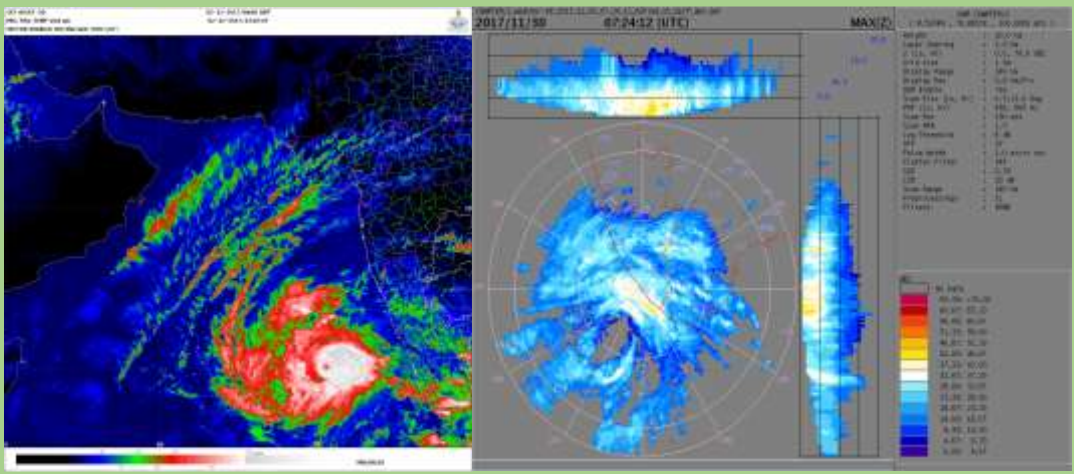
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Very Severe Cyclonic Storm,'OCKHI' over the Bay of Bengal (29 Nov.-05 Dec. 2017): A Report



Typical INSAT-3D enhanced colored IR imagery & DWR Thiruvananthapuram imagery

Cyclone Warning Division

India Meteorological Department

New Delhi

MARCH 2018

Very Severe Cyclonic Storm 'Ockhi' over the Bay of Bengal
(29 November-05 December 2017)

1. Introduction

Very Severe Cyclonic Storm (VSCS) Ockhi originated from a low pressure area which formed over southwest Bay of Bengal (BoB) and adjoining areas of south Sri Lanka & equatorial Indian Ocean in the forenoon (0830 IST) of 28th November. It became a well marked low pressure area in the early morning (0530 IST) of 29th over the same region. Under favourable environmental conditions, it concentrated into a Depression (D) over southwest BoB off southeast Sri Lanka coast in the forenoon (0830 IST) of 29th Nov. Moving westwards, it crossed Sri Lanka coast after some time. Continuing it's westward movement, it emerged into Comorin area in the evening (1730 IST) of 29th and intensified into a Deep Depression (DD) in the early hours (0230 IST) of 30th over the Comorin area and neighbourhood. It further moved northwestwards and intensified into a Cyclonic Storm (CS) in the forenoon (0830 IST) of 30th over the Comorin area. There was rapid intensification of Ockhi during its genesis stage, as it intensified into a CS at 0830 IST of 30th, after its genesis as a depression at 0830 IST of 29th (within 24 hrs). It further intensified into a Severe Cyclonic Storm (SCS) over Lakshadweep area in the early morning (0530 IST) of 01st Dec. and Very Severe Cyclonic Storm (VSCS) over southeast (SE) Arabian Sea to the west of Lakshadweep in the afternoon(1430 IST) of 01st Dec. It then moved northwards and reached its peak intensity of 85 knots (150-160 kmph) in the morning (0830 IST) of 4th Dec. It then moved north-northeastwards and weakened gradually into an SCS on 4th midnight (2330 IST), a CS in the morning of 5th (0830 IST), a DD in the afternoon of 5th (1430 IST) and D in the late evening (2030 IST) of same day. It crossed South Gujarat coast between Surat and Dahanu as a well marked low around early morning (0530 IST) of 6th Dec.

The observed track of the VSCS Ockhi is shown in Fig.1. The salient features of the system are as follows.

- **(i)** This was the fourth cyclonic storm developing over Comorin Sea (south of Kerala and Tamil Nadu and west of Sri Lanka). However, cyclone, Ockhi did not cross Tamil Nadu and Kerala coast and moved across Lakshadweep Islands. Previously two cyclones in 1912 and another in 1925 developed over Comorin Area **(Fig.2).** All these cyclones affected south Kerala and south Tamil Nadu. However the cyclone during 19-21 Nov. 1912 moved across south Tamil Nadu and Kerala on 19th Nov. and the cyclone during 6-10 Nov. 1925 crossed north Kerala coast on 10th Nov. Other cyclone in 1912 skirted Kerala coast.
- **(ii)** Thus, it was a rare cyclone with rapid intensification in genesis stage (from depression to cyclonic storm within 24 hours).
- **(iii)** Ockhi had a clockwise recurving track. The track length of the cyclone was 2538 km.
- **(iv)** The 12 hourly average translational speed of the cyclone was 15.0 kmph. However, it moved faster in it's genesis stage (29/0830 IST to 30/0830 IST) with 12 hourly average translational speed of 19 kmph.

(v) The life period of cyclone was 6 days & 18 hours against long period average of 4.7 days for very severe cyclonic storm over north Indian Ocean.

(vi) The peak maximum sustained surface wind speed (MSW) of the cyclone was 150-160 kmph gusting to 175 kmph (85 knots) during 0600 UTC of 2^{nd} to 0000 UTC of 3^{rd} December.

(vii) The lowest estimated central pressure was 976 hPa (from 0300 UTC of 2^{nd} to 0000 UTC of 3^{rd} December) with a pressure drop of 34 hPa.

(viii) The Velocity Flux associated with the system was $13.6X10^2$ knots against the normal of 19.76×10^2 over north Indian Ocean for post monsoon season based on data of 1990-2013.

(ix) The Accumulated Cyclone Energy (ACE) which is a measure of damage potential was about $9.29 X 10^4$ $knot^2$ against the normal of 9.0×10^4 over north Indian Ocean for post monsoon season based on data of 1990-2013.

(x) The Power Dissipation Index which is a measure of loss due to a cyclone was $6.63 X 10^6$ $knot^3$ against the normal of 5.3×10^6 over north Indian Ocean for post monsoon season based on data of 1990-2013.

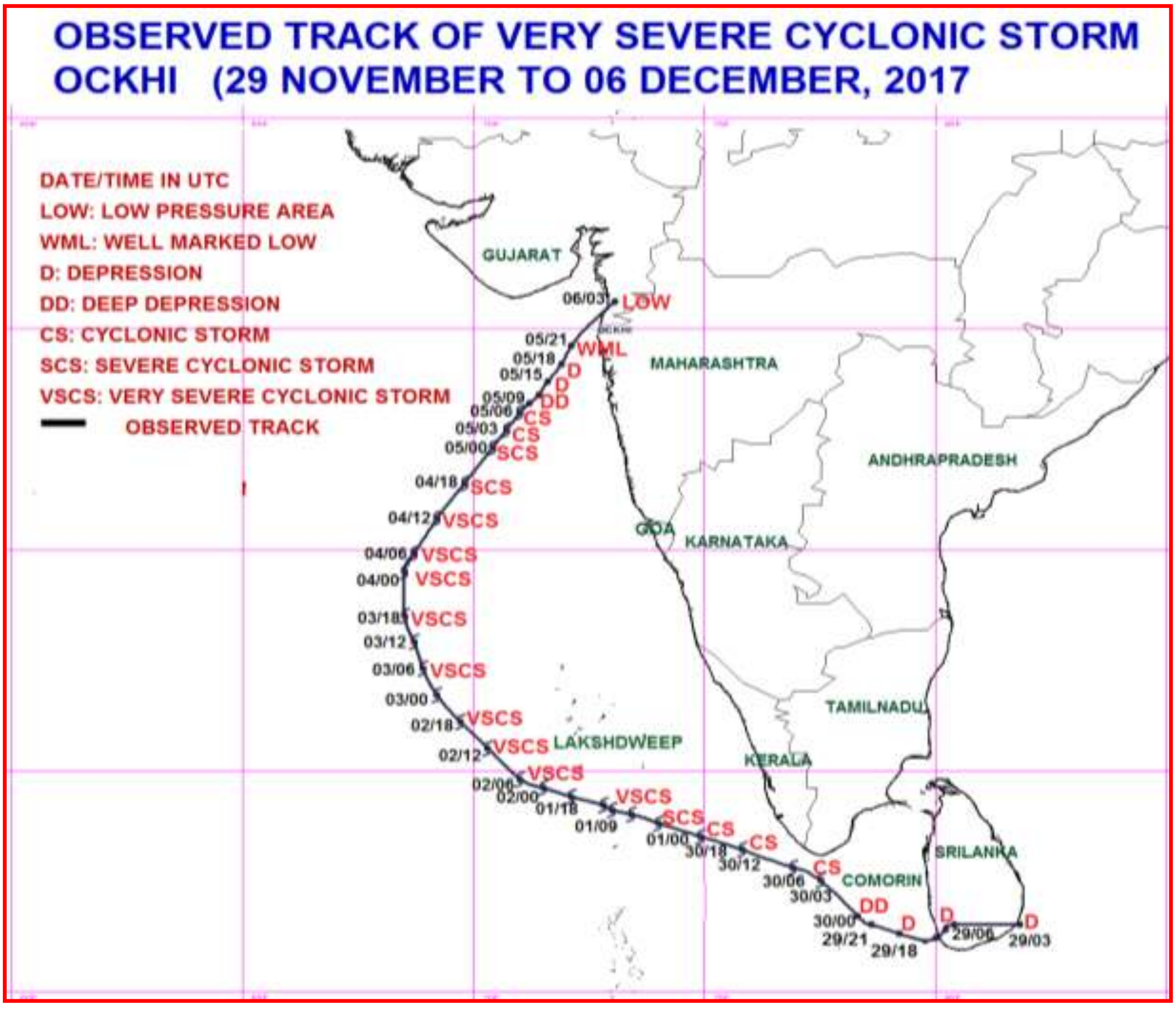


Fig.1: Observed track of VSCS Ockhi (29 Nov.–06 Dec, 2017) over Bay of Bengal

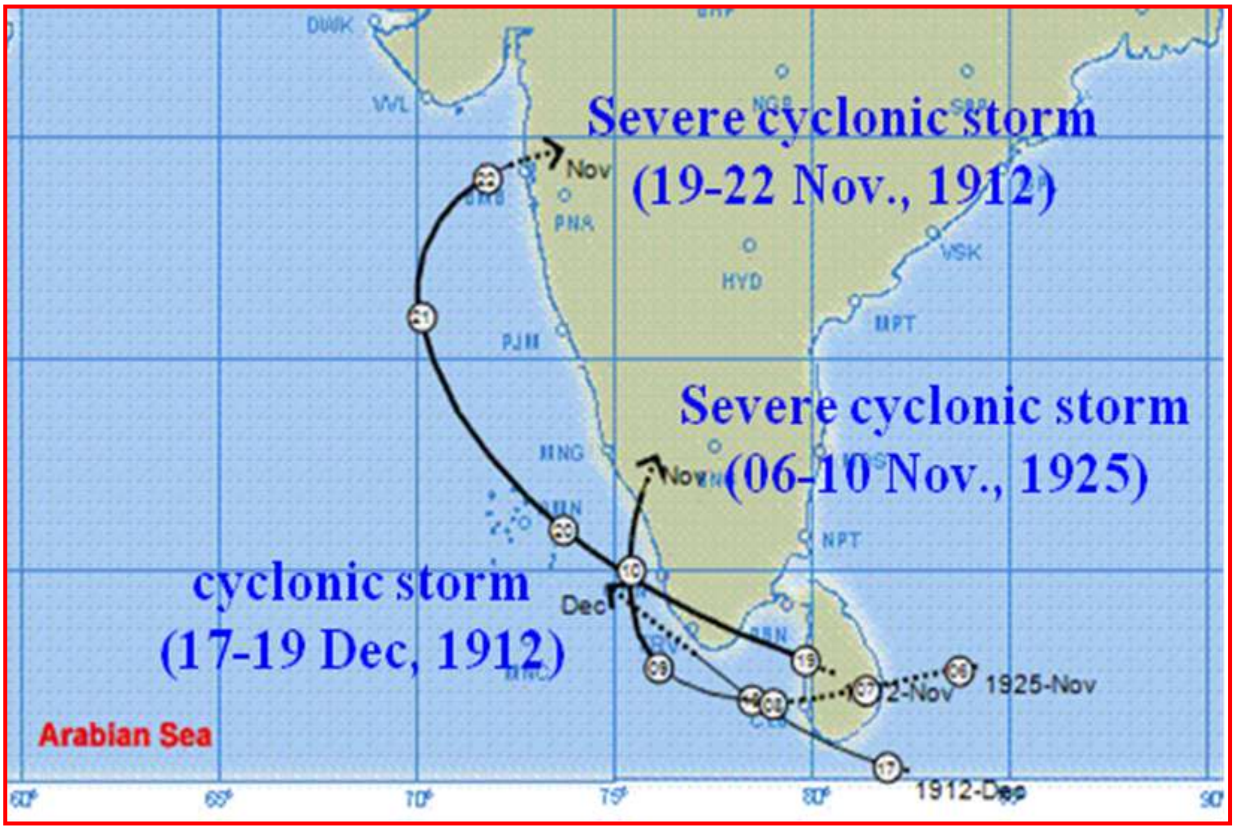


Fig.2: Climatological tracks of cyclones affecting Kerala and Kanyakumari during 1891-2016.

2. Monitoring of VSCS,'Ockhi'

The system was monitored & predicted continuously by India Meteorological Department (IMD) as it maintained round the clock watch and prepared a daily report on the diagnostics and prognostics of possible development of cyclogenesis commencing from 15th October 2017. A trough of low lay over southwest BOB and adjoining equatorial Indian Ocean off Southeast Sri Lanka coast on 27th November. Subsequent formation of low pressure area over southwest BOB and adjoining south Sri Lanka & adjoining equatorial Indian Ocean occurred on 28th November. At the genesis stage, the system was monitored mainly with satellite observations from INSAT 3D, 3DR, SCATSAT and ASCAT alongwith available ships, buoy and coastal observations. The system was also monitored by Doppler Weather Radar Chennai, Thiruvananthapuram, Karaikal, Kochi, Goa and Mumbai.

Various national and international NWP models and dynamical-statistical models were utilized to predict the genesis, track and intensity of the cyclone. IMD operationally runs a regional model, WRF for short-range prediction and one Global model GFS T1534 for medium range prediction (10 days). GFS model has been introduced in 2010, which is extensively used for short to medium range forecast of cyclones over the north Indian Ocean. It's resolution has been improved to 12 km since 2017 to provide forecast upto 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. 25^0S 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.

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. (For additional details refer to http://www.ncmrwf.gov.in/). 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 (NCUM) and ensemble model (NEPS) is that they do not use any TC relocation in the analysis. However, the ACCESS-TC model features TC relocation. The Met Office bi-variate approach to tracking TCs is used in the real-time to track the location of the CS ‘Vardah’. 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 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 center to the nearest local MSLP minimum (Hamming,2016). This is the adopted method in Met Office UK. The key advantage of the method is that it gives a strong signal of the approximate center of the TC even for weak systems and does not depend on the ‘*tcvitals*’ information for tracking.

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 Ockhi are presented and discussed.

IMD also runs cyclone specific Hurricane-WRF model for Tropical Cyclone track and intensity forecast over North Indian Ocean region for its operational requirements. The basic version of the model HWRFV (3.7+) which was operational at EMC, NCEP, USA was ported on IITM ADITYA HPCS machine with nested domain of 27 km, 9 km and 3 km horizontal resolution and 61 vertical levels with outer domain covering the area of 216X432, 106X204 and innermost domain 198X354 with Center of the system adjusted to the Center of the observed cyclonic storm. The outer domain covers most of the North Indian Ocean and the inner domain mainly covering the cyclonic vortex which moves along the movement of the system. The model has special features such as vortex initialization, coupled with Ocean model to take into account the changes in SST during the model integration, tracker and diagnostic software to provide the graphic and text information on track and intensity prediction for real-time operational requirement. Model has full physics configuration with cloud microphysics of eta-HWRF scheme (Rogers et al., 2001), radiation physics for short wave and long wave (GFDL schemes), surface layer (GFDL) and surface physics (GFDL slab model), planetary boundary layer physics (Hong and Pan, 1996) and cumulus physics (New simplified Arakawa-Schubert - Han and Pan, 2011). The Princeton Ocean Model (POM-TC) and Ocean coupler requires the customization of Ocean Model for Indian Seas. In this regards, IMD is working in collaboration with INCOIS, Hyderabad which is running the Ocean Models (POM)/Hybrid Co-ordinate Ocean Model (HYCOM) to support in porting the Ocean Model with Indian Ocean climatology and real time data of SST over Indian Seas. During cyclone Ockhi, the forecast was generated using POM-TC model. The model is run on real time six hourly basis based on 00, 06, 12 and 18 UTC initial conditions to provide 6 hourly track and intensity forecasts along with surface wind and rain swaths valid up to 126 hours. The model uses IMD GFS-T1534L64 analysis/forecast as first guess. The model is run with a resolution of 18km, 6km, and 2km from post-monsoon season in 2016.

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 Sri Lanka and Maldives, National & State Disaster Management

Agencies, general public and media since inception of the system over BOB till it's weakening.

Brief environmental conditions prior to genesis of system over BoB, life history of VSCS Ockhi, characteristic features and associated weather alongwith performance of various NWP models and operational forecast of IMD are presented and discussed in following sections.

3. Prevalent conditions over Bay of Bengal prior to genesis of cyclone, Ockhi

Due to active inter-tropical convergence zone (ITCZ) and associated meso-scale convection, the trough in easterly winds or low pressure systems developed over the southern part of BoB and moved westwards causing rainfall activity over the southern peninsular India in regular intervals. In this scenario, a low pressure area formed over Andaman Sea on 22nd Nov., under the influence of a remnant upper air cyclonic circulation from Gulf of Thailand. It lay over southeast and adjoining eastcentral BoB on 23rd, central part of south BoB on 24th, southwest BoB and adjoining equatorial Indian Ocean on 25th, southwest BoB and adjoining southeast Sri Lanka on 26th. It weakened and lay as a trough of low over southeast Arabian Sea and adjoining Maldives on 27th and over southeast Arabian Sea and adjoining Lakshadweep & Maldives on 28th Nov. 2017. It then moved away westwards and became less marked. It caused scattered heavy to very heavy rainfall over Tamil Nadu on 26th Nov and Kerala received isolated heavy rainfall on 26th and 27th.

Hence there was no remnant of any circulation system moving from Gulf of Thailand that intensified near Sri Lanka and later became cyclone, Ockhi over Comorin Sea. To justify the above, the INSAT-3D (IR) imageries during 21st to 30th Nov. 2017 are shown in Fig. 3. The environmental parameters like low level relative vorticity, lower level convergence, upper level divergence and vertical wind shear, SST and Ocean heat content during the period 27th-30th are shown in Fig.4 (a-f) (Source: CIMSS Tropical Cyclones, http://tropic.ssec.wisc.edu/ and http://www.aoml.noaa.gov/phod/cyclone/data/ni.html). The variation of these parameters during 21st November -6th December is presented in Fig. 5. The MJO index during the life period of Ockhi is presented in Fig.6 (Source: Climate Prediction Centre, NOAA, http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/CLIVAR/clivar_wh.shtml). These figures also indicate in-situ cyclogenesis of Ockhi on 29th over southwest BoB off southeast Sri Lanka coast.

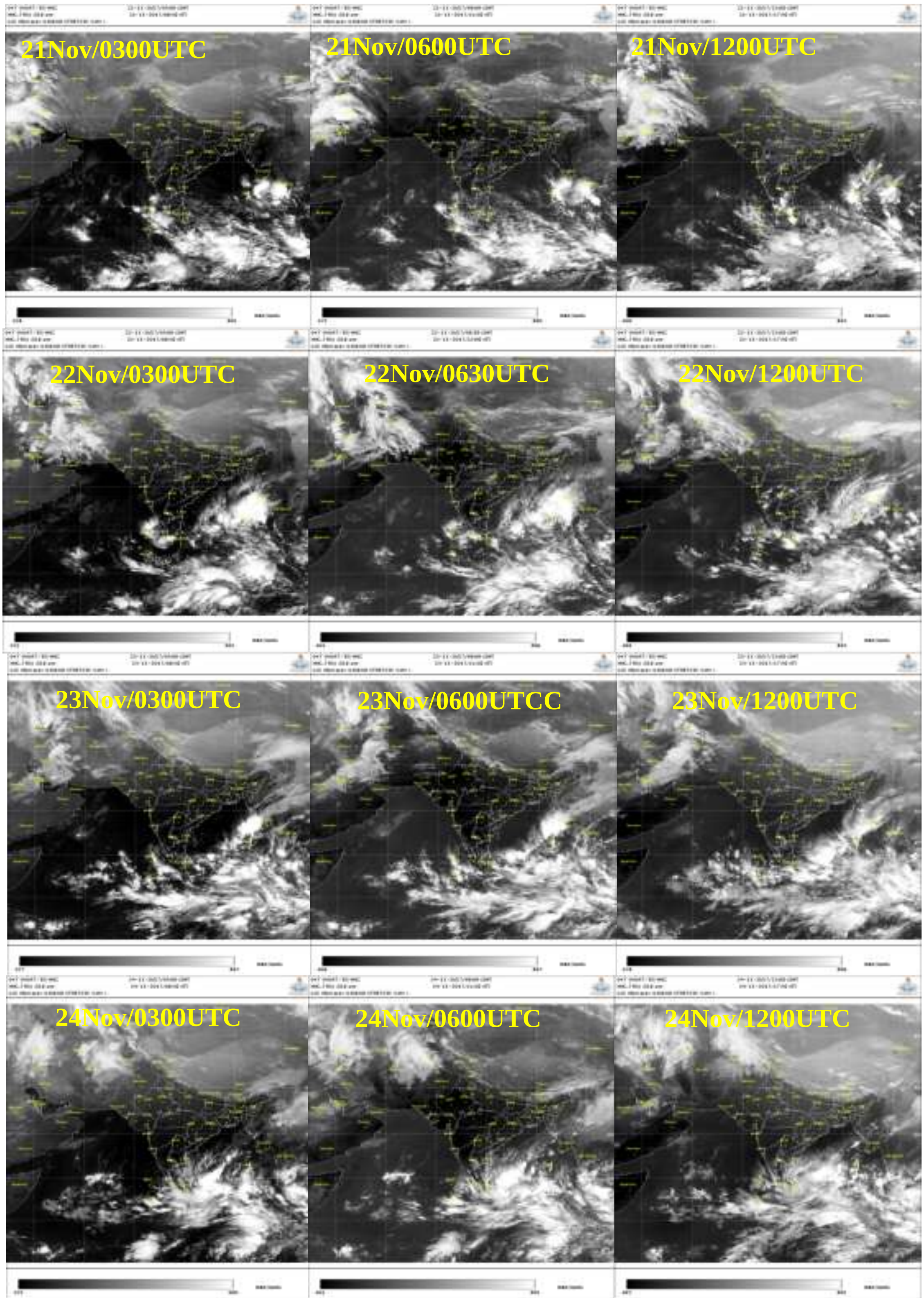


Fig.3:. INSAT-3D (IR) imageries during 21st to 30th Nov. 2017

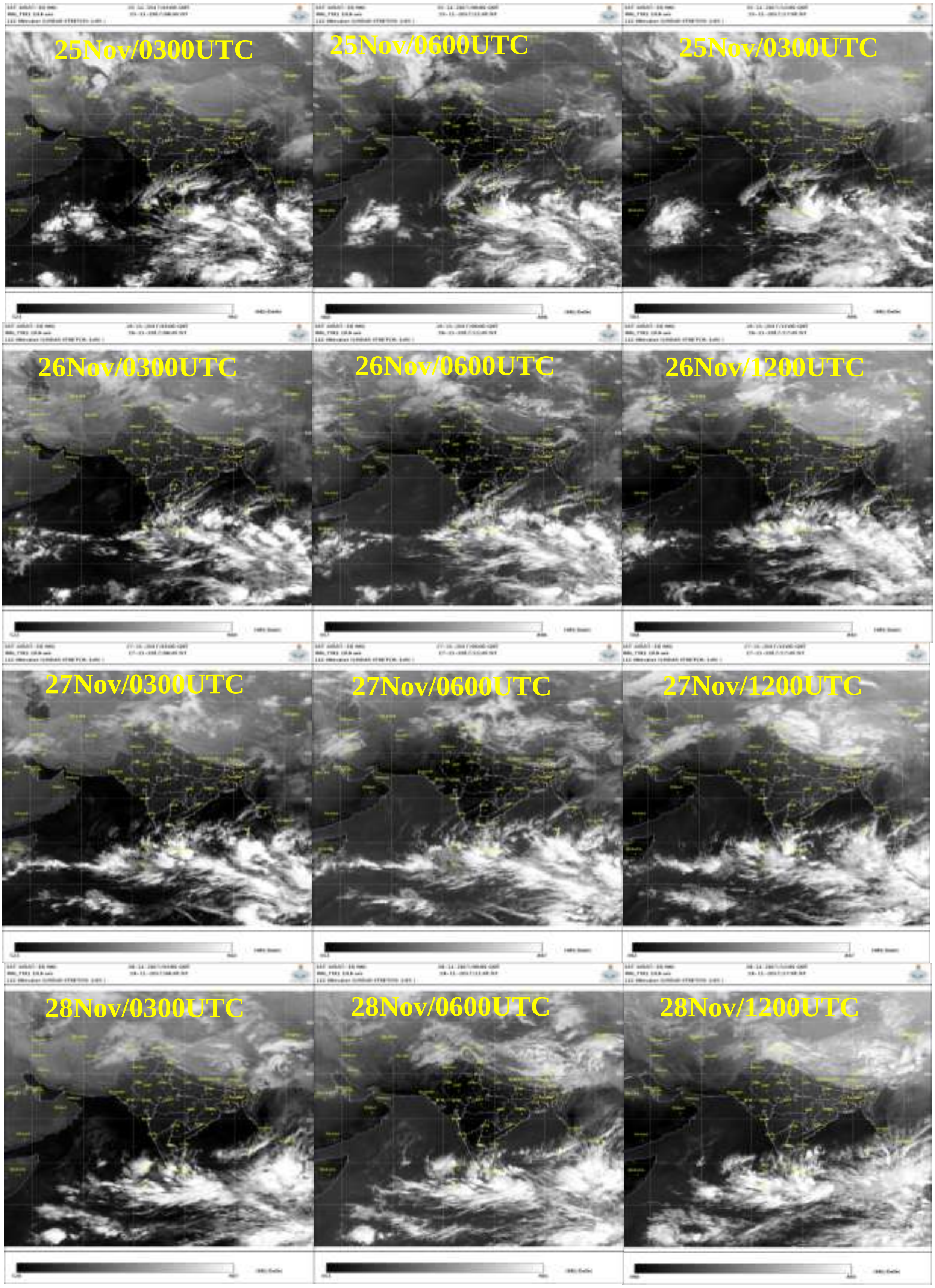


Fig. 3:.(Cont.) INSAT-3D (IR) imageries during 21st to 28th Nov. 2017

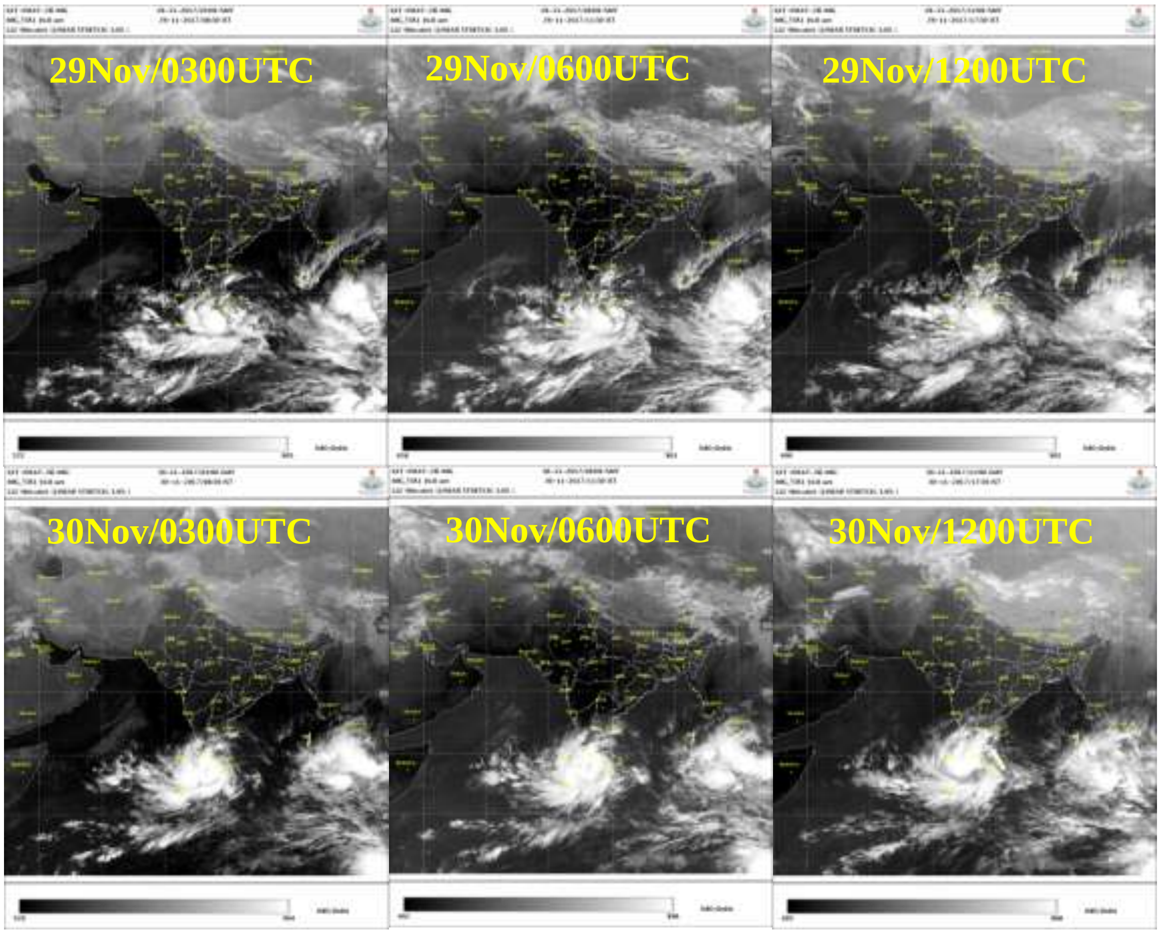


Fig. 3:.(contd.) INSAT-3D (IR) imageries during 29th to 30th Nov. 2017

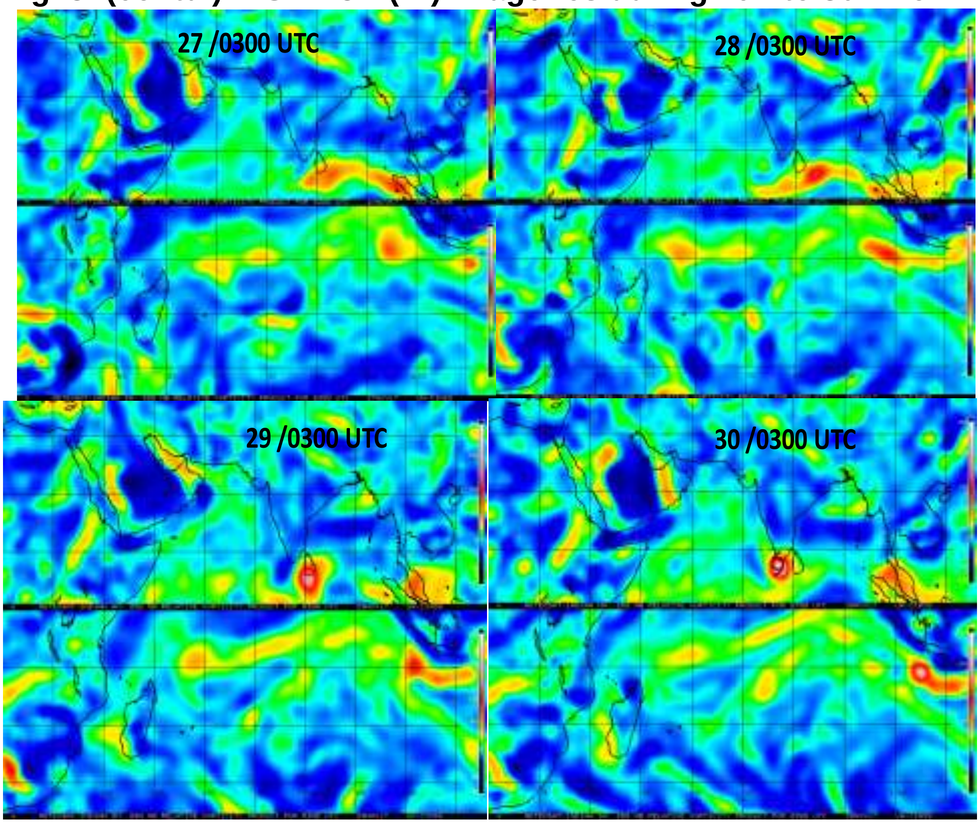


Fig. 4 (a) Vorticity at 850 hpa level based on 0300 UTC during the period 27th-30th.

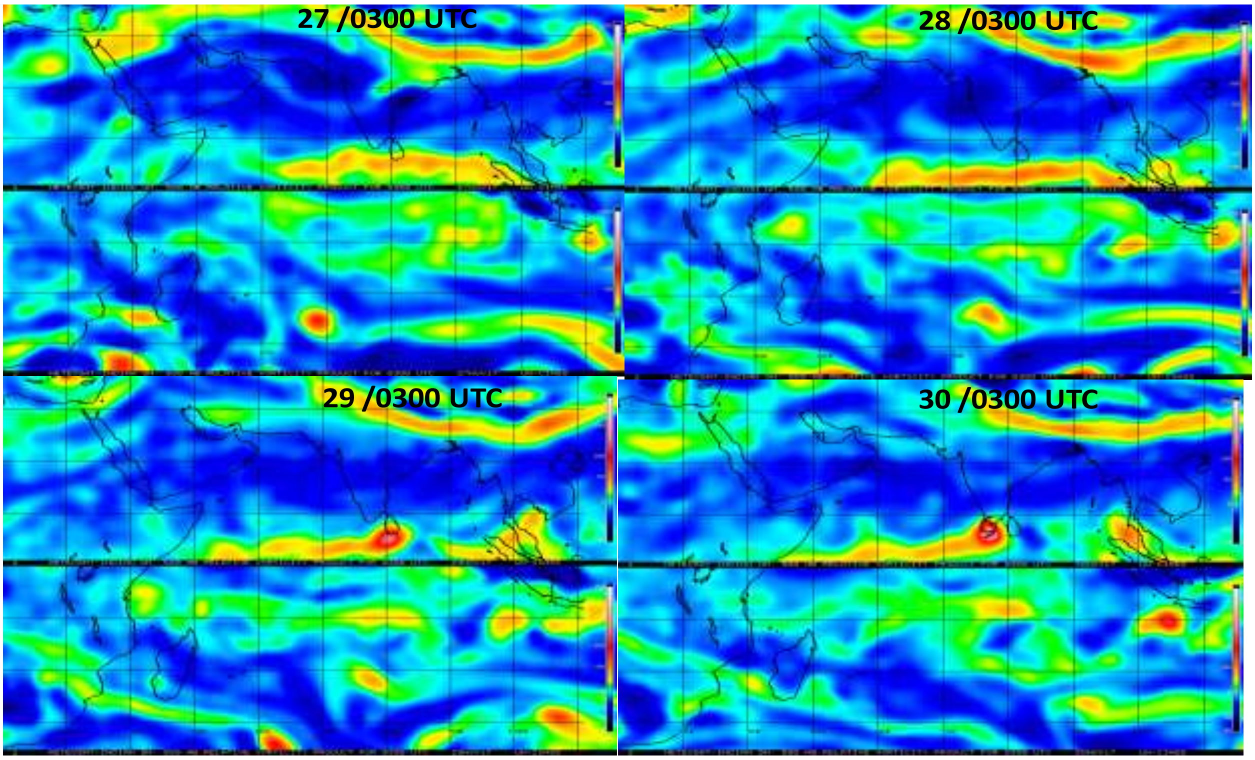


Fig. 4(a) (contd.) Vorticity at 500 hpa level during the period 27th-30th.

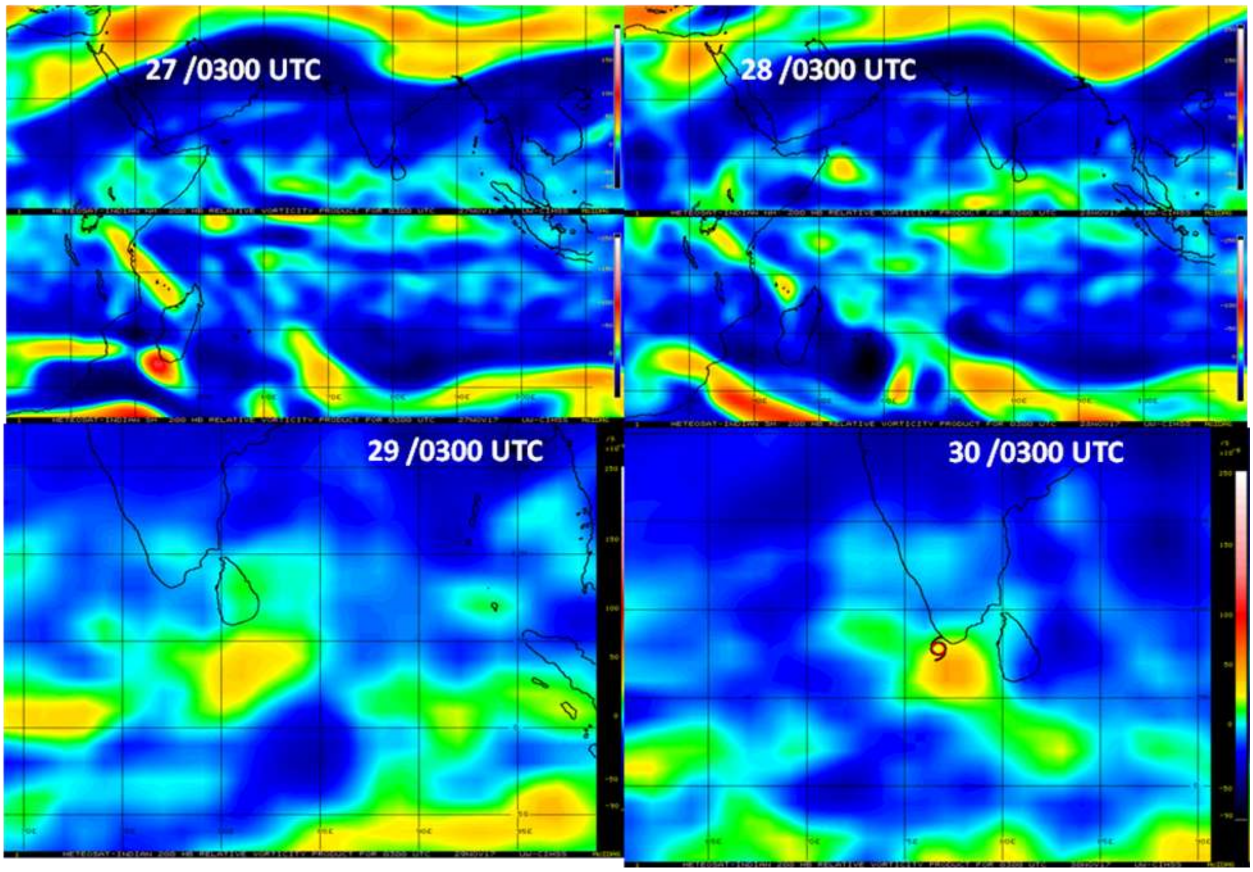


Fig. 4(a) (contd.) Vorticity at 200 hpa level during the period 27th-30th.

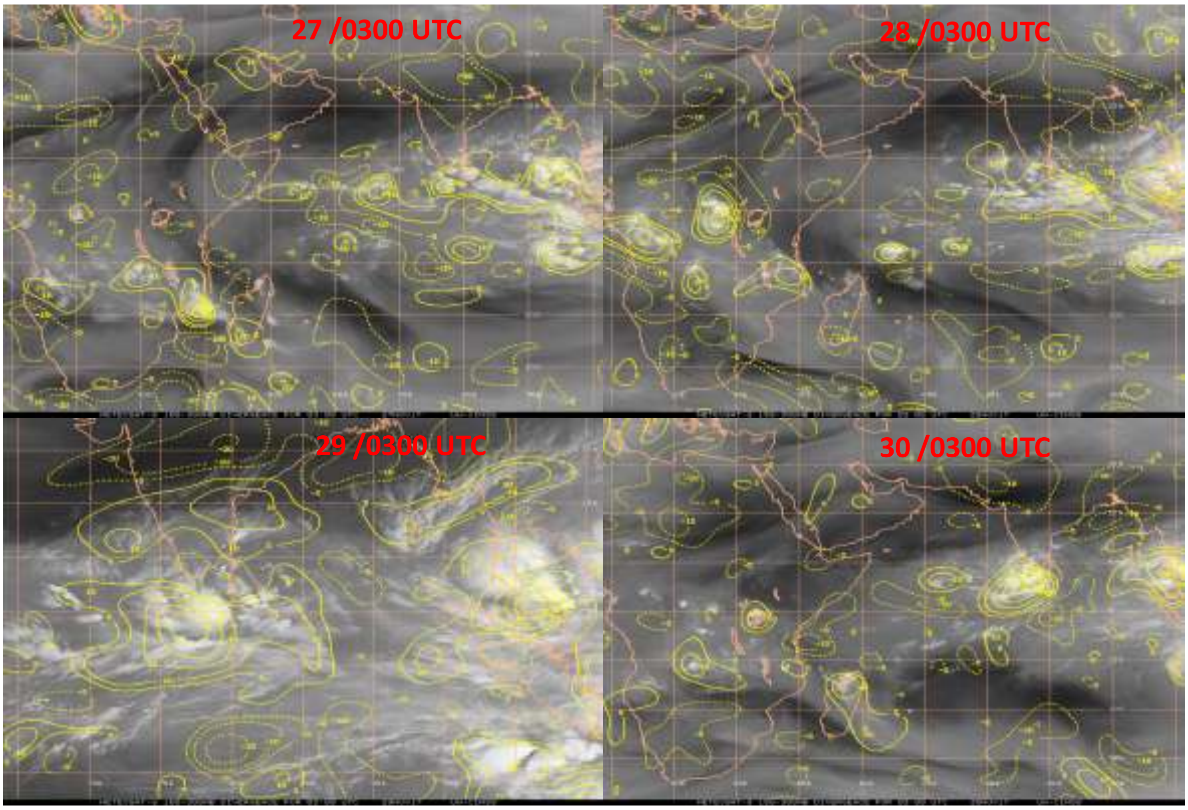


Fig. 4(b) Lower Level Convergence based on 0300 UTC during the period 27th-30th.

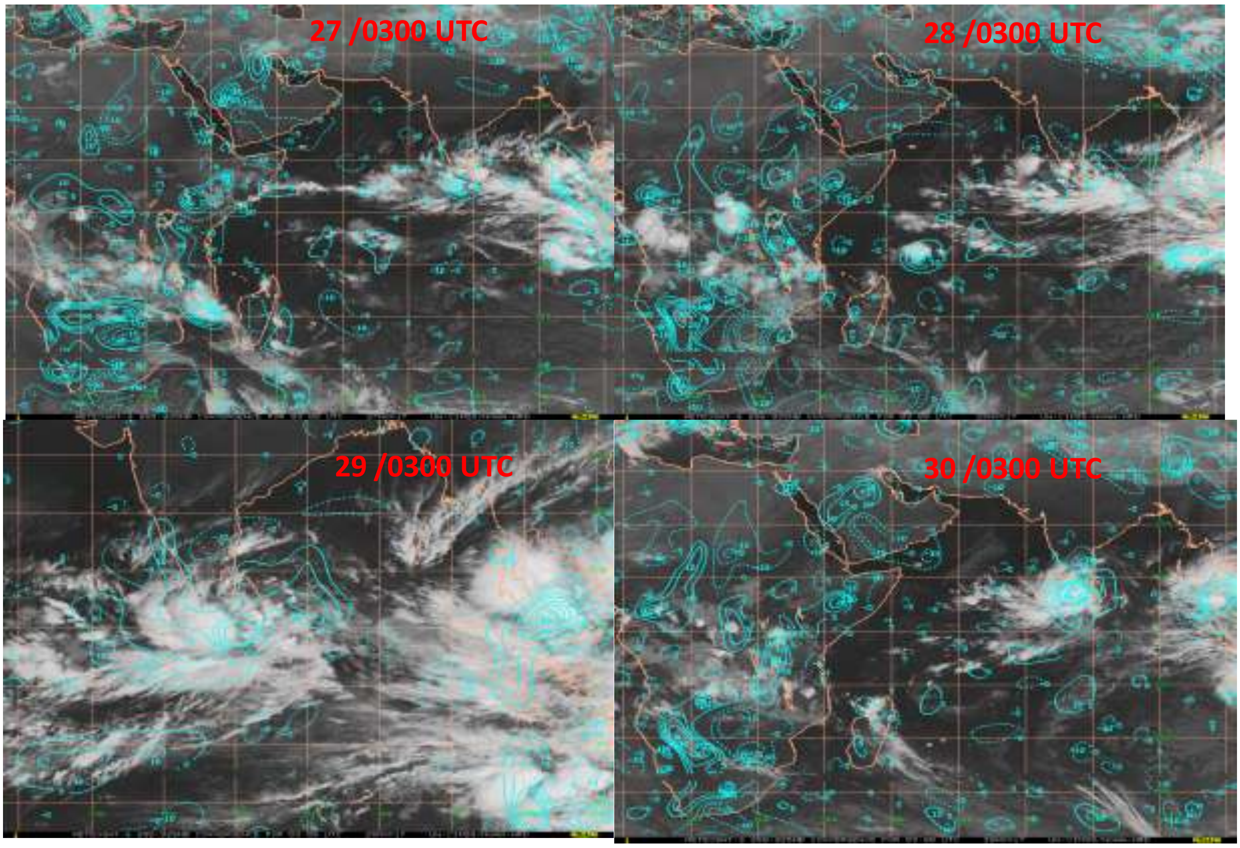


Fig. 4(c): Upper Level Divergence based on 0300 UTC during the period 27th-30th.

