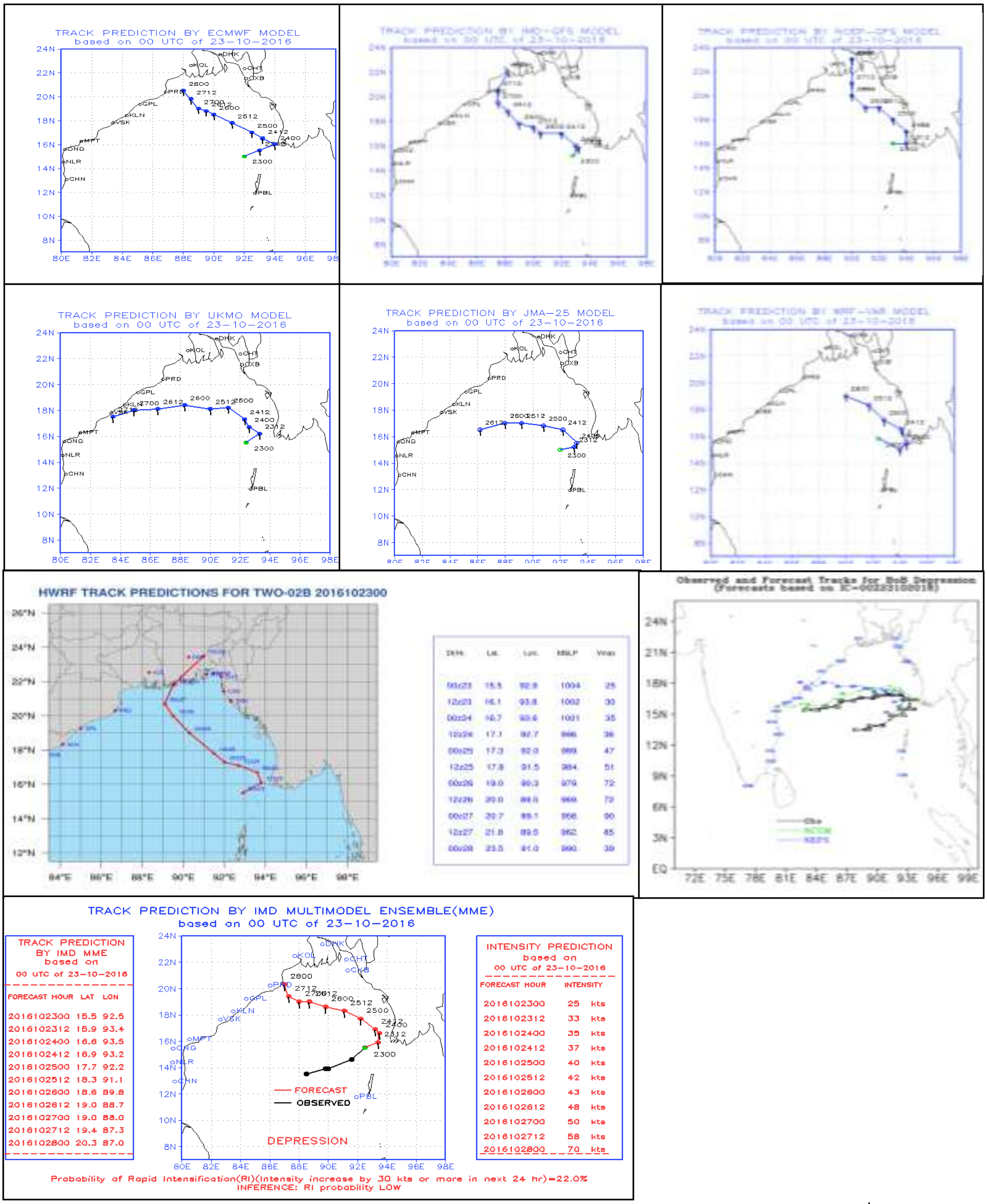


Fig. 13 (c) Track prediction by various NWP models based on 0000 UTC of 23rd October, 2016.

Based on initial conditions of 0000 UTC of 24th except UKMO and IMD GFS, all other models were predicting weakening over westcentral BoB. There was large divergence in track prediction by various models. Only UKMO, JMA, WRF-VAR and NCUM predicted west-southwestwards recurvature. There was large divergence in track prediction by various models.