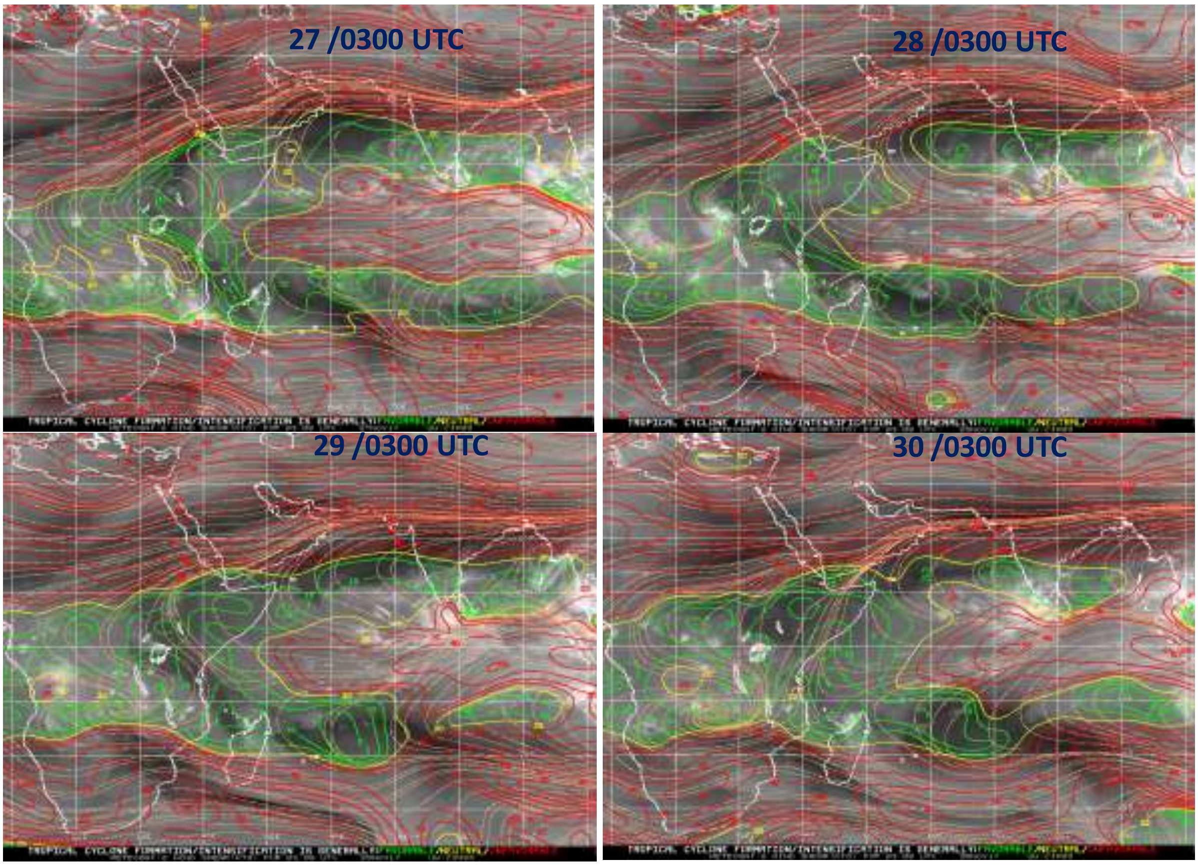


Fig. 4(d): Vertical wind shear based on 0300 UTC of during the period 27th-30th.

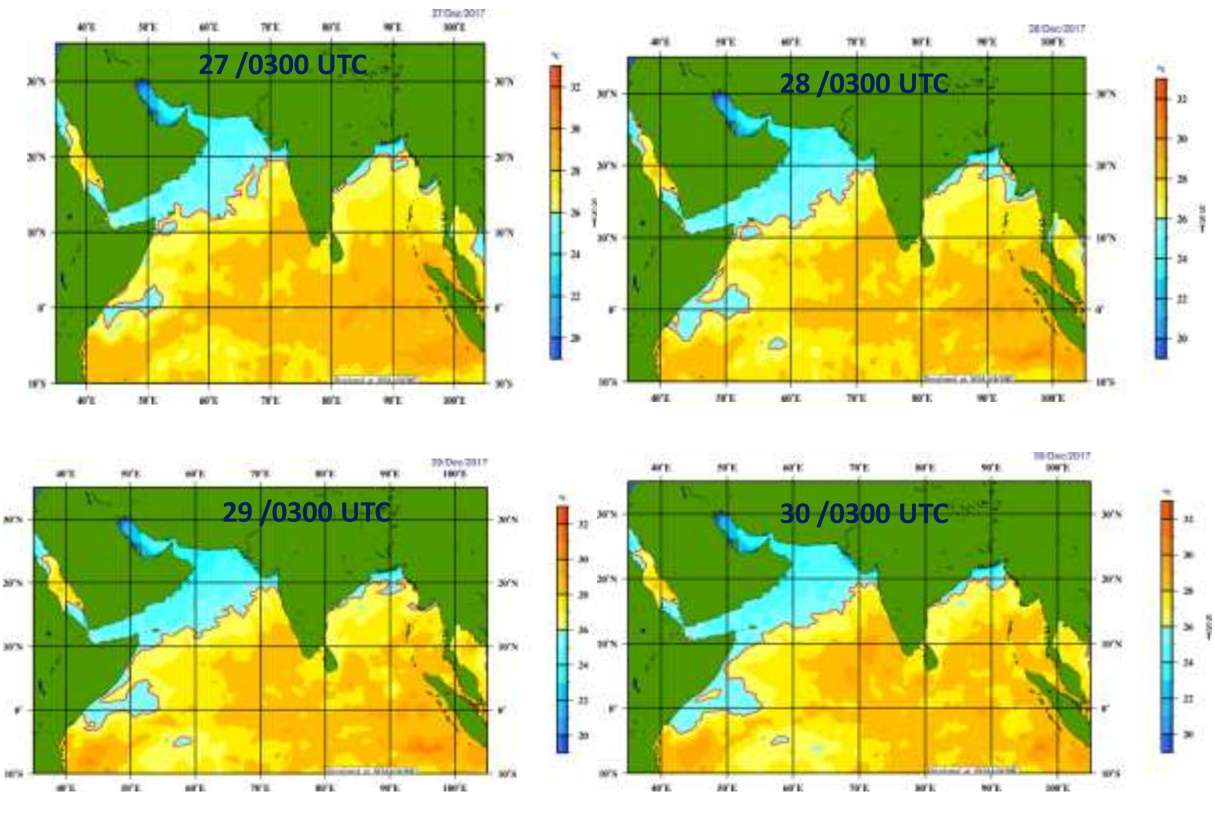


Fig. 4(e): Sea Surface Temperature (SST) during 27th-30th

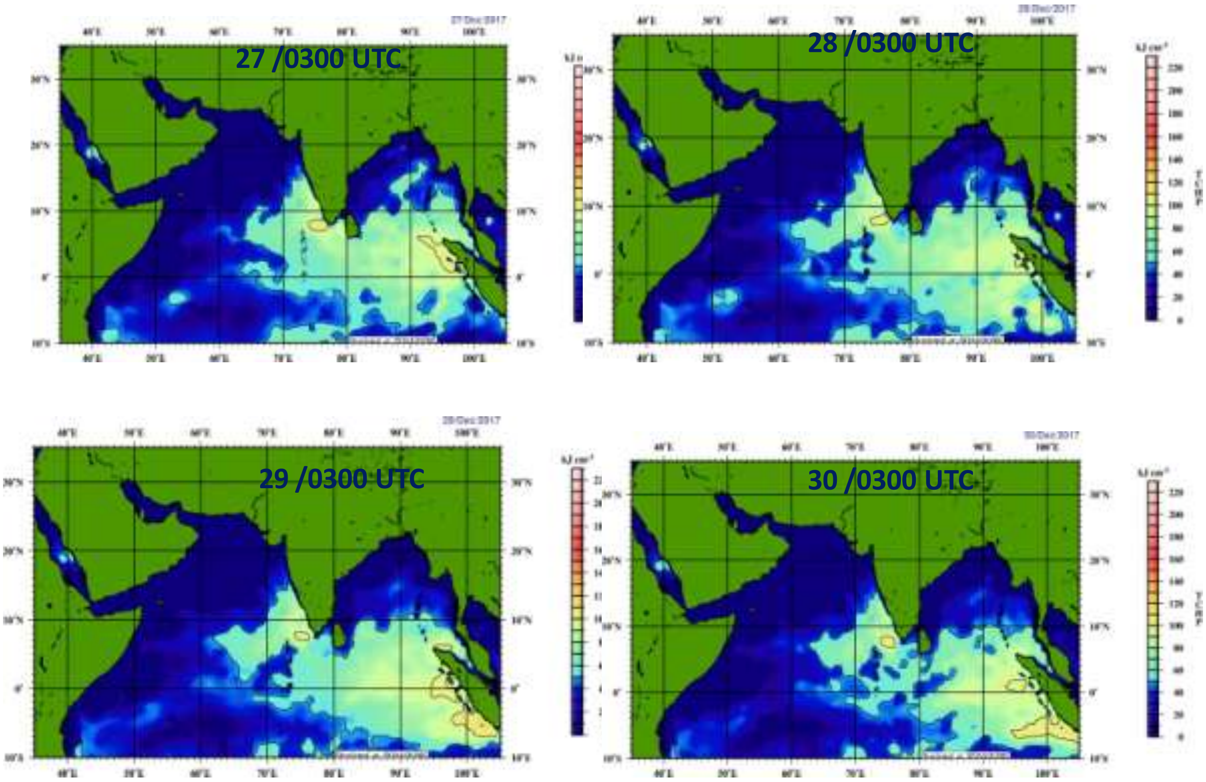


Fig. 4(f): Ocean Heat Content during the period 27th-30th.

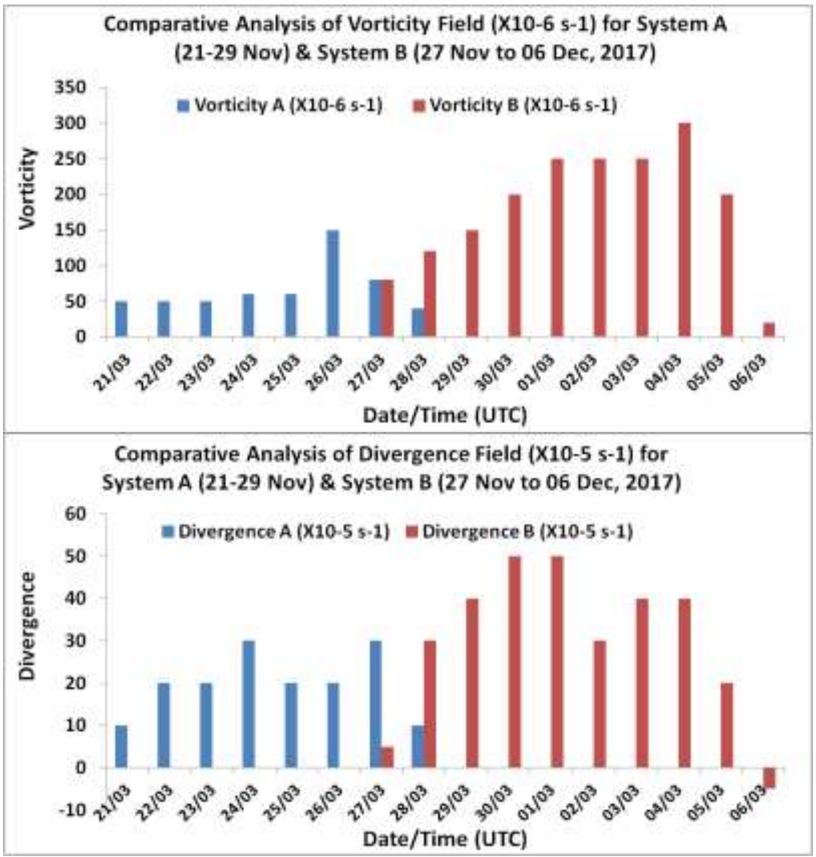


Fig.5: Comparative analysis of vorticity and divergence fields during 21-29 Nov and 27-06 Dec for the systems A (prior to genesis of Ockhi) and system B (Ockhi)

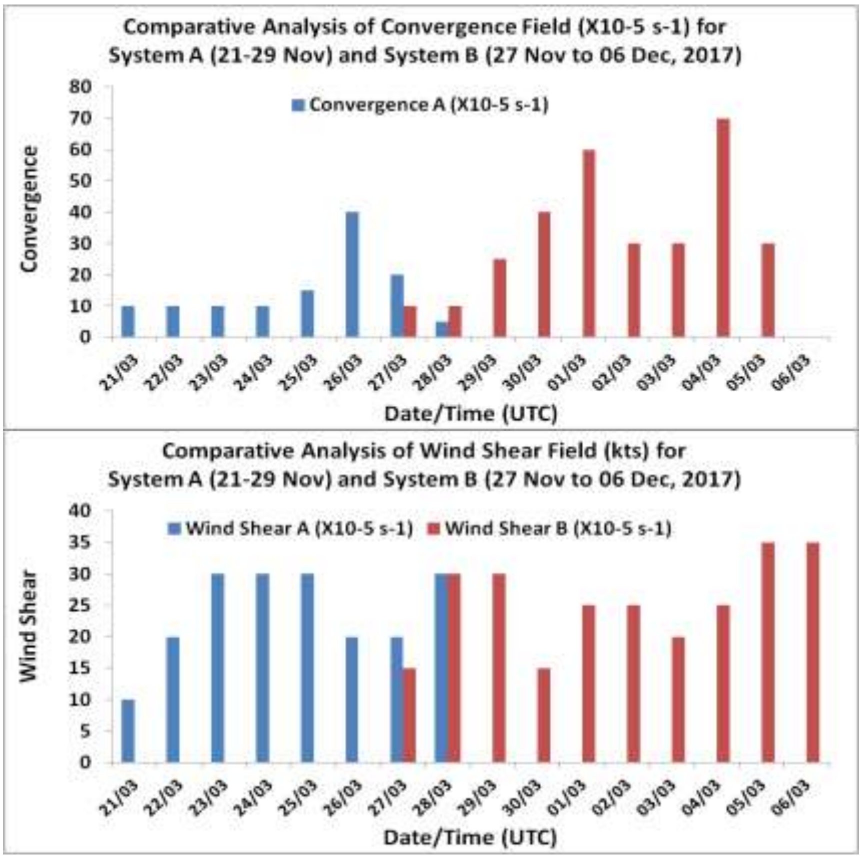


Fig.5 (contd.): Comparative analysis of convergence and wind shear fields during 21-29 Nov and 27 Nov-06 Dec for the systems A (prior to genesis of Ockhi) & system B (Ockhi)

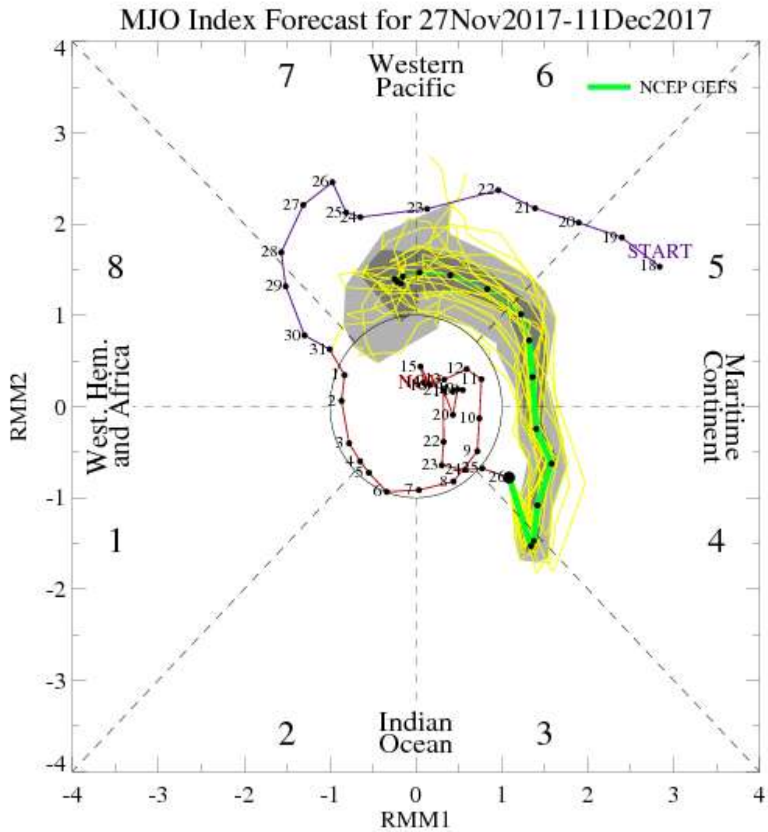


Fig. 6: MJO during the period 26th-Nov. to 10th Dec.

4. Brief life history of Ockhi

4.1. Genesis

At 0300 UTC of 27th, the sea surface temperature (SST) over southwest BoB and adjoining Sri Lanka coast was around 28-29˚C. The Ocean thermal energy was around 60-80 KJ/cm^2 over south of Comorin, 80-100 KJ/cm^2 over Comorin Area and >100 KJ/cm^2 over southwest Sri Lanka. The low level convergence was about 20x10^{-5} second^{-1} to the south of Comorin, the upper level divergence was around 30x10^{-5} second^{-1} to the south of Comorin, and the low level relative vorticity was about 80x10^{-6} second^{-1} to the southeast of Srilanka with vertical extension upto 500 hPa levels. The vertical wind shear of horizontal wind was low to moderate (5-10 knots) over southwest BoB off north Sri Lanka coast, 15-20 knots over east Comorin & adjoining Palk Strait, 20-30 knots over west Comorin and south. The Madden Julian Oscillation (MJO) index was in phase 4 with amplitude >1. The upper tropospheric ridge at 200 hPa level lay along 14^{0}N near 80^{0}E. Under these environmental conditions, a trough of low developed over southwest BoB and adjoining Sri Lanka on 27th November. At 0300 UTC of 28th, similar thermal conditions prevailed over southwest BoB and adjoining Sri Lanka coast. However, dynamical features over southwest BoB off Sri Lanka coast organized. The low level convergence was about 10x10^{-5} second^{-1} to the northeast and south of Sri Lanka. The upper level divergence was around 30x10^{-5} second^{-1} to the southeast of Sri Lanka. The low level relative vorticity increased to 120x10^{-6} second^{-1} over southwest BoB off south Srilanka with vertical extension upto 200 hPa level. The vertical wind shear of horizontal wind was moderate to high (15-30 knots) over southwest BoB and adjoining Sri Lanka coast. The MJO index continued in phase 4 with amplitude >1. The upper tropospheric ridge at 200 hPa level lay along 13^{0}N near 80^{0}E. All these conditions favoured the formation of low pressure area over southwest BoB and adjoining areas of south Sri Lanka & equatorial Indian Ocean in the forenoon (0830 IST) of 28th November.

At 0000 UTC of 29th, the sea surface temperature (SST) over southwest BoB and adjoining Sri Lanka coast was around 28-29˚C. The Ocean thermal energy was around 60-80 KJ/cm^2 over southwest BoB adjoining southeast Sri Lanka & south Comorin area and >80 KJ/cm^2 over north Comorin. However, dynamical features over southwest BoB off Sri Lanka coast further organized. The low level convergence was about 20x10^{-5} second^{-1} to the south of Sri Lanka near 5^{0}N. The upper level divergence increased and was around 40x10^{-5} second^{-1} to the south of Comorin. The low level relative vorticity increased and was about 150x10^{-6} second^{-1} to the south of Sri Lanka and adjoining coast with vertical extension upto 200 hPa level. The vertical wind shear of horizontal wind was high (30 knots) over Comorin and 15-20 knots over southwest BoB off southeast Sri Lanka coast. The wind shear over southwest BOB off southeast Sri Lanka coast showed decreasing tendency of about 10-20 knots during past 24 hrs. It showed increasing tendency of 5-10 knots over Comorin area. The MJO index continued in phase 4 with amplitude >1. The upper tropospheric ridge at 200 hPa level lay along 15^{0}N. All these conditions led to concentration of low into a Depression at 0830 IST of 29th, with centre near 6.5º N/81.8 ºE, about 80 km to the east-southeast of Hambantota (Sri Lanka) and 500 km east southeast of KanyaKumari (Tamil Nadu).

The best track parameters of the systems are presented in Table 1**.**

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm, 'Ockhi' over the Bay of Bengal during 29 Nov-05 Dec, 2017

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
29/11/2017	0300	6.5/81.8	1.5	1004	25	3	**D**
	0600	6.5/80.4	1.5	1004	25	4	D
	1200	6.2/80.0	1.5	1002	25	4	D
	1800	6.3/79.2	1.5	1002	25	4	D
	2100	6.5/78.6	2.0	1001	30	5	**DD**
30/11/2017	0000	6.7/78.3	2.0	1000	30	6	DD
	0300	7.5/77.5	2.5	999	35	7	**CS**
	0600	7.8/76.9	2.5	998	40	8	CS
	0900	7.9/76.4	3.0	996	45	10	CS
	1200	8.2/75.8	3.0	996	45	10	CS
	1500	8.3/75.4	3.0	996	45	10	CS
	1800	8.5/74.9	3.0	994	45	12	CS
	2100	8.6/74.5	3.0	994	45	12	CS
01/12/2017	0000	8.8/74.0	3.0	992	50	14	**SCS**
	0300	8.9/73.8	3.5	990	55	16	SCS
	0600	9.0/73.4	3.5	989	60	18	SCS
	0900	9.1/73.0	4.0	988	65	21	**VSCS**
	1200	9.2/72.8	4.0	986	65	22	VSCS
	1500	9.3/72.5	4.0	984	65	24	VSCS
	1800	9.4/72.1	4.0	982	70	26	VSCS
	2100	9.5/71.8	4.0	980	75	28	VSCS
02/12/2017	0000	9.6/71.5	4.5	978	80	30	VSCS
	0300	9.7/71.2	4.5	978	80	32	VSCS
	0600	9.8/71.0	4.5	976	85	34	VSCS
	0900	10.2/70.6	4.5	976	85	34	VSCS
	1200	10.5/70.3	4.5	976	85	34	VSCS
	1500	10.8/70.0	4.5	976	85	34	VSCS
	1800	11.1/69.7	4.5	976	85	34	VSCS
	2100	11.3/69.5	4.5	976	85	34	VSCS
03/12/2017	0000	11.7/69.2	4.5	976	85	34	VSCS
	0300	12.1/69.0	4.5	977	80	32	VSCS
	0600	12.3/68.9	4.5	978	75	30	VSCS
	0900	12.4/68.8	4.5	980	75	28	VSCS
	1200	12.9/68.7	4.5	982	75	28	VSCS

	1500	13.1/68.6	4.5	982	75	28	VSCS
	1800	13.5/68.5	4.5	982	75	28	VSCS
	2100	14.0/68.5	4.5	982	75	28	VSCS
04/12/2017	0000	14.5/68.5	4.0	984	70	24	VSCS
	0300	14.7/68.5	4.0	986	65	22	VSCS
	0600	14.9/68.7	4.0	986	65	22	VSCS
	0900	15.2/69.0	4.0	986	65	22	VSCS
	1200	15.7/69.2	3.5	988	60	18	VSCS
	1500	16.1/69.5	3.5	988	60	18	VSCS
	1800	16.5/69.8	3.5	990	55	16	**SCS**
	2100	16.9/70.1	3.5	992	55	14	SCS
05/12/2017	0000	17.3/70.4	3.5	994	50	12	SCS
	0300	17.7/70.7	3.0	996	45	10	**CS**
	0600	18.1/71.0	2.5	998	40	08	CS
	0900	18.3/71.2	2.0	1000	30	06	**DD**
	1200	18.5/71.4	2.0	1002	30	05	DD
	1500	18.8/71.6	1.5	1003	25	04	**D**
	1800	19.2/71.9	1.5	1004	20	03	D
	2100	**Weakened into a well marked low pressure area over northeast and adjoining east central Arabian Sea, south coastal Gujarat and north coastal Maharashtra**					

3.2. Intensification

As east-northeasterly to easterly winds prevailed over mid to upper tropospheric levels, the system moved westwards, crossed Sri Lanka coast and emerged into Comorin area in the evening (1730 IST) of 29th. At 1800 UTC of 29th, the upper tropospheric ridge ran along latitude 14^{0}N. The upper level winds were nearly easterly over the system region and were becoming east-southeasterly over southeast Arabian Sea. The system thus moved initially nearly westwards and then west-northwestwards. The SST over the region was 28-29 ^{0}C. The Ocean thermal energy was about 100 KJ/cm^{2} over the area. The vertical wind shear was low to moderate (10-20 knots) around the system centre. It was increasing to west and to the south. The low level relative vorticity was around 200 x 10 $^{-6}$ s^{-1} to the southwest of the system centre. Low level convergence was around 60 x 10 $^{-5}$ s^{-1} to the southwest of the system centre. Upper level divergence was about 50 x 10 $^{-5}$ s^{-1} to the southwest of the system center. Under these conditions, the system intensified into a deep depression at 2100 UTC of 29th and lay centered over Comorin area and neighbourhood near 6.5ºN/78.6ºE, about 185 km northwest of Galle (Sri Lanka) and 210 km south-southeast of Kanyakumari (Tamil Nadu).

With the similar favorable environmental conditions, the system moved west-northwestwards and intensified from DD into a CS over Comorin Area within six hours and lay near 7.5ºN/77.5ºE, about 340 km west-northwest of Galle, 60 km south of Kanyakumari, 120 km southwest of Thiruvananthapuram (43372) and 480 km east-southeast of Minicoy (43369) at 0300 UTC of 30th Nov. The observations indicated that there was continuous fall of pressure over entire India, being maximum over southern Peninsular India and Sri Lanka within 4 hPa till 1200 UTC of 29th. It further dropped to 4-6 hPa at 0300 UTC of 30th.There was also continuous negative departure of pressure from normal over entire India, being maximum over south Peninsula (within 4 hPa till 29/1200 UTC and by 8 hPa at 30/0300 UTC).

The upper tropospheric ridge shifted gradually northwards and at 0000 UTC of 1st December, it ran along latitude 17^{0}N. The winds were nearly southeasterly over southeast Arabian Sea. The SST over the region was 28-30^{0}C. The Ocean thermal energy was about 100 KJ/cm^2 over the area. The vertical wind shear increased and was moderate (20-25 knots) around the system centre. The low level relative vorticity increased and was about 250x10^{-6} s^{-1} around the system centre. Low level convergence was around 30x10 $^{-5}$ s^{-1} to the south of system centre and upper level divergence was about 50 x 10 $^{-5}$ s^{-1} to the south of the system centre. MJO index lay in phase 4 with amplitude more than 1. Under these conditions, the system moved west-northwestwards, intensified into a severe cyclonic storm and lay centered over southeast Arabian Sea near latitude 8.8ºN/74.0ºE, about 110 km north-northeast of Minicoy (Lakshadweep Island) at 0000 UTC of 1st Dec.

At 0900 UTC of 1st December, the system moved west-northwestwards, further intensified into a very severe cyclonic storm and lay centred over Lakshadweep area and adjoining southeast Arabian Sea near latitude 9.1ºN/73.0ºE, about 90 km north of Minicoy (Lakshadweep Island). The upper tropospheric ridge ran along latitude 15^{0}N. The winds at upper level were southeasterly over southeast Arabian Sea. The SST over the region was 28-30 ^{0}C. The Ocean thermal energy was about 100 KJ/cm^2 over the area. The vertical wind shear further increased and was high (20-25 knots) around the system centre. It was decreasing to the north of system centre. The low level relative vorticity was around 250x10^{-6} s^{-1} around the system centre. Low level convergence was around 30x10^{-5} s^{-1} to the southwest of system centre. Upper level divergence also decreased and was about 30 x 10 $^{-5}$ s^{-1} to the southwest of the system centre. Though the vertical wind shear was unfavorable and there was decrease in upper level divergence, the system continued to intensify due to favorable relative vorticity, MJO and high Ocean heat content and reached its maximum intensity of 85 knots at 0600 UTC of 2nd Dec. and lay over Lakshadweep area and adjoining southeast Arabian Sea near latitude 9.8ºN/71.0ºE.

At 0600 UTC of 2nd, the SST over the region was 29-30 ^{0}C. The ocean thermal energy was about 75-100 KJ/cm^2 over the area. It decreased towards the north. The low level relative vorticity was around 250x10^{-6} s^{-1} to the south of the system centre. Low level convergence was about 30x10 $^{-5}$ s^{-1} around the system centre. Upper level divergence was about 30 x 10 $^{-5}$ s^{-1} to the southwest of the system centre. The vertical wind shear was high.

From early morning of 3rd December, the system entered into an area of lower Ocean Heat content. At 0300 UTC of 3rd, the SST over the region was 28-29 ^{0}C. However, the ocean thermal energy was about 60-70 KJ/cm^2 over the area. It was decreasing towards the north. Though the low level relative vorticity was around 300x10^{-6} s^{-1} to the southwest of the system centre, low level convergence was around 30x10 $^{-5}$ s^{-1} to the southwest of the system centre, upper level divergence was about 30 x 10 $^{-5}$ s^{-1} to the northwest of the system centre and the vertical wind shear was moderate to high (15-25 knots) around the system centre and it was increasing towards north. Under these conditions, the system moved north-northwestwards and started weakening. It lay over eastcentral and adjoining southeast Arabian Sea near latitude 12.1ºN and longitude

69.0ºE at 0300UTC of 3rd. The system was steered by peripheral winds in association with anticyclone over BoB.

At 0300 UTC of 4th, the low level relative vorticity was about $300 \times 10^{-6}\ s^{-1}$ to the south of the system centre. Low level convergence was about $40 \times 10^{-5}\ s^{-1}$ around the system centre. Upper level divergence was about $70 \times 10^{-5}\ s^{-1}$ around the system centre. The vertical wind shear was high (20-30 knots) around the system centre. The wind shear was increasing towards north. The SST over the region was 27-28^{0}C. The Ocean thermal energy was about 30-50 KJ/cm^2 over the area. It was further decreasing towards the north. Total precipitable water (TPW) imagery at that time indicated cold and dry air entering into the system. The warm and moist air advection to the system centre showed gradual decrease. The system was steered by winds at the periphery of the anti cyclone over BoB and a deep trough in middle and upper tropospheric levels running along 60^{0}E to the north of 17^{0}N. All these features indicated that Ocean heat content supported with high vertical wind shear helped in further weakening of the system with north-northeastward movement.

At 1200 UTC of 4th, the low level relative vorticity decreased and was about $200 \times 10^{-6}\ s^{-1}$ to the southeast of the system centre. Low level convergence decreased and was around $30 \times 10^{-5}\ s^{-1}$ to the northeast of the system centre. Upper level divergence decreased and was about $30 \times 10^{-5}\ s^{-1}$ to the northeast of the system centre. The vertical wind shear was high (25-30 knots) around the system centre and it showed increasing tendency towards north. The SST over the region was 28-29 ^{0}C. It was decreasing to the north becoming 25-26 ^{0}C off Gujarat coast. The ocean thermal energy was about 30-50 KJ/cm^2 over the area and it was further decreasing towards the north. There was dry and cold air intrusion of mid-latitude westerlies in the middle and upper tropospheric levels. The TPW imagery at that time indicated cold and dry air entering into the system. The warm and moist air advection to the system centre continued to decrease. Under these environmental conditions, the system continued to weaken. The total precipitable water imageries (TPW) during 29 November-05 December are presented in Fig.3.

There was gradual increase in dry and cold air intrusion from mid latitude westerlies, decrease in warm & moist air advection into the core of system, increase in vertical wind shear and decrease in Ocean thermal energy as the system moved north-northeastwards. There was also decrease in upper level divergence and lower level convergence. All these features led to weakening of the system into SCS at 1800 of 4th, CS at 0300 UTC of 5th, DD at 0900 UTC of 5th and D at 1500 UTC of same day. Finally, the system weakened into a well marked low pressure area over northeast Arabian Sea and adjoining eastcentral Arabian Sea, south coastal Gujarat and north coastal Maharashtra and crossed south coast of Gujarat between Surat and Dahanu as a well marked low around early morning (0000 UTC) of 6th Dec.

These imageries indicate continuous warm and moist air advection from southeast sector into the system till 30th night. The dry air enveloped the outer core of the system from north and west from 1st December. The same process continued on 2nd also with dry and cold air reaching upto southwest sector in the outer core region. Accordingly, the warm and moist air incursion was limited only from southeast sector. On 3rd, the warm and mosit air incursion from southeast sector further decreased significantly and by midnight of 3rd, the inner core was completely cut off from warm air advection and was completely surrounded by cold dry air. Accordingly, rapid weakening of the system started from early morning of 4th.

To conclude, the intensification/weakening was largely governed by the Ocean heat content. However, the rapid weakening on 4th and 5th Dec was facilitated by dry &

cold air intrusion and high vertical wind shear under the influence of a trough in mid-latitude westerlies in middle and upper tropospheric levels running along 60^0E to the north of 17^0N in the morning of 4^{th} Dec.

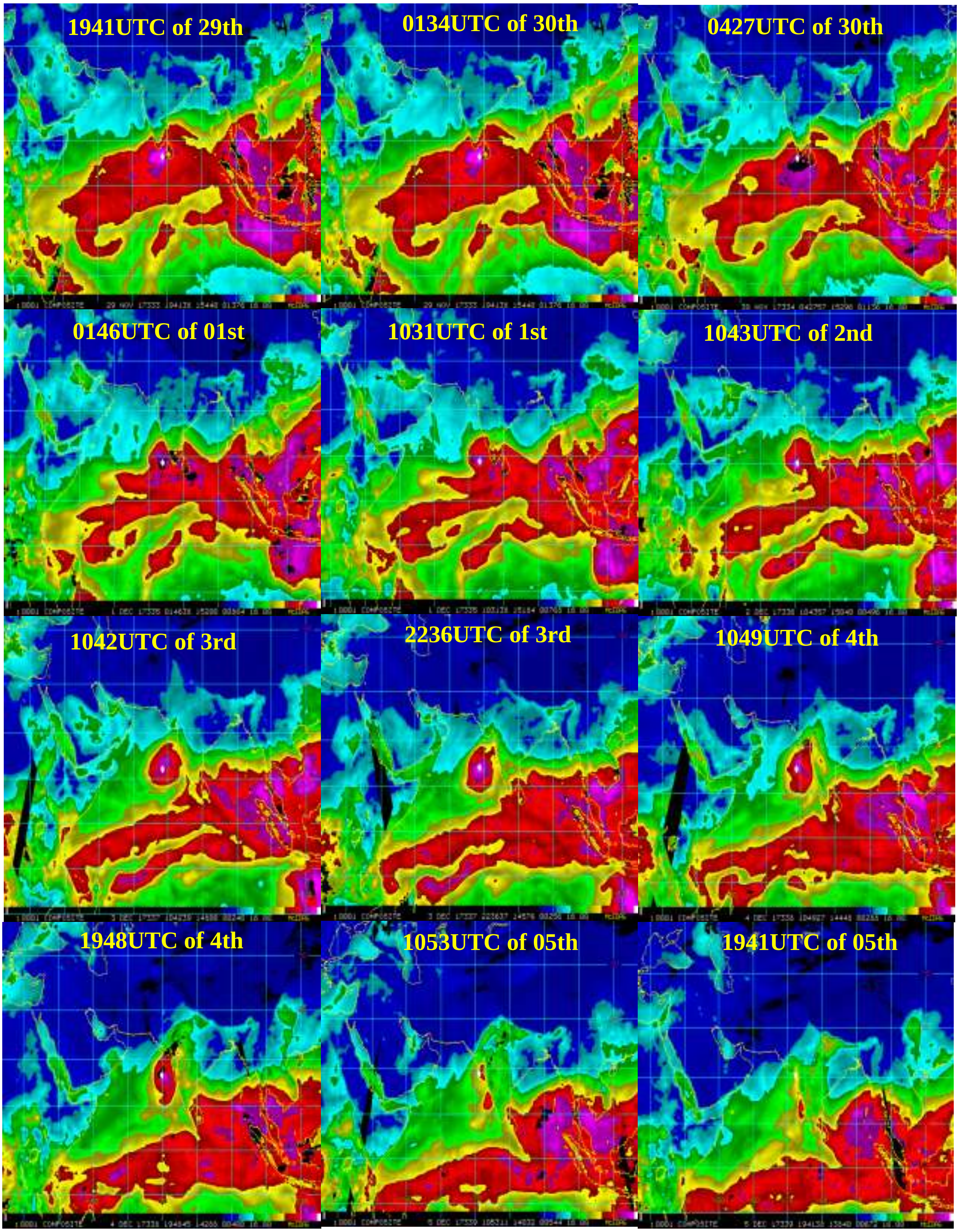


Fig. 6: Total Precipitable Water Imageries during 29 Nov.-06 Dec., 2017

4.3. Movement

Under the influence of easterly winds prevailing over mid to upper tropospheric levels, VSCS Ockhi moved initially westwards till 0600 UTC of 29th. Thereafter, it moved west-southwestwards till 1800 UTC of same day. From 2100 UTC of 29th, the system moved west-northwestwards under the influence of east-southeasterly winds prevailing over southeast Arabian Sea. The system moved nearly northwards from 2100 UTC of 3rd to 0300 UTC of 4th and north-northeastwards thereafter, as the system was steered by winds in the periphery of the anticyclone over BoB and a deep trough in middle and upper tropospheric levels running along 60^{0}E to the north of 17^{0}N. The twelve hourly movement (speed & direction) of VSCS Ockhi is presented in Fig.7

The 12 hourly average translational speed of the cyclone was about 15.29 kmph. The system moved very fast during during 0000 to 1200 UTC of 30th under the influence of strong easterly/ east-southeasterly winds prevailing over the region in middle and upper troposphere. The system had a track length of about 2538 km during its life period.

The mean wind in middle and deep layer around the system centre is presented in Fig.5. It indicates that the mean deep layer winds between 200-850 hPa levels steered the west-northwestward movement of the system from 1200 UTC of 29th onwards, northward movement during early hours of 4th and north-northeast movement thereafter. The initial westerly movement of the system was in association with the easterlies prevailing over southwest BoB in upper levels. The mean wind speed between 200-850 hpa levels was initially easterly till 1200 UTC of 30th. Thereafter, it became east-southeasterly till 0300 UTC of 1st December and southeasterly till 0000 UTC of 2nd. It then gradually changed becoming southerly by 1200 UTC of 3rd December and then south-southwesterly till it's dissipation. Considering the magnitude of mean wind speed between 200-850 hPa levels, it was 10kts initially, reaching about 13 kts by 1200 UTC of 30th. Thereafter, the wind speed gradually decreased becoming minimum of 7kts at 1500 UTC of 2nd December. It then gradually increased becoming 10 kts till 0000 UTC of 4th. It then increased rapidly reaching upto 20 kts by 1200 UTC of 5th. Considering the mean wind speed between 500-850 hPa levels, during genesis stage the variation was almost similar to that between 200-850 hPa levels. During genesis, it was around 7 kts. It then increased gradually reaching maximum of 12 kts at 1500 UTC of 30th November. It then decreased gradually reaching minimum of 2 kts by about 1500 UTC of 2nd. It then increased gradually reaching to 12 kts by 1200 UTC of 5th. These features suggest that the steering wind changed with intensification/weakening of the system. During SCS and higher intensity stage, the system was steered by the mean wind between 200-850 hPa levels and during D/DD/CS stage, it was steered by 500-850 hPa levels wind. It is mainly due to the fact that with the lower intensity, the vertical extension of the system was less which was also indicated in the vorticity field.

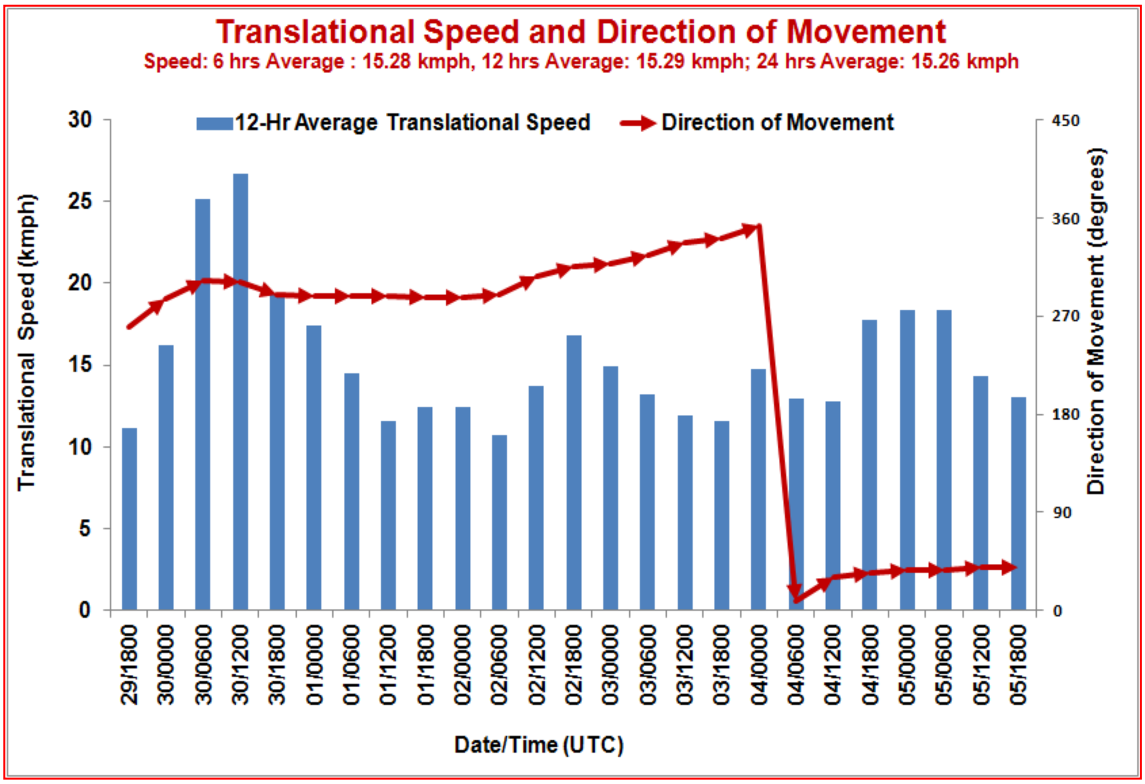


Fig.7: Twelve hourly average translational speed (kmph) and direction of movement in association with VSCS Ockhi

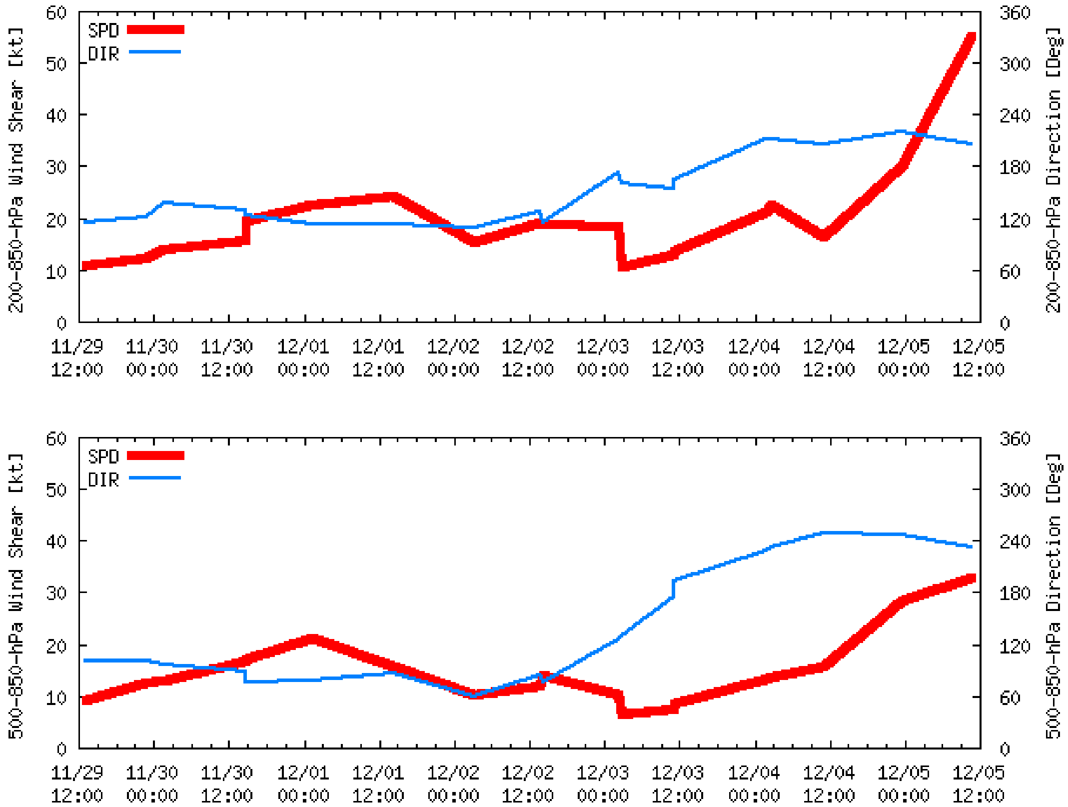


Fig.8 Wind shear in the middle and deep layer around the system during 29th Nov. to 05th Dec. 2017.

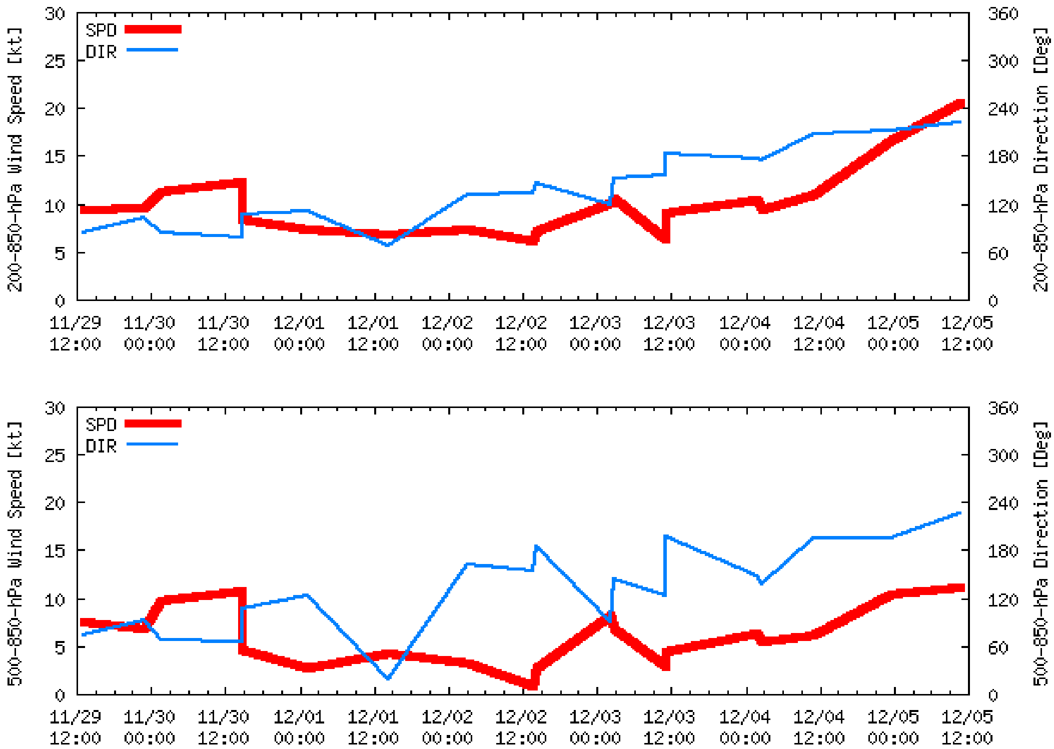


Fig.8 (contd.): Wind speed in the middle and deep layer around the system during 29th Nov. to 05th Dec. 2017.

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

The lowest estimated central pressure and the maximum sustained wind speed are presented in Fig.9 (a). The lowest estimated central pressure had been 976 hPa during 0600 UTC of 2nd to 0000 UTC of 3rd December. The estimated maximum sustained surface wind speed (MSW) was 85 knots during the same period. The ECP and Vmax graph indicates that the system intensified from 1800 UTC of 29th November (25 knots) to 1200 UTC of 30th (45 knots) maintained its intensity for next six hours and again increased from 1800 UTC of 30th November (45 knots) to 0600 UTC of 2nd December (85 knots), maintained its intensity till 0300 UTC of 30th and started weakening thereafter.

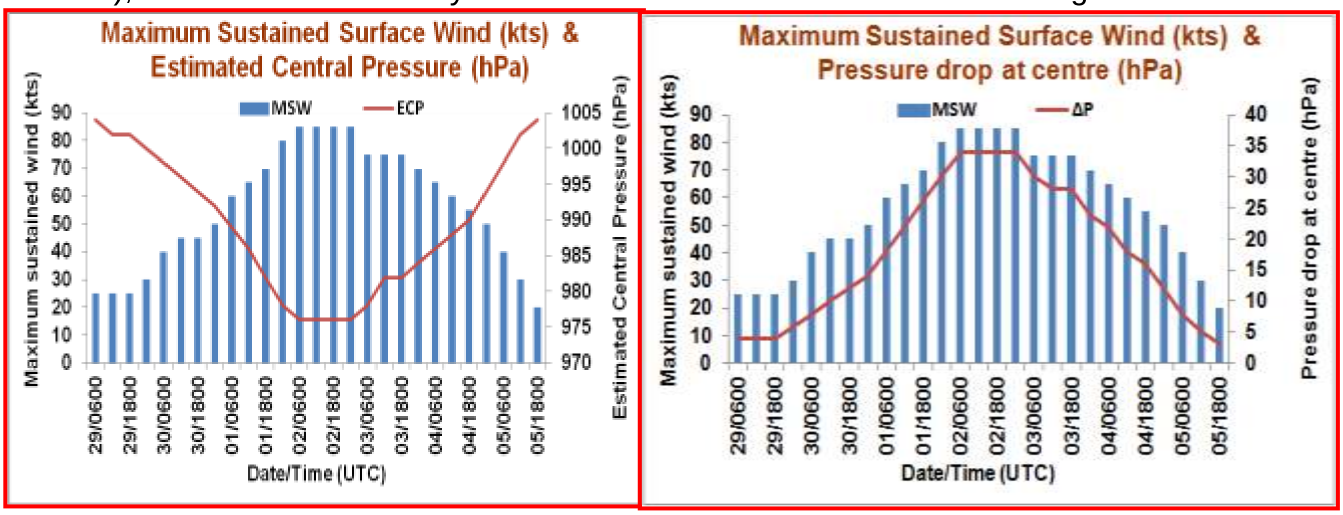


Fig.9 (a) Maximum sustained wind speed and (a) Lowest estimated central pressure & Pressure drop at centre

The 24 hour change in intensity (kts) ending at date and time is presented in Fig.9 (b). The system intensified rapidly from 1800 UTC of 30th to 0000 UTC of 2nd (increase in wind speed by 30 kts during past 24 hours). Similarly rapid weakening was observed during 0600 of 4th to 1800 UTC of 5th December. However, the SCIP and RI model of IMD did'nt predict rapid intensification (RI) and rapid weakening (RW). Based on 0000 UTC of 2nd, 3rd and 4th, RI model predicted probability of rapid intensification as Moderate. Though the intensity forecast showed weakening trend. Though it predicted Rapid Weakening (55 to 23 knot) based on 00 UTC of 5th Dec., it still predicted the system to cross the coast as a Depression (23 knots). As discussed earlier, the Ocean Heat Content is one of the most important parameters for intensification/weakening of low pressure systems. The currently available SCIP and RI model of NWP Division of IMD does not take into consideration the Ocean Heat Content as a predictor. HWRF model also underestimated weakening on 5th predicting 52 knots to 33 knots based on 00 UTC of 5th Dec., hence the system to cross as a DD/ marginal CS.

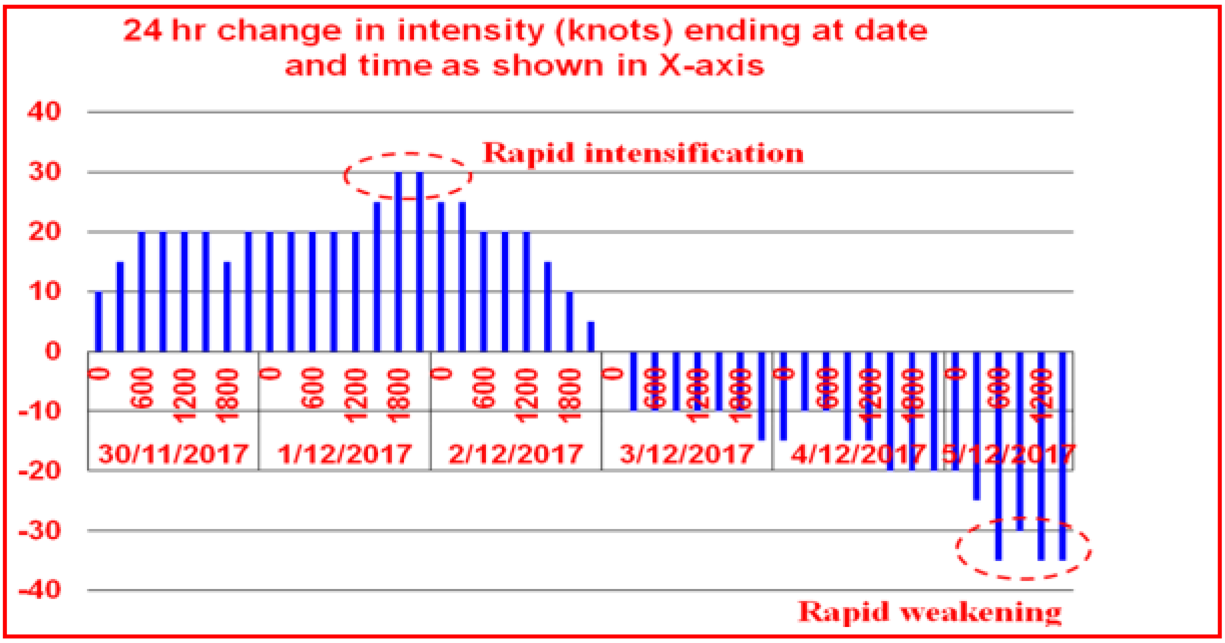


Fig. 9(b): 24 hour change in intensity (kts) ending at date and time during 30th Nov. to 5th Dec.

During the movement of TC OCKHI over Comorin, Maldives, Lakshadweep and southeast Arabian Sea during 30th to 4th December, the pressure and wind charts from various self recording instruments of IMD are presented in Fig. 9 (d-). The Vaisala Pressure Sensor at Kanyakumari reported minimum pressure of 997.4 hPa at 0300 UTC of 30th November (Fig. 9(c-z)).

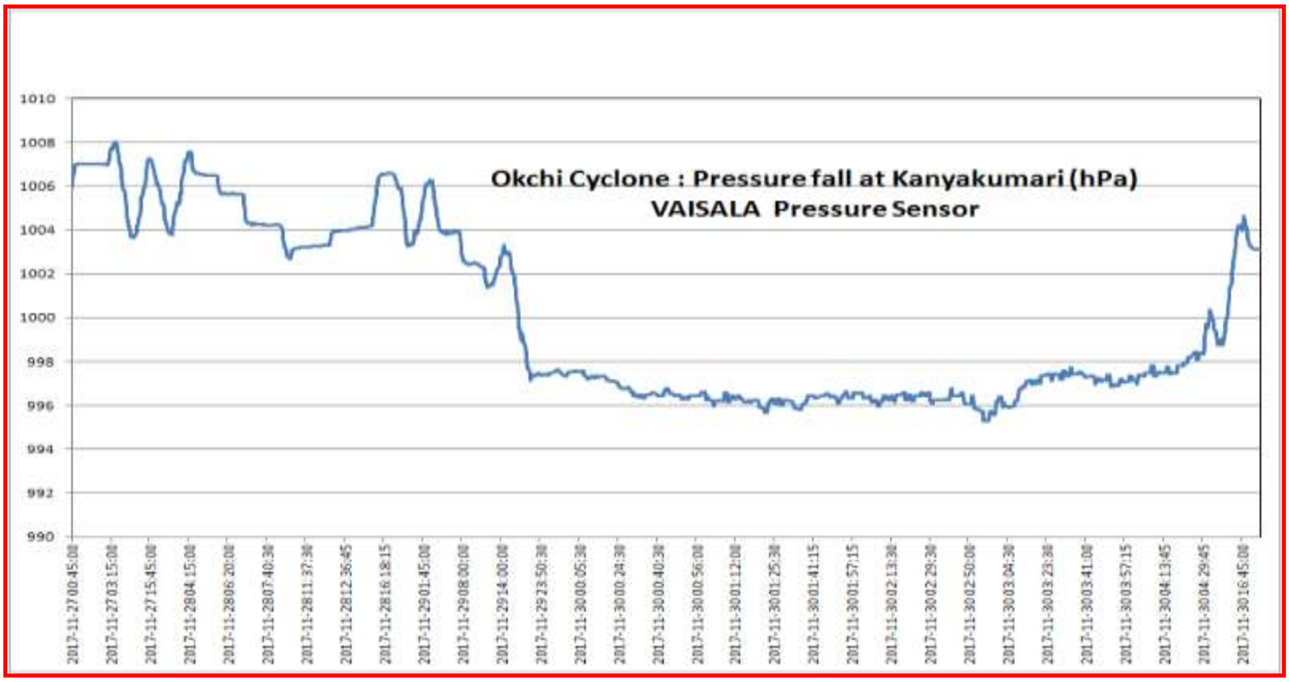


Fig. 9 (c): Pressure fall at Kanyakumari as recorded by Vaisala Pressure Sensor during 0000 UTC of 27th Nov to 1600 UTC of 30th Nov.

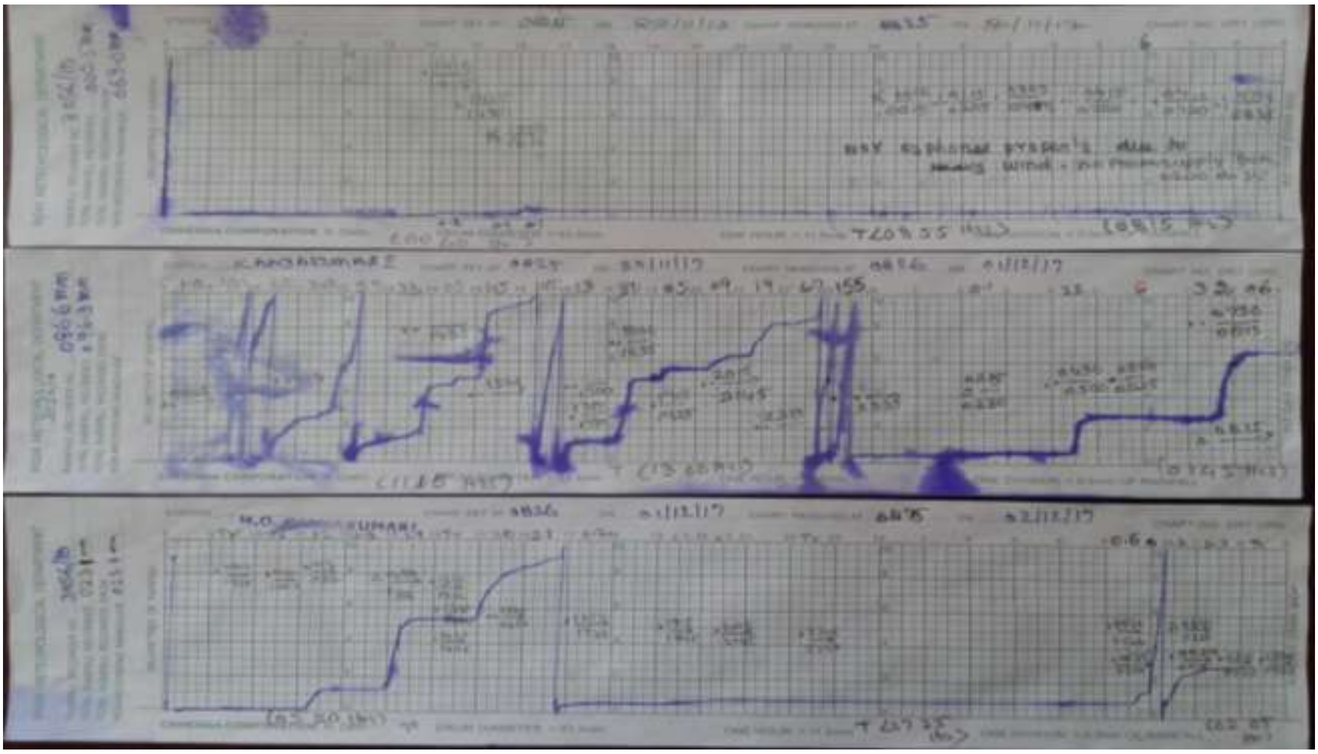


Fig. 9 (d): Autographic rainfall charts from M.O. Kanyakumari on 29th-30th Nov. and 1st Dec.

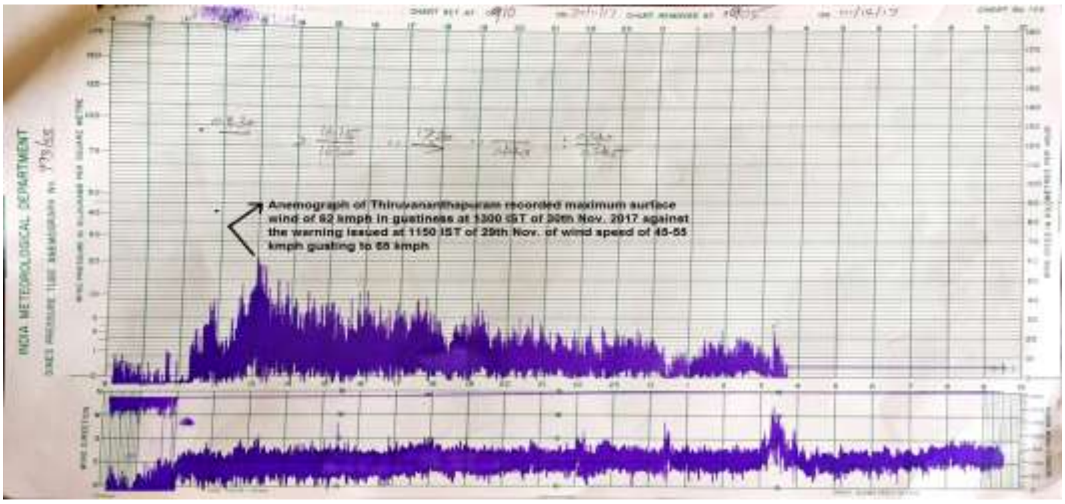


Fig.9 (e): Anemograph record of 30th November over Thiruvananthapuram.

It recorded 62 kmph in gustiness at 1300 IST of 30th Nov. The threshold wind speed of 45 kmph was recorded over Thiruvananthapuram from 1230 IST of 30th Nov. Onwards

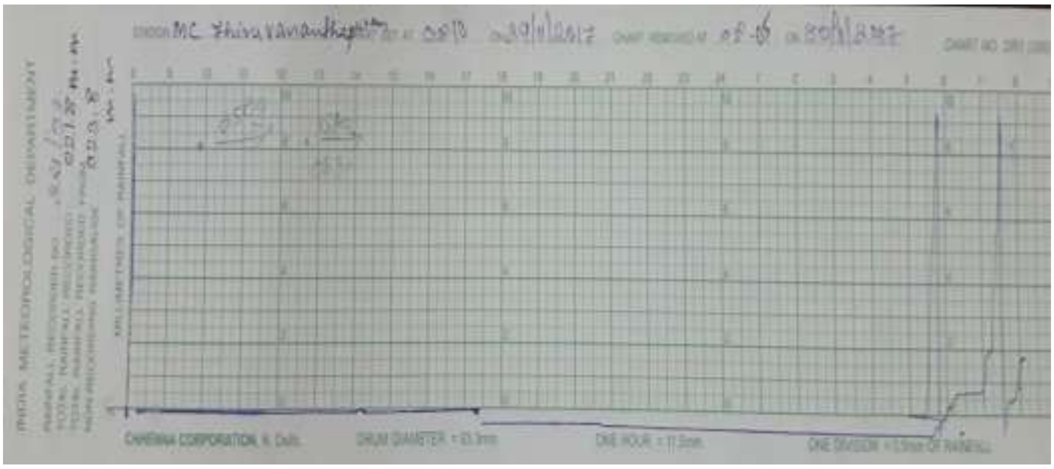


Fig. 9 (f): Autographic rainfall charts from M.C. Thiruvananthapuram on 30th Nov.

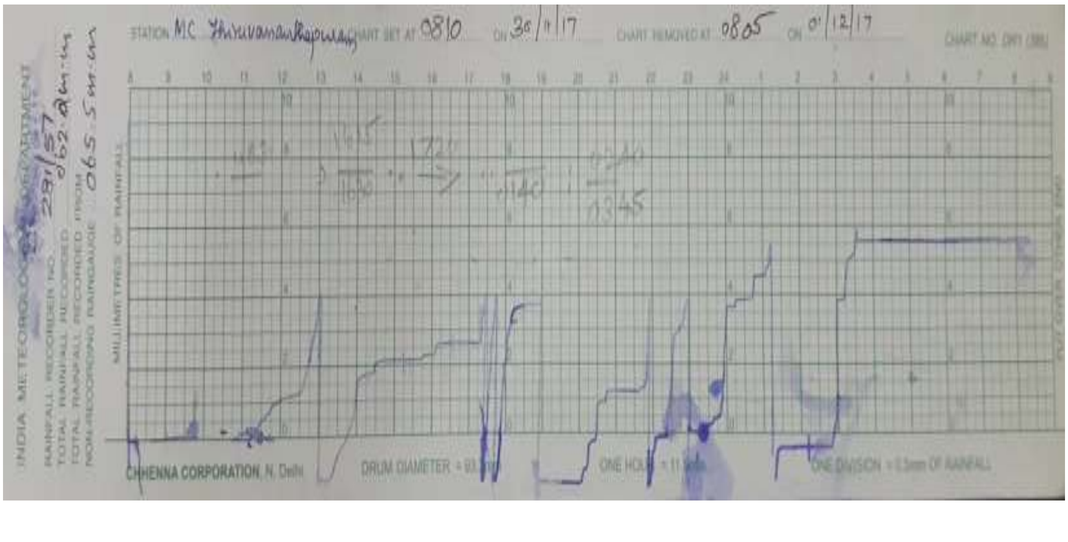


Fig. 9 (g): Autographic rainfall charts from M.C. Thiruvananthapuram on 1st Dec.

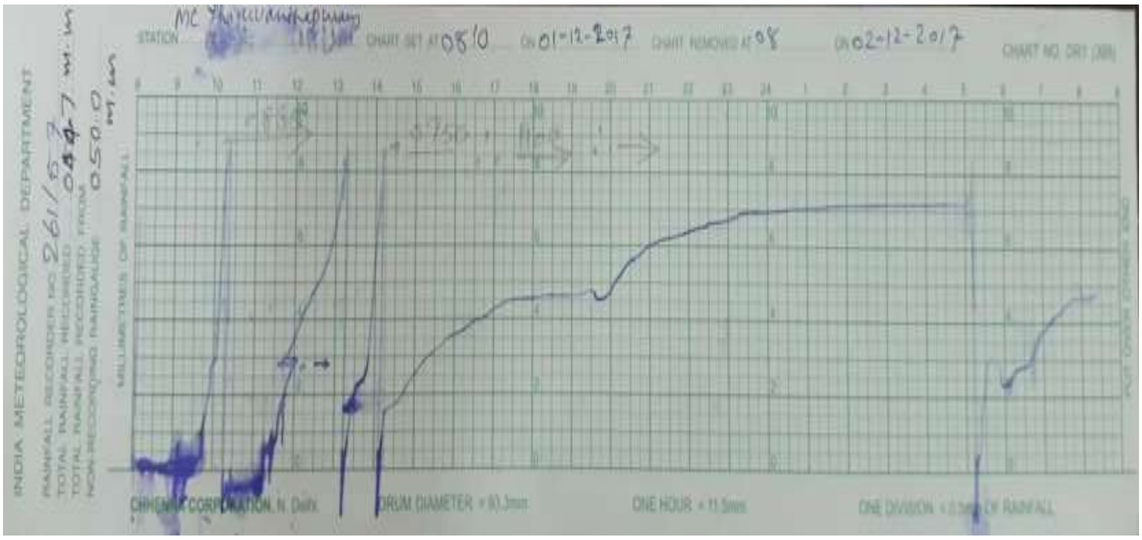


Fig. 9 (h): Autographic rainfall charts from M.C. Thiruvananthapuram during 1st Dec to 2nd Dec.

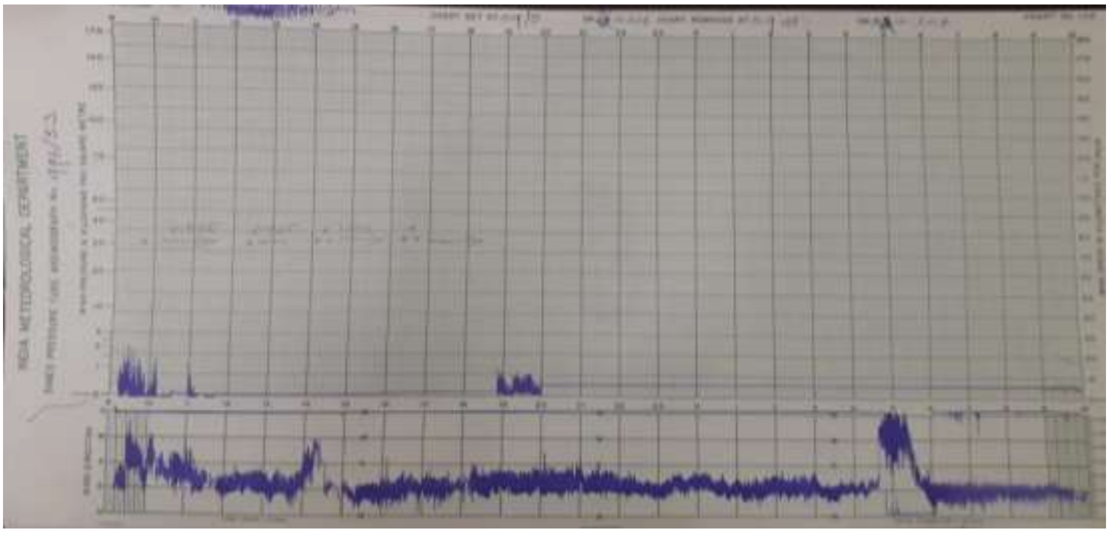


Fig. 9 (i): Autographic Wind chart from M.C. Thiruvananthapuram on 2nd Dec.

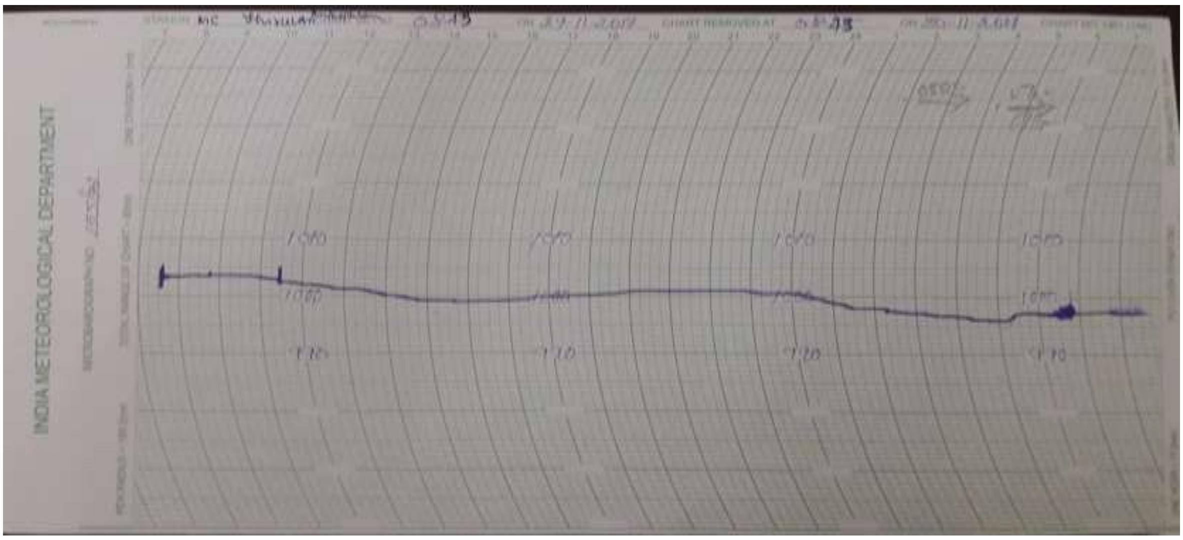


Fig. 9 (j): Autographic Pressure chart from M.C. Thiruvananthapuram on 30th Nov.

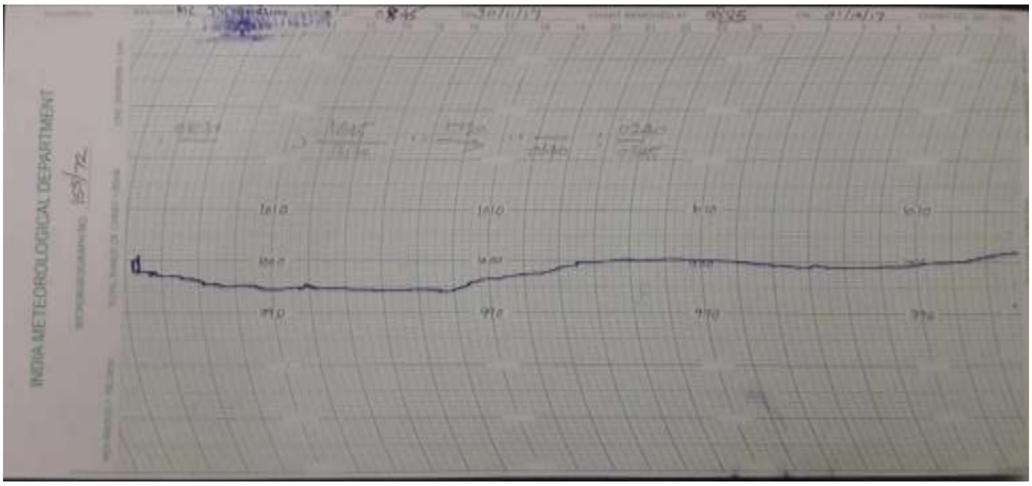


Fig. 9 (k): Autographic Pressure chart from M.C. Thiruvananthapuram on 1st Dec.

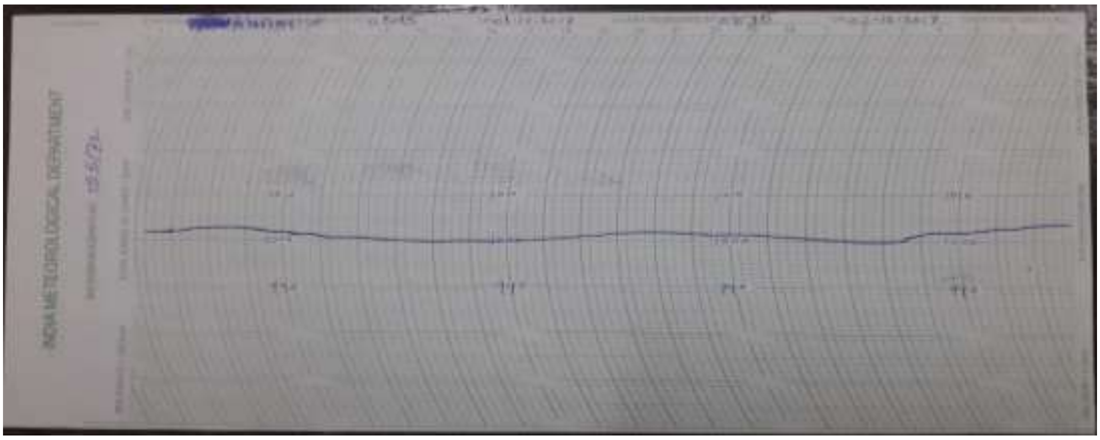


Fig. 9 (l): Autographic Pressure chart from M.C. Thiruvananthapuram on 2nd Dec.

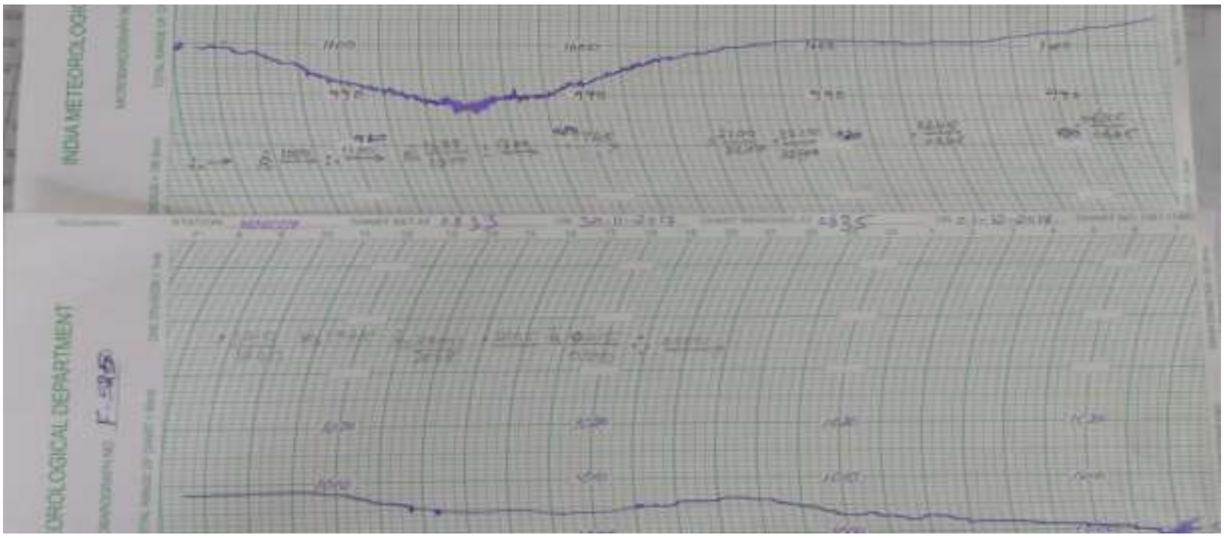


Fig. 9 (m): Autographic Pressure chart from Minicoy during 30 Nov. to 1st Dec.

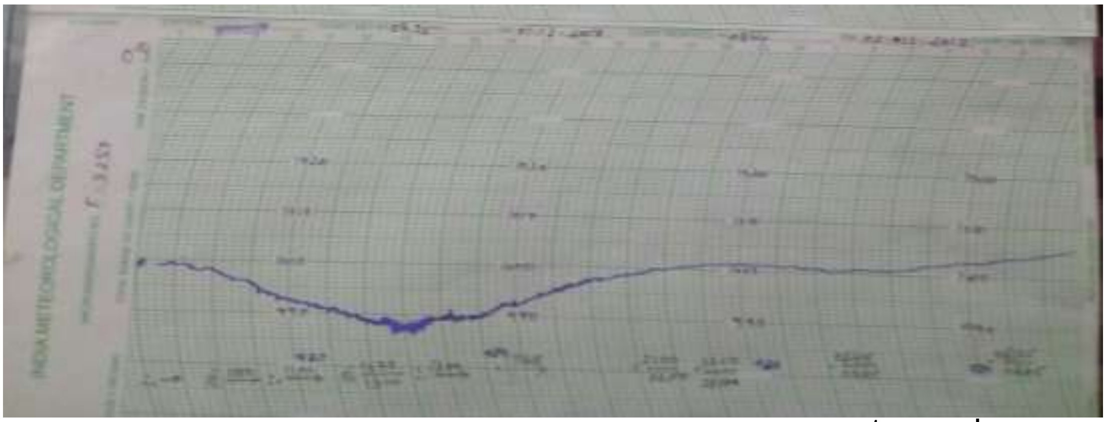


Fig. 9 (n): Autographic Pressure chart from Minicoy during 1st to 2nd Dec.

Fig. 9 (o): Autographic Rainfall chart from Minicoy during 1st to 2nd Dec.

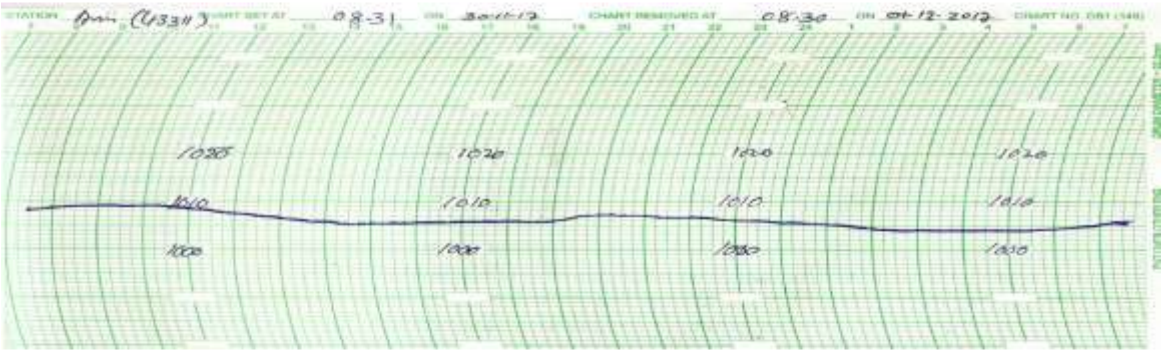


Fig. 9 (p): Autographic Pressure chart from Amini Divi during 30th Nov.-1st Dec

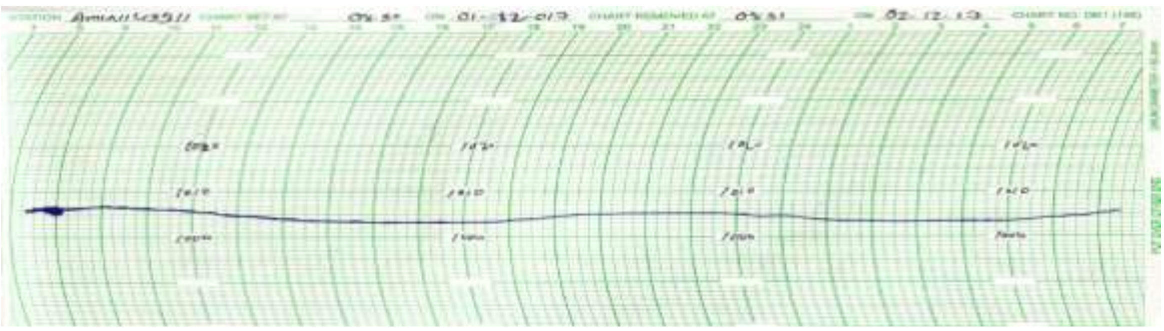


Fig. 9 (p): Autographic Pressure chart from Amini Divi during 1st Dec-2nd Dec

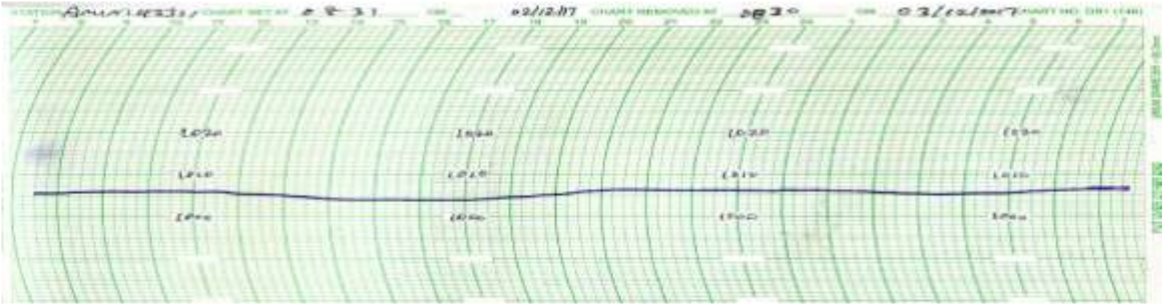


Fig. 9 (q): Autographic Pressure chart from Amini Divi during 2nd Dec-3rd Dec.

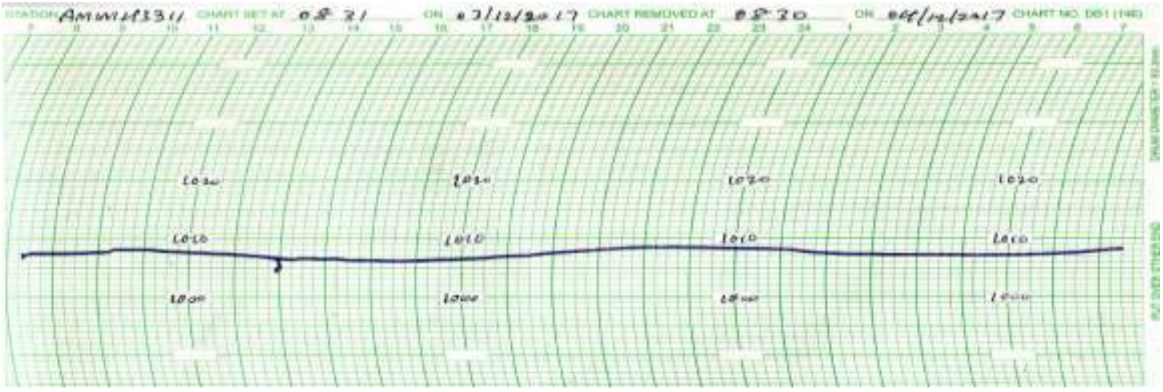


Fig. 9 (r): Autographic Pressure chart from Amini Divi during 3rd Dec-4th Dec

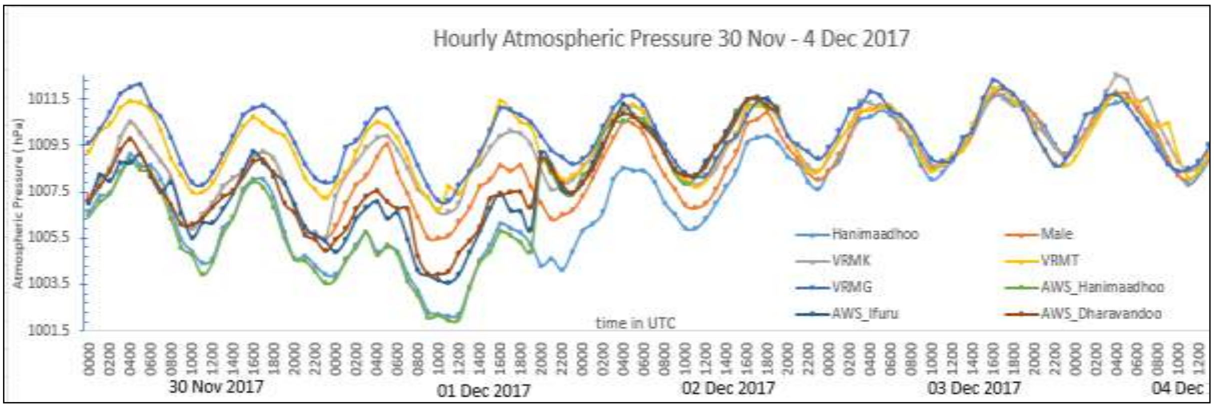


Fig. 9(s): Hourly Pressure Drop over Maldives during 30th Nov. to 4th Dec.

As the TC OCKHI passed northeastern sector of Maldives, the pressure drop was observed in the station located in the central and northern Maldives. Lowest pressure observed during this period among the local stations in the Maldives was 1001.9hPa recorded in the in the northern-most station (H.Dh. Hanimaadho, WMO location No. 43533) at 1100 UTC of 01 Dec 2017. Hourly pressure drop over Maldives (Source: Maldives Meteorological Department) is presented in Fig. 9 (s).

5. Features observed through satellite and Radar

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D imageries. Satellite imageries of international geostationary and polar orbiting satellites were also considered.

5.1 INSAT-3D features

Typical INSAT-3D visible/IR imageries, enhanced colored imageries and enhanced IR imageries are presented in Fig.7. Intensity estimation using Dvorak's technique suggested that the system attained the intensity of T 1.5 at 0600 UTC of 29th November. The system was characterized by loosely defined cloud lines far from a very large area of cold overcast (Shear Pattern). Associated moderate to intense convection lay over southwest BoB and adjoining Sri Lanka & Equatorial Indian Ocean. Thereafter, the system was overland till 1200 UTC of 29th. Hence, T No. could not be estimated. Thereafter, it emerged into Comorin Area. The cloud mass started organising thereafter. At 2100 UTC of 29th, the cloud mass showed curved band pattern measuring 0.45 in logarithmic spiral. The system attained intensity of T 2.0. Associated intense to very intense convection lay over Comorin Area and adjoining Maldives & Equatorial Indian Ocean. At 0300 UTC of 30th, the cloud mass further organized. The system attained intensity of T 2.5. The cloud mass showed curved band pattern measuring 0.60 in logarithmic spiral scale. Associated intense to very intense convection lay between latitude 3ºN to 10 ºN and longitude 72.0ºE to 80.0ºE and the area covering extreme south Tamil Nadu, south Kerala, Gulf of Mannar & Comorin Area. At 0900 UTC of 30th, the intensity was T 3.0. The convection wrapped 0.85 on logarithmic spiral. Associated intense to very intense convection lay between latitude 3ºN to 10 ºN and longitude 72.0ºE to 80.0ºE and the area covering extreme south Tamil Nadu, south Kerala, Gulf of Mannar & Comorin Area. At 0000 UTC of 1st December, the cloud mass further organized. The convection wrapped 0.90 on logarithmic spiral with white banding in enhanced IR. The intensity of the system was T 3.5. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 5ºN to 13 ºN and longitude 70.0ºE to 78.0ºE. At 0900 UTC of 1st December, intensity became T 4.0. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 6ºN to 11.5 ºN and longitude 67.0ºE to 75.0ºE. At 0600 of 2nd, the system was characterized by off white eye surrounded by light grey and embedded in medium grey resulting in T 4.5. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 7ºN to 14.5 ºN & longitude 65.5ºE to 74.0ºE and Lakshadweep area. At 0300 UTC of 3rd December, the system centre was embedded in black and with 2.5^0 of Central Dense Overcast region yielding T 4.5. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 9ºN to 14.0 ºN & longitude 66.0ºE to 73.0ºE and Lakshadweep area. At 0300 UTC of 4th, intensity of the system was T 4.0 with disorganisation of cloud. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 12ºN to 20ºN & longitude 66ºE to 72ºE. Thereafter it showed rapid disorganisation. At 0300 UTC of 5th. Intensity of the system was T 3.0. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 16ºN to 20.5ºN & longitude 67ºE to 73ºE. At 0600 UTC of 5th, system was characterized by circularly defined cloud lines far from a very small area of cold overcast (Shear Pattern). Intensity of the system was T 2.0. Associated broken low/medium clouds with embedded intense to very intense convection lay over area between latitude 16ºN to 20.5ºN & longitude

67ºE to 73ºE, south Gujarat, north Maharashtra and adjoining Gulf of Cambay. At 1800 UTC of 5th, intensity of the system was T 1.0. Associated broken low/medium clouds with embedded isolated weak convection lay over area between latitude 18ºN to 21ºN & longitude 69ºE, southeast Gujarat, north Konkan and adjoining Gulf of Cambay. IMD satellite positions and corresponding intensity are presented in Table 2.