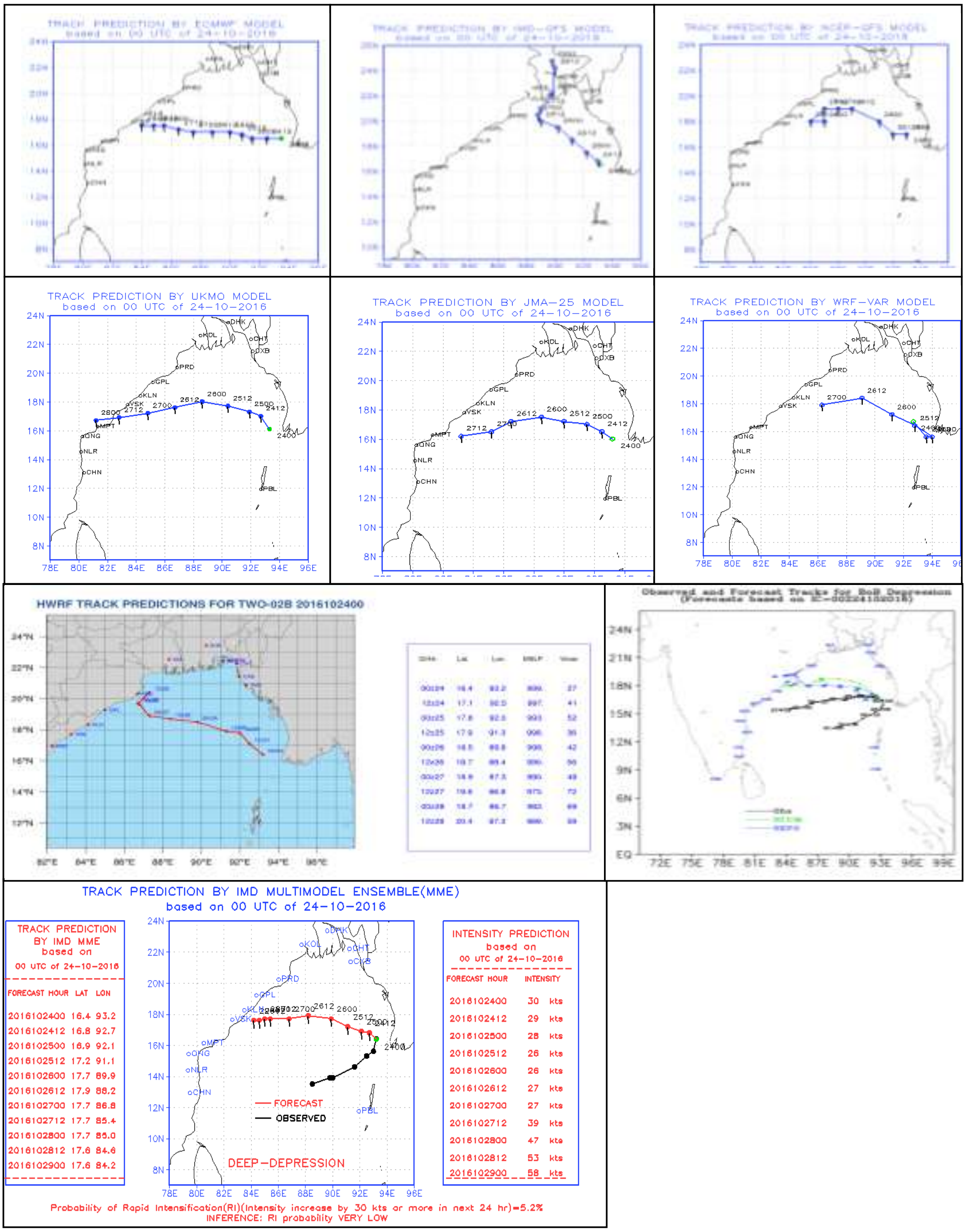


Fig.13 (d) Track prediction by various NWP models based on 0000 UTC of 24th October, 2016.

Based on initial conditions of 0000 UTC of 25th except WRF-VAR, all other models were predicting weakening over westcentral BoB. There was large divergence in model guidance w.r.t. track and time of west-southwestwards recurvature. UKMO, MME, JMA and HWRF were predicting west-southwestwards movement of the system.

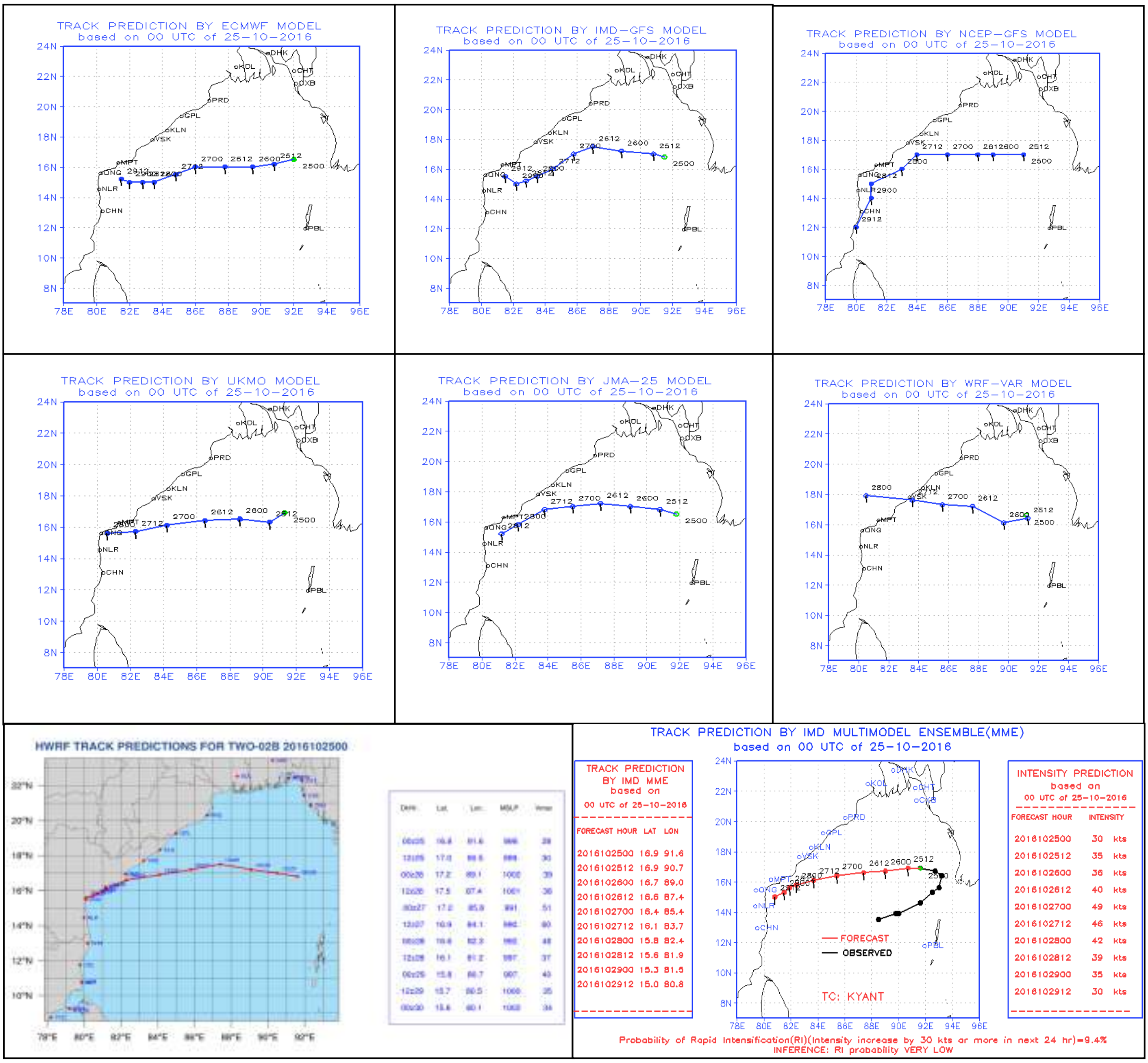


Fig.13 (e) Track prediction by various NWP models based on 0000 UTC of 25th October, 2016.

Based on initial conditions of 0000 UTC of 26th except WRF-VAR and HWRF, all other models were predicting weakening over westcentral BoB. Many models here predicted west-southwestwards towards south Andhra Pradesh coast.