Table 2: Satellite based positions and intensity of VSCS Ockhi

Date/Time (UTC)	Position (lat./long.) in degrees	Dvorak's T.No.	Date/Time (UTC)	Position (lat./long.) in degrees	Dvorak's T.No.
28/1800	6.0/82.8	T 1.0	02/1200	10.4/70.3	T 5.0
28/2100	6.0/82.4	T 1.0	02/1500	10.7/69.8	T 5.0
29/0000	6.0/82.4	T 1.0	02/1800	11.0/69.7	T 5.0
29/0300	6.0/81.5	T 1.0	02/2100	11.3/69.5	T 5.0
29/0600	6.0/81.5	T 1.5	03/0000	11.8/69.2	T 4.5
29/0900	6.0/81.0	T 1.5	03/0300	12.0/69.0	T 4.5
29/1200	6.0/80.1	T 1.5	03/0600	12.3/68.8	T 4.5
29/1500	6.2/79.5	T 1.5	03/0900	12.4/68.7	T 4.5
29/1800	6.3/79.2	T 1.5	03/1200	12.7/68.5	T 4.5
29/2100	6.5/78.6	T 2.0	03/1500	13.0/68.5	T 4.5
30/0000	6.7/78.3	T 2.0	03/1800	13.5/68.5	T 4.5
30/0300	7.5/77.5	T 2.5	03/2100	14.0/68.5	T 4.5
30/0600	7.6/76.6	T 3.0	04/0000	14.4/68.5	T 4.5
30/0900	7.8/76.4	T 3.0	04/0300	14.4/68.6	T 4.0
30/1200	8.3/75.8	T 3.0	04/0600	14.9/68.9	T 4.0
30/1500	8.4/75.3	T 3.0	04/0900	15.1/68.9	T 4.0
30/1800	8.5/74.9	T 3.0	04/1200	15.7/69.2	T 3.5
30/2100	8.6/74.4	T 3.5	04/1500	16.1/69.6	T 3.5
01/0000	8.8/74.0	T 3.5	04/1800	16.5/69.7	T 3.5
01/0300	8.8/73.8	T 3.5	04/2100	17.0/69.8	T 3.5
01/0600	8.9/73.3	T 3.5	05/0000	17.8/70.0	T 3.5
01/0900	8.9/72.9	T 4.0	05/0300	18.8/70.5	T 3.0
01/1200	9.0/72.7	T 4.0	05/0600	18.8/70.8	T 2.5
01/1500	9.1/72.5	T 4.0	05/0900	18.9/71.4	T 2.5
01/1800	9.3/72.0	T 4.0	05/1200	19.2/71.9	T 2.0
01/2100	9.3/71.8	T 4.0	05/1500	19.9/72.0	T 1.5
02/0000	9.5/71.5	T 4.5	05/1800	20.1/72.2	T 1.0
02/0300	9.5/71.2	T 4.5	05/2100	20.3/72.6	T 1.0
02/0600	9.8/71.0	T 4.5	06/0000	LLC	LLC
02/0900	10.2/70.6	T 5.0			

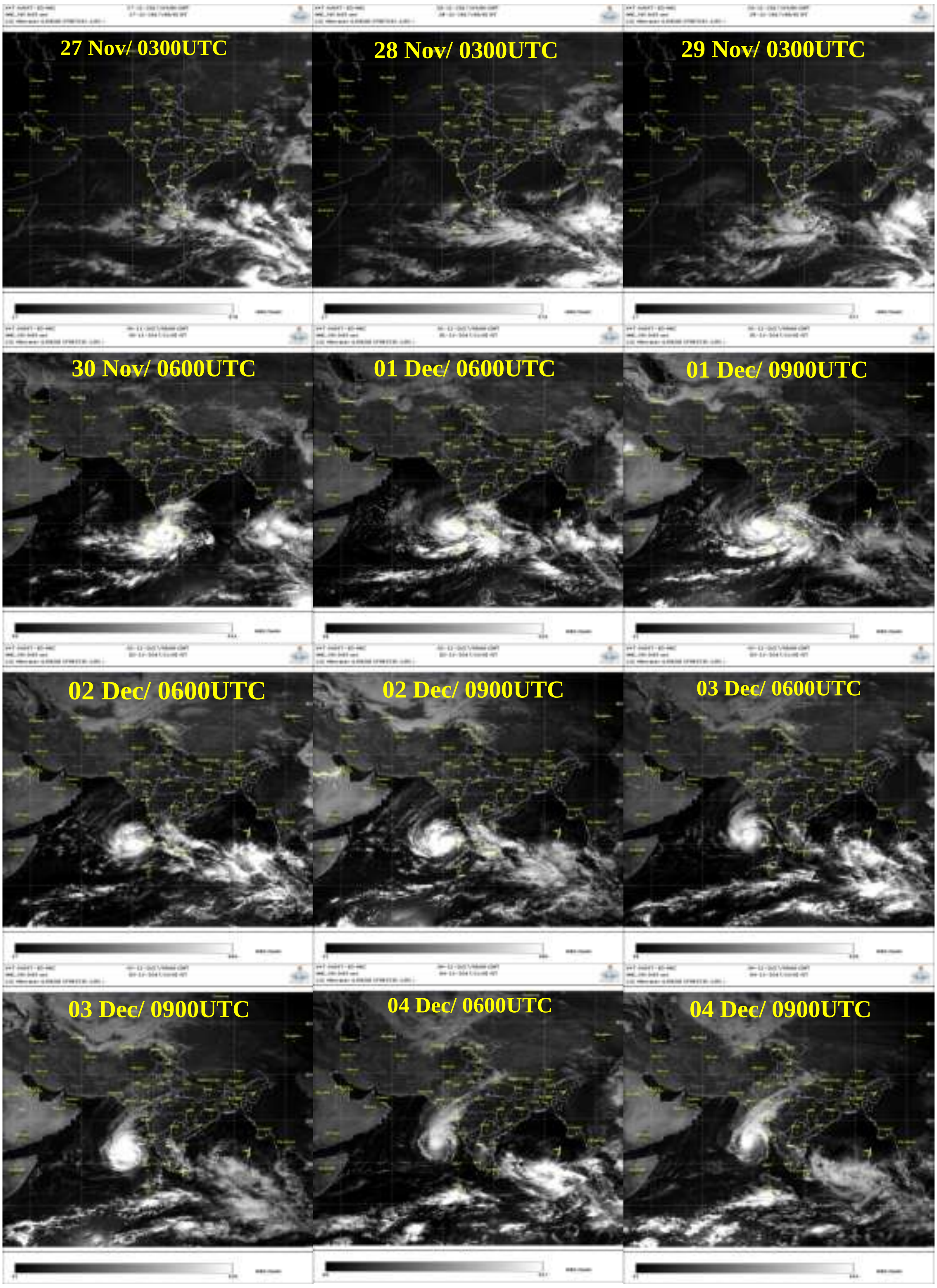


Fig. 10a: INSAT-3D visible imageries during life cycle of VSCS Ockhi (28 November-05 December, 2017)

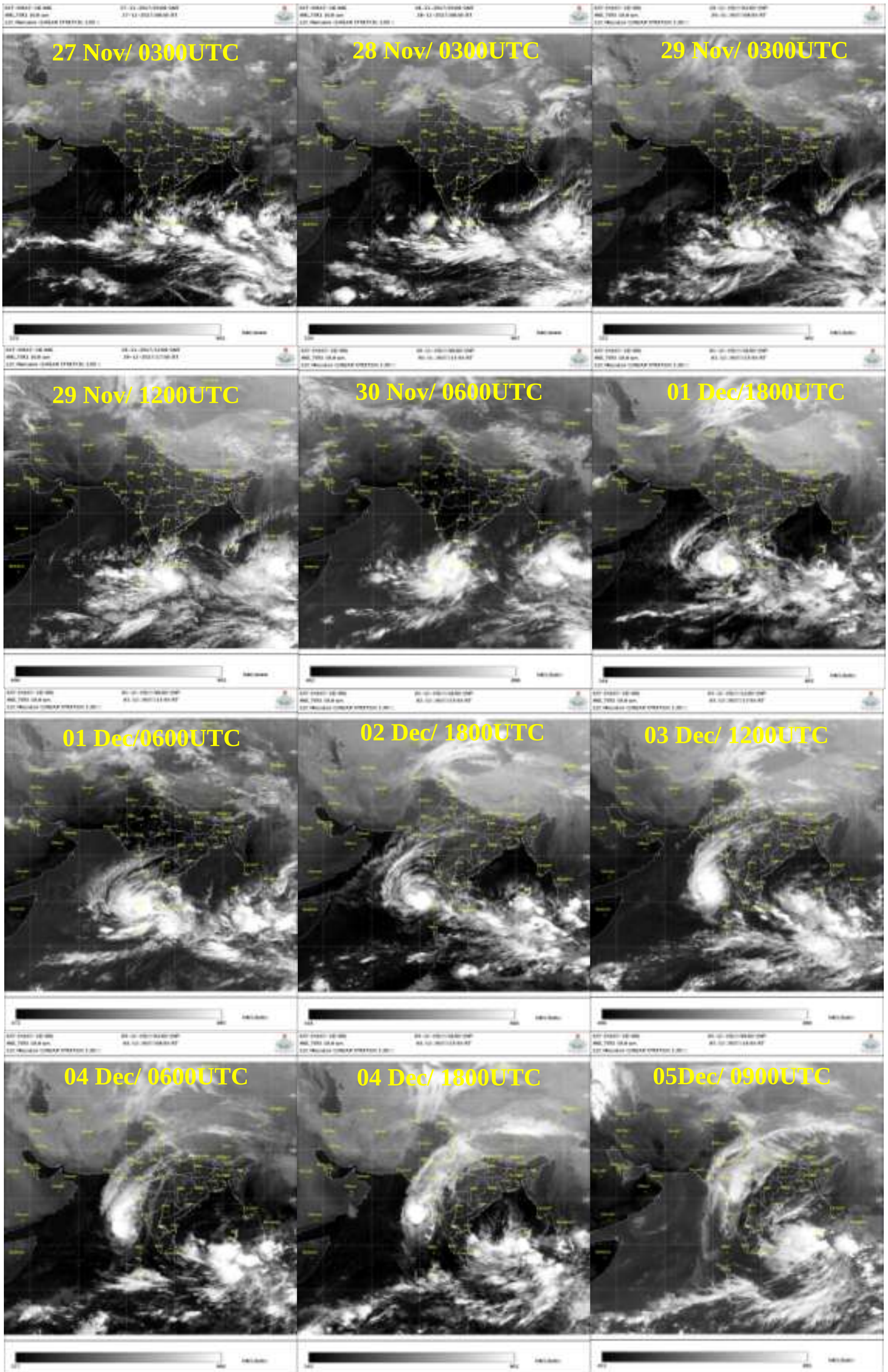


Fig. 10b: INSAT-3D IR imageries during life cycle of VSCS Ockhi (28 November-05 December, 2017)

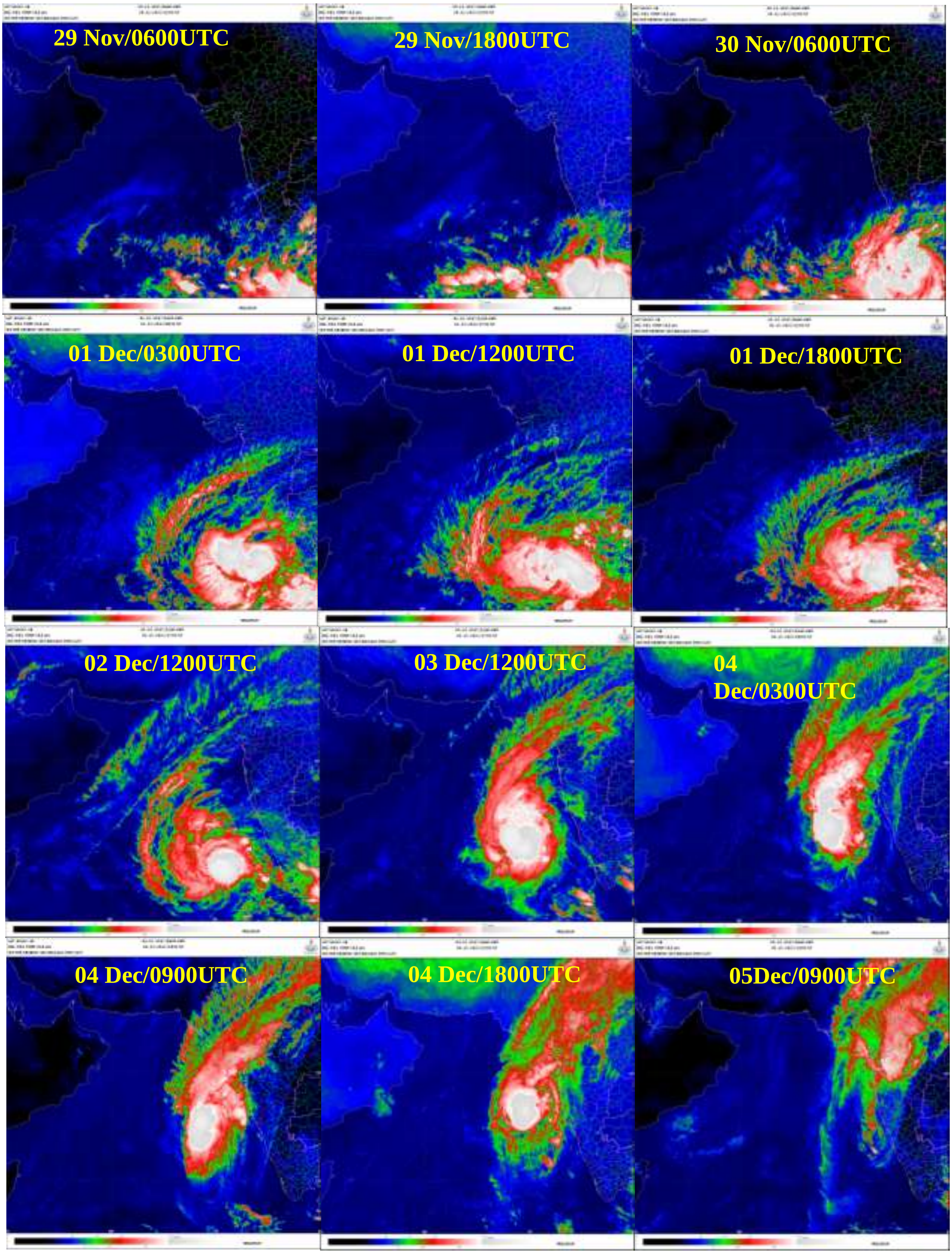


Fig. 10c: INSAT-3D enhanced colored imageries during life cycle of VSCS Ockhi (28 November-05 December, 2017)

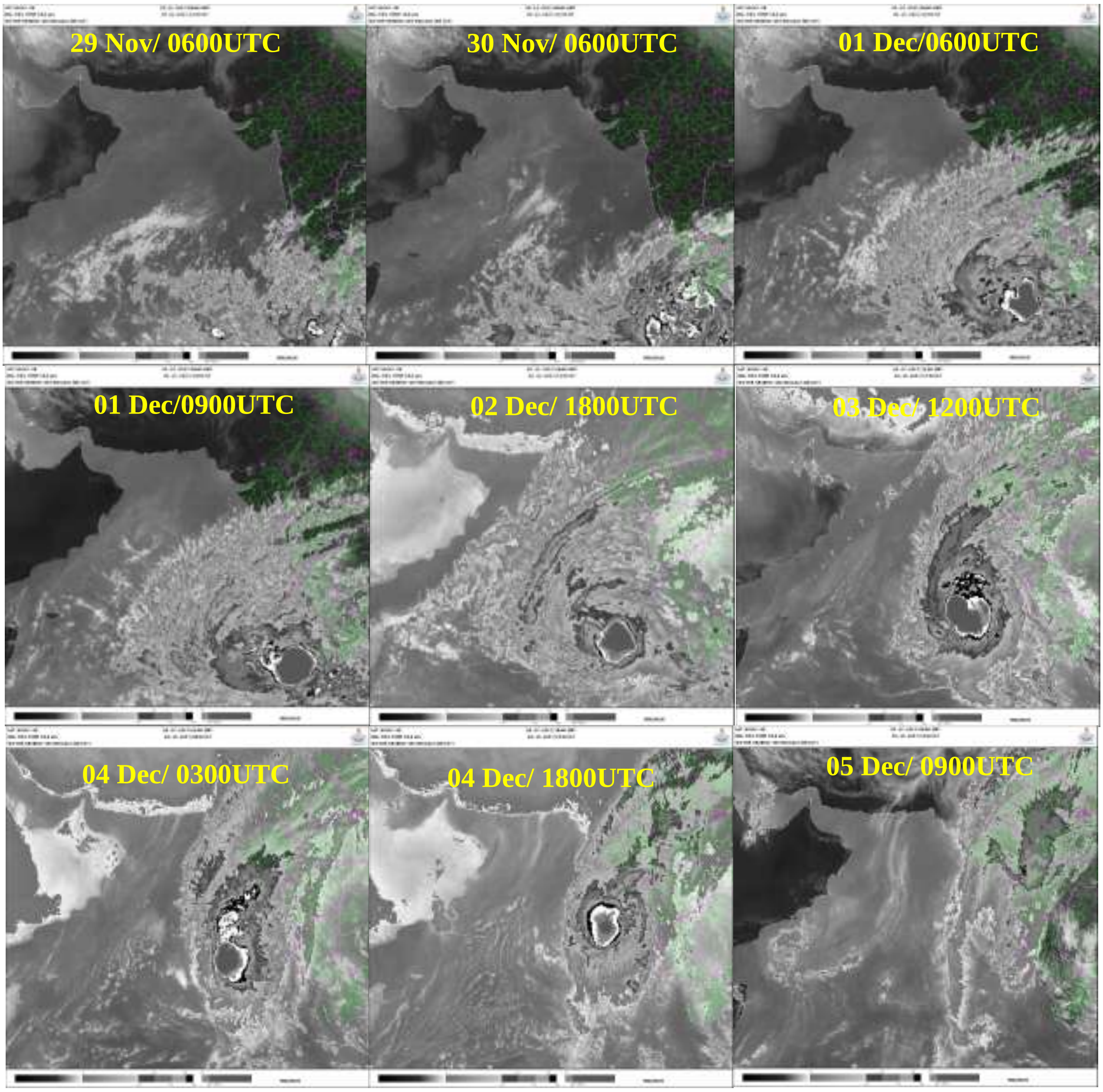


Fig. 10d: INSAT-3D enhanced IR imageries during life cycle of VSCS Ockhi (28 November-05 December, 2017)

5.2 Microwave features

F-15, F-16, F-17, GPM and GCOM-W1 microwave imageries of the VSCS Ockhi covering its life period from 26th November to 5th December 2017 are presented in Fig.9 (a). 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 imageries during 2121 UTC of 26th to 1940 UTC of 28th indicate that prior to development of Ockhi, some circulation persisted over south of Sri Lanka that caused rainfall over south of Sri Lanka and adjoining equatorial Indian Ocean on 27th and 28th. At 1940 UTC of 28th, the convection extended upto Comorin area. On 29th morning a small patch of intense convection was seen over southwest BoB and another bigger intense zone was seen over Comorin area.

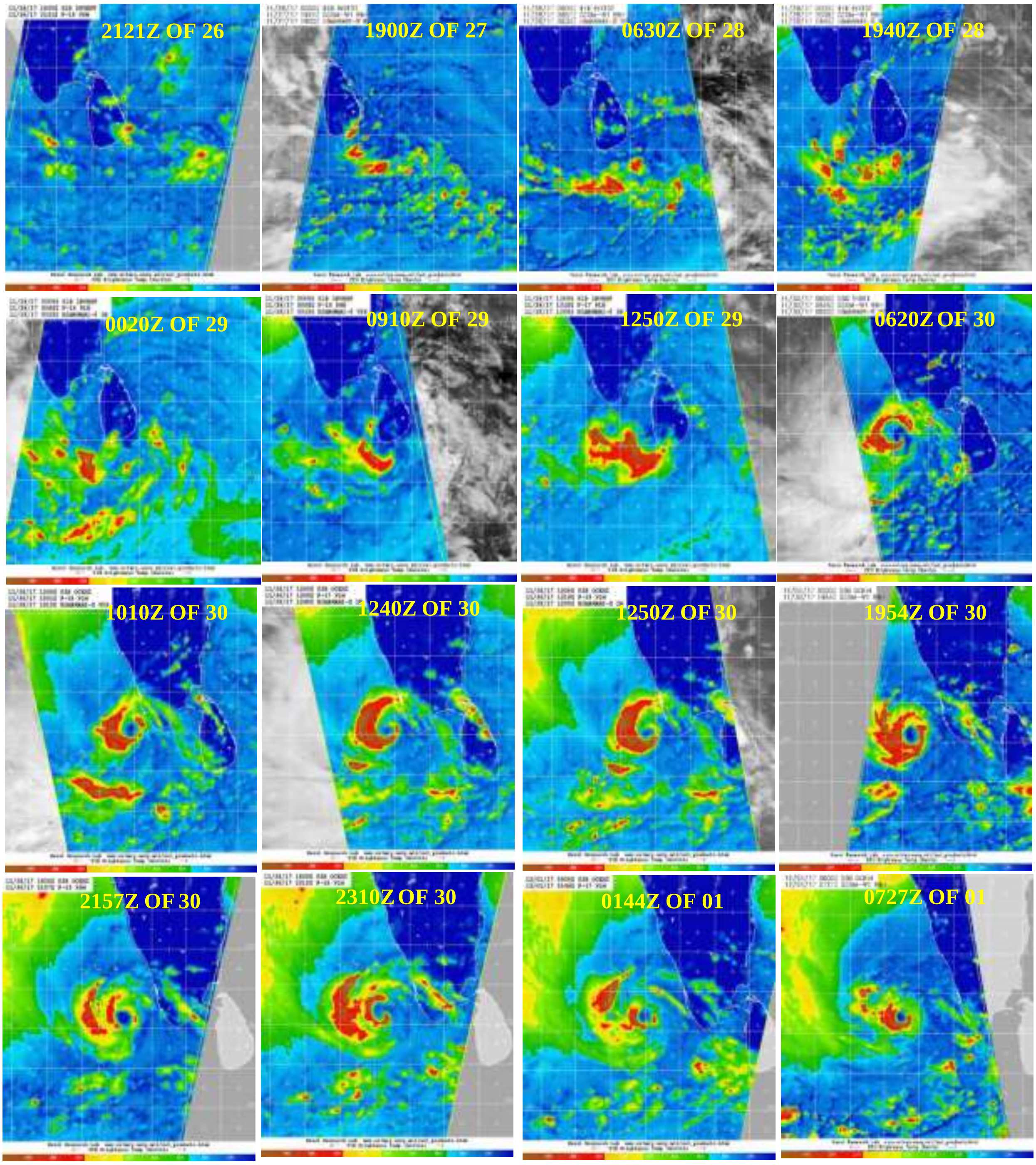


Fig. 11 (a): Microwave imageries during life cycle of VSCS Ockhi (26th November-1st December)

The convection over Comorin started organising from 0020 UTC of 29th. At 0620 UTC of 30th, the circulation got organised. Spiral structure was seen from 1010 UTC of 30th with spiral bands covering the eye completely by 1954 UTC of 30th. Till 0251 UTC of 3rd, intense convection was seen over western and southern sector of system. Thereafter, convection flared north-north-eastwards. The weakening of the system from 3rd midnight onwards was also well captured in microwave imageries.

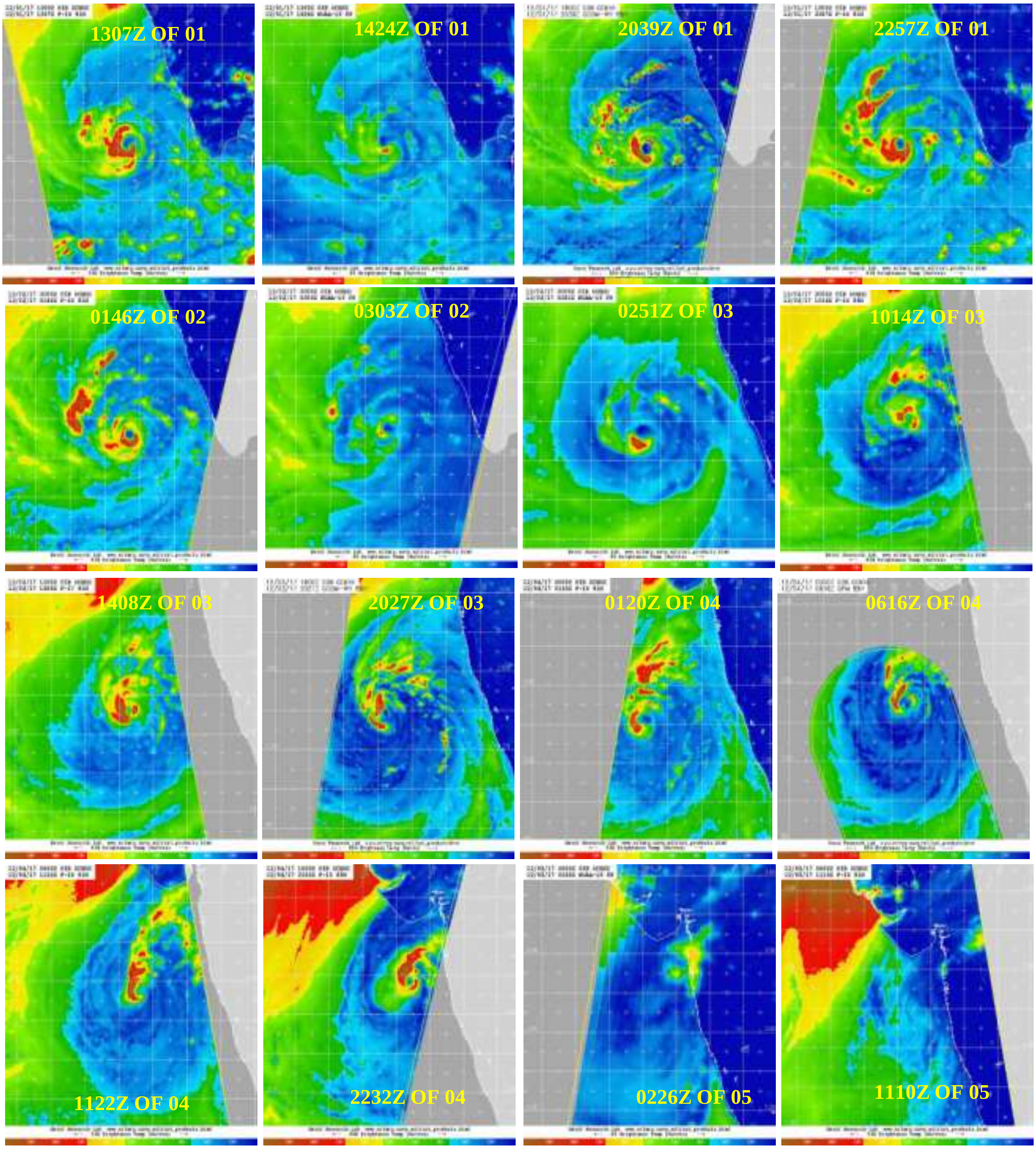


Fig. 11 (b): Microwave imageries during life cycle of VSCS Ockhi (1st December-5th December)

5.3: Features observed through SCATSAT imageries

Typical imageries from polar satellite, SCATSAT are presented in Fig. 10. SCATSAT passes are available twice a day at around 0300 UTC and 1700 UTC at http://mosdac.gov.in/scorpio/SCATSAT_Data. The observations based on 0259 UTC of 27th indicated cyclonic circulation over southernmost Sri Lanka and adjoining southwest

BoB near 5.8^0N/80.7^0E . According to Analog model developed by SAC, ISRO, Ahmedabad the Matching Index (MI) for cyclogenesis was 0.75. (MI>0.6) Stronger winds were seen in southwest and northwest sector. The imagery based on 1438 UTC of 28th indicated large scale cross equatorial flow into the circulation from southeast sector. The circulation centre lay over 6.3^0N/80.7^0E with MI of 0.82. Stronger winds were seen over south and southeast sectors of circulation centre. The imagery based on 0259 UTC of 29th indicated strengthening of system with MI of 0.74. stronger winds were seen to the south of system. However, at 1528 UTC of 29th, the SCATSAT imagery indicated slight weakening of circulation with MI of 0.49. At 0348 UTC of 30th November, it again showed weakening of system with MI of 0.34. Hence, MI was not consistent in predicting cyclogenesis of Ockhi.

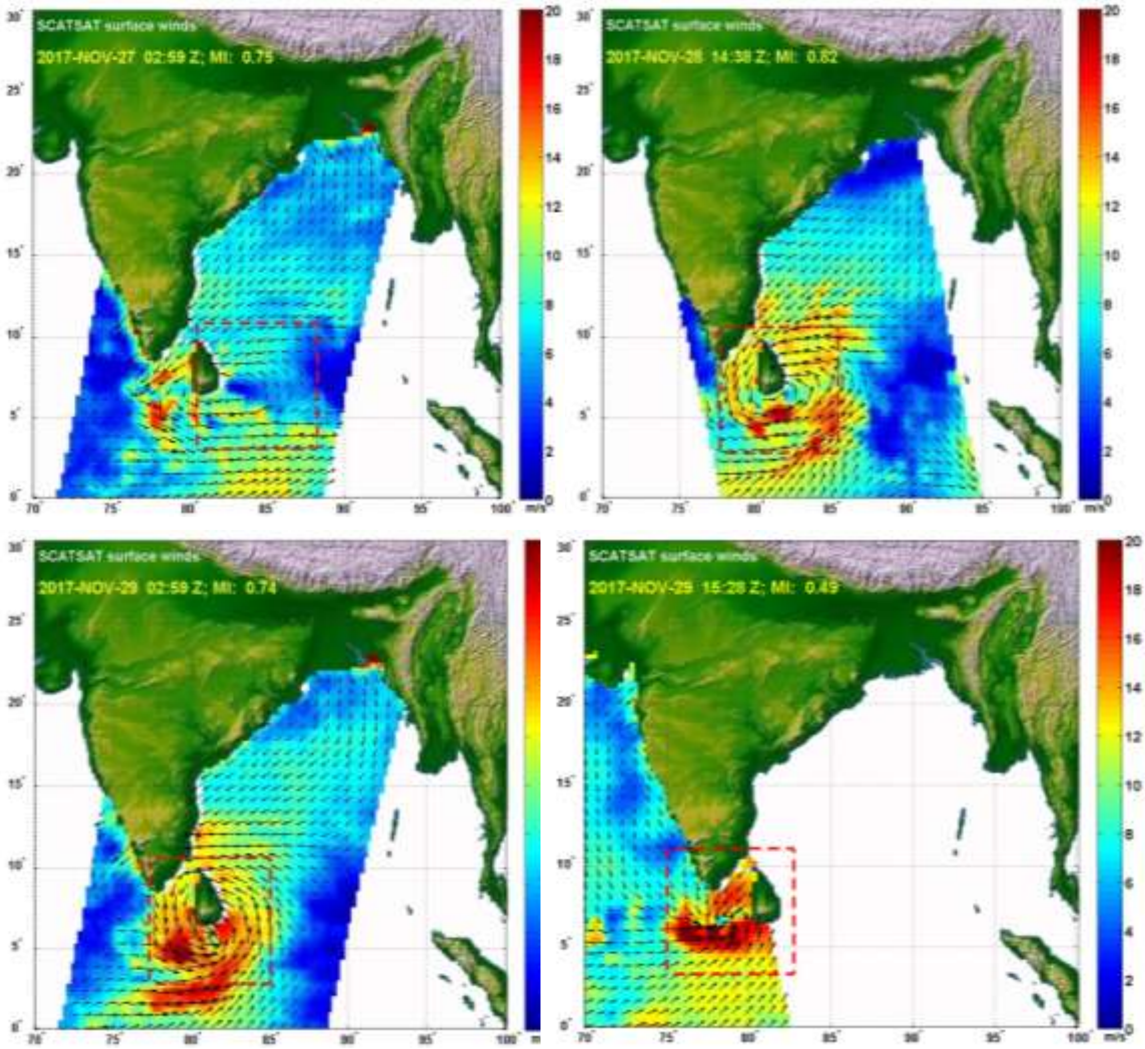


Fig. 12(a): Imageries from SCATSAT during VSCS Ockhi (27-29 November)

From 0259 UTC of 1st December, it picked up the circulation correctly and suggested MI of 0.73. Stronger winds were seen in eastern sector. At 0348 UTC of 2nd December, strong winds were seen in southwest sector also. On 3rd (1528 UTC) and 4th (0348 UTC) December, the stronger winds were seen around the system centre in all sectors. However, at 1528 UTC of 5th December, strong winds were seen near North Maharashtra coast with MI of 0.62. Thus SCAT Sat imageries based on analog technique for forecast of cyclogenesis (intensification upto T 2.5 or more) could not capture correctly the genesis, intensification and weakening of system. It rather showed weakening during genesis phase. Similarly, during weakening phase on 5^{th} December SCATSAT over-estimated the intensity by indicating MI > 6.0. However, SCATSAT could detect the wind distribution and intensity very well during D/DD/CS stage.

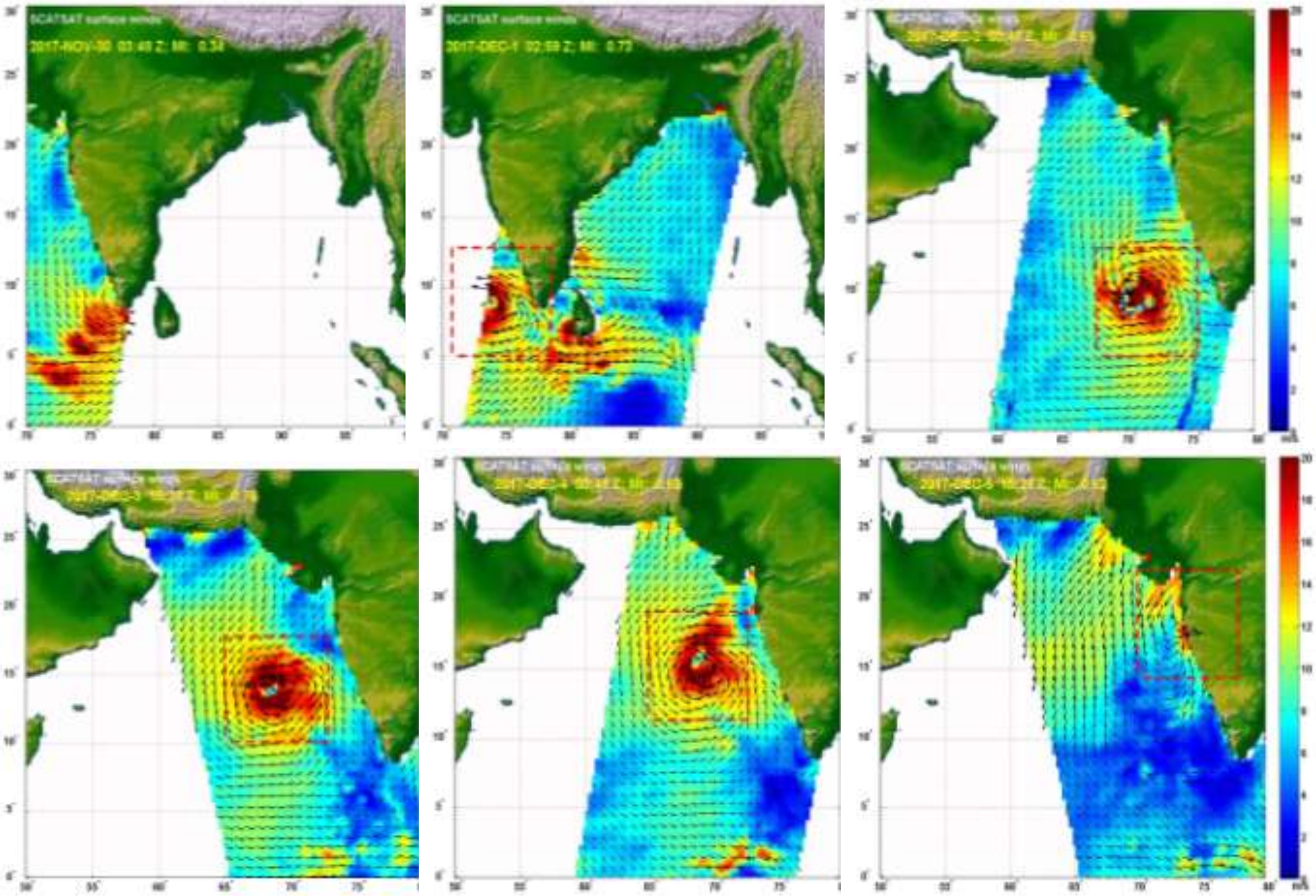


Fig. 12(b): Imageries from SCATSAT during VSCS Ockhi (30 Nov-05 Dec)

5.4. Features observed through ASCAT imageries:

Images from ASCAT helped in location of system centre and region of stronger winds. It could capture at 27/1538 UTC, a circulation over southwest BoB off south of Sri Lanka and a fresh circulation centre over southwest BoB off southeast Sri Lanka. This further strengthens that cyclone Ockhi developed from a fresh low pressure area over southwest BoB on 28^{th}. At 1637 UTC of 29^{th}, 1 minute average winds of the order of 30-35 kts were seen over Comorin Area. Corresponding 3-minute average winds are 25-30 kts. At 0454 UTC of 1^{st}, the system was centered over Lakshadweep area near 9.0^0N/74.0^0E and winds of the order of 40-45 kts were seen in the southwest sector. However, at that time winds of 55kts prevailed over the region. Thus as expected, intensity was under-estimated in SCS/VSCS stage. At 1657 UTC of 3^{rd}, it indicated that the system was centered near 13.2^0N /68^0E with maximum winds of 35kts seen in eastern sector. At this time the system was centered near 13.0^0N /68.6^0E with MSW of 75 kts. At 0529 UTC of 4^{th}, it indicated system centered near 14.6^0N /68.8^0E with maximum winds of the order of 40-45 kts in the northeast sector. At 0600 UTC of 4^{th}, the system was centered near 14.9^0N /68.7^0E with MSW of 65 kts. It can be concluded that ASCAT imageries could predict the centre quite accurately. It could also very well detect intensity in the stage of D/DD/CS. It could not pick up intensity of the system correctly in SCS/VSCS stage as expected.

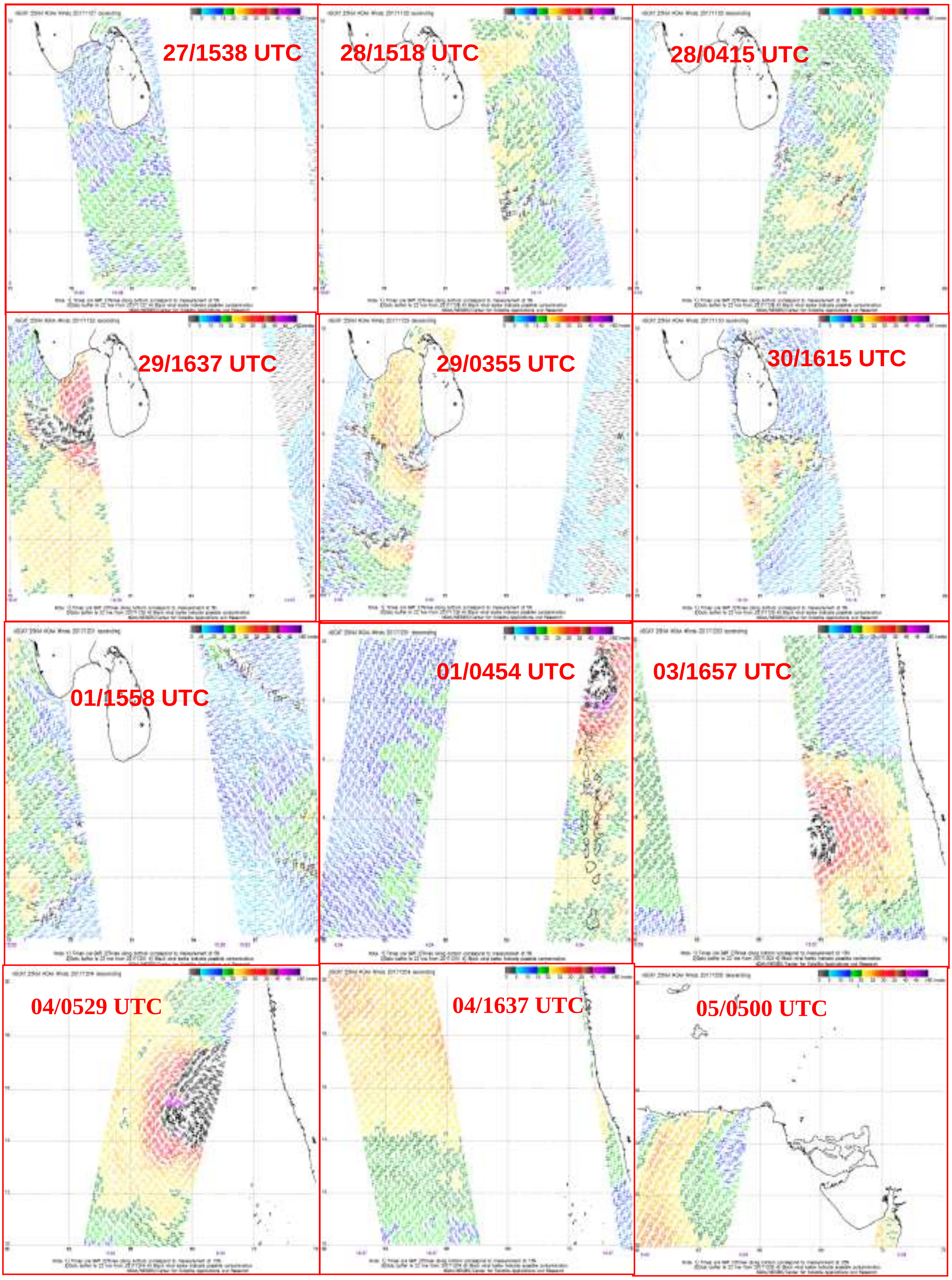


Fig. 12 (c): ASCAT imageries during life cycle of VSCS Ockhi (27 November-05 December)

5.5. Features observed through Radar

As the system developed over southwest BoB off southeast Sri Lanka, emerged into Comorin Area and moved across southeast and eastcentral Arabian Sea, it was well captured by DWR Thiruvananthapuram and Kochi. The associated convection was also detected by DWR Chennai, Karaikal, CDR Goa and DWR Mumbai. However, it was close to DWR Thiruvananthapuram followed by Kochi during genesis and intensification phase. Hence detailed analysis has been made based on the product of these two DWRs. DWR Chennai, Karaikal, Goa and Mumbai being away from the centre of system, could not detect the specific features of genesis and intensification. Typical Radar imageries from these Radars as received are presented in Fig. 10.