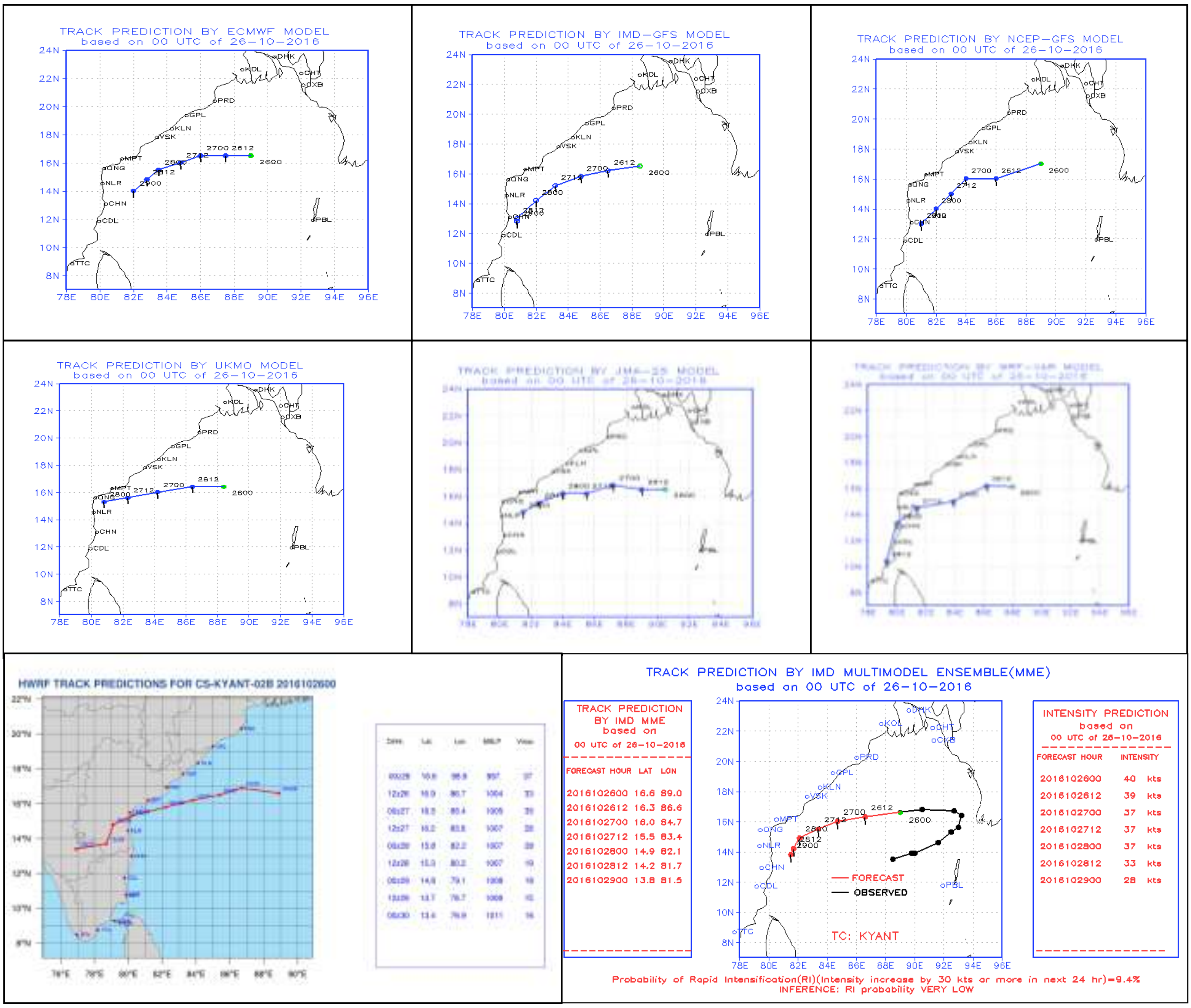


Fig. 13 (f) Track prediction by various NWP models based on 0000 UTC of 26th October, 2016.

Based on initial conditions of 0000 UTC of 27th except UKMO and WRF-VAR, all other models were predicting weakening over westcentral BoB.

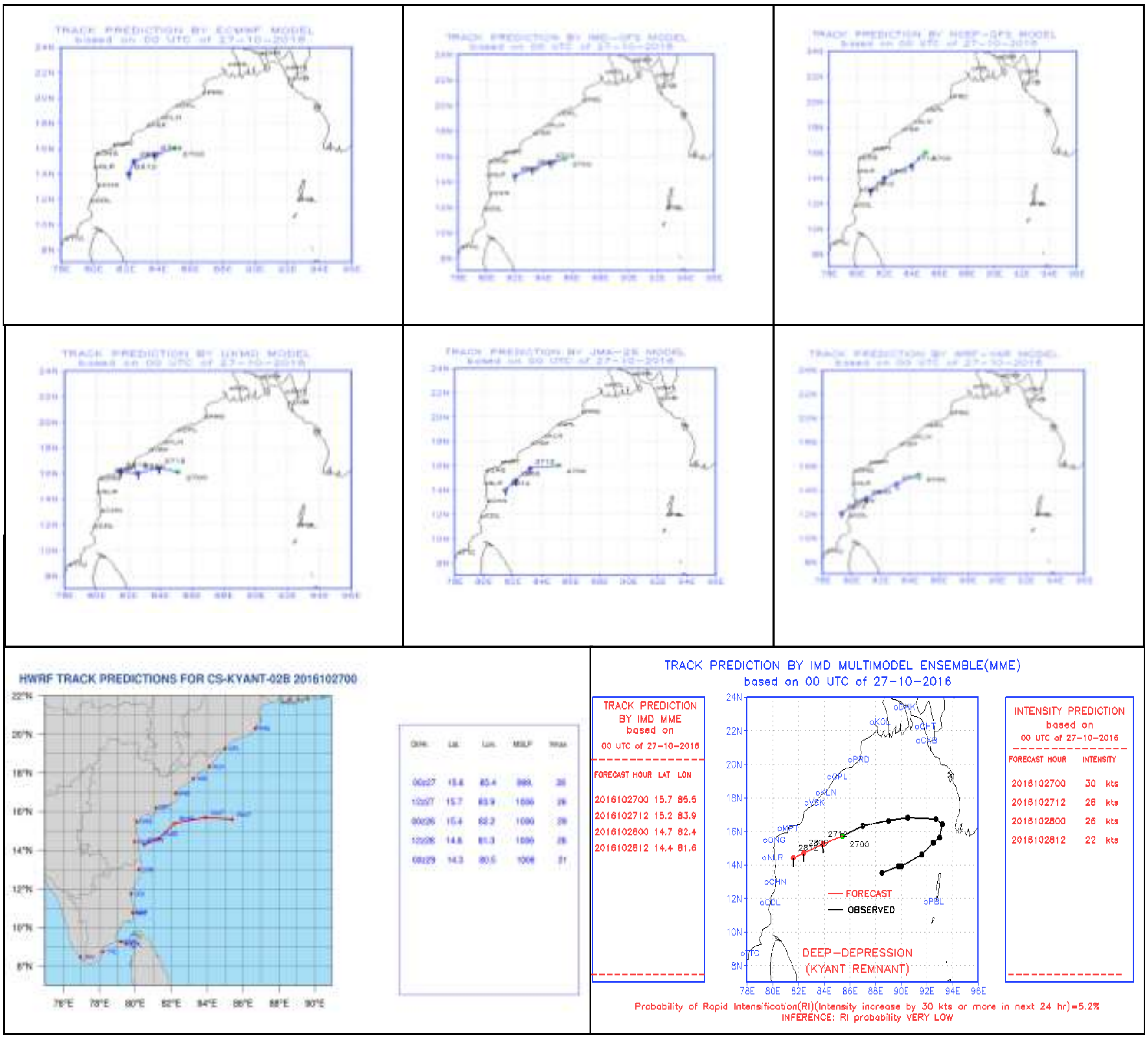


Fig.13 (g) Track prediction by various NWP models based on 0000 UTC of 27th October, 2016.

Hence to conclude, since beginning most of the models were predicting anticlockwise recurving track and weakening over westcentral BoB. From 26th morning, most of the models suggested weakening over westcentral BoB off Andhra Pradesh coast. Overall UKMO and NCUM performed better.

Ensemble track and Strike Probability forecast

The forecast based on ensemble members predicted 20-40% probability of landfall over south Andhra. The probabilistic and deterministic track forecast by National Centre for Environment Prediction (NCEP), Meteorological Service, Canada (MSC), UK Meteorological Office (UKMO) and consolidated forecast by these centres based on initial conditions of 1200 UTC of 25th and 26th October are presented in Fig. 14 (a-b). Based on 1200 UTC of 25th initial conditions, both MSC and NCEP predicted 20-40% strike probability over south Andhra Pradesh and adjoining north Tamil Nadu. Individual deterministic tracks predictions of MSC group were wide spread showing landfall varying from south Odisha to south Andhra Pradesh coasts. NCEP members narrowed over south Andhra Pradesh coast. All members ensemble showed 20-40% strike probability over south Andhra Pradesh coast.

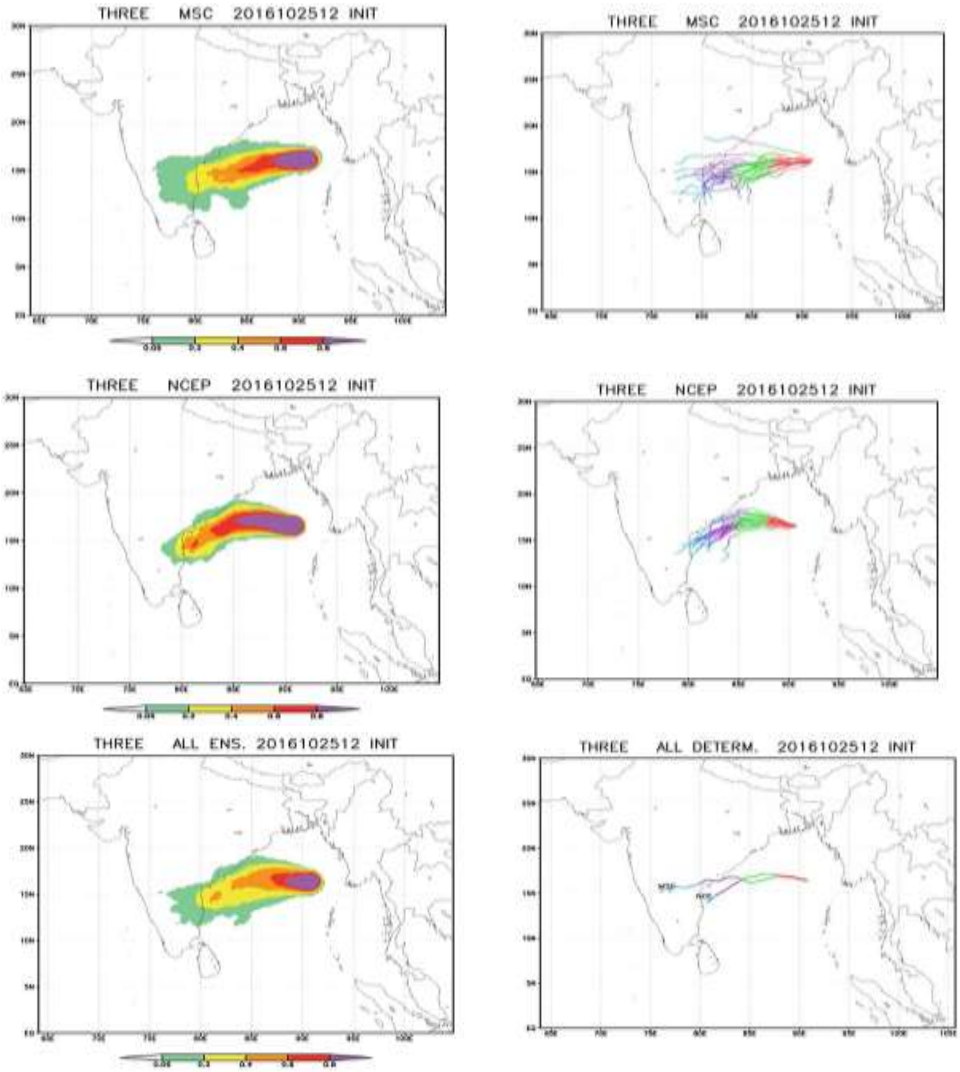


Fig. 14 (a): EPS track and strike probability forecast based on 1200 UTC of 25th October.

Based on the initial conditions of 1200 UTC of 26th October ensemble of MSC and UKMO members predicted 20-40% and 40-60% strike probability over south Andhra Pradesh and adjoining north Tamil Nadu. Ensemble of NCEP members predicted > 80%

strike probability over north Tamil Nadu and adjoining south Andhra Pradesh. All members ensemble showed 20-40% strike probability over south Andhra Pradesh and adjoining north Tamil Nadu coast.