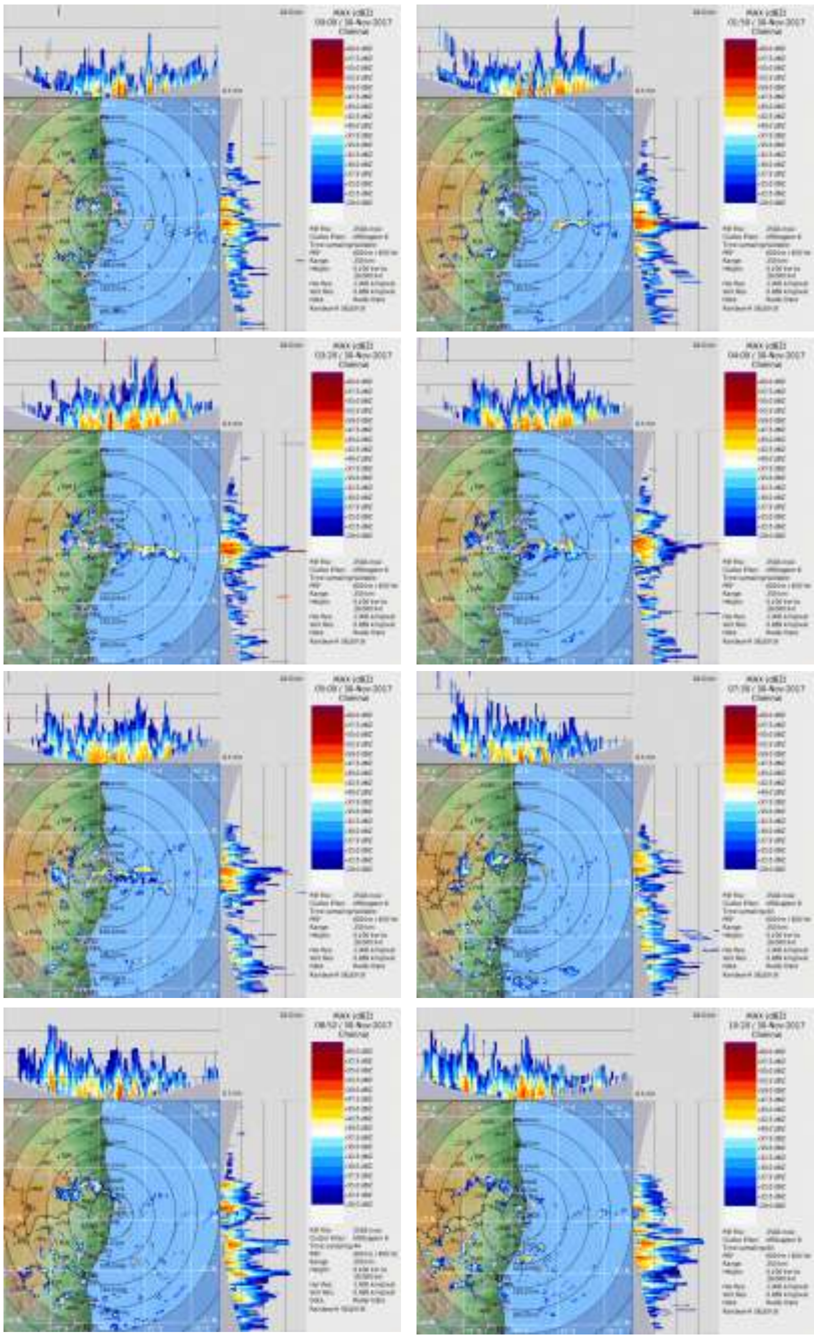


Fig. 10 (a): DWR Chennai Maximum Reflectivity (dBz) imageries during 0000-1020 UTC of 30th November

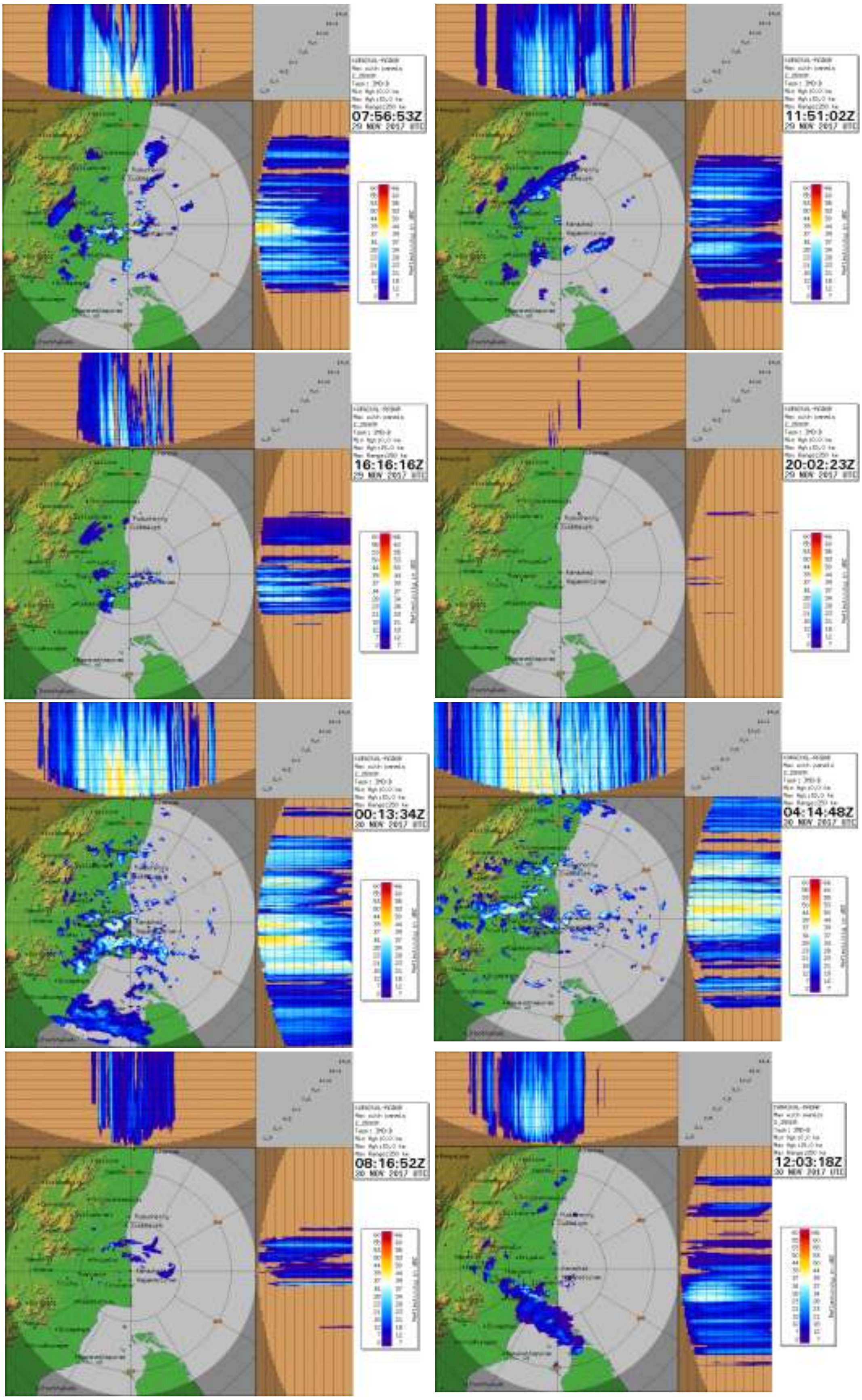


Fig. 10(b): DWR Karaikal Maximum Reflectivity (dBz) imageries during 0756 UTC of 29th-1203 UTC of 30th November

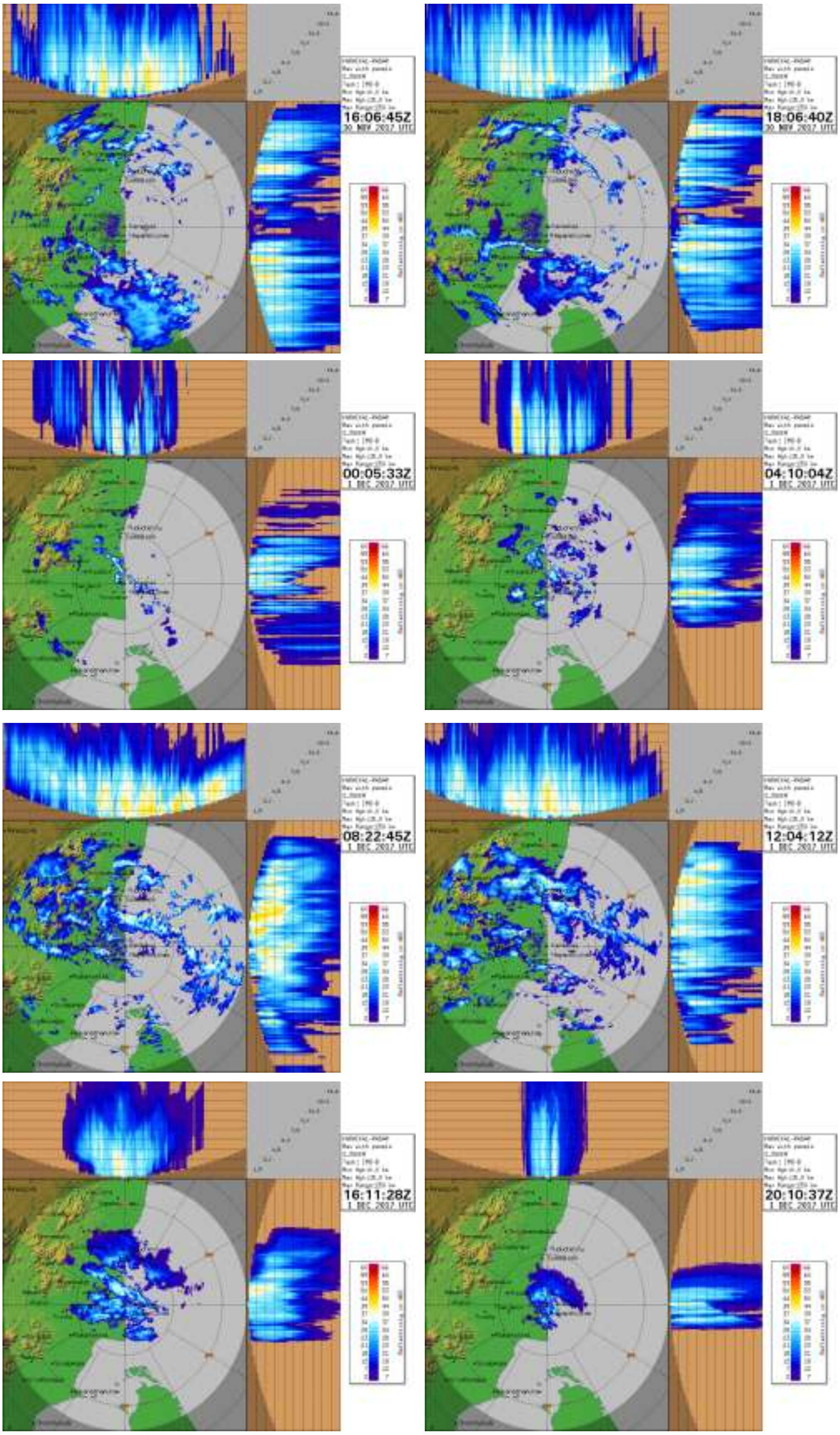


Fig. 10 (c): DWR Karaikal Maximum Reflectivity (dBz) imageries during 1606 UTC of 30th November -2010 UTC of 1st December

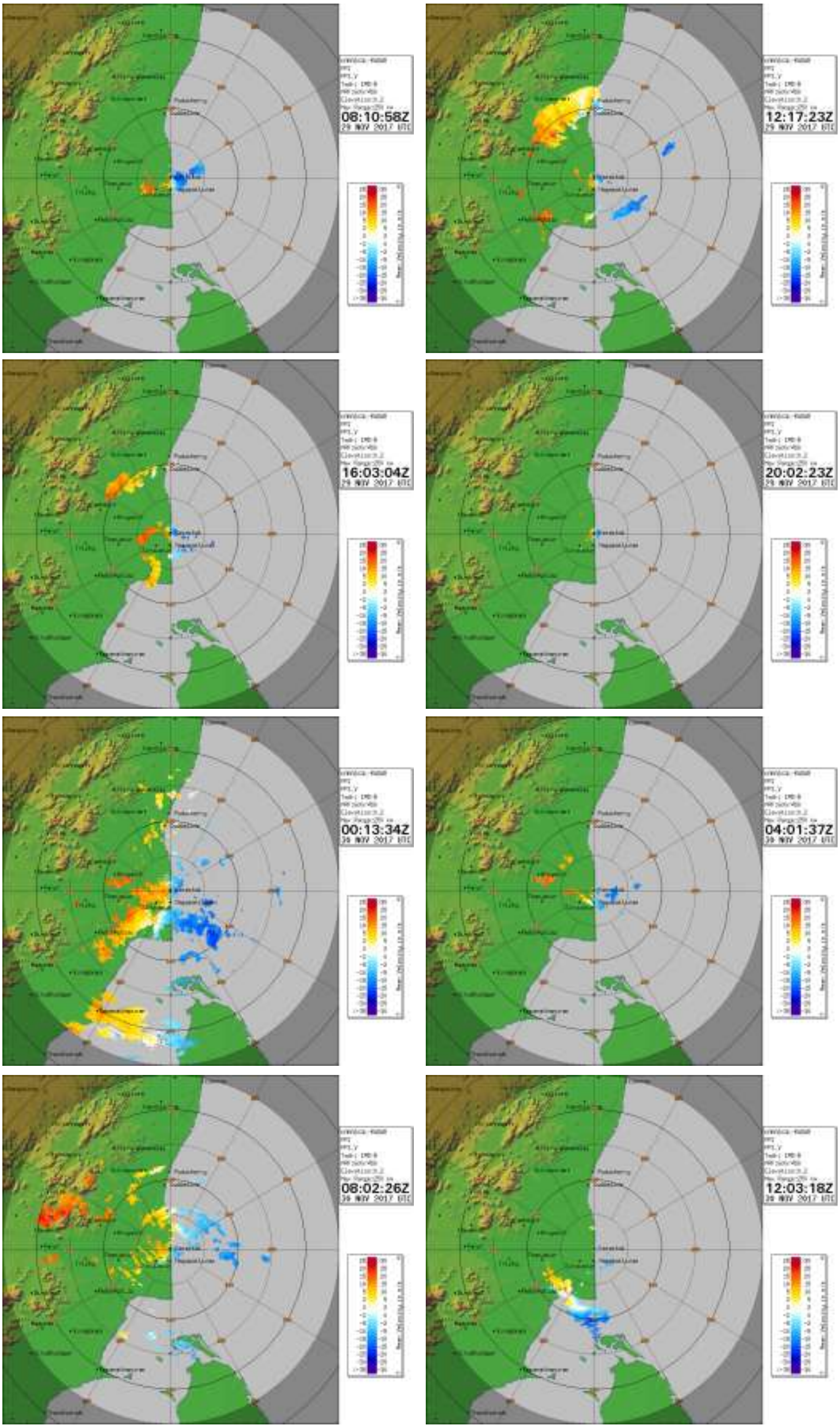


Fig. 10 (d): DWR Karaikal radial velocity (m/s) imageries during 0810 UTC of 29th - 1203 UTC of 30th November

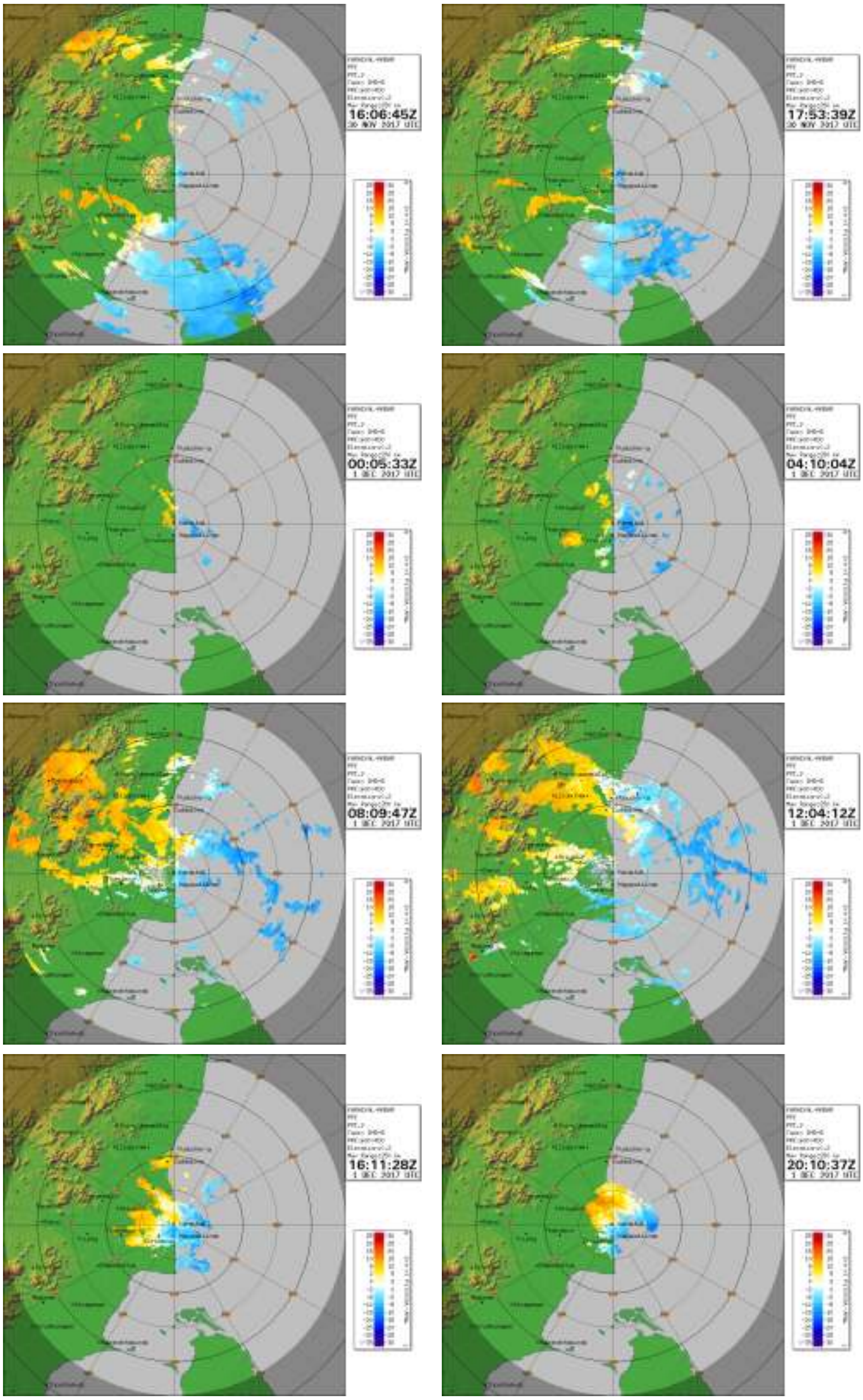


Fig. 10 (e): DWR Karaikal radial velocity (m/s) imageries during 1606 UTC of 30th November -2010 UTC of 1st December

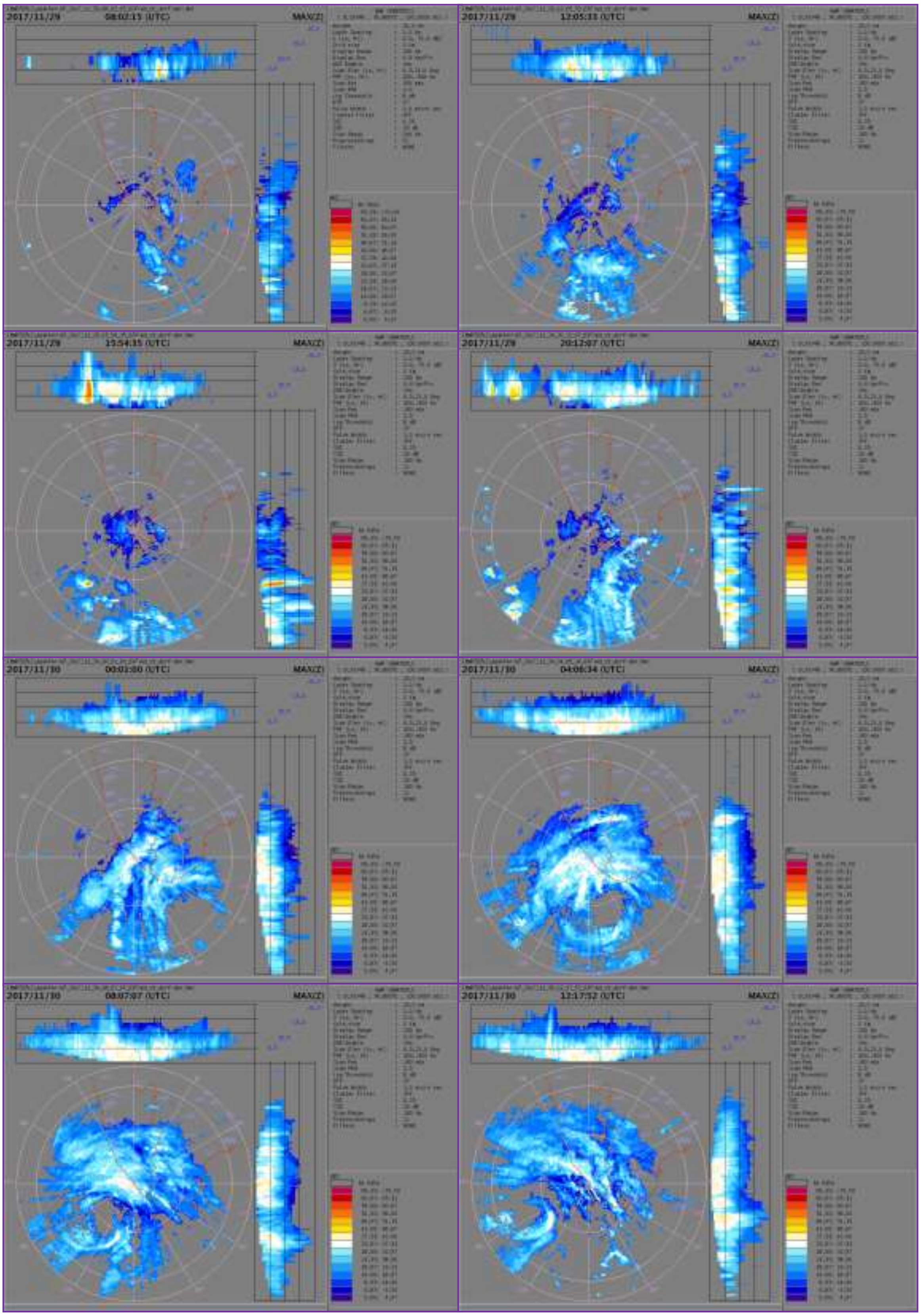


Fig. 10 (f): DWR Thiruvananthapuram Maximum Reflectivity (dBz) imageries during 0802 UTC of 29th -1217 UTC of 30th November

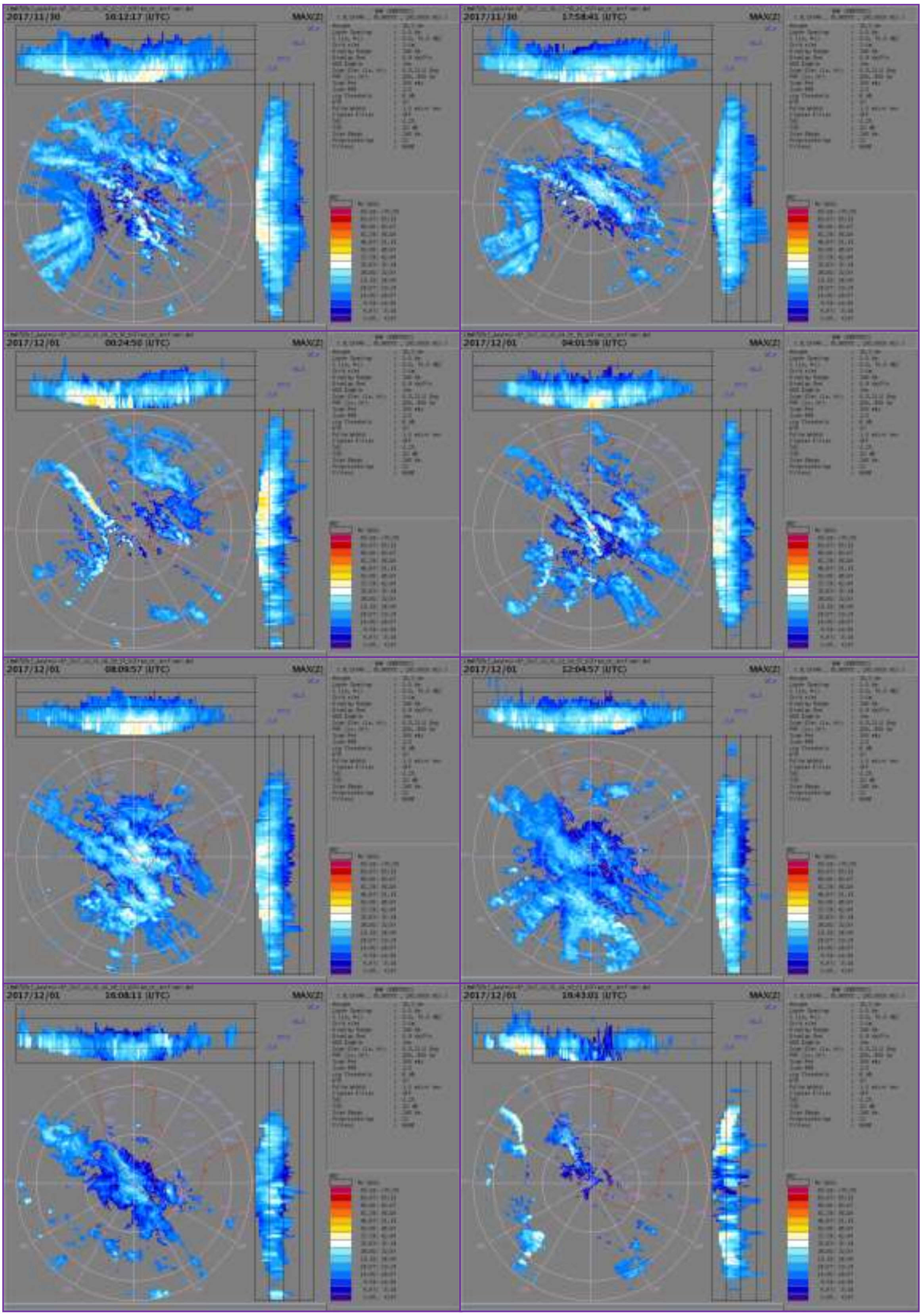


Fig. 10 (g): DWR Thiruvananthapuram Maximum Reflectivity (dBz) imageries during 1612 UTC of 30th November-1947 UTC of 1st December

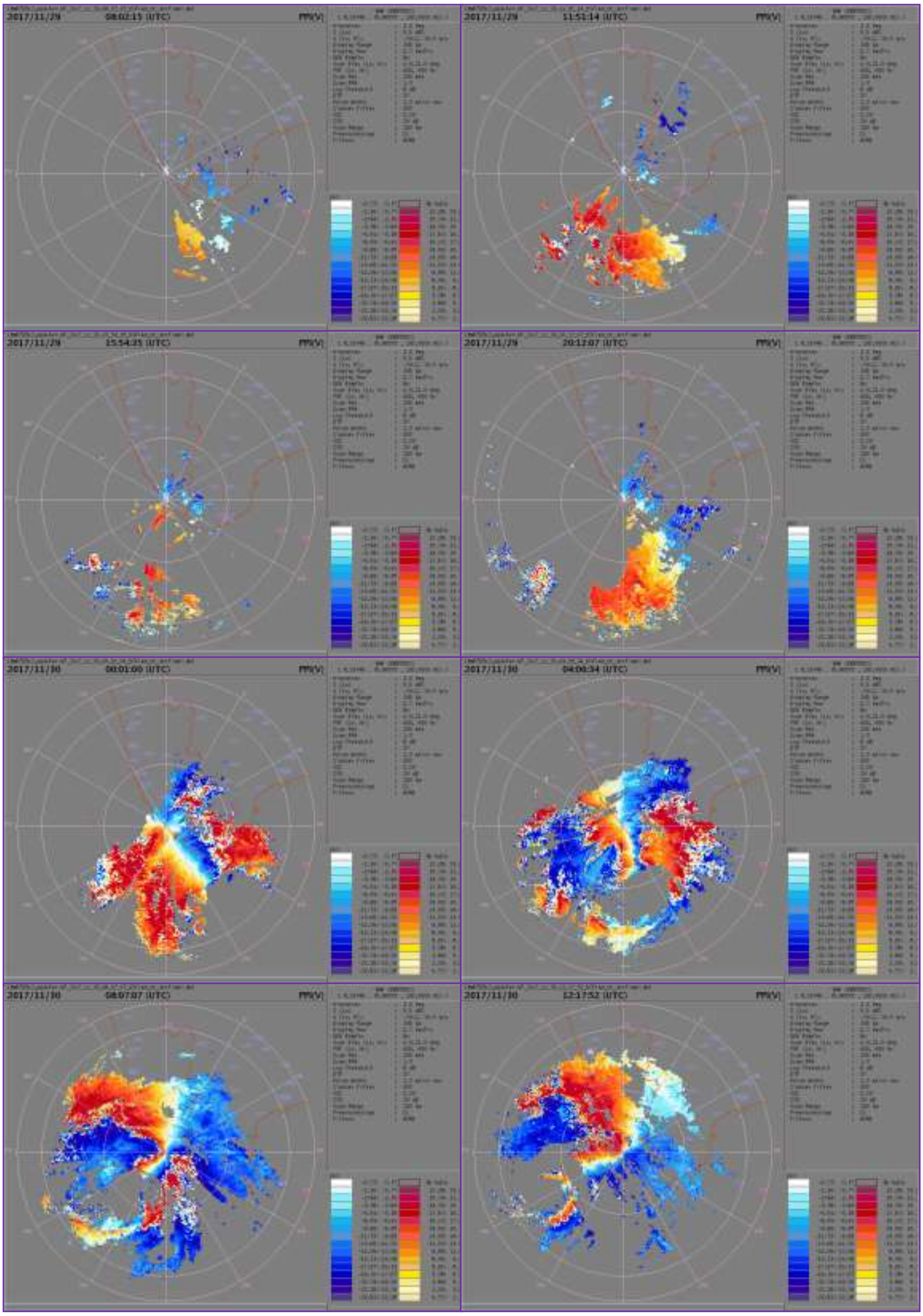


Fig. 10 (h): DWR Thiruvananthapuram radial velocity (m/s) imageries during 0802 UTC of 29th -1217 UTC of 30th November

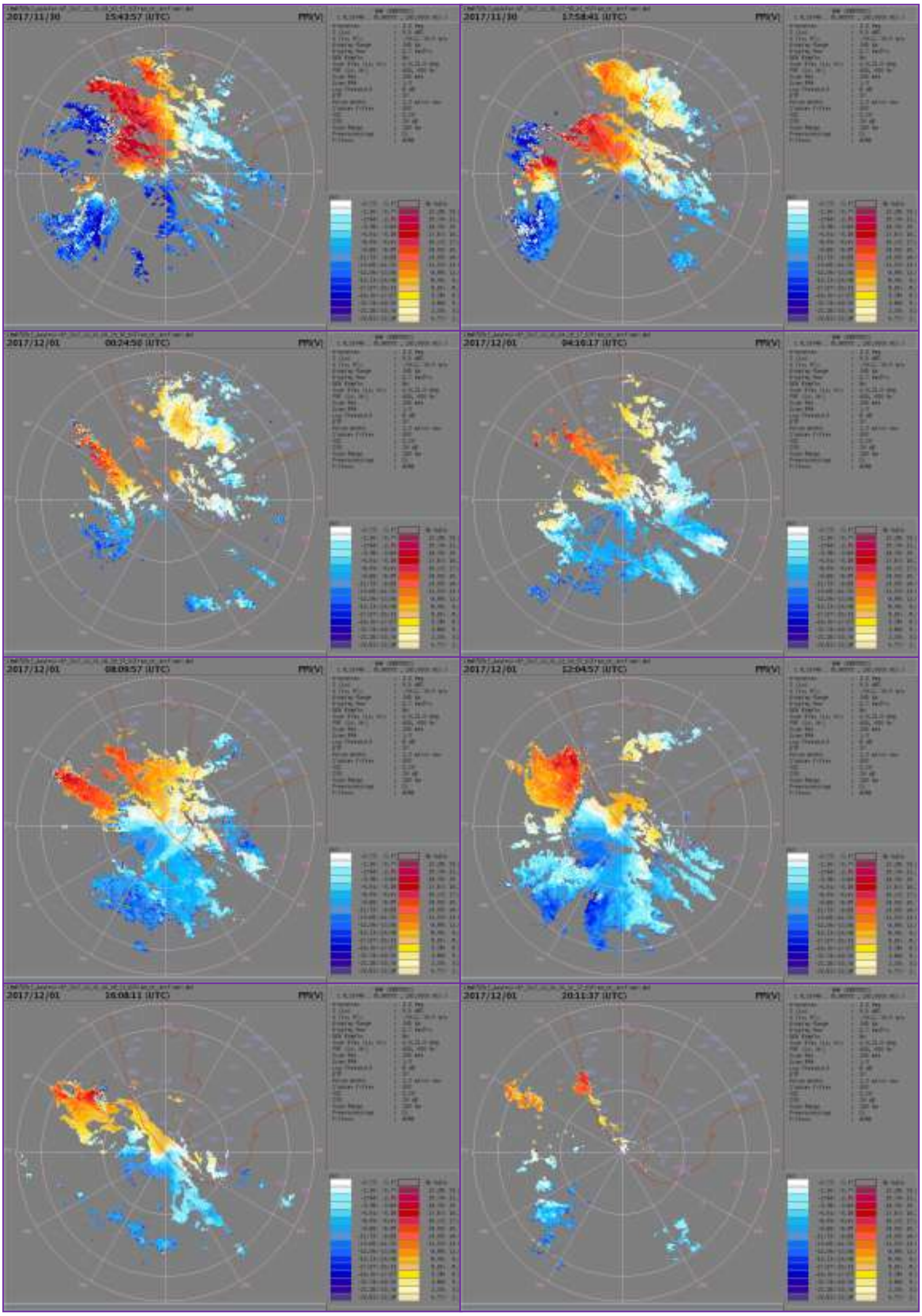


Fig. 10 (i): DWR Thiruvananthapuram radial velocity (m/s) imageries during 1543 UTC of 30th November-2011 UTC of 1st December

Imageries from CDR Kochi are presented in Fig.10 (j). The VSCS Ockhi was captured by CDR Kochi during 0000 UTC of 29th November to 2nd December. The hourly observations from CDR Kochi are presented in Table 3 & 4.

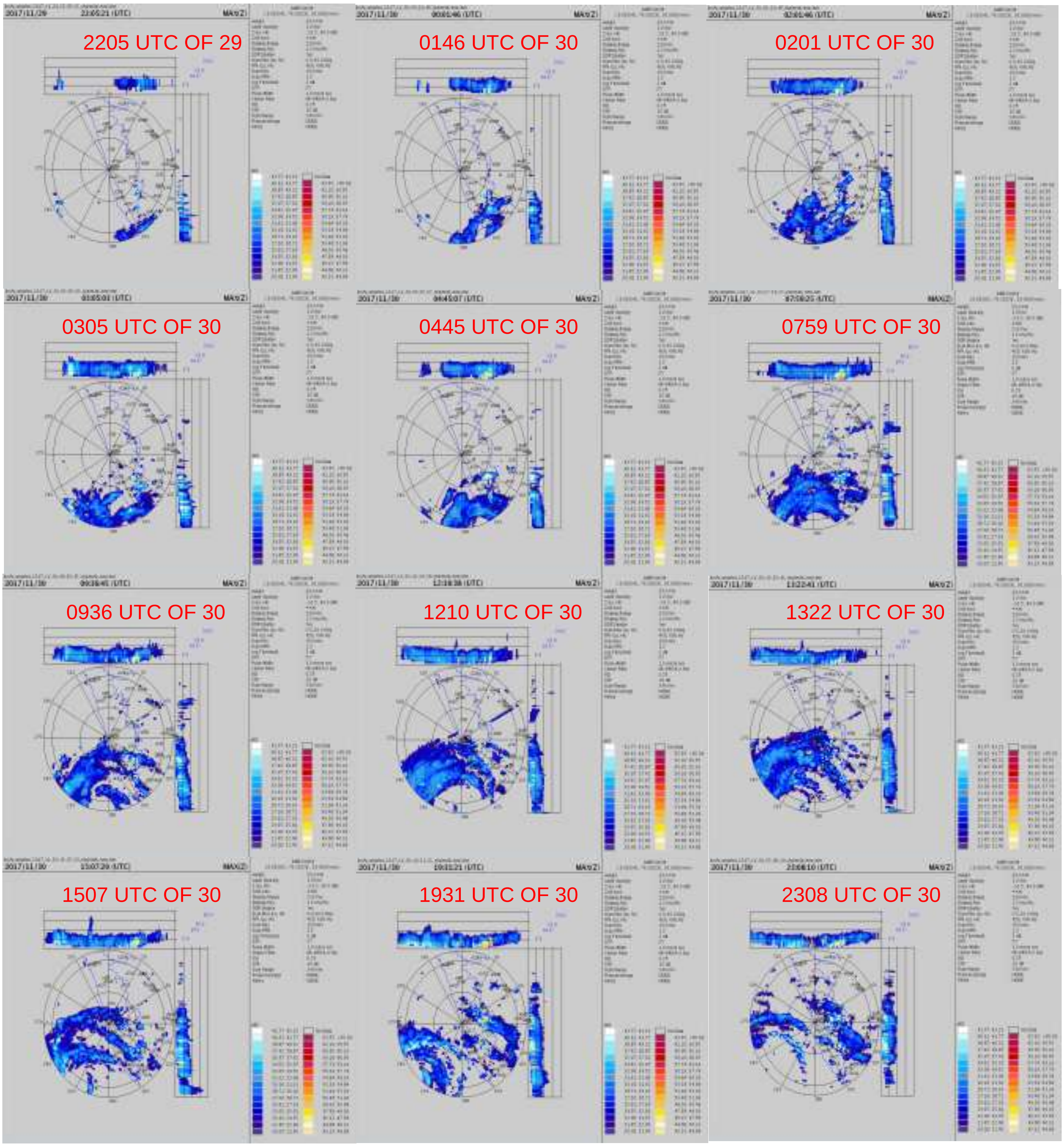


Fig. 10 (j): CDR Kochi Maximum Reflectivity (dBz) imageries during 2205 UTC of 29th November-2308 UTC of 30th November

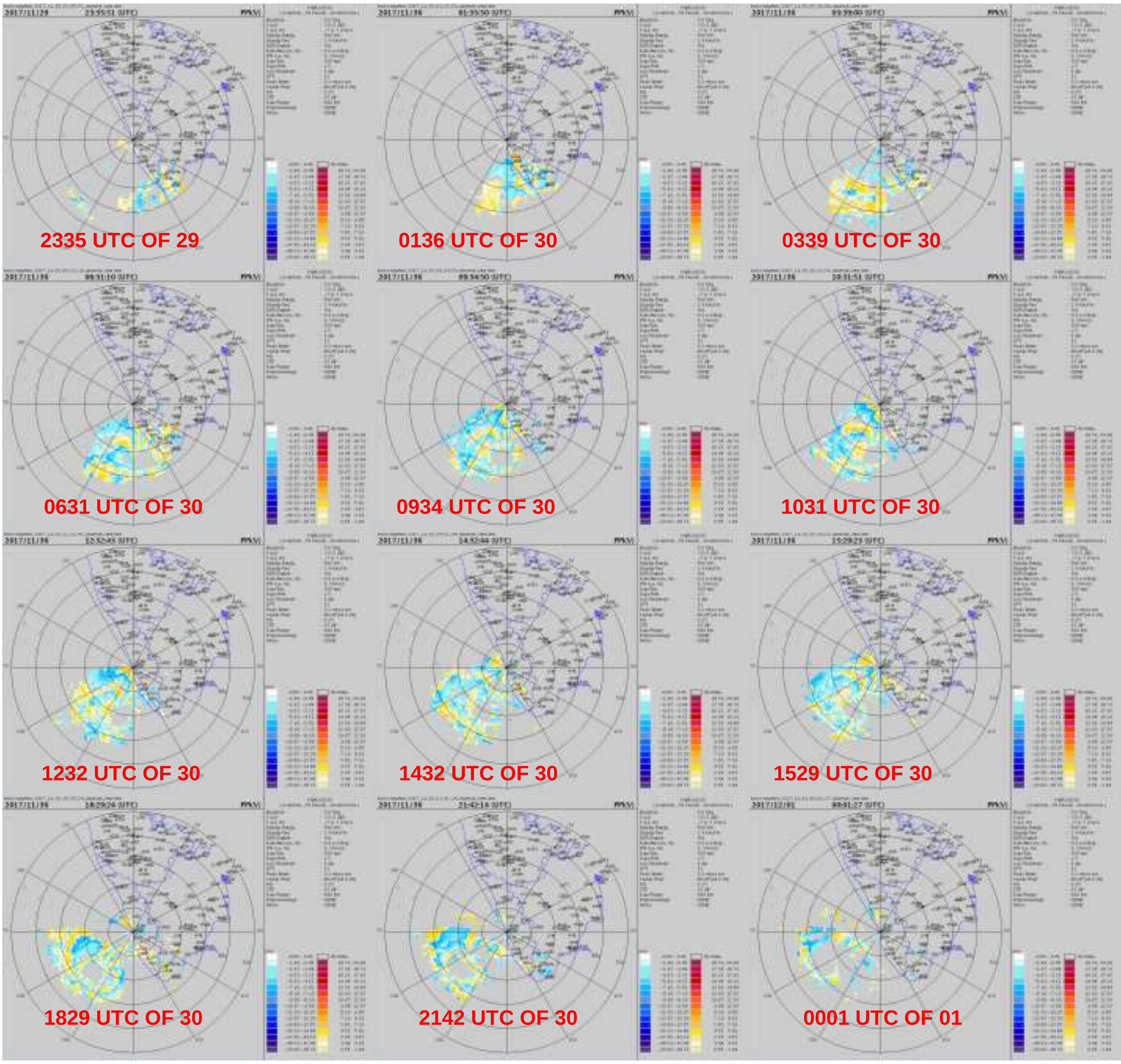


Fig. 10 (k): CDR Kochi Plan Position Indicator radial velocity (PPI_V) imageries during 2335 UTC of 29th November-0001 UTC of 1st December

As per CDR Kochi Radar observations, maximum radial velocity of 44.7 m/s was recorded at 1907 UTC of 30th November in south-southwest direction (211^0) at a distance of 223 km at a height of 2.92 km above station level. As per the standard procedure the radial velocity has been converted to surface wind. Utilizing the mean wind speed profile, based on dropsonde observations over Atlantic Ocean in the eyewall region of cyclones, radar based radial wind observations at a given height has been converted initially into wind at 700 hPa level (W_{700hPa}) and then at surafce level (W_{10m}). The wind is first converted to 700 hPa level as the WC-130J flies at this level and dropsonde is released into the cyclone field from this level. A suitable conversion factor for changing the radar wind at a given height to the 700 hPa level has been used based on Franklin etal, (2000) and Powel & Black (1990). The standard vertical profile of wind based on dropsonde observation over the north Atlantic has been used for the above purpose.

Table 3 (a): DWR Kochi observations of maximum sustained surface winds associated with VSCS Ockhi during 29th November-02 December

Date/ Time in UTC	Azimuth (deg)	Range (km)	Height (km)	Latitude (deg)	Longitude (deg)	Radial Velocity in m/s	Conversion factor .	$W_{700\ hPa}$ in m/s	W_{10m}= (7)X0.73 (kt) @1
-1	-2	-3	-4	-5	-6	-7	-8	-9	10
29/0000	196	212	2.64	Centre ill defined		17.31	1.03	16.81	24
29/2205	155	222	2.9			23.78	1.01	23.54	33
29/2301	175	226	3			18.27	1	18.27	26
30/0101	178	229	3.08			28.53	1	28.53	40
30/0201	200	230	3.11			24.01	1	24.01	34
30/0305	143	237	3.3			-32.9	1	-32.9	-47
30/0407	143	213	2.67	7.519	77.242	-28.31	1.03	-27.49	-39
30/0509	179	224	2.95	7.712	77.016	36.14	1.01	35.78	51
30/0609	185	218	2.79	7.827	76.766	37.23	1.02	36.5	52
30/0711	161	207	2.52	7.802	76.546	-38.69	1.03	-37.56	-53
30/0811	193	226	3	7.968	76.339	36.17	1	36.17	51
30/0900	170	236	3.28	8.007	76.159	-39.34	1	-39.34	-56
30/1008	204	223	2.92	8.019	76.004	40.62	1.01	40.22	57
30/1110	201	217	2.77	8.007	75.836	41.09	1.02	40.28	57
30/1210	206	211	2.62	8.058	75.771	40.84	1.03	39.65	56
30/1310	209	207	2.52	8.121	75.629	38.04	1.03	36.93	52
30/1410	224	191	2.15	8.275	75.487	41.74	1.05	39.75	56
30/1507	218	191	2.15	8.287	75.344	43.28	1.05	41.22	58
30/1607	228	221	2.87	8.351	75.176	41.14	1.01	40.73	58
30/1707	231	211	2.62	8.439	74.943	41.95	1.03	40.73	58
30/1807	235	223	2.92	8.439	74.839	42.49	1.01	42.07	60
30/1907	211	223	2.92	8.413	74.698	-44.7	1.01	-44.26	-63
30/1955	241	217	2.77	8.425	74.659	40.64	1.02	39.84	56
30/2057	240	221	2.87	8.553	74.606	42.62	1.01	42.2	60
30/2156	241	221	2.87	8.604	74.477	42.17	1.01	41.75	59
30/2320	226	230	3.11	8.717	74.217	-34.95	1	-34.95	-49
01/0003	266	222	2.9	8.806	74.126	29.09	1.01	28.8	41
01/0102	270	152	1.36	8.819	74.074	30.75	1.07	28.74	41
01/0202	271	179	1.88	8.882	73.944	31.23	1.05	29.74	42
01/0302	252	225	2.98	8.918	73.698	19.96	1	19.96	28
01/0402	259	230	3.11	8.904	73.529	26.29	1	26.29	37

01/0502	260	231	3.14	8.778	73.44	22.64	1	22.64	32
01/0602	197	93	0.51	8.774	73.272	-16.6	1.21	-13.72	-19
01/0702	242	117	0.8	8.773	73.116	-22.48	1.08	-20.81	-29
01/0845	261	50	0.15	8.758	72.961	32.82	0.92	35.67	51
01/0921	263	50	0.15			23.47	0.92	25.51	36
01/1011	264	232	3.17			16.27	1	16.27	23
01/1111	268	102	0.61			28.02	1.06	26.43	37
01/1201	259	237	3.3			15.26	1	15.26	22
01/1301	265	229	3.08			23.77	1	23.77	34
01/1401	221	167	1.64			18.79	1.07	17.56	25
01/1502	269	226	3			22.95	1	22.95	32
01/1607	270	232	3.17			19.93	1	19.93	28
01/1707	268	239	3.36			21.47	1	21.47	30
01/1807	224	207	2.52			-24.35	1.03	-23.64	-33
01/1907	227	218	2.79			-23.97	1.02	-23.5	-33
01/2105	290	232	3.17			23.99	1	23.99	34
01/2140	240	140	1.15			-18.84	1.07	-17.61	-25
02/0028	239	105	0.65			-22.24	1.06	-20.98	-30
02/0104	262	154	1.39			-15.95	1.07	-14.91	-21
02/0204	294	216	2.74			17.86	1.02	17.51	25
02/0307	298	198	2.31			14.41	1.04	13.86	20
02/0407	317	217	2.77	Centre ill defined		19.13	1.02	18.75	27

–ve radial velocity indicates winds were directed towards Radar Station, @1 Powell and Black estimation

Table 3 (b): Final observations from DWR Kochi of centre and 3-minute average maximum sustained wind (kts) for VSCS Ockhi during 29th Nov.02 Dec

Date/ Time in UTC	Latitude (deg)	Longitude (deg)	W_{10m}= (7)X0.73 (kt)
(1)	(2)	(3)	(4)
29/0000			24
29/2205			33
29/2301	Centre ill defined		26
30/0101			40
30/0201			34
30/0305			-47
30/0407	7.519	77.242	-39
30/0509	7.712	77.016	51
30/0609	7.827	76.766	52
30/0711	7.802	76.546	-53
30/0811	7.968	76.339	51
30/0900	8.007	76.159	-56
30/1008	8.019	76.004	57

30/1110	8.007	75.836	57
30/1210	8.058	75.771	56
30/1310	8.121	75.629	52
30/1410	8.275	75.487	56
30/1507	8.287	75.344	58
30/1607	8.351	75.176	58
30/1707	8.439	74.943	58
30/1807	8.439	74.839	60
30/1907	8.413	74.698	-63
30/1955	8.425	74.659	56
30/2057	8.553	74.606	60
30/2156	8.604	74.477	59
30/2320	8.717	74.217	-49
01/0003	8.806	74.126	41
01/0102	8.819	74.074	41
01/0202	8.882	73.944	42
01/0302	8.918	73.698	28
01/0402	8.904	73.529	37
01/0502	8.778	73.44	32
01/0602	8.774	73.272	-19
01/0702	8.773	73.116	-29
01/0845	8.758	72.961	51
01/0921	Centre ill defined		36
01/1011			23
01/1111			37
01/1201			22
01/1301			34
01/1401			25
01/1502			32
01/1607			28
01/1707			30
01/1807			-33
01/1907			-33
01/2105			34
01/2140			-25
02/0028			-30
02/0104			-21
02/0204			25
02/0307			20
02/0407			27

The hourly observations of centre and radial wind at an elevation of 0.5 degree on 30th November, 2018 from DWR Thiruvananthapuram are presented in Table 4 (a-b). As per DWR Thiruvananthapuram, maximum radial velocity of 26.2 kts was recorded at 1528 IST (1000 UTC) of 30th November in northwest direction (304^0) at a distance of 60 km at a height of 0.52 km above station level. There is need to develop an algorithm to derive surface wind distribution from the radial wind distribution at certain elevation.