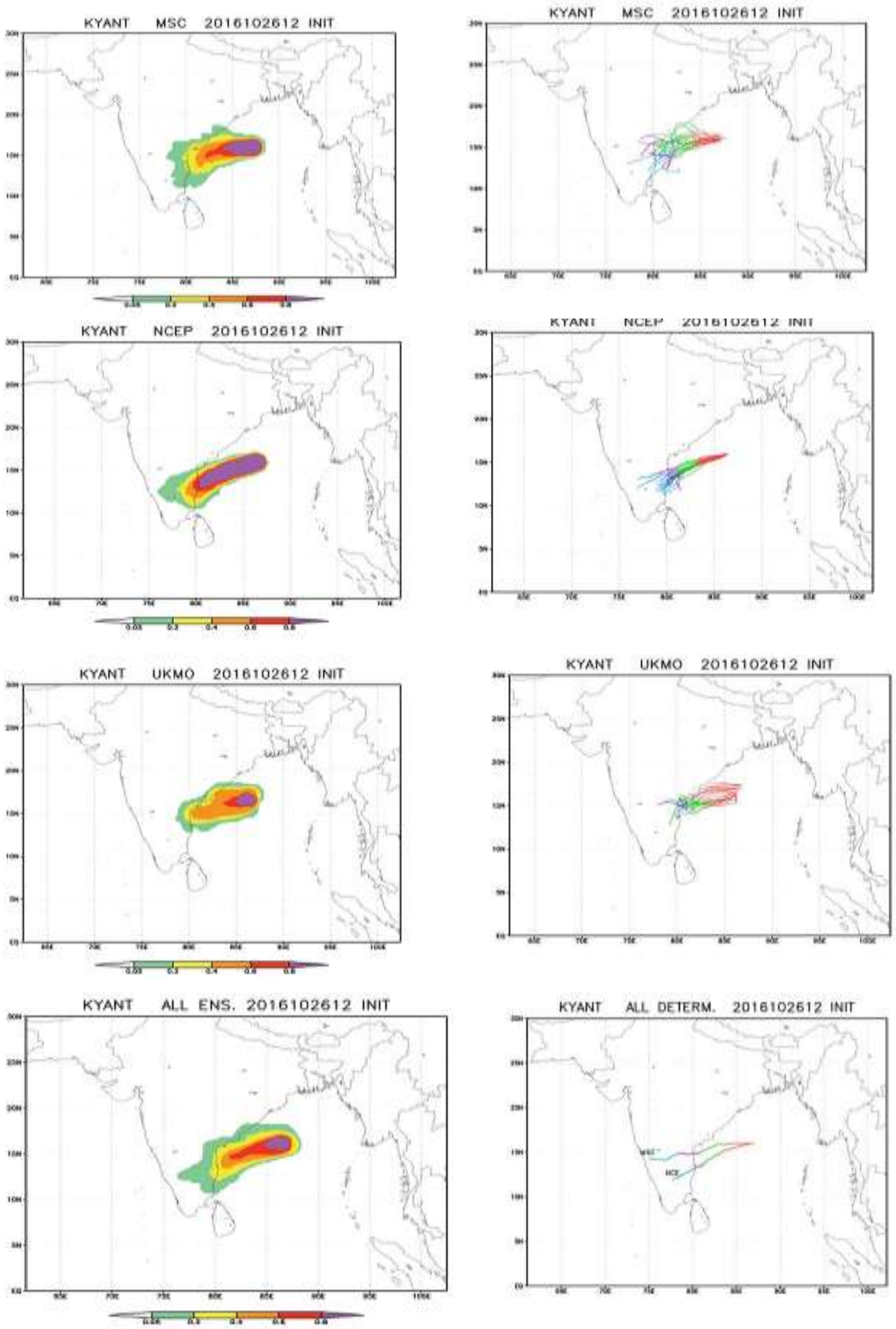


Fig. 14 (b): EPS track and strike probability forecast based on 1200 UTC of 26th October.

10.3 Track and Intensity Forecast Errors by various Models:

The average track forecast errors (Direct Position Error) in km at different lead period (hr) of various models are presented in Table 2. The average cross track errors

(CTE) and along track errors (ATE) are presented in Table 3 (a-b). From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors of IMD-MME were significantly less for all lead periods. Cross track errors contributed towards the DPE as the system had anticlockwise recurving track.

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

Model	Lead time									
	12 hr	**24 hr**	**36 hr**	**48 hr**	**60 hr**	**72 hr**	**84hr**	**96hr**	**108hr**	**120hr**
IMD-GFS	41(9)	74(8)	119(7)	165(6)	201(5)	295(4)	400(4)	370(3)	604(3)	701(2)
IMD-WRF	115(9)	140(8)	174(7)	194(6)	214(5)	190(4)	-	-	-	-
JMA	68(9)	101(8)	96(7)	115(6)	131(5)	132(4)	129(4)	-	-	-
NCEP	72(9)	98(8)	127(7)	155(6)	214(5)	268(4)	354(4)	384(3)	519(3)	396(2)
UKMO	76(9)	104(8)	92(7)	147(6)	172(5)	210(4)	202(4)	220(3)	161(3)	141(2)
ECMWF	53(9)	109(8)	76(7)	96(6)	133(5)	207(4)	272(4)	335(3)	455(3)	442(2)
IMD-HWRF	41(23)	81(20)	104(18)	153(16)	212(14)	330(12)	407(10)	513(8)	473(6)	475(3)
IMD-MME	48(9)	62(8)	52(7)	77(6)	118(5)	161(4)	208(4)	235(3)	321(3)	252(2)
NCUM	83(13)	118(14)	139(13)	147(13)	140(13)	165(12)	188(13)	202(12)	209(11)	205(8)
NEPS	58(5)	124(6)	155(6)	187(5)	200(5)	216(4)	231(4)	251(3)	137(3)	109(2)

Table-3 a. Average cross-track forecast errors (CTE) in km

Model	Lead time									
	12 hr	**24 hr**	**36 hr**	**48 hr**	**60 hr**	**72 hr**	**84hr**	**96hr**	**108hr**	**120hr**
IMD-GFS	30	54	90	137	149	243	310	327	488	594
IMD-WRF	86	79	71	120	181	173	-	-	-	
JMA	49	40	56	79	99	73	88	-	-	
NCEP	60	66	78	125	163	198	269	290	372	331
UKMO	54	55	66	115	134	195	194	215	154	102
ECMWF	44	51	36	59	82	164	173	244	363	414
IMD-HWRF	11	24	51	105	168	213	268	320	308	325
IMD-MME	28	32	40	65	88	124	145	163	247	229

Table-3b. Average along-track forecast errors (ATE) in km

Model	Lead time									
	12 hr	**24 hr**	**36 hr**	**48 hr**	**60 hr**	**72 hr**	**84hr**	**96hr**	**108hr**	**120hr**
IMD-GFS	17	43	63	81	116	156	233	163	291	156
IMD-WRF	52	97	137	124	98	63	-	-	-	
JMA	27	84	61	73	79	91	72	-	-	
NCEP	25	62	81	79	109	164	221	250	310	166
UKMO	32	77	44	69	88	70	54	44	30	94
ECMWF	19	83	59	67	82	102	191	226	226	136
IMD-HWRF	25	41	56	151	244	313	415	466	457	453
IMD-MME	28	51	30	35	62	79	131	160	180	64

The intensity forecast errors of IMD-SCIP model and HWRF model are presented in Table 4. For lead period beyond 60 hours errors were higher in case of HWRF as the model could not pick up rapid weakening of the system. The probability of rapid intensification (RI) index of IMD is shown in Table 5.