Table 4 (a): Hourly observations of centre from DWR Thiruvananthapuram

Time (UTC)	Range (from DWR to centre) km	Centre latitude (deg.)	Centre longitude (deg.)
0:58:16	166.37	7.3814	77.8249
1:55:30	157.4	7.3816	77.6913
2:12:24	144.92	7.4053	77.5185
2:55:02	135.02	7.46	77.4322
4:06:34	112.5	7.5849	77.2123
5:03:47	92.99	7.7097	76.9922
6:01:00	86.28	7.772	76.7327
6:55:49	77.61	7.9044	76.5675
8:07:07	85.43	7.9587	76.355
9:04:20	107.39	7.966	76.0796
9:47:18	114.4	8.0048	75.9772
10:53:25	135.03	8.1132	75.7172
12:03:12	145.18	8.0818	75.6308
13:13:17	148.47	8.1517	75.5754
13:55:56	162.97	8.2369	75.4177
15:04:29	181.62	8.3452	75.2282

Table4(b): DWR Thiruvanathapuram observations of maximum sustained surface winds associated with VSCS Ockhi on 30th November

Date/ Time in UTC	**Azimuth (deg)**	**Range (km)**	**Height (km)**	**Radial Velocity in m/s**	**Conversion factor .**	**$W_{700\ hPa}$ in m/s**	**3 minute average W_{10m}= (7)X0.73 (kt) @1**	**3 minute average W_{10m} (outer vortex)= (7)X0.78 (kt) @2**	**3 minute average W10m (eye wall)= (7) X0.91(kt) @3**
-1	**-2**	**-3**	**-4**	**-5**	**-6**	**-7**	**8**	**9**	**10**
15:28	301.6	15	0.131	4.266	1.12	3.8	4.9	5.2	6.1
15:28	294.7	30	0.262	11.46	1.13	10.1	12.9	13.8	16.1
15:28	304	45	0.393	13.61	1.2	11.3	14.5	15.4	18.0
15:28	299.9	60	0.524	19.82	1.2	16.5	21.1	22.5	26.2
16:38	278	15	0.131	12.03	1.12	10.7	13.7	14.6	17.1
16:38	295	30	0.262	12.47	1.13	11.0	14.1	15.0	17.5
16:38	303.3	45	0.393	15.88	1.2	13.2	16.9	18.0	21.0

16:38	299.7	60	0.524	14.56	1.2	12.1	15.5	16.5	19.3
17:23	311.5	15	0.131	12.38	1.12	11.1	14.1	15.1	17.6
17:23	311.7	30	0.262	12.05	1.13	10.7	13.6	14.5	16.9
17:23	312.7	45	0.393	15.53	1.2	12.9	16.5	17.6	20.6
17:23	306.5	60	0.524	9.387	1.2	7.8	10.0	10.7	12.4
18:29	315.5	15	0.131	6.523	1.12	5.8	7.4	7.9	9.3
18:29	302	30	0.262	9.897	1.13	8.8	11.2	11.9	13.9
18:29	290.7	45	0.393	12.69	1.2	10.6	13.5	14.4	16.8
18:29	316.2	60	0.524	12.3	1.2	10.3	13.1	14.0	16.3
18:29	313.7	75	0.655	13.77	1.19	11.6	14.7	15.8	18.4
19:40	305.4	45	0.393	16.12	1.2	13.4	17.1	18.3	21.3
19:40	298.6	60	0.524	7.758	1.2	6.5	8.2	8.8	10.3
19:40	310.8	75	0.655	11.47	1.19	9.6	12.3	13.1	15.3
21:02	314	15	0.131	2	1.12	1.8	2.3	2.4	2.8
21:02	317	30	0.262	9.519	1.16	8.2	10.5	11.2	13.0
21:02	312.3	45	0.393	11.47	1.2	9.6	12.2	13.0	15.2
21:56	312.3	15	0.131	5.104	1.12	4.6	5.8	6.2	7.2
21:56	296	30	0.262	8.406	1.13	7.4	9.5	10.1	11.8
21:56	308.4	60	0.524	15.09	1.2	12.6	16.0	17.1	20.0
21:56	313.4	75	0.655	7.053	1.19	5.9	7.6	8.1	9.4
21:56	308.1	90	0.786	10.86	1.14	9.5	12.1	13.0	15.1
22:55	302	15	0.131	2.809	1.12	2.5	3.2	3.4	4.0
22:55	310.5	30	0.262	7.928	1.13	7.0	8.9	9.6	11.1
22:55	311	45	0.393	10.8	1.2	9.0	11.5	12.3	14.3

@1 Powell and Black estimation
@2 Franklin etal estimation in outer vortex
@3 Franklin etal estimation in eyewall region

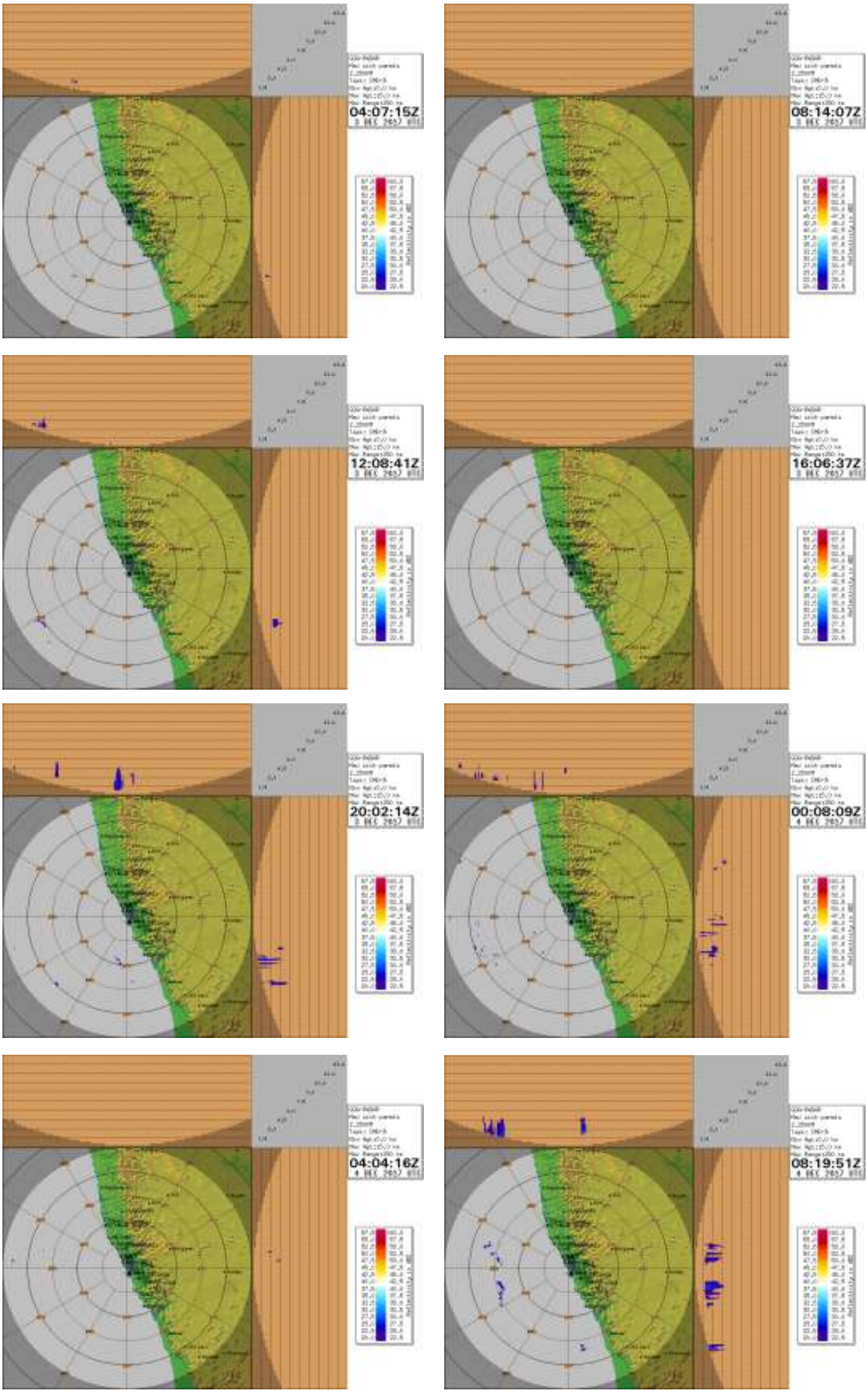


Fig. 10 (l): DWR Goa maximum reflectivity (dBz) imageries during 0407 UTC of 3rd -0819 UTC of 4th December

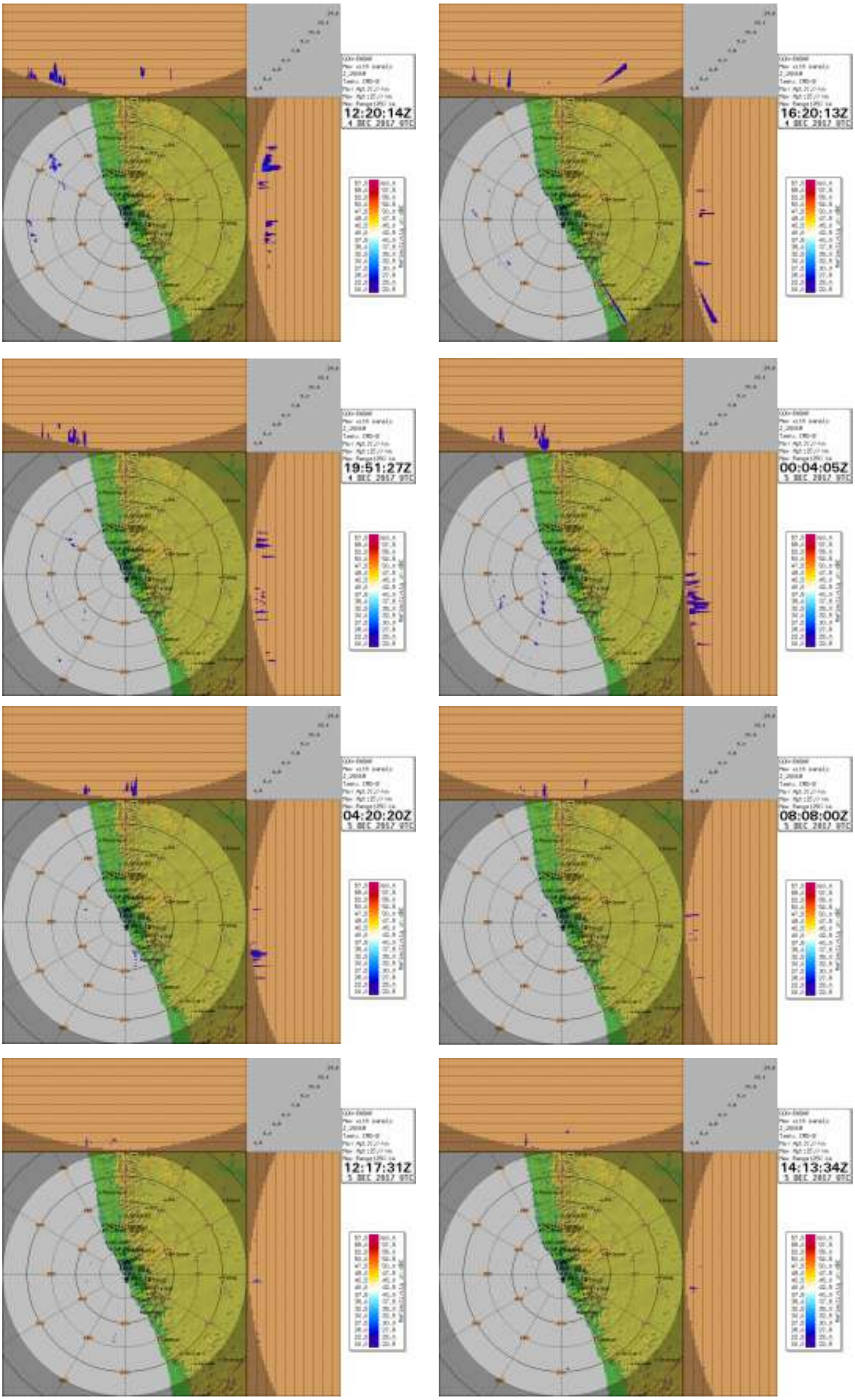


Fig. 10 (m): DWR Goa maximum reflectivity (dBz) imageries during 1220 UTC of 4th -1413 UTC of 5th December

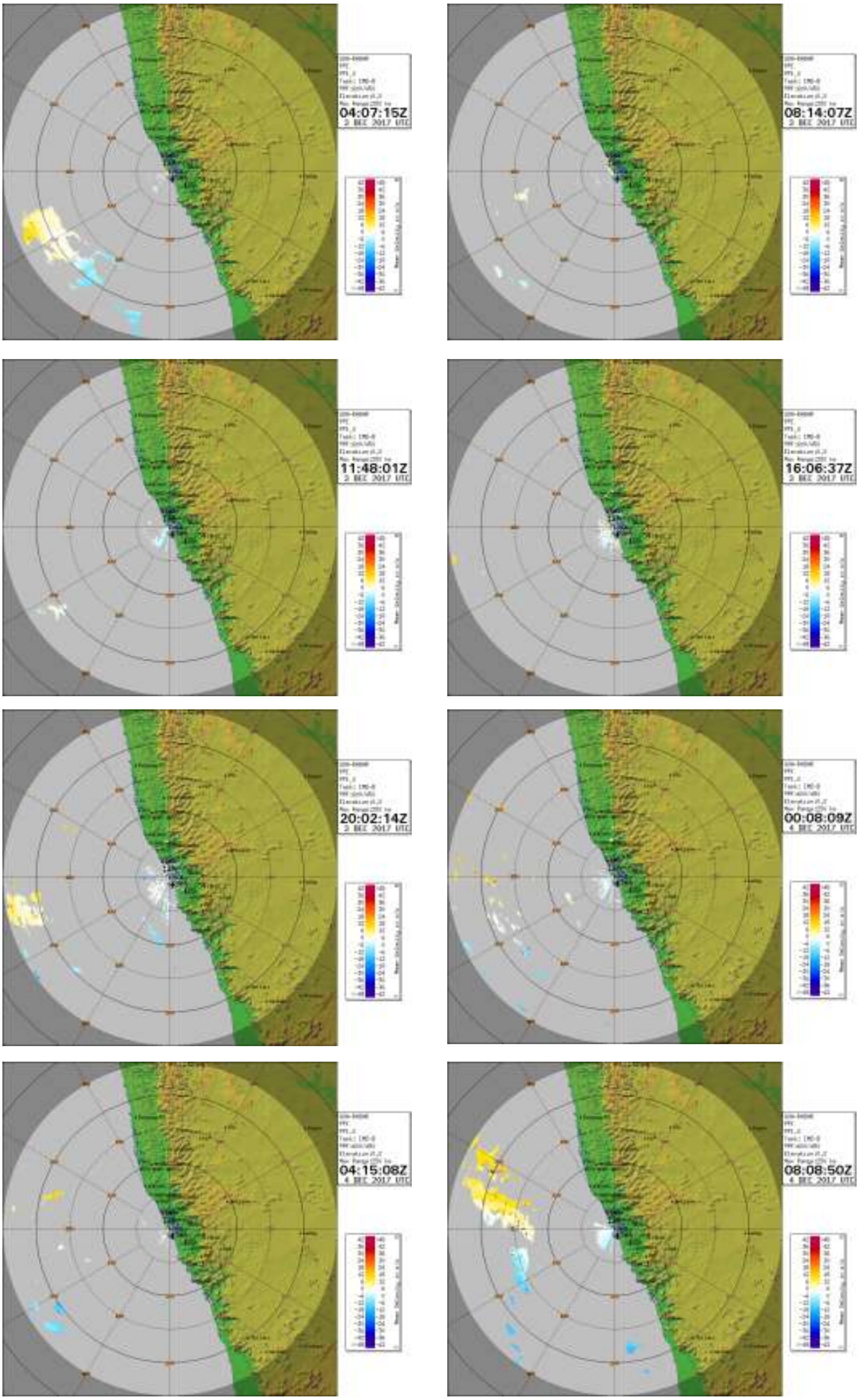


Fig. 10 (n): DWR Goa Plan Position Indicator (PPI_V) radial velocity (m/s) imageries during 0407 UTC of 3rd -0808 UTC of 4th December

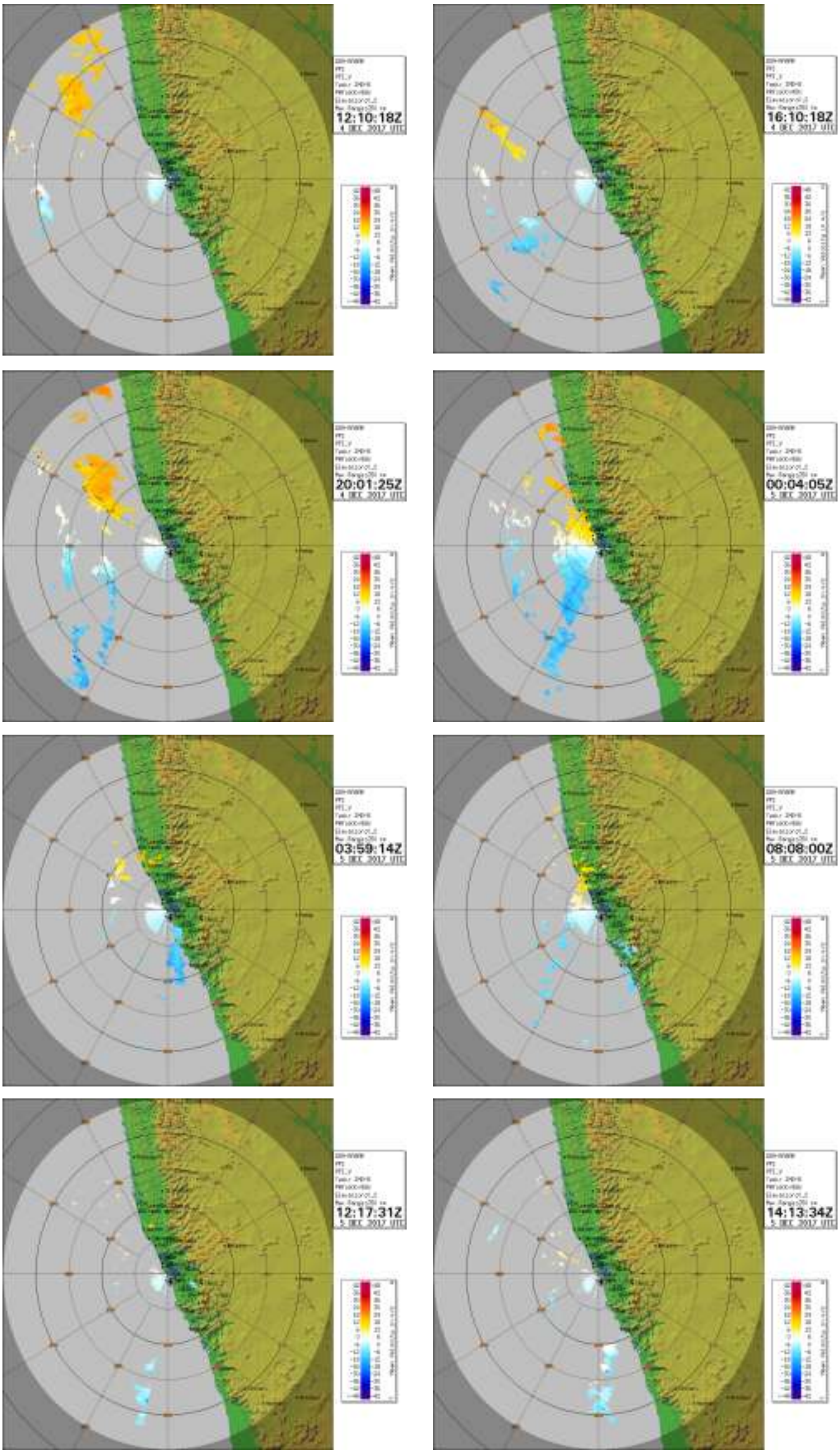


Fig. 10 (O): DWR Goa Plan Position Indicator (PPI_V) radial velocity (m/s) imageries during 1210 UTC of 4th -1413 UTC of 5th December

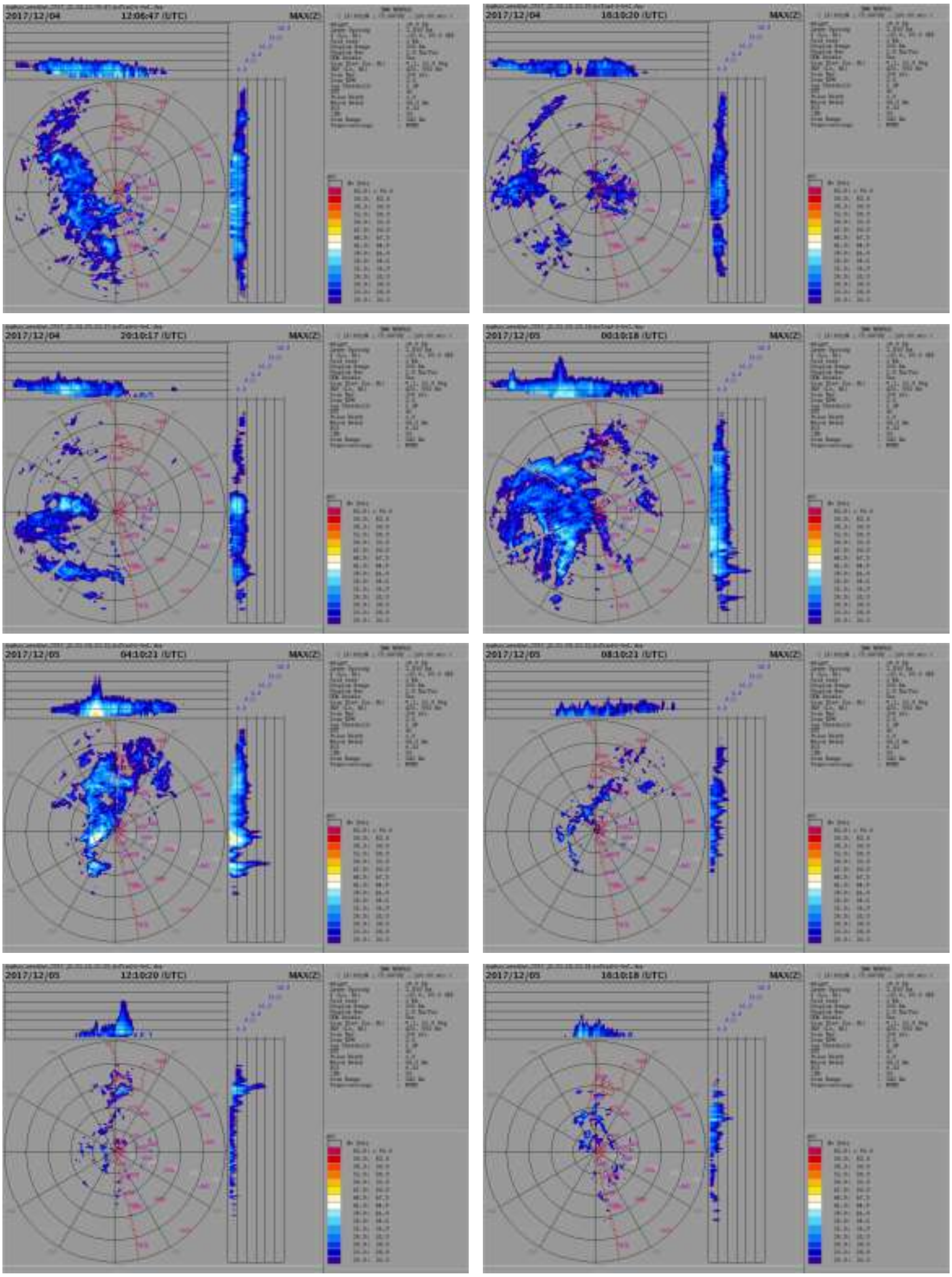


Fig. 10 (p): DWR Mumbai Max Reflectivity (dBZ) imageries during 1206 UTC of 4th -1610 UTC of 5th December

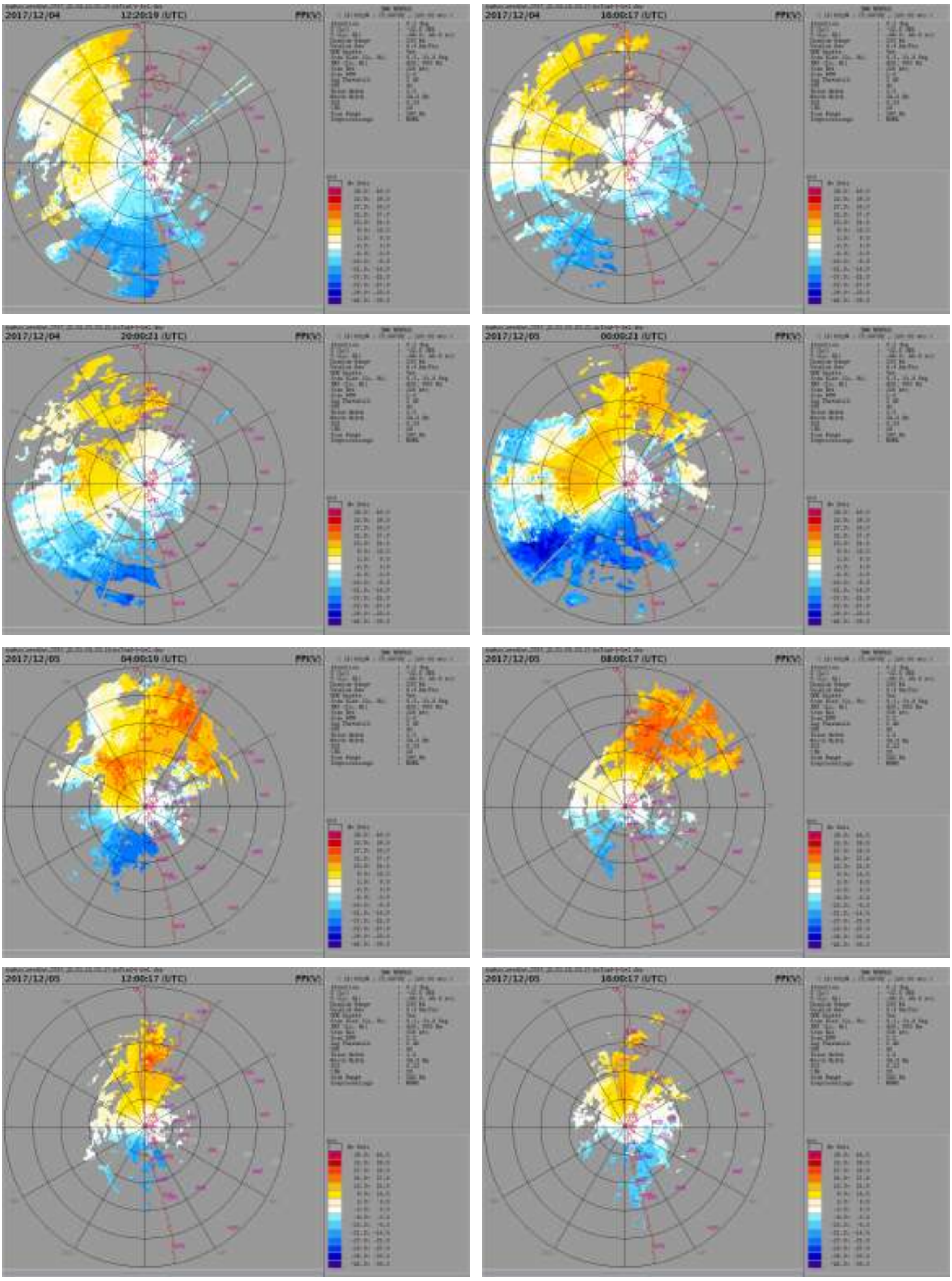


Fig. 10 (q): DWR Mumbai Plan Position Indicator (PPI_V) imageries during 1220 UTC of 4th -1600 UTC of 5th December

6. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 27th November-6th December are presented in Fig.11. The forecast field parameters based aforementioned initial conditions are given in Annexure-1. The analysis field based on 0000 UTC observations of 27th showed a feeble trough of low over southwest BoB and adjoining Sri Lanka coast. The forecast field indicated formation of low over Sri Lanka and neighbourhood on 29th, becoming well marked on 30th over the same area and weakening into a low again on 01st December over southwest and adjoining southeast BoB.

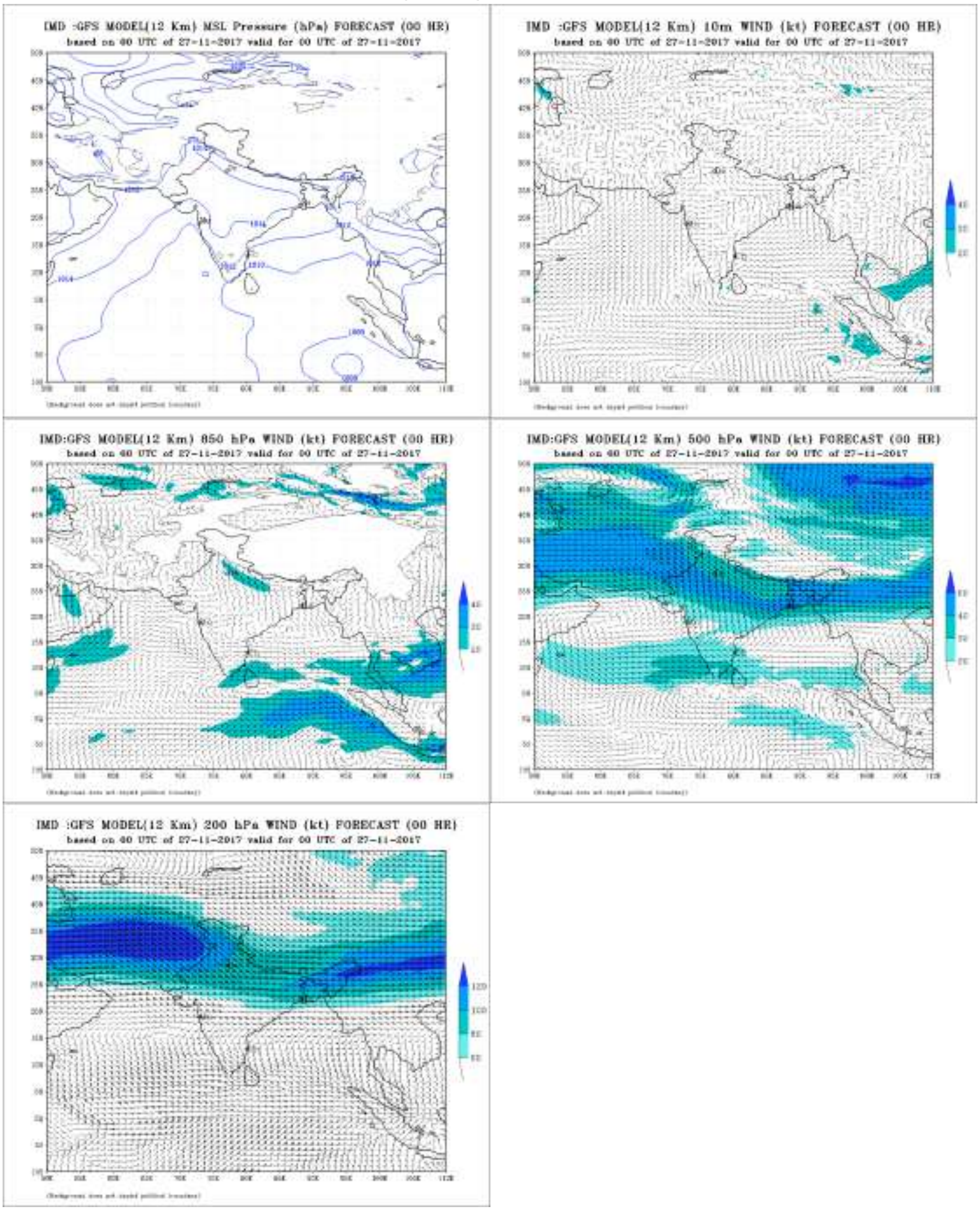


Fig.11 (a): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 27th November

The analysis field based on 1200 UTC observations of 27th showed an extended low over southwest BoB and adjoining Sri Lanka coast. The forecast field indicated formation of depression over southwest Bob on 29th, moving eastwards and intensifying into deep depression over southwest BoB and adjoining southeast BoB on 30th. On 1st and 2nd it indicated merger with the system coming from Malay Peninsula.

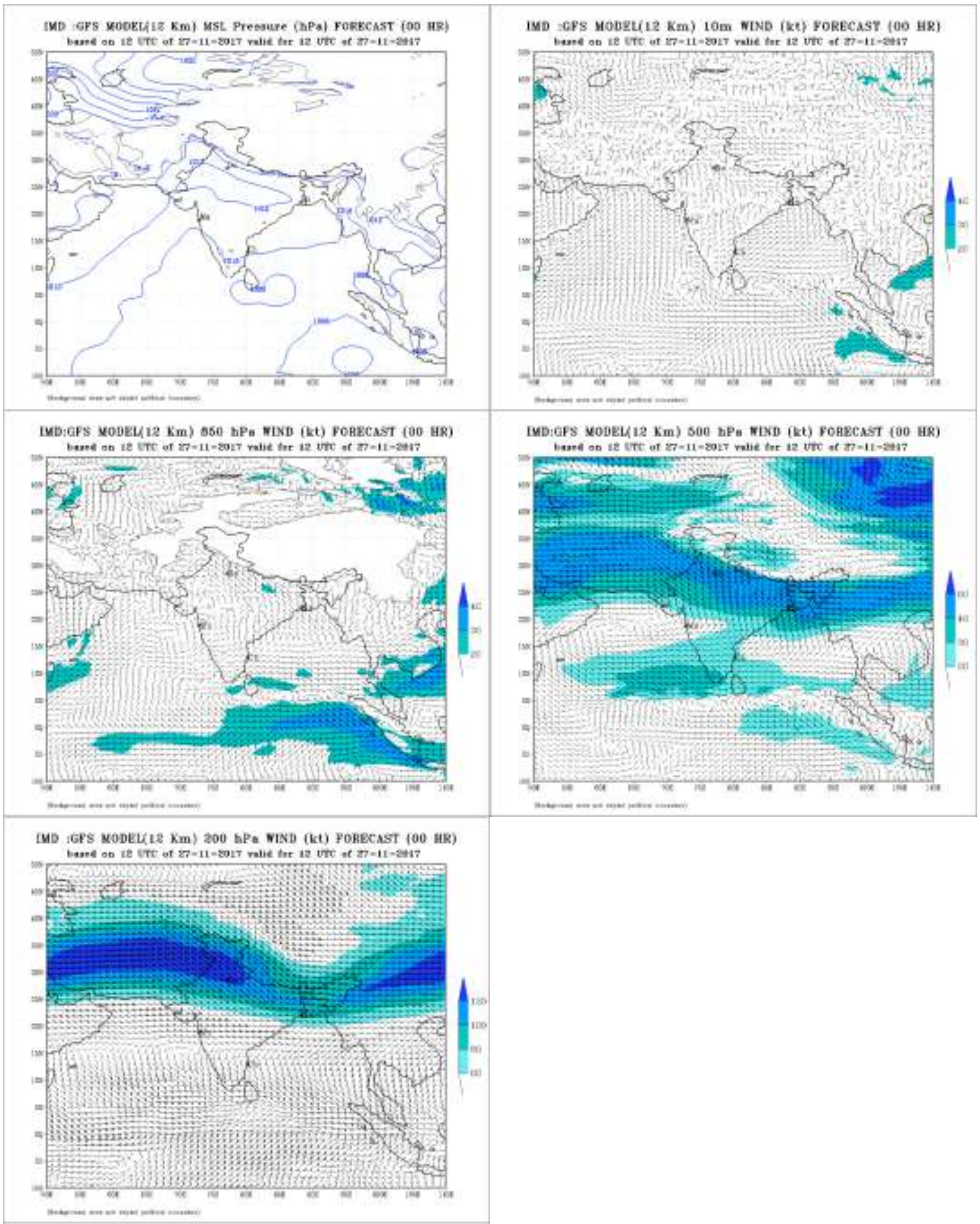


Fig.11 (b): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 1200 UTC of 27th November

The analysis field based on 0000 UTC observations of 28th showed a well-marked low over Sri Lanka and neighborhood on 28th. The forecast field showed that it persisted on 30th over the same area, weakened into a low again on 02nd December over SE Bay and become less marked on 04th.

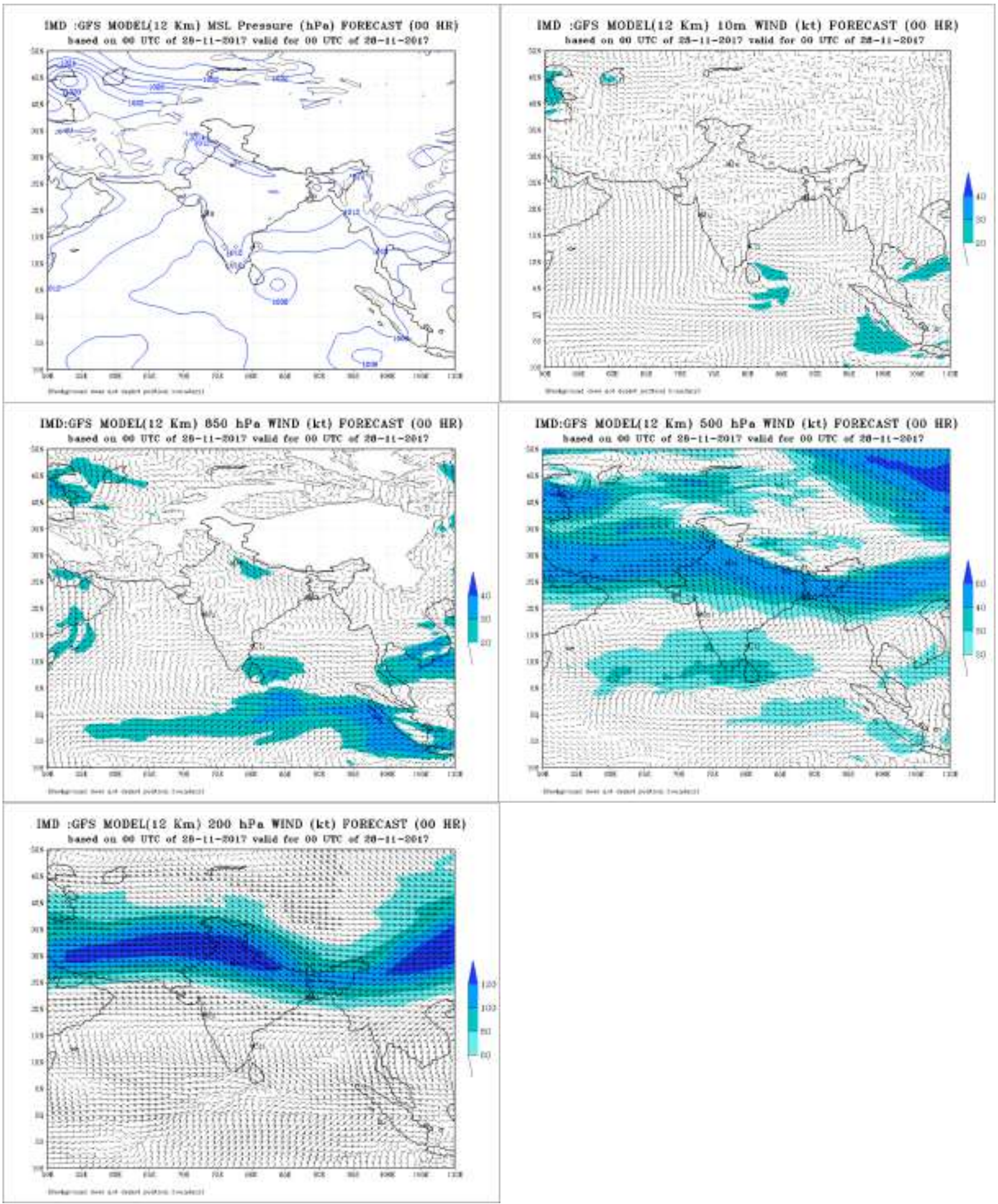


Fig.11 (c): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 28th November

The analysis field based on 1200 UTC observations of 28th showed a well-marked low over Sri Lanka and neighborhood on 28th. The forecast field showed that the system moved westwards and lay as Depression over southwest BoB and adjoining southwest Sri Lanka. Moving westwards, it intensified into CS over Comorin on 30th. It moved north-northwestwards and lay as depression over Lakshadweep on 1st. On 2nd and 3rd, it intensified into deep depression over Lakshadweep.

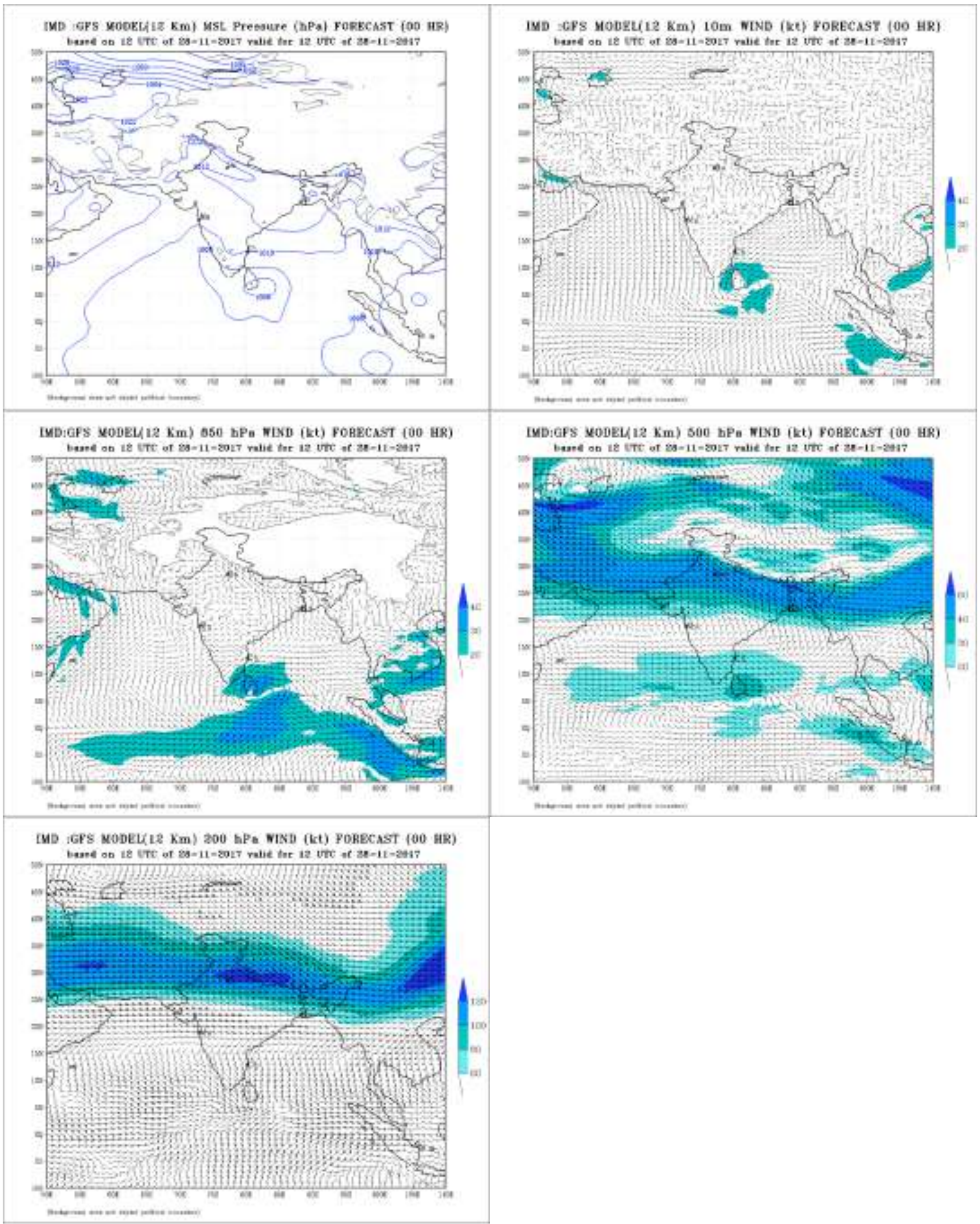


Fig.11 (d): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 1200 UTC of 28th November

The analysis field based on 0000 UTC observations of 29th showed a depression over Comorin off extreme southwest Sri Lanka. The forecast field showed that it would move west-northwestwards and intensify into a deep depression on 03rd December over southeast Arabian Sea. Thereafter, it would move in northeast direction and weaken into a depression close to south Maharashtra- Karnataka coasts on 06th December and further into a low pressure area on 07th December over eastcentral BoB.