Table 4: Intensity forecast errors by IMD SCIP and IMD-HWRF models

Lead time →	**12 hr**	**24 hr**	**36 hr**	**48 hr**	**60 hr**	**72 hr**	**84hr**	**96hr**	**108hr**	**120hr**
IMD-SCIP (AAE)	1.9 (9)	4.0 (8)	5.7 (7)	11.3 (6)	9.6 (5)	6.3 (4)	8.8 (4)	11.7 (3)	14.3 (3)	11.0 (2)
IMD-SCIP (RMSE)	2.4	4.5	6.4	12.2	10.5	7.1	9.0	14.4	17.3	14.2
IMD-HWRF (AAE)	7.9 (23)	8.5 (20)	9.4 (18)	12.1 (16)	22.5 (14)	29.1 (12)	35.9 (10)	36.0 (8)	44.5 (6)	39.6 (3)
IMD-HWRF (RMSE)	9.9	11.3	12.7	14.1	25.9	30.5	37.8	43.8	48.0	45.6

Table 5: Probability of Rapid intensification

Forecast based on	**Probability of RI predicted**	**Chances of occurrence predicted**	**Intensity changes(kt) occurred in 24h**
00UTC/21.10.2016	5.2 %	Very low	2
00UTC/22.10.2016	5.2 %	Very low	6
00UTC/23.10.2016	22 %	Low	5
00UTC/24.10.2016	5.2 %	Very low	-2
00UTC/25.10.2016	9.4 %	Very low	-4
12UTC/25.10.2016	5.2 %	Very low	-5
00UTC/26.10.2016	9.4 %	Very low	7
12UTC/26.10.2016	5.2 %	Very low	-1

10.4. Heavy rainfall forecast by HWRF model

The forecast rainfall swaths by HWRF model are presented in fig.16. It indicates that the HWRF model predicted the occurrence of rainfall over coasts of north Andhra Pradesh and Odisha on 27th, Gangetic West Bengal on 28th, Odisha on 29th, north Andhra Pradesh on 30th, north Andhra Pradesh and Odisha coasts on 31st October & 2nd November. HWRF could not capture initial conditions correctly. Large track forecast errors contributed towards variations in forecast rainfall associated with the system.

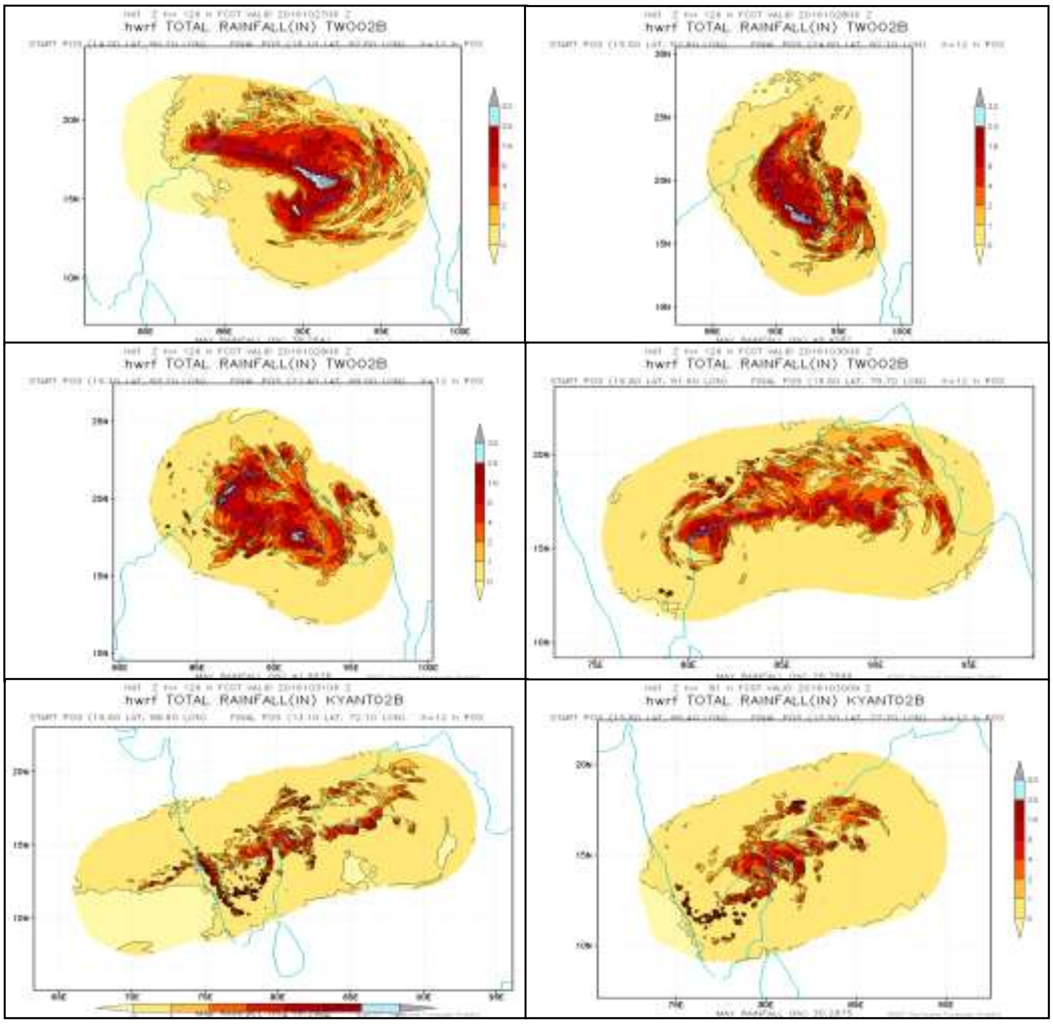


Fig.16: 126 hour heavy rainfall forecast by HWRF based on initial conditions of 0000 UTC of 22nd -27th November.