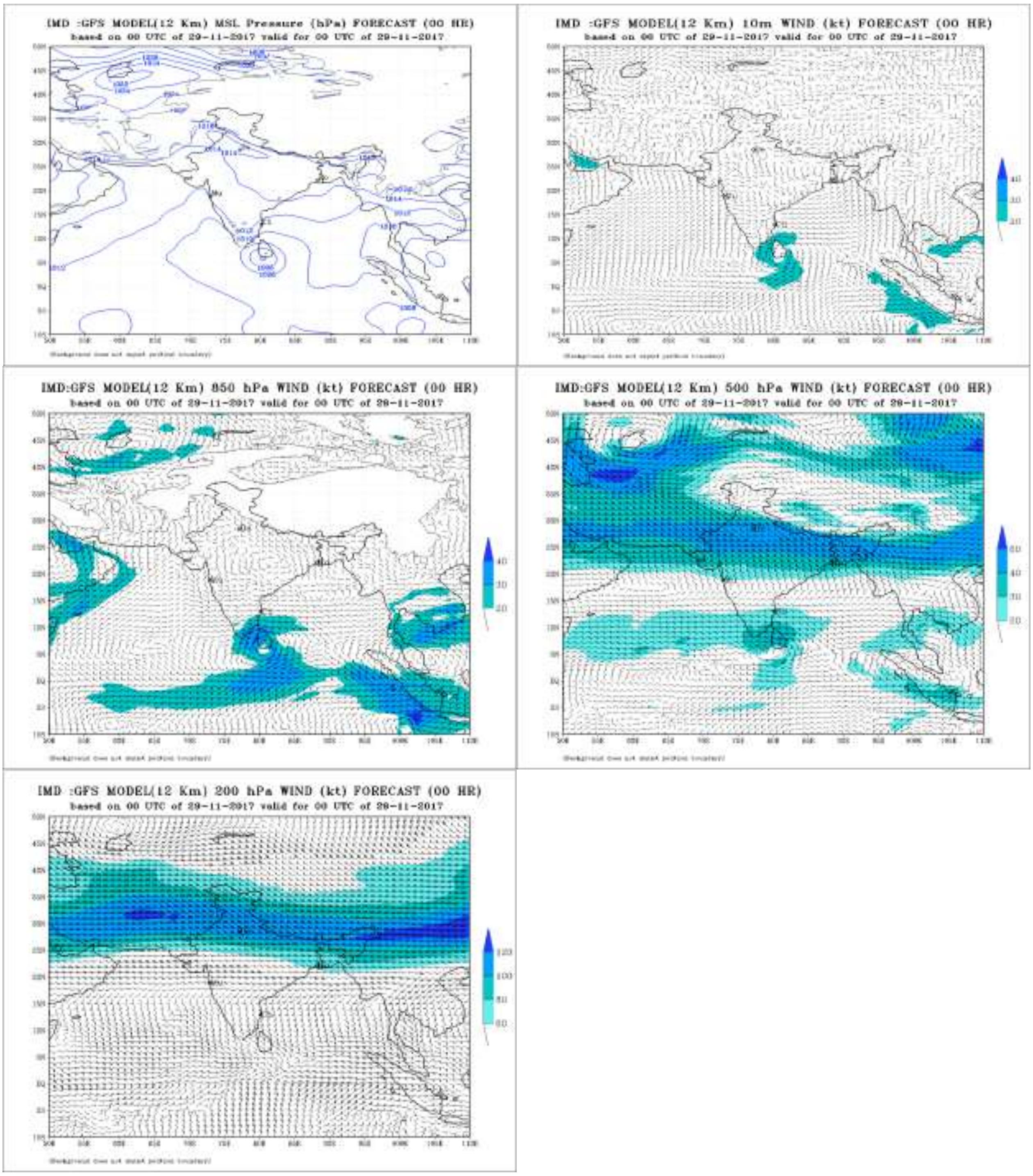


Fig.11 (e): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 29th November

The analysis field based on 1200 UTC observations of 29th showed a depression over Comorin off extreme southwest Sri Lanka. The forecast field showed that it moved north-northwestwards and lay as depression over Comorin on 30th. It moved westwards and lay as deep depression over Maldives on 1st. Moving westwards it lay as a CS over southeast AS on 2nd and SCS over southeast AS. Moving northwards, it lay as a deep depression over eastcentral AS on 4th.

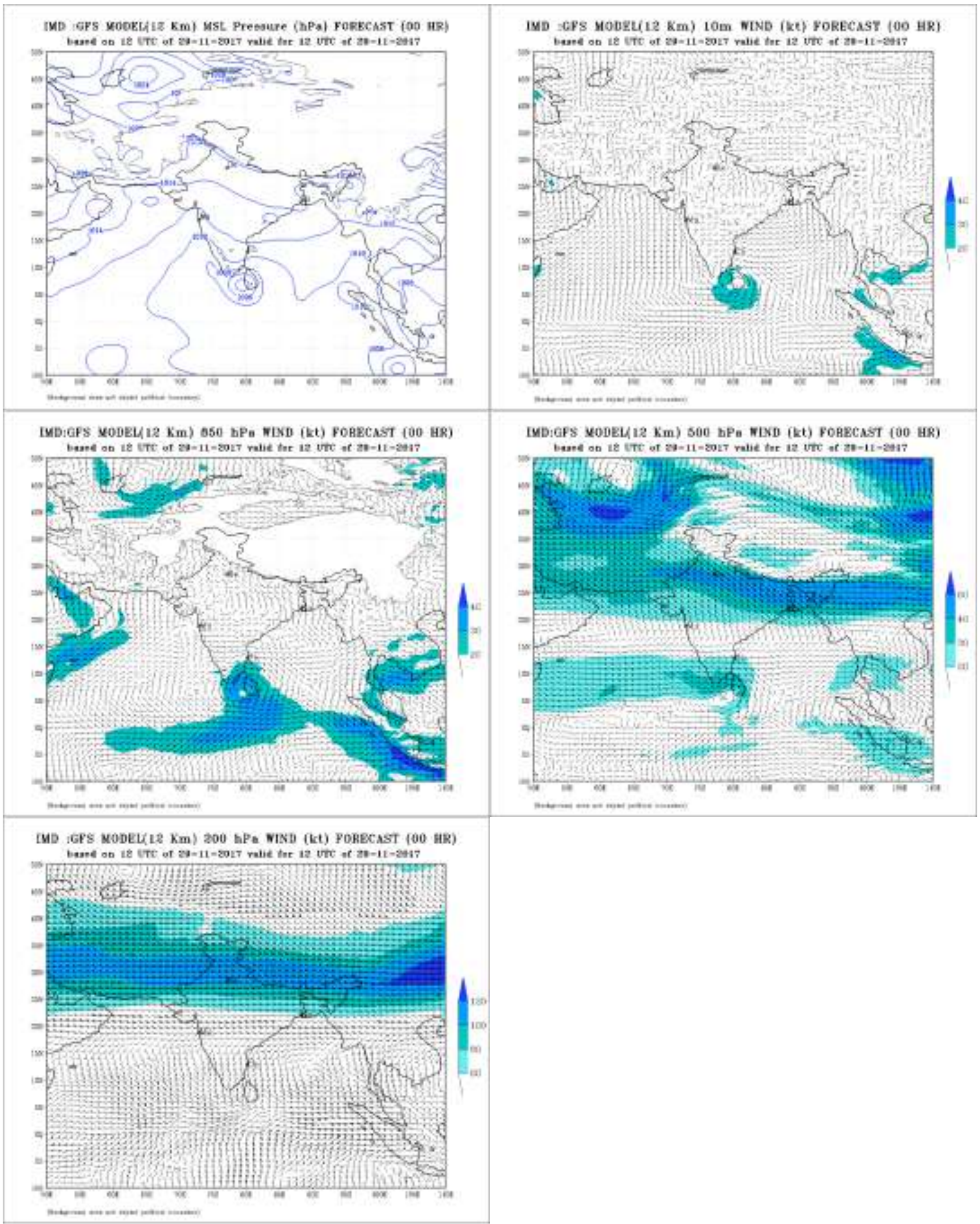


Fig.11 (f): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 1200 UTC of 29th November

The analysis based on 0000 UTC of 30th Nov indicated weakening of system and detected as a low over Comorin area to the south of Sri Lanka on 30th. The forecast field indicated that it would move west-northwestwards. Intensify into a deep depression on 01st December over Lakshadweep area and adjoining southeast Arabian Sea. Thereafter it would become a cyclonic storm on 02nd and weaken into a well marked low pressure area on 07th December over east central Arabian Sea. IMD GFS could not capture the rapid intensification of system from DD and CS during 30th.

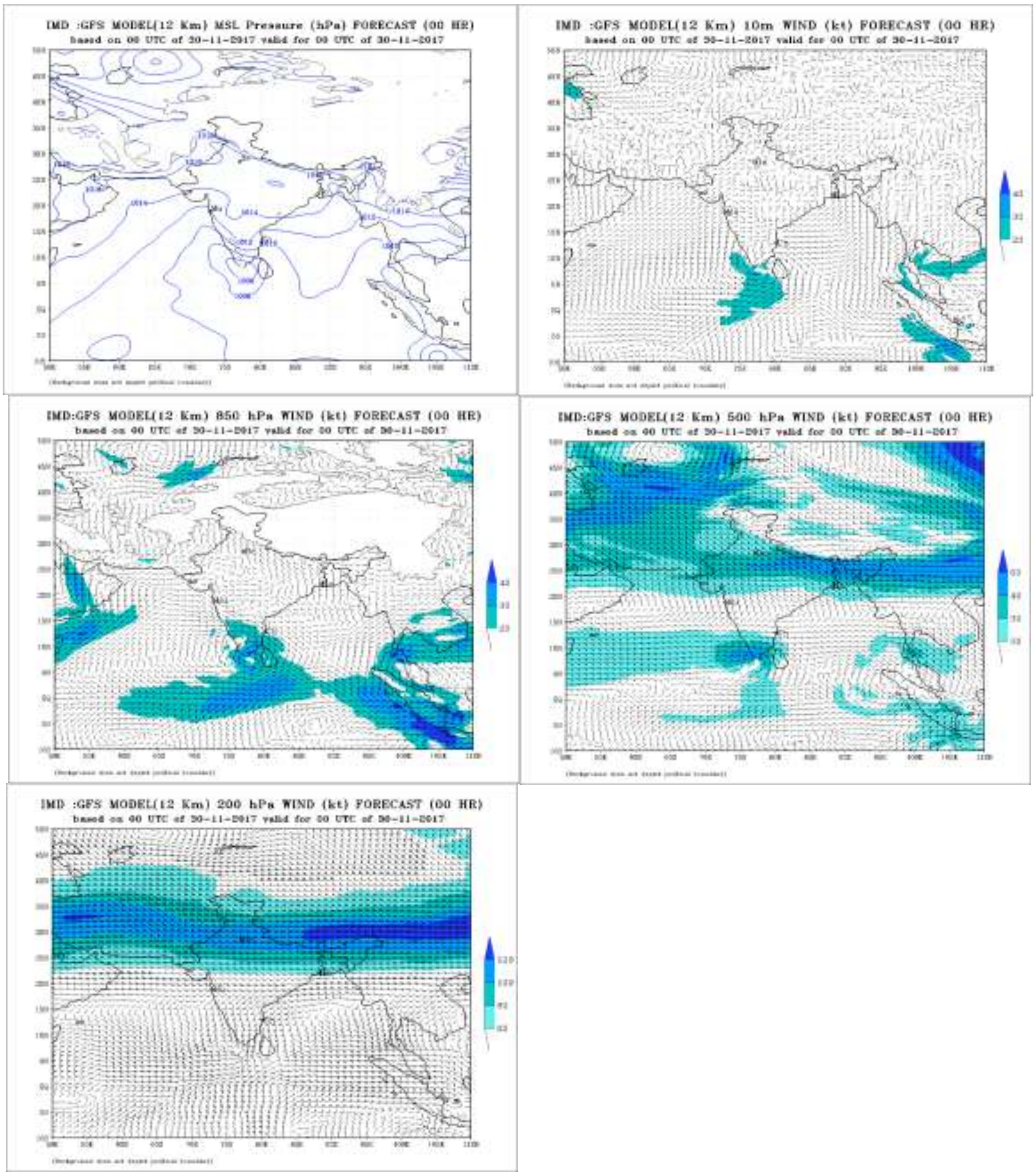


Fig.11 (g): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 30th November

The analysis based on 0000 UTC of 1st December indicated cyclonic storm over Lakshadweep Area on 01st December. The forecast field indicated that the system would move northwestwards, intensify further over EC Arabian Sea on 04th. Further moving NNW, it would weaken on 5th and cross south Gujarat north Maharashtra coasts as a low pressure area on 06th. The model underestimated the intensity of the system. However, it could pick up the landfall over south Gujarat north Maharashtra coasts as a low pressure area.

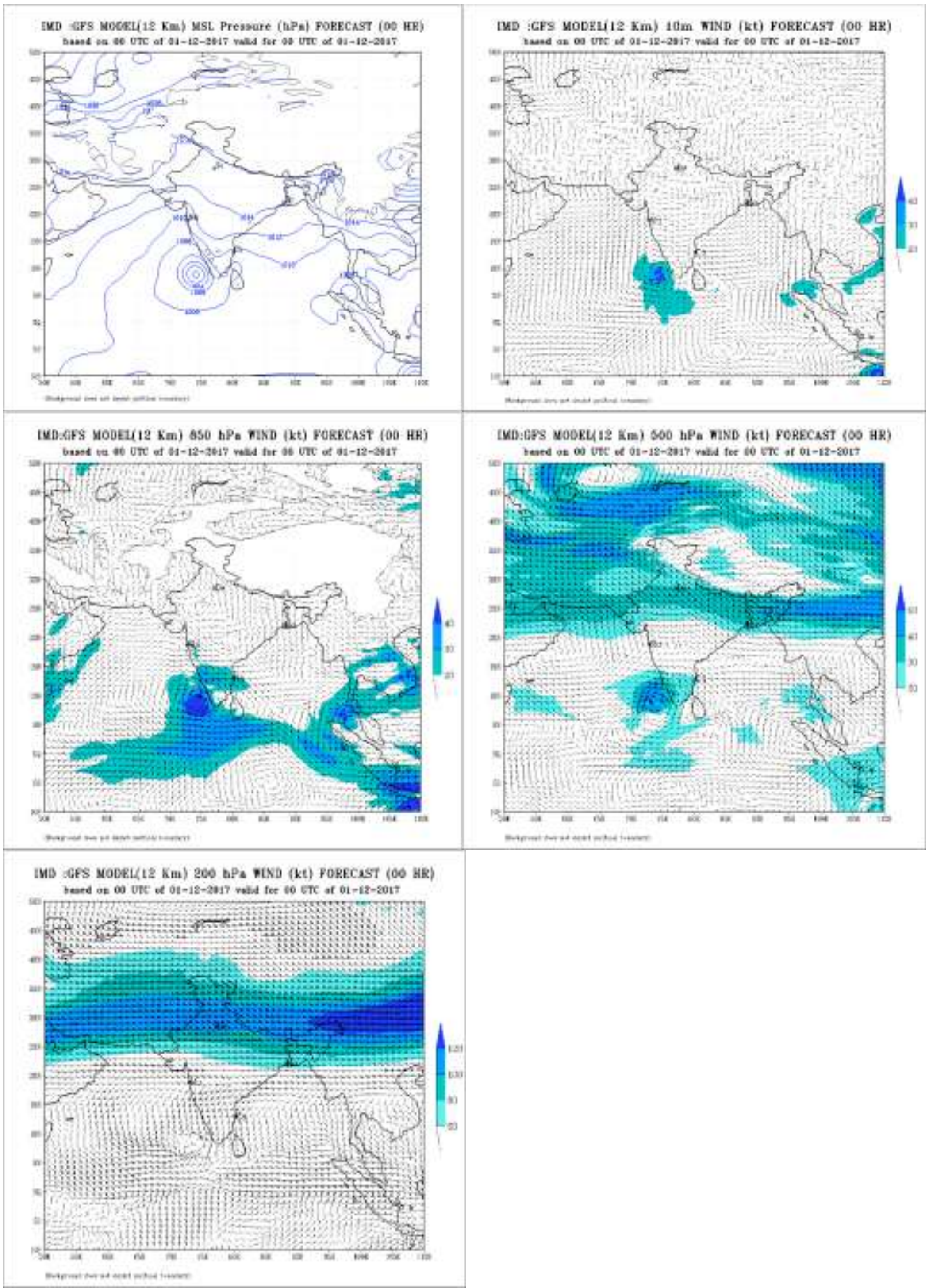


Fig.11 (h): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 1st December

The analysis based on 0000 UTC of 2nd December indicated further intensification of system over Lakshadweep Area on 2nd December. The forecast field indicated that the system would move northwestwards till 04th and then move in NNW and weaken on 5th into a deep depression over east central AS. The model picked up the intensification of system over Lakshadweep area and weakening of system over east central AS on 5th correctly.

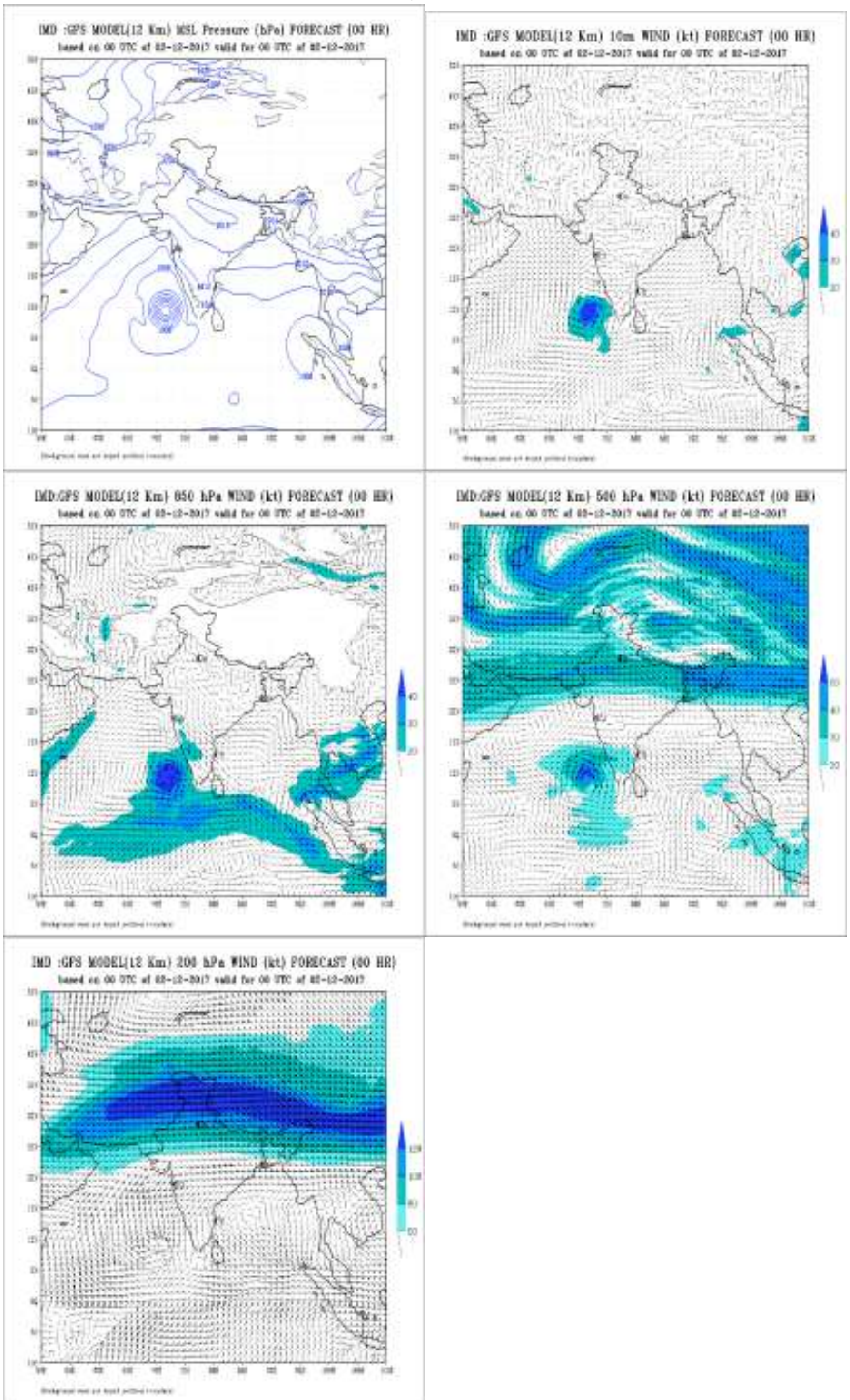


Fig.11 (i): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 2nd December

The analysis based on 0000 UTC of 3rd December indicated west-northwestward movement of system. The forecast field indicated that the system would move northwestwards till 04th and then move in NNW and weaken on 5th into a deep depression over eastcentral AS. The model picked up the intensification of system over Lakshadweep area and weakening of system over eastcentral AS on 5th correctly.

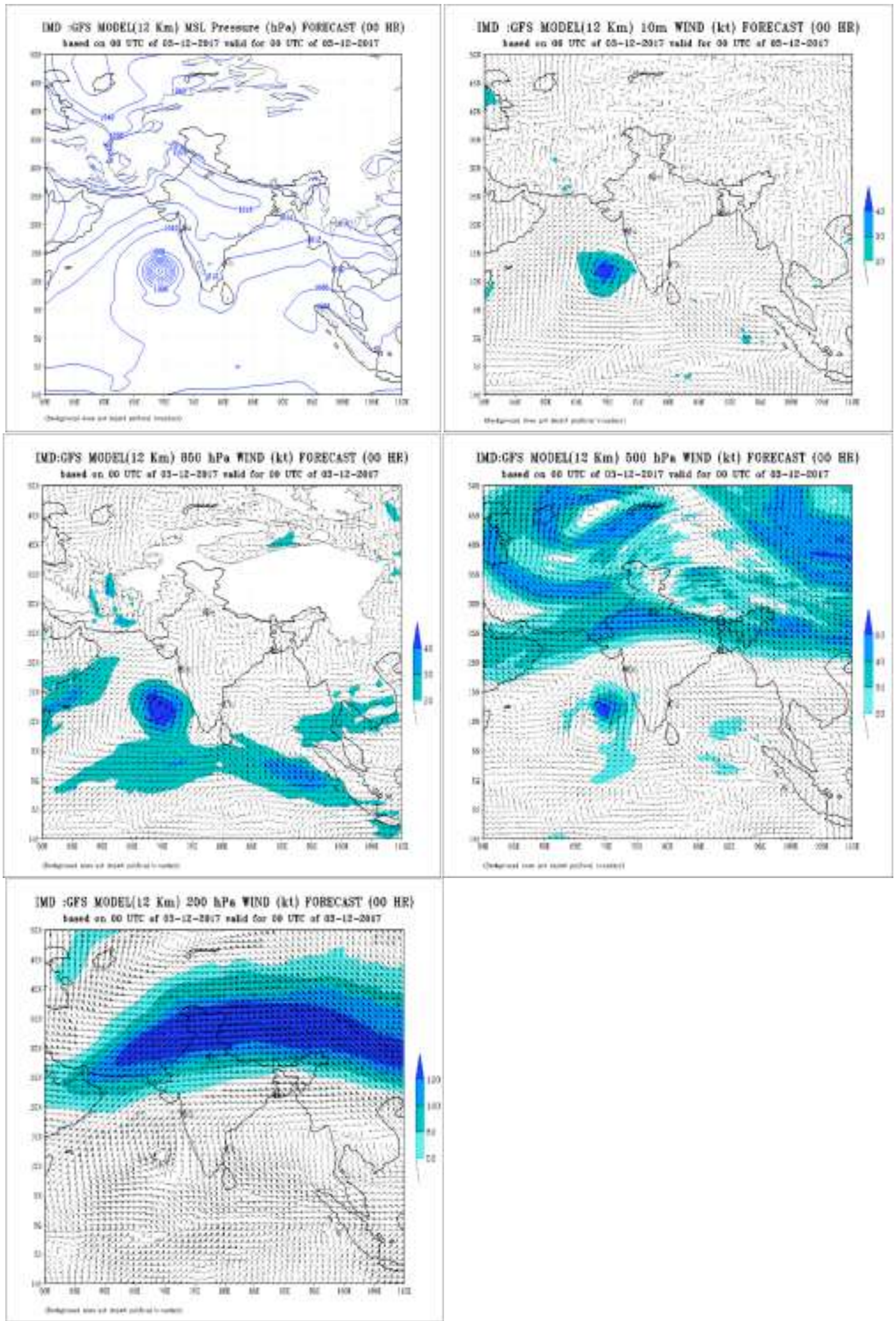


Fig.11 (j): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 3rd December

The analysis based on 0000 UTC of 4th December indicated weakening and detected a severe cyclonic storm over eastcentral AS on 4th December. The forecast field indicated that the system would move northeastwards and weaken into a cyclonic storm on 5th over northern parts of EC Arabian Sea and into a well marked low pressure area on 6th off south Gujarat and north Maharashtra coasts. Thereafter, it would cross south Gujarat coast after 0000 UTC of 6th and become less marked after some time. It could capture the trough in westerlies near 50^0E responsible for steering the system north-northeastwards.

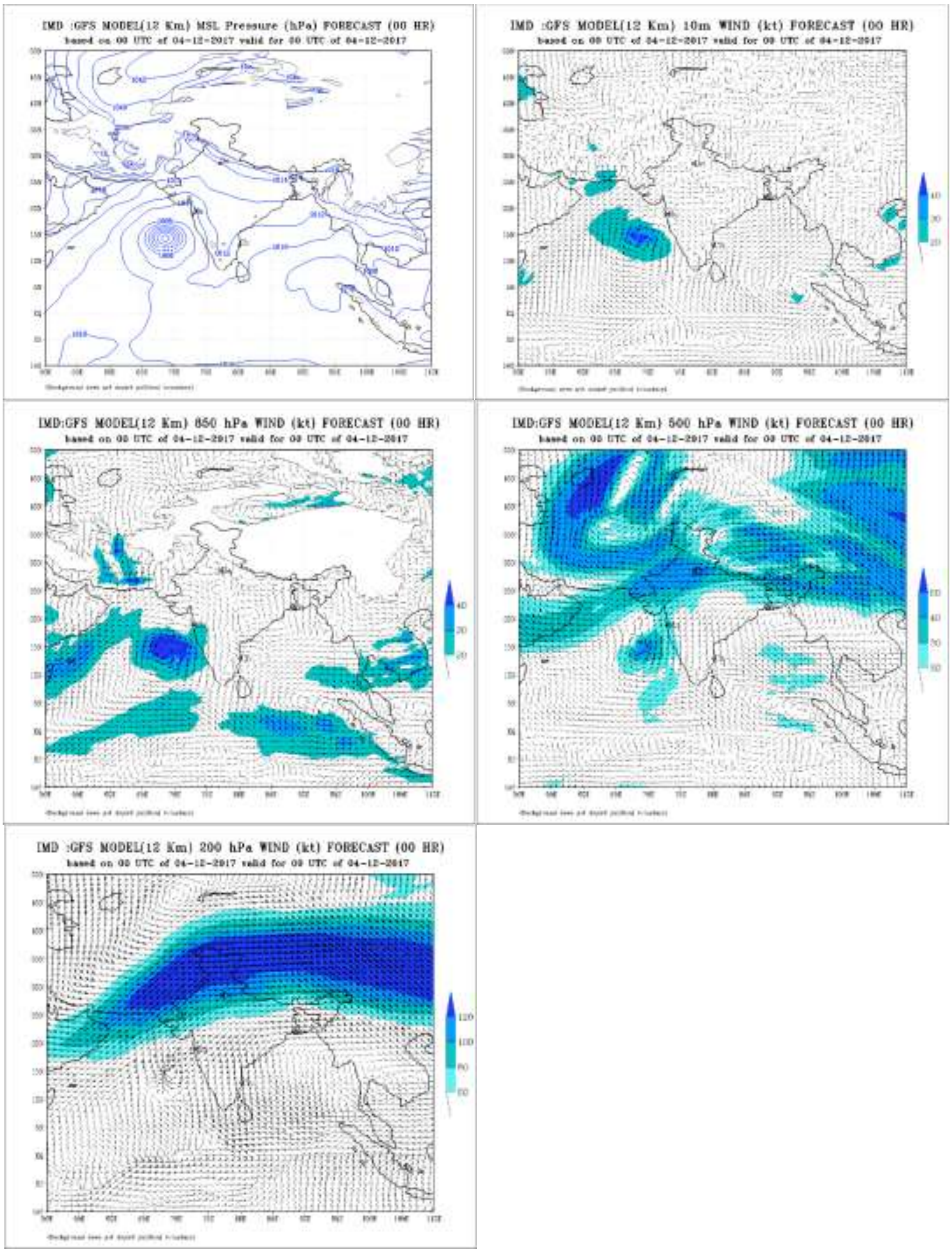


Fig.11 (k): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 4th December

The analysis based on 0000UTC of 05th December indicated a cyclonic storm over eastcentral AS on 5th December. The forecast field indicated that the system would move northeastwards and weaken over northern parts of eastcentral AS and into a low pressure area off south Gujarat and north Maharashtra coasts on 6th. Trough in westerlies was well captured by the model. It could also predict that the system would weaken into a low pressure area before crossing south Gujarat and north Maharashtra coasts.

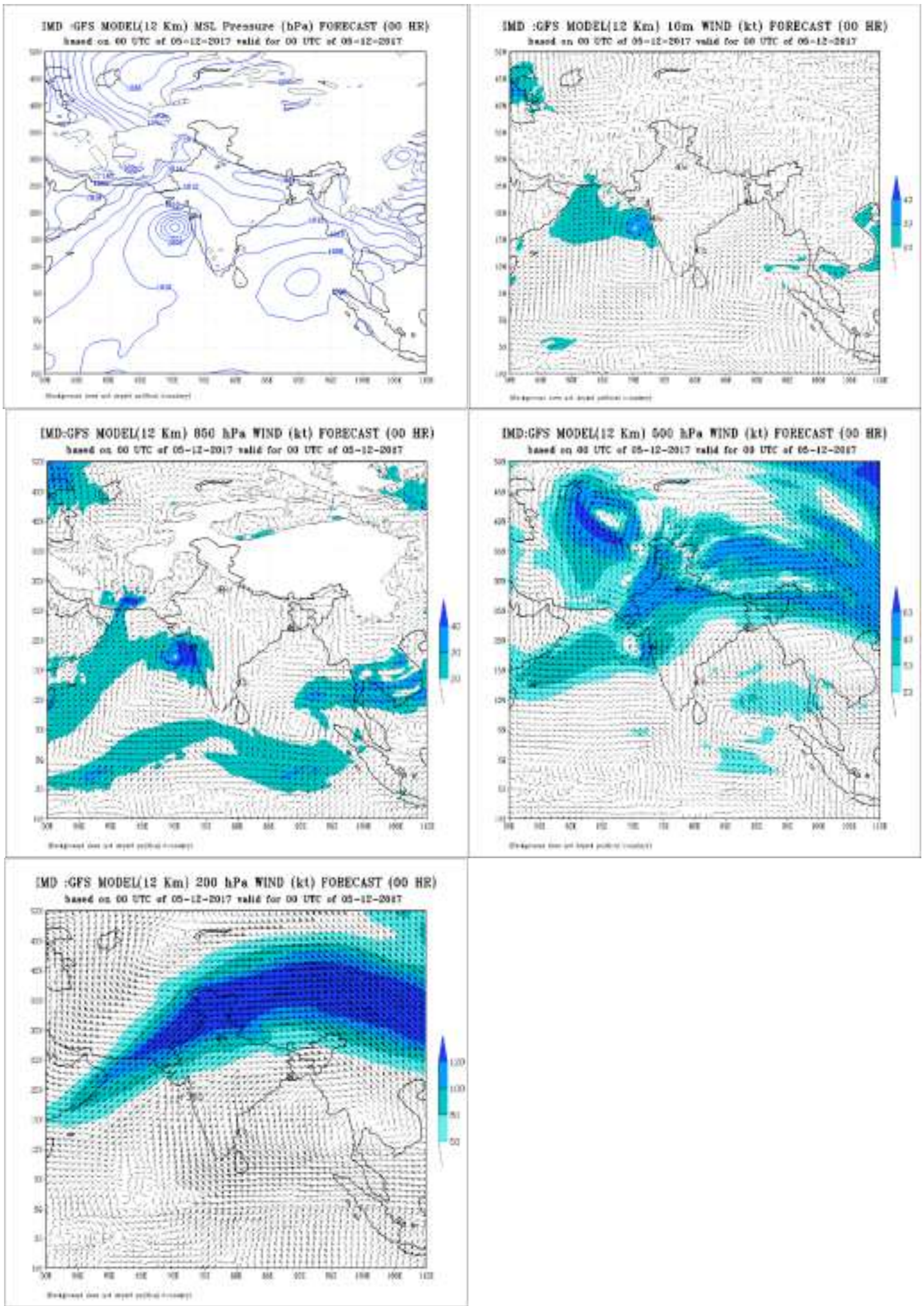


Fig.11 (l): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 5th December

The analysis based on 0000UTC of 06th December indicated that the system has weakened into a low over eastcentral and adjoining northeast AS and coastal Maharashtra and south coastal Gujarat.

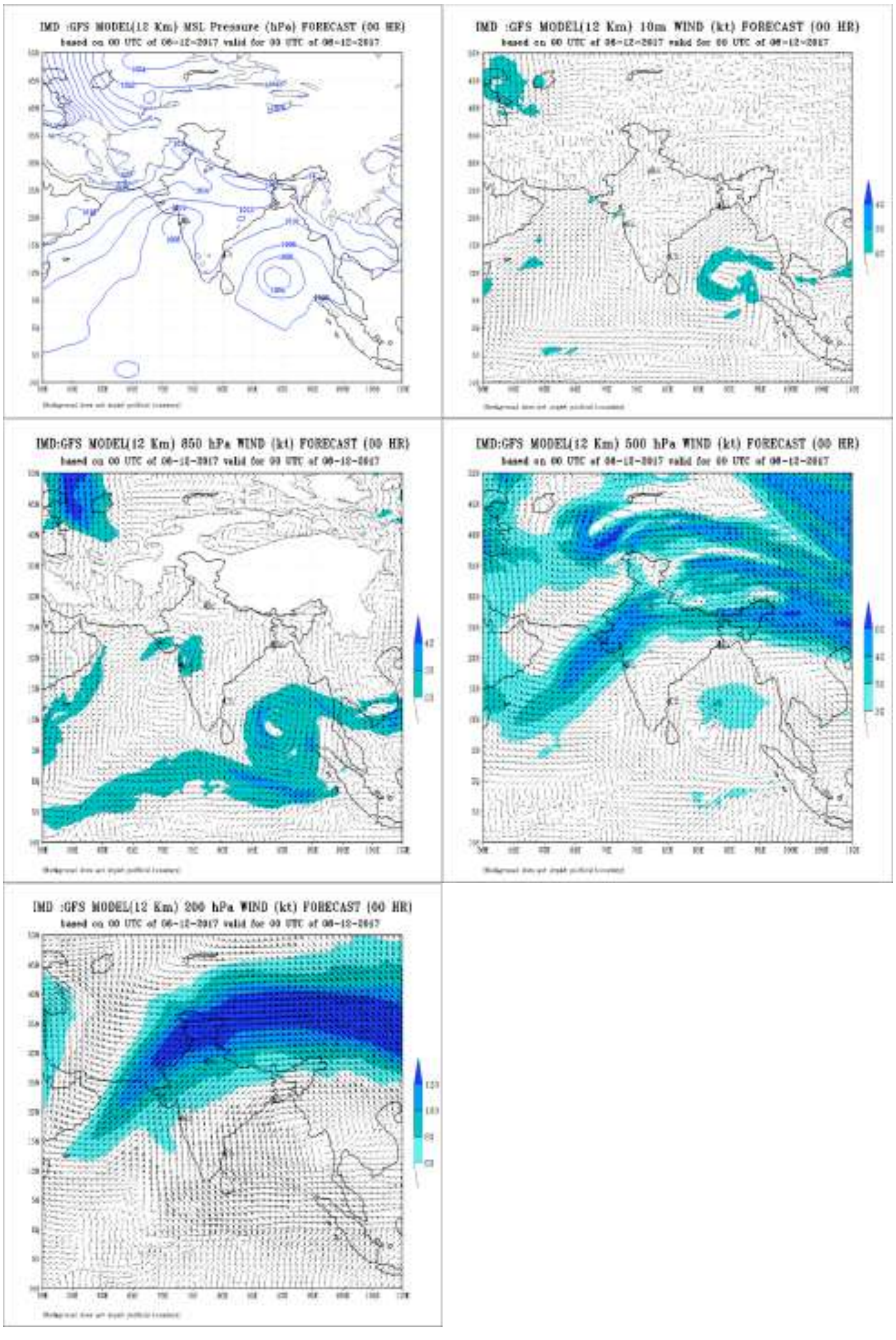


Fig.11 (m): IMD GFS analysis of MSLP, 10m wind, 850, 500 & 200 hPa winds based on 0000 UTC of 6th December

Hence to conclude, on 27th and 28th IMD GFS didn't show genesis of system. On 29th, it could not capture the rapid intensification of system on 30th. On 30th, it rather showed weakening of system. However, from 1st onwards, it could indicate that the system would intensify further, move northwestwards initially & north-northeastwards from 4th onwards and cross north Maharashtra-south Gujarat coasts as a depression/low.

6.1. NWP Guidance on Genesis:

Numerical Weather Prediction Model guidance from various models including IMD GFS, ECMWF, NCUM, NEPS and JMA during 21st to 30th November is discussed in Table 5. The NWP charts from IMD GFS model are placed at Annexure-2, ECMWF charts are placed at Annexure-3, NCUM at Annexure-3, NEPS at Annexure-4 and JMA at Annexure-5.

Table 5: Numerical weather Prediction Model guidance during 21st-30th November.

Date/Time	Model Analysis
21/00	IMD GFS indicated an Ext LPA over SW Bay on 24th which also becomes less marked the following day. Another low forms on 25th & 26th over southern parts of SE Bay. NCUM indicated LPA over Comorin on 21st becoming insignificant on 22nd. Low over SE BoB on 23rd. Low over south Andaman Sea movig westwards during 24th-26th. NEPS indicated a LPA over Gulf of Thailand and Ex. LPA over Comorin Area off SW Sri Lanka on 21st and LPA over SE BoB on 23rd becoming insignificant thereafter. JMA didn't indicate any cyclogenesis during 21-26.
22/00	IMD GFS indicated an LPA over SE Bay on 26th moving WNW and lay as LPA over SW BoB on 27th. NCUM indicated two LPAs over SE and SW BoB during 23rd – 26th. NEPS indicated LPA on 22nd, 23rd & 25th over Gulf of Thailand, EC BoB and SE BoB respectively. JMA didn't indicate any cyclogenesis during 22-27.
23/00	IMD GFS indicated an LPA over SE BoB during 26th-27th moving westwards & becoming WML on 28th over SE Bay NCUM indicated an Ext low over SW BoB and LPA over SE AS on 25th. On 27th 2 LPAs over SW BoB NEPS indicated LPA over SE BoB on 23rd moved nearly northwards & lay over EC BoB on 24th. No system on 25th & 26th. LPA over Gulf of Thailand on 27th . 2 LPAs over SE BoB & south Andaman Sea. JMA indicated no cyclogenesis during 23-28.
24/00	IMD GFS indicated Ext LPA over SE BoB on 24th becoming insignificant on 24th. A fresh LPA over SW BoB moving westwards from 26th to 29th. WML over south Kerala on 29th. NCUM indicated LPA over SW BoB on 25th, LPA SE BoB on 26th. Moved WNWwards and lay over SW BoB on 27th becoming insignificant on 28th. Ext LPA over Maldives on 29th. NEPS indicated a CS over north Andaman Sea and an LPA over Thailand on 24th. LPA over SW BoB on 25th becoming insignificant on 26th. Fresh LPA over SW BoB on 27th moving towards north Tamil Nadu till 29th. Another LPA over SW BoB on 29th.

	JMA indicated no cyclogenesis during 24-29.
25/00	IMD GFS indicated LPA over SW BoB on 25th. Moved westwards & lay as LPA off SE Sri Lanka coast on 26th, LPA over SW Sri Lanka on 27th, Ex. Low over Comorin on 28th becoming low on 28th over Comorin and DD over Maldives on 29th. ECMWF indicated no depression on 29th and 30th. NCUM indicated LPA over equatorial Indian Ocean on 25th. Fresh low over Thailand on 26th. Moving nearly westwards lay as low over SE BoB on 27th, D over SW BoB on 28th, Low over SW BoB off south TN coast on 29th, LPA over Lakshadweep on 30th. Another fresh LPA over south Andaman Sea on 30th. NEPS indicated LPA over SE BoB on 25th becoming less marked on 26th. Fresh Ext. LPA over SE BoB on 27th. Moved WNWwards and lay as CS over SW BoB on 28th. Moved westwards & lay as DD over north TN coast on 29th and LPA over north Kerala on 30th. JMA indicated an Ex. LPA over SW AS on 28th becoming less marked thereafter.
25/12	IMD GFS indicated LPA over SW BoB on 25th. Moved westwards & lay as LPA over SW BoB on 26th. Moved nearly westwards & lay as LPA over Comorin on 27th. Lay as WML over SW BoB off SW Sri Lanka coast on 28th. Moved NNWwards & lay as LPA over Comorin on 29th. Another fresh LPA over SE BoB on 29th. Two LPAs over SE BoB on 30th. ECMWF indicated LPA over SW BoB on 25th. On 26th, it moved westwards lay over Comorin & fresh LPA over SW BoB off NE Sri Lanka coast. On 27th, both became insignificant. On 28th, LPA over SW BoB which persisted till 30th/12Z. On 29th, Ex.LPA over SE AS. Moved WNWwards & lay over SE As on 30th. NCUM indicated an Ex.LPA over Lakshadweep & LPA over SW BoB off SW Sri Lanka coast on 25th. On 26th, LPA over Comorin. No system on 27th. On 28th, LPA over Lakshadweep & SE AS. On 29th, LPA over SE BoB & SW BoB. D over SE BoB, LPA over Comorin & another LPA over equatorial Indian Ocean adj Maldives on 30th. NEPS indicated no system. JMA indicated Ex.Low over SW AS on 27th.
26/00	IMD GFS indicated an LPA over Maldives & Ex. LPA over South Sri Lanka on 27th. LPA over Comorin & fresh LPA over SE BoB on 28th. Ex. LPA over Maldives and another over south Andaman Sea on 29th. Ext. LPA over SE AS & WML over north Andaman Sea on 30th. Ext. LPA over SE As & DD over south Andaman Sea o 1st. ECMWF indicated LPA over Comorin on 26th, moved WSWwards lay over Maldives on 27th & 28th, insignificant on 29th & 30th and moved westwards lay as Ext. LPA over SE AS on 1st . It also indicated fresh LPA over SW BoB on 27th, persisted over same area on 28th, insignificant on 29th & 30th and again persisted over same area on 1st. NCUM indicated an LPA over SW BoB off SE Sri Lanka coast & another off south Sri Lanka on 26th. Ex. LPA over Maldives on 27th, insignificant on 28th. Fresh LPA over south Andaman Sea on 28th, insignificant on 29th, LPA over SW BoB on 30th & 1st. On 1st a fresh LPA over SE AS. NEPS indicated LPA over SW BoB and another over SW AS on 26th. Insignificant on 27th & 28th. Fresh Ex. LPA over SE AS on 29th, moved northwards lay as Ex. LPA over SE AS on 30th, moved westwards las as Ex. LPA over SE AS on 1st. It also indicated fresh LPA over SW BoB on 29th, insignificant on 30th. Fresh LPA over SE BoB on 1st. JMA indicated Ex. LPA over SW AS on 26th. No significant system thereafter.