11. Operational Forecast Performance

11.1 Operational Genesis forecast

(i) IMD first predicted genesis of depression over southwest BoB on 21st October based on the observations of 0300 UTC of 19th October.

(ii) Depression formed at 0000 UTC of 21st October. At 0000 UTC of 20th October, IMD predicted genesis with fair (26-50%) probability on 21st .

11.2 Operational track forecast error and skill

The operational average track forecast errors and skills (compared to climatological and persistence (CLIPER) forecasts) are shown in Table 6. The track forecast errors for 24, 48 and 72 hours lead period have been 80, 200 and 422 km against the long period average (LPA) of 98, 146 and 183 km respectively. The track forecast errors have been higher than the LPA for lead period beyond 48 hours mainly due to recurving track. However, the skill in operational track forecast compared to CLIPER forecast has been higher than long period average for all lead periods.

Table 6: Average Track forecast error in association with CS KYANT

Lead Period (hrs)	N	Average track forecast error (km)	Skill (%)	LPA (2011-15)	
				Track forecast error (km)	Skill (%)
12	17	51.3	61.7	59.1	41.4
24	15	80.2	75.5	97.5	48.5
36	13	122.8	79.1	120.0	58.1
48	11	200.8	77.3	145.5	62.7
60	09	289.8	75.5	160.4	67.8
72	07	422.8	72.1	183.2	69.3
84	05	486.9	73.5	204.0	71.3
96	03	553.2	73.4	239.6	70.4

N: No. of observations verified, LPA: Long Period Average (2011-15)

11.4 Operational Intensity forecast error and skill

The operational intensity forecast errors and skill compared to persistence forecast in terms of absolute error (AE) and root mean square error (RMSE) are presented in Table 7. The operational AE in intensity forecast has been significantly less than LPA as it was about 6, 9 and 13 knots against LPA of 12, 17 and 18 knots for 24, 48 and 72 hours lead period. Similarly, operational RMSE in intensity forecast has been about 8, 11 and 14 knots against LPA of 15, 22 and 22 knots for 24, 48 and 72 hours lead period respectively.

Table 7: Average Intensity forecast error in association with CS KYANT

Lead Period (hrs)	N	Average Intensity Error (kts)		LPA Intensity forecast Error (kts) (2011-15)		Gain in Skill (%) against Persistence		LPA Gain in Skill (%) against Persistence (2011-15)	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	17	2.9	4.2	7.1	9.4	23.6	20.4	20.9	27.9
24	15	5.6	7.9	11.5	14.9	19.3	15.8	36.4	40.1
36	13	9.3	11.2	14.8	19.2	29.1	26.3	49.4	52.0
48	11	9.2	11.4	16.9	21.6	22.4	18.6	55.8	59.6
60	09	10.0	11.1	17.6	22.0	6.1	27.2	62.3	67.0
72	07	13.1	14.4	17.6	22.1	-83.2	-0.4	67.3	72.0
84	05	20.3	21.8	20.0	27.3	-44.8	-5.2	73.4	76.4
96	03	30.2	30.9	18.0	21.8	-6.7	5.6	79.5	82.0

N: No. of observations verified; AE: Absolute Error; RMSE: Root Mean Square Error, LPA: Long Period Average (2011-15).

The skill in intensity forecast with reference to AE is about 19%, 22% and -83% against the LPA of 36%, 56% and 67% respectively for 24, 48 and 72 hours lead period. The skill was negative for lead period beyond 72 hours as the system rapidly weakened which could not be predicted accurately.

11.4. Adverse weather forecast verification

The verifications of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Table 8-9. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table – 8 .Verification of Heavy Rainfall Forecast

<table>
<tr><th colspan="3">Table : Heavy Rainfall warning issued by IMD and realized heavy rainfall</th></tr>
<tr><th>Date /Time</th><th>Warning issued</th><th>Realized weather during past 24 hrs ending at 0830 hrs IST</th></tr>
<tr><td>21-Oct-2016 0830 IST</td><td>Heavy rainfall at isolated places over Andaman Islands</td><td rowspan="8">27 Oct. 2016
Tamilnadu & Puducherry: Pechiparai-8,
28 Oct. 2016
Coastal Andhra Pradesh: Kalingapatnam-7, Visakhapatnam-7
29 Oct. 2016
Nil
30 Oct. 2016
Tamilnadu & Puducherry: Tiruvaiyaru-7,
31 Oct. 2016
Tamilnadu & Puducherry: Udumalpet-12, Vadipatti-12, Pollachi-11, Pechiparai-10, Tirumayam-8, Tirupathur-7, Peelamedu Ap-7,</td></tr>
<tr><td>22-Oct-2016 0830 IST</td><td>Nil</td></tr>
<tr><td>23-Oct-2016 0830 IST</td><td>Nil</td></tr>
<tr><td>24-Oct-2016 0830 IST</td><td>Nil</td></tr>
<tr><td>25-Oct-2016 0830 IST</td><td>Nil</td></tr>
<tr><td>26-Oct-2016 0830 IST</td><td>Heavy rainfall at isolated places over south coastal Andhra Pradesh on 28th to 30th October 2016 and over north coastal Tamilnadu on 29th to 31st October 2016.</td></tr>
<tr><td>27-Oct-2016 0830 IST</td><td>Heavy rainfall at isolated places over south coastal Andhra Pradesh during 28th to 30th October 2016 and over north coastal Tamilnadu from 28th evening to 31st October 2016.</td></tr>
<tr><td>28-Oct-2016 0830 IST</td><td>Heavy rainfall at isolated places over Andhra Pradesh and north coastal Tamilnadu during next 72 hours</td></tr>
</table>

Table 9. Verification of Gale Wind Forecast

<table>
<tr><th colspan="3">Table : wind warning issued by IMD and realized wind</th></tr>
<tr><th>Date /Time</th><th>Warning issued</th><th>Realised wind speed (kmph)</th></tr>
<tr><td>21-Oct-2016 0830 IST</td><td>Squally winds speed reaching 45-55 kmph gusting to 65 kmph over Andaman Islands & adjoining Sea areas during next 48 hours.</td><td rowspan="8">21 Oct 2016
Portblair: 61 (20.02 IST)
Nancowry: 22 (17.30 IST)

22 Oct 2016
Portblair: 70 (16.53 IST)
Nancowry: 19 (08.30 IST)

23 Oct 2016
Portblair: 51(10.26 IST)

27 Oct 2016
Visakhapatnam 32 (10.26 IST and 18.45 IST)

28 Oct 2016
Visakhapatnam 24 (00.10 IST)</td></tr>
<tr><td>22-Oct-2016 0830 IST</td><td>Squally winds speed reaching 45-55 kmph gusting to 65 kmph over Andaman Islands and adjoining Sea areas during next 48 hours.</td></tr>
<tr><td>23-Oct-2016 0830 IST</td><td>Squally winds speed reaching 45-55 kmph gusting to 65 kmph over Andaman Islands & adjoining Sea areas during next 24 hours.</td></tr>
<tr><td>24-Oct-2016 0830 IST</td><td>Squally winds speed reaching 45-55 kmph gusting to 65 kmph along and off Odisha and west Bengal coasts from 27th October 2016.</td></tr>
<tr><td>25-Oct-2016 0830 IST</td><td>Squally winds speed reaching 45-55 kmph gusting to 65 kmph along and off Odisha and north coastal Andhra Pradesh coasts from 27th October 2016 onwards.</td></tr>
<tr><td>26-Oct-2016 0830 IST</td><td>Squally winds speed reaching 45-55 kmph gusting to 65 kmph along & off south Odisha on 27th and along & off Andhra Pradesh coasts from 27th to 30th October 2016</td></tr>
<tr><td>27-Oct-2016 0830 IST</td><td>Squally winds speed reaching 35-45 kmph gusting to 55 kmph along & off Andhra Pradesh coast during next 24 hours.</td></tr>
<tr><td>28-Oct-2016 0830 IST</td><td>Squally winds speed reaching 35-45 kmph gusting to 55 kmph along & off Andhra Pradesh coast during next 24 hours.</td></tr>
</table>

12. Bulletins issued by IMD

12.1 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 upto120 hrs or till the system weakened into a low pressure area. The above forecasts were issued from the stage of deep depression onwards along with the cone of uncertainty in the track forecast.
- **Cyclone structure forecast for shipping and coastal hazard management** The radius of maximum wind and radii of MSW ≥28 knots, ≥34 knots, ≥50 knots and ≥64 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36, +48, +60, +72, +84 and +120 hrs lead period.
- **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 vitals were prepared every six hourly 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.
- **Tropical cyclone forecasts and adverse weather warning bulletins:** The tropical cyclone forecasts alongwith expected adverse weather like heavy rain, gale wind and storm surge were issued with every three hourly update during cyclone period to the central, state and district level disaster management agencies including MHA NDRF, NDMA, Andhra Pradesh, Tamil Nadu, Puducherry, Odisha and Andaman & Nicobar Islands. The bulletin also contained the expected damage and suggested action by disaster managers and general public. These bulletins were also issued to Railways, surface transport, Defence including Indian Navy & Indian Air Force, Ministry of Agriculture, Ministry of Information and Broadcasting etc.
- **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.
- **Warning and advisory through social media:** Daily updates were uploaded on facebook 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 and hourly updates on the day of landfall through press release, e-mail, website and SMS.
- **Warning and advisory for marine community:** The three/six hourly bulletins were issued by the cyclone warning division at New Delhi and cyclone warning centres of IMD at Chennai, Kolkata, Visakhapatnam and Bhubaneswar to ports, fishermen, coastal and high sea shipping community
- **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.

Bulletins issued by Cyclone Warning services of IMD in association with the system are given in Table 10 (a-b).

Table-10 a: Bulletins issued by Cyclone Warning Division, New Delhi

S.N.	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	42	1. IMD's website 2. FAX and e-mail to Control Room NDM, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Dir. Indian Railways, Indian Navy, IAF, Chief Secretary- Odisha, Andhra Pradesh, West Bengal, Telangana.
2	RSMC Bulletin for WMO/ ESCAP Panel countries	25	1. IMD's website 2. All WMO/ESCAP member countries through GTS and E-mail. 3. Indian Navy, IAF by E-mail
3	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	18	1. Met Watch offices in Asia Pacific regions though 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
4	Cyclone Warnings through SMS	14,920	SMS through (i) IMD network for disaster managers (once daily and twice on 28th October) (400 No.) (ii) IMD's public registration using Department of Electronics and Information Technology network (14,520)
5	Cyclone Warnings through Social Media	Once daily	Cyclone Warnings were uploaded on Social networking sites like Face book and Tweeter

Table-10 b: Bulletins issued by ACWC Kolkata/ CWC Bhubaneswar/ CWC VZK

S.No.	Type of Bulletin	No. of Bulletins issued by		
		ACWC Kolkata	CWC Bhubaneswar	CWC VZK
1.	Sea Area Bulletins	28	-	-
2.	Coastal Weather Bulletins	19	23	23
3.	Fishermen Warnings issued	34	37	16
4.	Port Warnings	46	23	10
5.	Heavy Rainfall Warning	-	1	-
6.	Gale Wind Warning	NIL	-	-
7.	Information & Warning issued to State Govt & other Agencies	-	25	12
8.	SMS	1	600	170

13. Summary and Conclusion

Cyclonic Storm (CS) Kyant developed on 21st October with the formation of a depression (D) over eastcentral BoB (BOB). Initially, it moved east-northeastwards towards Myanmar coast and steadily intensified into a deep depression (DD) on 23rd morning. Thereafter, it changed its direction of movement and recurved west-northwestwards. It intensified into a CS in the morning of 25th over eastcentral BOB. Thereafter, it again changed its direction of movement and moved west-southwestwards towards westcentral BOB off Andhra Pradesh coast. It maintained its intensity till midnight of 26th and thereafter weakened gradually becoming DD in the early hours 27th and D in the same evening. It weakened into a well marked low pressure area over westcentral BOB off Andhra Pradesh coast in the morning of 28th. The track followed by the system was rare in nature as it experienced two recurvatures during its life period. The recurvature was anticlockwise against the normal clockwise recurvature over the BOB. While the rate of intensification was slow and steady, the rate of weakening was rapid. IMD utilized all available resources to monitor and predict the system. Though the system was moving towards Myanmar, no landfall over Myanmar was predicted by IMD. No Cyclone Alert/Warning was issued for any coastal state of India.

14. Acknowledgements

RSMC New Delhi duly acknowledges the valuable information from NCMRWF, IIT Bhubaneswar, IIT-Delhi, INCOIS and NIOT Chennai for monitoring the system and preparation of this report. The inputs from Agrimeteorology Division, Pune, NWP Division, Satellite Division and Information System & Services Divisions at IMD HQ New Delhi and Area Cyclone Warning Centre (ACWC) Chennai & Kolkata and Cyclone Warning Centre (CWC) Vishakhapatnam and Bhubaneswar are also appreciated for their timely inputs required for monitoring the system and for compilation of this report.