26/12	IMD GFS indicated LPA over Lakshadweep on 26th becoming insignificant on 27th. Fresh LPA over SE BoB on 27th. Fresh LPA over south Andaman Sea on 28th. On 29th, LPA over south Andaman Sea and Fresh LPA over SW BoB off Sri Lanka coast. On 30th, Ext LPA over Comorin and LPA over SE BoB. On 1st, LPA over SE AS and CS over south Andaman Sea. ECMWF indicated LPA over South Sri Lanka on 26th becoming D on 27th and LPA on 28th over same area. On 29th, moved WNWwards & lay as Ext Low over Maldives. It moved NNWwards & lay as LPA over Maldives and fresh LPA over Sri Lanka on 30th. On 1st, two D/DD seen over SE AS and SE BoB. NEPS indicated no cyclogenesis during 26 Nov – 1 Dec. JMA indicated LPA over Comorin on 27th becoming insignificant on 28th and again developing as LPA on 29th.
27/00	IMD GFS indicated feeble LPA over Maldives on 27th. Fresh Ext LPA over SW BoB and LPA over Gulf of Thailand on 28th. On 29th, LPA over SW BoB. On 30th, LPA over SW BoB and fresh D over Gulf of Thailand. On 1st, D/DD over south Andaman Sea & fresh LPA over SE BoB. On 2nd, DD over SE BoB. ECMWF indicated LPA over Comorin on 29th moved WNWwards lay as D over Lakshdweep on 30th, moved westwards lay as CS over SE AS on 1st and 2nd. It also indicated fresh LPA over Sri Lanka on 30th becoming insignificant thereafter. It also showed fresh D over southeast BoB on 1st moving WNWwards and lay as DD over SE BoB on 2nd. NCUM indicated LPA over north Andaman Sea on 27th becoming insignificant on 28th, 29th. LPA over Comorin on 28th becoming insignificant on 29th. Fresh LPA over SW BoB off SE SriLanka and another off SW Sri Lanka on 30th. On 1st Ext LPA over Comorin and fresh LPA over south Andaman Sea. On 2nd, LPA over Comorin and LPA over SE BoB NEPS indicated a D over EC AS and DD over SW BoB on 27th. Both becoming insignificant till 2nd. On 2nd, fresh Ext LPA over south Andaman Sea. JMA indicated LPA over Comorin on 28th & 29th becoming WML on 30th and insignificant thereafter.
27/12	IMD GFS indicated Ext LPA over SW BoB on 27th becoming WML over same area on 28th. On 29th WML over SE BoB, lay as D over SE BoB on 30th, DD over SE BoB on 1st . Ext LPA over Thailand on 29th becoming D over south Andaman Sea on 30th & 1st. On 2nd both merged and lay as D over SE BoB. ECMWF indicated LPA over Sri Lanka on 28th , moved WSWwards lay as LPA over Comorin on 29th, moved NNWwards lay as D over Lakshadweep on 30th, moved WNWwards lay as CS over southeast AS on 1st and 2nd. It also indicated LPA over SE BoB on 28th, insignificant on 29th. Fresh LPA over south Andaman Sea on 30th, moved WNWwards lay as D over SE BoB on 1st, moved westwards and lay as CS over SE BoB on 2nd. NCUM indicated LPA over SW BoB off south Sri Lanka on 27th, LPA over SW BoB off SE Sri Lanka on 28th, LPA over SW BoB off south Sri Lanka on 29th, fresh Ex LPA over Lakshadweep and LPA persisted over SW BoB on 30th. On 1st fresh D over south Andaman Sea becoming SCS over SE BoB on 2nd. NEPS indicated no cyclogenesis during 27th to 2nd. JMA indicated LPA overSW BoB on 27th, 28th and over Comorin on 29th and 30th.
28/00	IMD GFS indicated LPA over Gulf of Thailand and adjoining Malay Peninsula on 29th, becoming D over south Andaman on 30th and DD over south Andaman Sea on 1st. Moved WNWwards lay as DD over SE BoB on 2nd , moved WNWwards and lay as D over SE BoB. It also indicated WML over SW BoB on 28th. Moved

	westwards lay as WML over south Sri Lanka on 29th, D over Comorin on 30th becoming WML over Comorin on 1st and low over same area during 2nd-3rd. ECMWF indicated Extended LPA over south Sri Lanka on 29th , moved WNWwards lay as DD over Comorin on 30th, moved NWwards lay as CS over southeast AS on 1st, moved WNWwards lay as SCS on 2nd and 3rd. It also indicated fresh DD over south Andaman Sea on 1st, moved westwards lay as CS over SE BoB on 2nd, moved WNWwards and lay as SCS over SE BoB on 3rd. NCUM indicated Ex. LPA over SW BoB on 28th becoming insignificant on 29th & 30th. Fresh Ex Low over SE AS on 1st , becoming insignificant on 2nd and again as Ex. Low on 3rd. It also indicated fresh LPA over south Andaman Sea on 30th, moved northwards lay as D over north Andaman Sea on 1st, moved westwards lay as D over SE BoB on 2nd, moved westwards lay as D over SE BoB on 3rd.
28/12	IMD GFS indicated LPA over Gulf of Sumatra on 28th, moved WNWwards lay over south Andaman Sea as Ex LPA on 29th, moved NNWwards lay over SE BoB as D on 30th, moved ENEwards lay as DD over SE BoB on 1st, moved WNWwards lay as DD over SE BoB on 2nd, moved WNWwards lay as DD over SW BoB on 3rd. It also indicated another LPA over SW BoB off Sri Lanka on 28th, moved WNWwards lay as D over Comorin on 29th, DD on 30th & weakening from 1st onwards, moved WNWwards lay as D over Lakshadweep on 2nd and D over SE AS on 3rd. ECMWF indicated Low over Comorin on 28th, moved WNWwards lay as DD over Comorin on 29th, moved WNWwards lay as SCS over SE AS on 1st, moved WNWwards lay as SCS over SE AS on 2nd, moved WNWwards lay as CS over EC AS on 3rd. It also indicated D over Andaman Sea on 30th, moved westwards lay as DD over southeast BoB on 1st, moved WNWwards lay as CS over SE BoB on 2nd and moved WNWwards lay as SCS over SE BoB on 3rd. NCUM indicated LPA over Lakshadweep on 28th becoming insignificant thereafter. It also indicated an Ex LPA over SW BoB off SW Sri Lanka on 28th, moved WNWwards lay as LPA over SW BoB off south Sri Lanka on 29th, moved WNWwards lay as LPA over Comorin on 30th, moved WNWwards lay as Es. LPA over Lakshadweep on 1st, insignificant on 2nd, fresh LPA over SE AS on 3rd. NEPS indicated no cyclogenesis during 28-3rd. JMA indicated WML over SW BoB off SE Sri Lanka on 28th, moved WNWwards lay as WML over Comorin on 29th & 30th, moved WNWwards lay as D over Lakshadweep on 1st becoming insignificant thereafter.
29/00	IMD GFS indicated WML over SW BoB off south Sri Lanka on 29th, moved westwards lay as DD over Comorin on 30th, moved NWwards lay as D over Comorin on 1st, moved WNWwards lay as D over Lakshadweep on 2nd, moved NNWwards lay as D over Lakshadweep on 3rd, moved WNwwards lay as D over SE AS on 4th. It also indicated D over south Andaman Sea on 1st, moved WNWwards lay as DD over SE BoB on 2nd, moved WNWwards lay as CS over SE BoB on 3rd , moved WNwwards lay as CS over SE BoB on 4th. ECMWF indicated LPA over SW BoB and another over south Sri Lanka on 29th, merged and moved westwards and lay as CS over Comorin on 30th, moved WNWwards lay as SCS on 1st and 2nd, moved WNWwards lay as CS over SE AS on 3rd, moved Nwwards lay as CS over EC AS on 4th. It also indicated D over south Andaman Sea on 1st, CS over southeast BoB on 2nd, 3rd and 4th.. NCUM indicated LPA over SW BoB south of Sri Lanka on 29th, moved WNWwards lay as D over Comorin on 30th, moved WNWwards lay as D over Maldives on 1st, moved WNwwards lay as SCS over SE AS on 2nd, moved WNWwards lay as SCS over EC AS on 3rd , moved northwards lay as SCS over EC AS on 4th. It also

	indicated LPA over north Andaman Sea on 30th, fresh LPA over south Andaman Sea on 1st, moved westwards lay as D over south Andaman Sea on 2nd, moved WNWwards lay as DD over SE BoB on 3rd , moved WNWwards lay as CS over SE BoB on 4th. NEPS indicated D over Comorin on 30th, moved westwards lay as D over Maldives on 1st, moved NWwards lay as CS over SE AS on 2nd, moved NNWwards lay as SCS over EC AS on 3rd , moved westwards lay as SCS over EC AS on 4th. JMA indicated D over SW BoB off SW Sri Lanka coast on 29th, moved WNWwards lay as D over Comorin on 30th, moved WNWwards lay as CS over Lakshadweep off north Kerala coast on 1st, moved WNWwards lay as DD over Lakshadweep on 2nd, becoming insignificant thereafter.
29/12	IMD GFS indicated D over SW BoB & adjoining Comorin on 29th, moved westwards lay as DD over Comorin on 30th, moved WNWwards lay as D over Maldives on 1st, moved WNWwards lay as DD over SE AS on 2nd, moved NNWwards lay as CS over EC AS on 3rd, moved NNEwards lay as DD over EC AS on 4th.(Recurvature) It also indicated D over south Andaman Sea on 1st, moved NWwards layas D over SE BoB on 2nd, moved WNWwards lay as D over SE BoB on 3rd, moved WNWWards lay as D over SE BoB on 4th. ECMWF indicated D over Comorin on 29th, moved WNWwards lay CS over southeast AS near south Kerala coast on 30th, moved WNWwards lay as SCS over southeast AS on 1st, moved WNWwards lay as SCS over SE AS on 2nd, moved WNWwards lay as SCS over EC AS on 3rd, moved WNWwards lay as DD over EC AS on 4th. It also indicated another D over southeast BoB on 2nd and 3rd. NCUM indicated D over SW BoB off south Sri Lanka on 29th, moved NWwards lay as DD over Comorin on 30th, moved WNWwards lay as D over Lakshadweep on 1st, moved NWwards lay as DD over Lakshdweep on 2nd, moved WSWwards lay as DD over SE AS on 3rd, moved westwards lay as SCS over EC AS on 4th. It also indicated LPA over Malay Peninsula on 1st, persisting over same area on 2nd, moved WNWwards lay as D over south Andaman Sea on 3rd, moved westwards lay as D over south Andaman Sea & adjoining SE BoB on 4th. NEPS indicated no cyclogenesis during 29-4th. JMA indicated DD over SW BoB off south Sri Lanka on 29th, moved WNWwards lay as DD over Comorin off south Kerala coast on 30th, moved WNWwards lay as CS over Lakshadweep on 1st, moved WNWwards lay as CS over EC AS on 2nd.
30/00	IMD GFS indicated LPA/WML over Comorin on 30th, moved WNWwards lay as DD over Lakshadweep off south Kerala coast on 1st, moved WNWwards lay as D over Lakshadeep on 2nd, moved WNWwards lay as DD over EC AS on 3rd& 4th over EC AS, moved westwards lay as D over EC AS on 5th. ECMWF indicated a cyclonic storm over Comorin Area on 30th, which moving west-northwestwards intensify into a severe cyclonic storm on 01st December over Lakshadweep area and adjoining SE Arabian Sea. It then moved northeastwards and weakens further into a depression on 5th and weakened into well marked low on 6th and less marked by 07th over EC Arabian Sea. It also indicated low over south Andaman Sea and adjoining Malay Peninsula on 30th Nov. which moving westward becomes a depression on 05th December SE Bay. Further moving north-westwards, it becomes depression on 07th over SW Bay. It lies off south coastal Andhra Pradesh at 0000 UTC on 08th December as a deep depression/ CS and crosses south Andhra Pradesh coast (near about lat. 160 N) around 0000 UTC of 8th Dec. and weakens gradually thereafter. NCUM indicated DD over SW BoB south of Sri Lanka on 29th, moved WNWwards

	lay as SCS over Comorin off south Kerala coast on 30th, moved WNWwards lay as SCS over Lakshadweep on 1st, moved WSWwards lay as SCS over SE AS on 2nd, moved NNWwards lay as SCS over EC AS on 3rd, moved NNWwards lay as SCS over EC AS on 4th, moved NEwards lay as SCS over NE AS on 5th. NEPS indicated LPA over WC BoB on 30th & SCS over Thailand on 30th. Fresh CS over Comorin on 1st, moved WNWwards lay as CS over Lakshadweep on 2nd, moved NNWwards lay as CS over EC AS on 3rd, moved northwards lay as SCS over EC AS on 4th, moved NNWwards lay as CS over EC AS on 5th.
30/12	IMD GFS indicated D over Comorin on 30th, moved WNWwards lay as CS over Lakshadweep on 1st, moved WNWwards lay as CS over SE AS on 2nd, moved NWwards lay as CS over EC AS on 3rd, moved NNWwards lay as CS over EC AS on 4th, moved ENEwards lay as D over EC AS on 5th (Recurvature). It also indicated LPA over Malay Peninsula on 30th, moved WNWwards lay as LPA over south Andaman Sea on 1st, moved WNWwards lay as LPA over SE BoB on 2nd & 3rd, moved WNWwards lay as D over SW BoB on 4th, moved NWwards lay as D over SW BoB on 5th. NCUM indicated SCS over Comorin off south Kerala coast on 30th, moved WNWwards lay as SCS over north Kerala coast on 1st, moved WNWwards lay as SCS over SE AS on 2nd, moved NWwards lay as SCS over EC AS on 3rd, moved NEwards lay as SCS over EC AS (recurvature) on 4th, moved NNEwards lay as D over south Gujarat on 5th. It also indicated LPA over Malay Peninsula on 30th, moved westwards lay as LPA over south Andaman Sea on 1st, moved WNWwards lay as LPA over south Andaman Sea on 2nd, moved SWwards lay as LPA over SE BoB on 3rd, moved NNWwards lay as LPA over SE BoB on 4th, moved NNWwards lay as DD over SE BoB on 5th.

Hence to conclude there were limitations in NWP model guidance in prediction of genesis (formation of depression) and its intensification into CS over Comorin area. Most of the models including GFS, JMA, NCUM & NEPS indicated limitation in predicting genesis and intensification of OCKHI. There was over warning over BOB and AS even during formation of OCKHI over Comorin area. No system was predicted over Comorin. The ECMWF products analyses indicated limitation in predicting genesis and intensification of OCKHI before 29th. Among all the models, ECMWF was better, but it could also indicate intensification based on 0000 UTC of 29th only.

7. Realized Weather:

7.1 Rainfall:

(a) Indian States:

- It caused isolated heavy rainfall over south Tamil Nadu on 28th and 29th, scattered heavy to very heavy rainfall & isolated extremely heavy rainfall over south Tamil Nadu on 30th Nov. and 1st Dec and isolated heavy to very heavy rainfall on 2nd Dec.
- It caused isolated heavy rainfall over south Kerala on 29th Nov. and 1st Dec. and isolated heavy to extremely heavy rainfall on 30th Nov.

- It caused scattered heavy to very heavy rainfall over Lakshadweep on 01st and 2nd Dec.
- There was heavy rainfall over north coastal Maharashtra and adjoining south coastal Gujarat on 5th Dec.
- There was no heavy rainfall over Tamil Nadu on 27th and over Kerala on 28th.
- It clearly indicates that there was occurrence of two separate spells of heavy rainfall over Tamil Nadu and Kerala in association with the low pressure system (22nd to 28th November) and cyclone, Ockhi 29th November to 5th December).

Rainfall associated with VSCS Ockhi based on IMD-NCMRWF GPM merged gauge rainfall data is depicted in Fig 12.

(Rainfall spatial distribution: Isolated places : <25%, A few places: 26-50%, Many places: 51-75%, Most places: 76-100% of total stations in the region;
Quantitative distribution: Moderate rainfall: 15.6-64.4, Heavy rain : 64.5 – 115.5 mm, Very heavy rain: 115.6 – 200.4 mm, Extremely heavy rain: 200.5 mm or more).

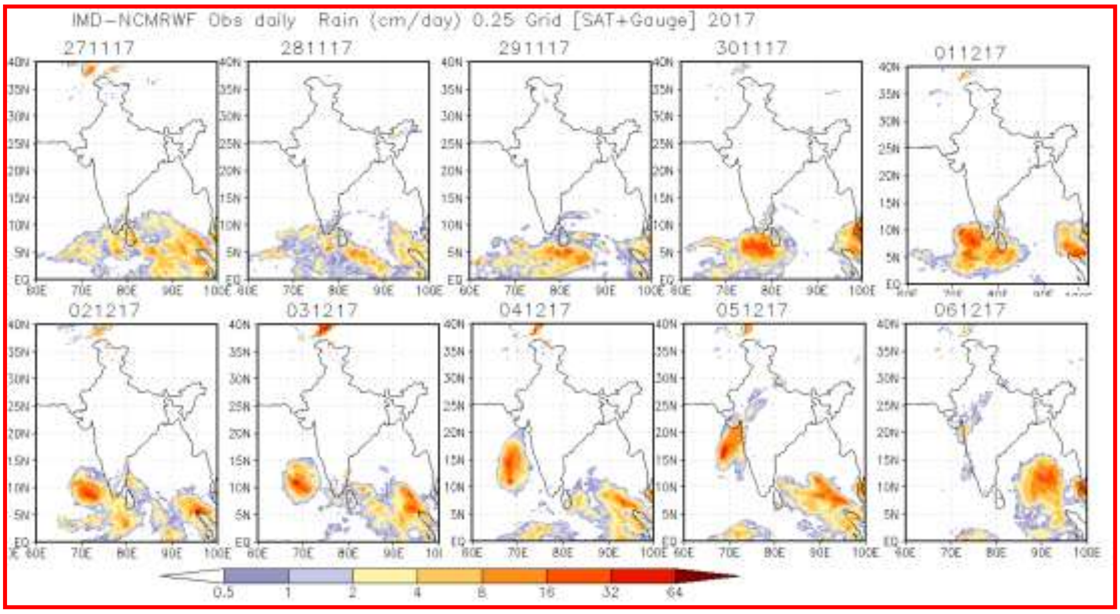


Fig.12: IMD-NCMRWF GPM merged gauge rainfall during 27th November– 5th December

Realized 24 hrs accumulated rainfall **(≥7cm)** ending at 0830 hrs IST of date is presented below:

(a) Indian States

<u>27 November 2017</u>

Tamil Nadu & Puducherry: Rameswaram-14, Chembarabakkam-12, Chembarambakkam, Chennai & Sirkali-10 each, Kancheepuram-9, Vedaranyam-8, Poonamalle, Kolapakkam, Chidambaram, Poonamallee, Anaikaranchatram, Kollid and Anna University-7 each.

South Interior Karnataka:-Imangala

Kerala:-Kollam

28 November 2017
Kerala:-Piravam-7

29 November 2017
Tamilnadu & Puducherry:-Nannilam-7
30 November 2017
Tamil Nadu & Puducherry: Vallam, Thuckalay and Puducherry-7 each
Kerala: Aryankavu-15

1 December 2017
Tamil Nadu & Puducherry: Papanasam (District: Tirunelveli)-45, Manimutharu-38, Mylaudy-19, Thenkasi-17, Thuckalay, Pechiparai, Gudalur & Bhoothapandy-16 each, Watrap-15, Maniyachi, Eraniel & Colachel-14 each, Nagercoil, Kodaikanal & Coonoor PTO-13 each, Kuzhithurai, Srivilliputhur, Satankulam, Shencottah, Ayikudi, Coonoor, Samayapuram & Srivaikuntam-12 each, Ottapadiram, Tiruchendur & Kovilpatti each, Tuticorin, Ambasamudram, Uttamapalayam & Kanyakumari-10 each, Radhapuram, Polur, Kovilpatti, Madavaram, Sankarankoil & Sattur-9 each, Arani, Sivaganga, Sivagiri, Uthiramerur, Rajapalayam, Anna University, Grand Anaicut, Uthagamandalam, Chembarabakkam & DGP Office-8 each and Musiri, Vadipatti, K.Paramathi, Karur, Vilathikulam, Anna UTY, Lalgudi, Ambur, Padalur, Panchapatti, Mayanur, Thamaraipakkam, K Bridge, Cholavaram, Nanguneri, Periyakulam, Kalugumalai & Chennai(N)-7 each
Kerala: Aryankavu-26, Myladumpara AGRI-12, Varkala & Punalur-9 each and Trivandrum AERO &, Neyyattinkara-8 each
Lakshadweep: Minicoy-19.

2 December 2017
Tamil Nadu & Puducherry: Sathanur Dam-23, Sirkali-19, Chidambaram & Anaikaranchatram (Kollid)-18 each, Chidambaram AWS-17, Virudachalam & Chengam-15 each, Gingee-14, Mylam AWS & K.M.Koil-14 each, Tirukoilur, Vilupuram, Coonoor PTO & Karaikal-13 each, Cuddalore, Sethiathope & Tiruvannamalai-12 each, Pondicherry-11, Mayanur, Paramathivelur & Polur-10 each, Parangipettai, Kallakurichi, Kodavasal, Nagapattinam, Vanur, Mayiladuthurai, Sankarapuram,& Eraniel, Jayamkondam, Rayakottah, Neyveli AWS, Kuzhithurai, Ariyalur & Tindivanam-9 each, Tiruvaiyaru, Tozhudur, Srimushnam, Valangaiman, Tiruvarur, Ulundurpet, Papanasam (District: Thanjavur) &, Kothagiri-8 each and Harur, Panruti, Needamangalam, Thuckalay, Uthangarai, Nagercoil, Arani & Attur-7 each.
Kerala: Trivandrum AERO-8 and Perinthalamanna & Angadipuram-7 each
Lakshadweep: Minicoy-14

3 December 2017
Tamil Nadu & Puducherry: Tiruvarur-14, Pandavaiyar Head & Kodavasal-13 each, Valangaiman & Nannilam-12 each, Nagapattinam-11, Needamangalam,

Kumbakonam, & Karaikal-9 each, Thiruthuraipoondi, Aduthurai AWS & Tiruvadanai-8 each and Thiruvidaimaruthur-7

<u>6 December 2017</u>

Konkan & Goa: Dahanu-10, Talasari & Colaba-8 each and Palghar AGRI-7

Gujarat Region: Umergam & Vapi-9 each and Pardi, Waghai, Vansda & Gandevi ARG-7 each

(b) Maldives:

Heaviest rainfall was 175 millimeters recorded on 30 Nov, at the AWS located in the Ifuru Island. Many islands reported flooding and damage to house hold items ware reported from several islands. Realised rainfall over Maldives is presented in Fig.13.

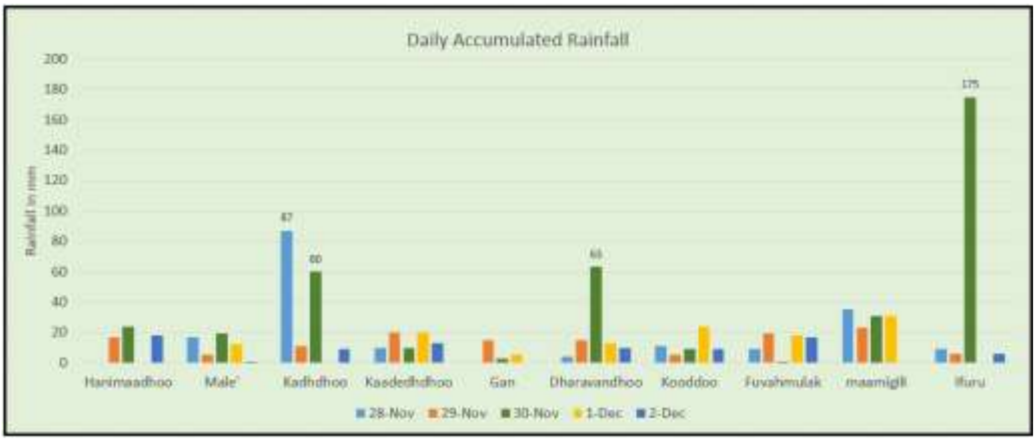


Fig.13: Realised Rainfall over Maldives during 28th Nov. -2nd Dec..

7.2: Realised Wind:

(a) India:

Thiruvananthapuram recorded 62 kmph in gustiness at 1300 IST of 30th Nov. The threshold wind speed of 45 kmph was recorded over Thiruvananthapuram from 1230 IST of 30th Nov. onwards. Anemograph record of Thiruvananthapuram on 30th November is presented in Fig.14.

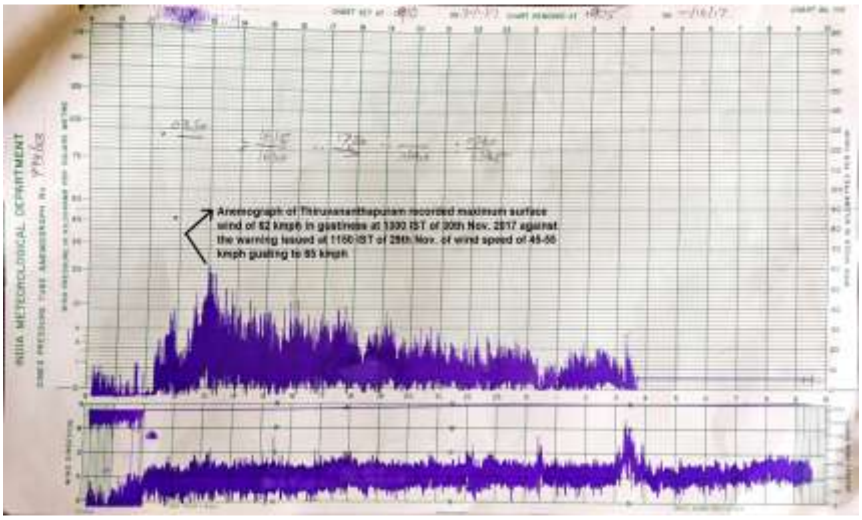


Fig.14 Anemograph record of Thiruvananthapuram on 30th November

Gale wind of the order of 65-75 kmph gusting to 85 kmph over Kanyakumari (KYK) and Thiruvananthapuram (TRV) during 30thNov-01stDec 2017 and winds of the order of 100-160 kmph gusting to 180 kmph were observed over Lakshadweep Islands during 01st-02nd Dec.

(b) Maldives:

On 30 November, the AWS station of Alif Dhaalu Maamigili and Baa Dharavandhoo had recorded the maximum gust winds of 56 and 54 miles per hour respectively. Moreover, the strong gust winds of 59 and 51 miles per hour were also recorded at the AWS station of Alifu Dhaalu Maamingili and the National Meteorological Office, Hulhule respectively on 1st of December. In addition the average strong winds of 20 – 30 miles per hour prevailed over the country on the 1st of December. Realised wind over Maldives during 28th Nov to 2nd Dec. is presented in Fig. 15.

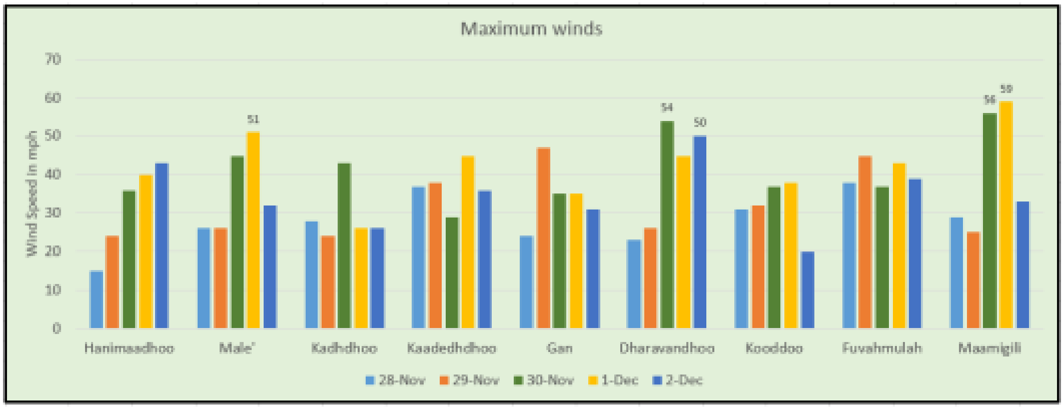


Fig. 15 Realised wind over Maldives during 28 Nov. to 2nd Dec..

8. Damage due to VSCS Ockhi

8.1. Damage over India:

(a) Damage over Tamil Nadu: As per report from Ministry of Home affairs, Govt. of India, about 35 persons lost their lives and 199 went missing. About 6,868 houses were damaged in Tamil Nadu. (Source: http://www.thehindu.com/news/national/tamil-nadu/ockhi-killed-93-damaged-over-10000-houses-minister/article22289551.ece). Several areas of south coastal Tamil Nadu experienced inland flooding and inundation due to heavy to extremely heavy rainfall on 30th Nov and 01st Dec 2017. Gale Wind caused extensive damages to electrical poles, transformers, agricultural plantation, mechanized and country boats of fishermen, houses and roads aside from 5 uprooting of thousands of trees. A few damage photographs are presented in Fig.16.

Fig. 16 (a) Flood hit Kanyakumari (Source: rediff.com, news dated 1st Dec.)

Fig. 16 (b) Damage due to gale winds over Kanyakumari (Source: M.O. Kanyakumari & *IndiaToday.in, New Delhi, 30th Nov 2017)*

Damage over Kerala: As per report from Ministry of Home affairs, Govt. of India, Kerala state witnessed loss of lives of 75 persons and 137 fisherment went missing. About 3600 houses were damaged by cyclone Ockhi.

Fig. 16 (c): A car struck in mud at Pampa, Triveni (Source: The New Indian Express 01st Dec 2017)

Fig. 16 (d): A tree fell over autorikshaw at Sreekanteshwaram in Thiruvananthapuram, (Source:h*ttp://english.mathrubhumi.com/news/kerala/cyclone-ockhi-closes-in-on-kerala-coast-1.2424815*)

Fig. 16 (e): Trees felling in Thiruvananthapuram, (Source: United News of India, Thiruvananthapuram dated 30th Nov)

Damage over Lakshadweep: No death was reported from Lakshdweep Islands. However normal life at Kalpeni, Minicoy and Kavaratti was badly hit by cyclone.

Fig. 16 (f): Uprooted trees and flooded streets in Lakshadweep
Source: http://indianexpress.com/article/india/cyclone-ockhi-lakshadweep-islands-suffer-over-rs-500-cr-loss-mp-mohammad-faizal/

Fig. 16 (g) Damaged Trees in Minicoy (Source: The Hindu dated 3rd Dec 2017)

Fig. 16 (h) Damaged Trees in Minicoy (Source: Officials M.O. Minicoy)

Damage over Karnataka: No death was reported from Karnataka. As per media reports**,** three houses were damaged and 15 coconut palms were uprooted and some washed away in Ullal, Someshwar-Uchil areas near Mangaluru.
(Source: http://www.thehindu.com/news/national/karnataka/cyclone-ockhi-damages-three-houses-uproots-trees-in-ullal/article21253626.ece)

Fig. 16 (i) Coconut trees and road side compound wall washed away as high waves lash the sea shore at Someshwara Uchila port near Mangaluru on 3rd December

(b) **Damage over Goa:** No loss of life reported from Goa. As per media reports about 30 shacks were damaged in Goa. The damage was felt the most at Pernem sub-district bordering Maharashtra. About 12 beaches were affected by sea water.

(c) **Maharashtra:** Unseasonal rain and inclement weather due to cyclone Ockhi severely impacted grape farms in Maharashtra. As per estimates by Brihanmumbai Municipal Corporation's (BMC) solid waste management (SWM) Department, Cyclone Ockhi dumped more than 80 tonnes of waste from the Arabian Sea on the Mumbai beaches. (Source:http://www.hindustantimes.com/mumbai-news/cyclone-ockhi-has-dumped-80-000-kg-of-trash-on-mumbai-s-beaches-says-bmc/story-xVuWmiAgXzutx7850C39AL.html). The Government of Maharashtra declared holiday

(d) **Gujarat:** No significant damage was reported from Gujarat

Damage over Maldives:

There were no human casualty during due to this event.

Fig. 16 (j) A boat and a barge capsized due to rough seas. (b) Trees uprooted due to strong winds

Damage over Sri Lanka:

As per media reports about 27 persons lost their lives due to landslides caused by heavy rains and gale wind associated with VSCS Ockhi (Source: http://micetimes.asia/flooding-in-sri-lanka-and-the-island-of-java-dozens-dead/).

Fig.16 (k): Damage due to gale winds over Sri Lanka (Source: http://www.dailymirror.lk/article/Rains-gale-force-winds-wreck-havoc-in-Colombo-141362.html)

9. Performance of operational NWP models

9.1. NWP Models for cyclogenesis:

9.1 Genesis Potential Parameter (GPP) for VSCS Ockhi

The predicted zone of cyclogenesis for VSCS Ockhi based on 0000 UTC initial conditions during 27th to 30th November is presented in figure 17. The analysis based on 0000 UTC of 27th indicated a potential zone for cyclogenesis over southwest BoB off Sri Lanka coast and another over Comorin Area. The zone over south Comorin moved westwards and the zone near Sri Lanka hovered near south Sri Lanka during next 5 days. The zone to the east of Sri Lanka become extended on 28th, reduced intensity on 29th and again elongated on 30th ,1st & 2nd while moving southwestwards.

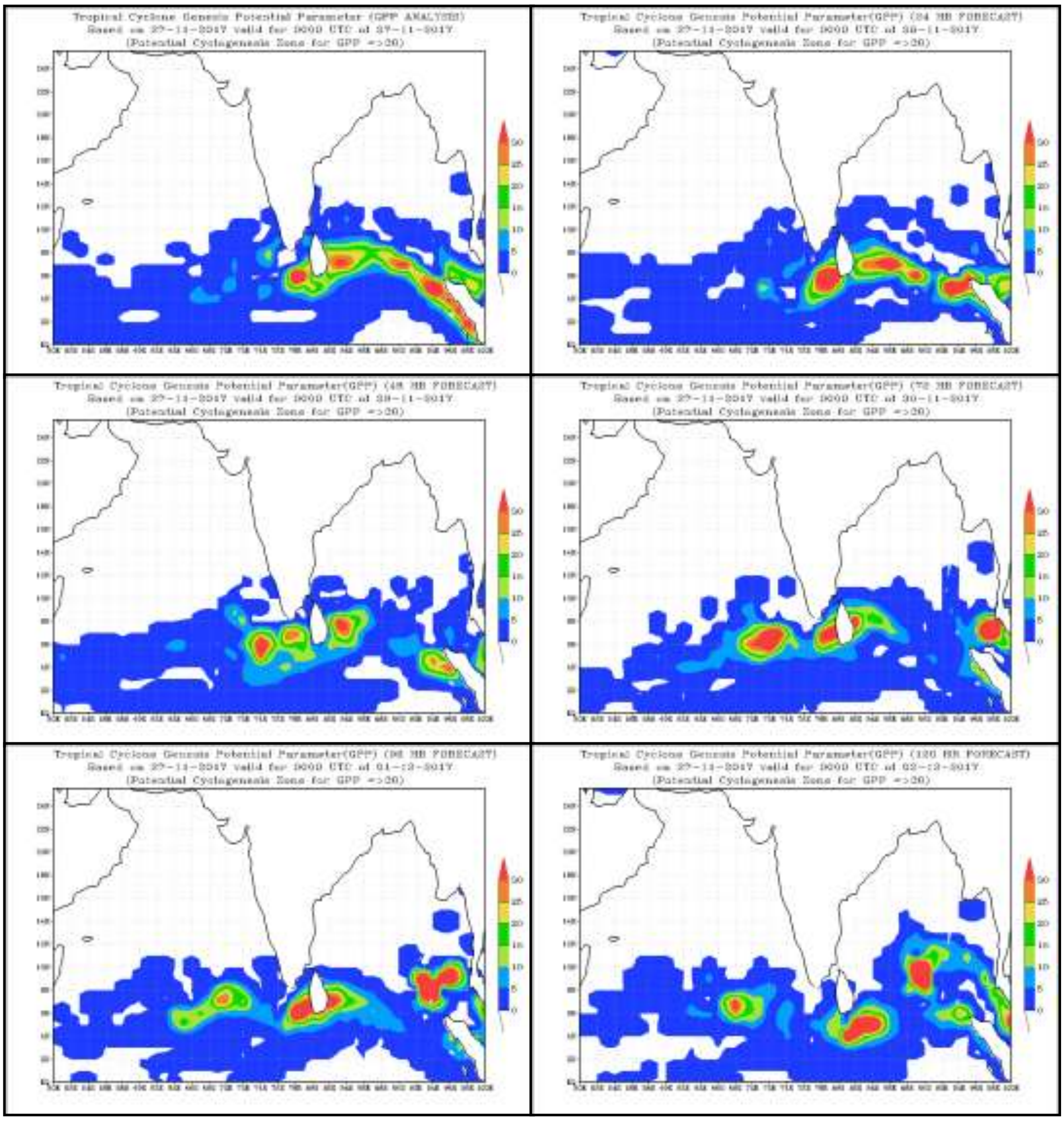


Fig. 17 (a): GPP analysis and forecast based on 0000 UTC of 27th November.

GPP analysis and forecast based on 1200 UTC of 27th November indicated two potential zones of cyclogenesis one each over southwest BoB and the other over Comorin area on 27th. The zone over Comorin became insignificant on 28th, appeared again on 29th & 30th and becoming insignificant thereafter. The other over southwest BoB off southeast Sri Lanka persisted till 2nd December. It also indicated potential zone of cyclogenesis over Andaman Sea on 30th with westwards movement till 2nd over southeast BoB. On 2nd, it indicated more potential of cyclogenesis over southeast BoB rather than southwest BoB or Arabian Sea.

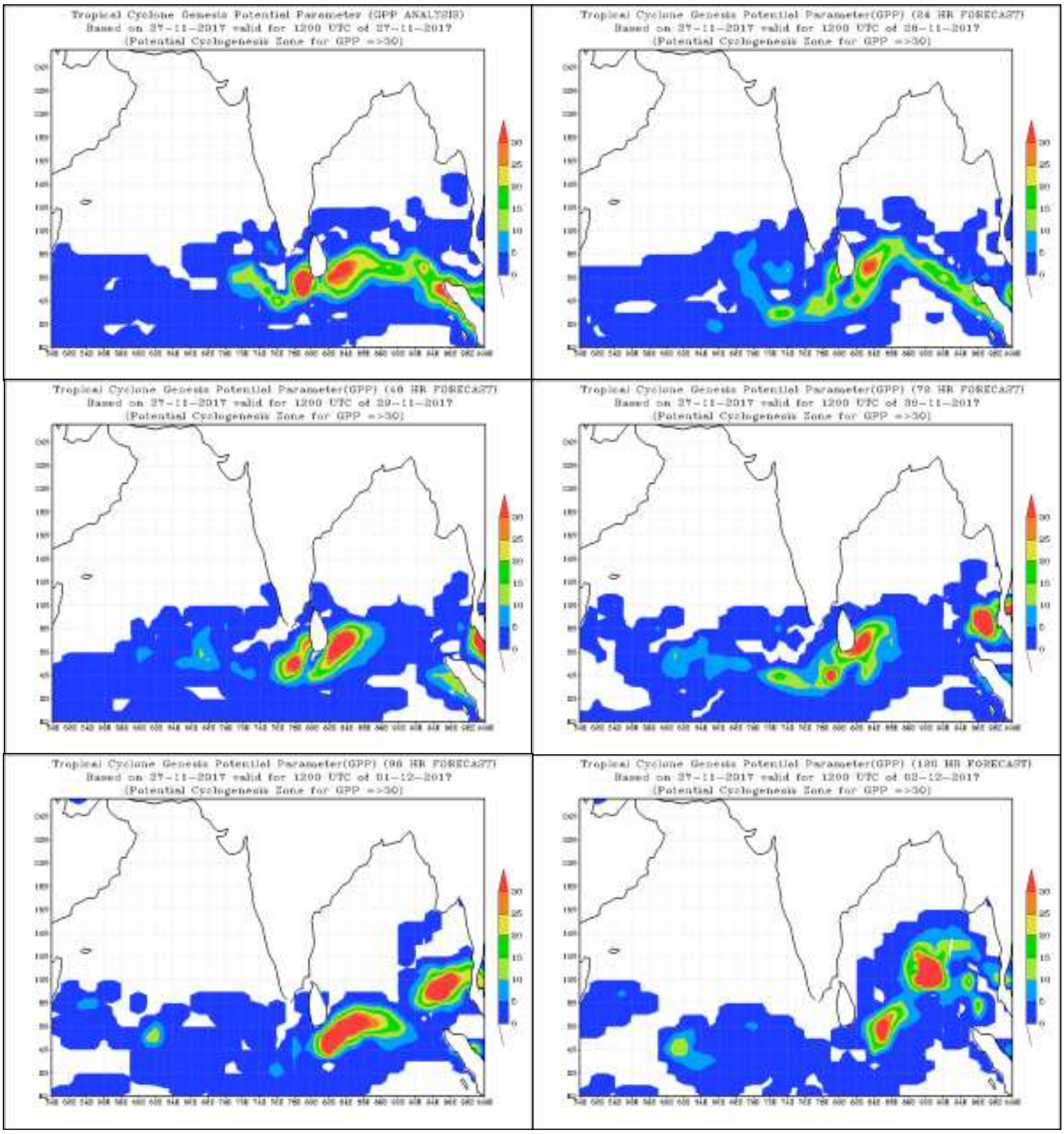


Fig.17 (b) : GPP analysis and forecast based on 1200 UTC of 27th November.

The analysis based on 0000 UTC of 28th indicated an elongated zone of cyclogenesis over southwest BoB off Sri Lanka coast moving westwards and signs of weakening from 1st onwards.

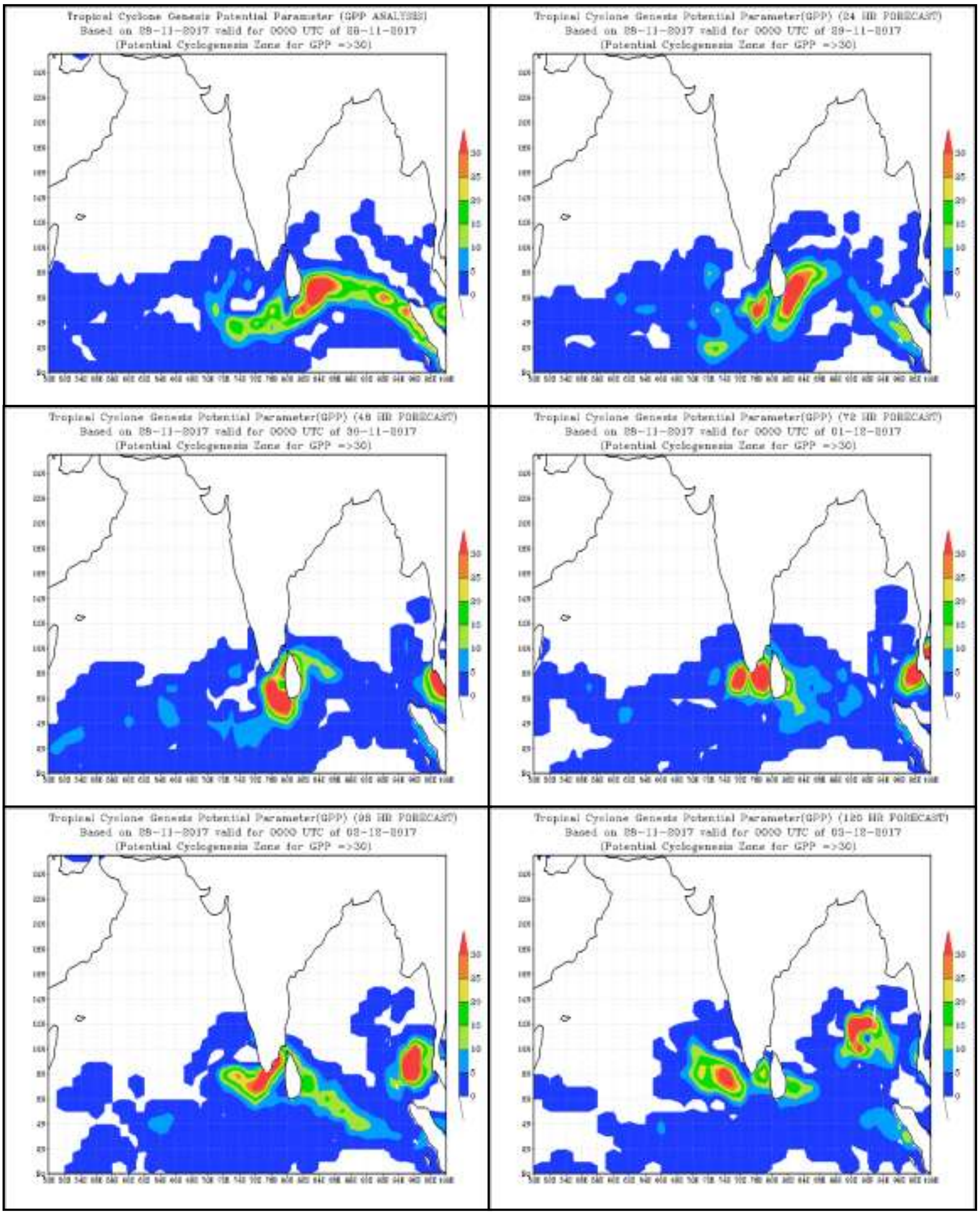


Fig. 17 (c): GPP analysis and forecast based on 0000 UTC of 28th November.

The GPP analysis and forecast fields based on 1200 UTC of 28th, indicated a potential zone for cyclogenesis over southwest BoB off southeast Sri Lanka and another off southwest Sri Lanka on 28th. On 29th the potential zone of cyclogenesis lay over Comorin area and thereafter it moved north-northwestwards across Lakshadweep Islands and southeast Arabian Sea. It also indicated a potential zone over Andaman Islands on 30th which moved west-northwestawards and lay over southeast and adjoining southwest Bay of Bengal on 2nd Dec., but with lesser intensity as compared to the zone over Arabian Sea.

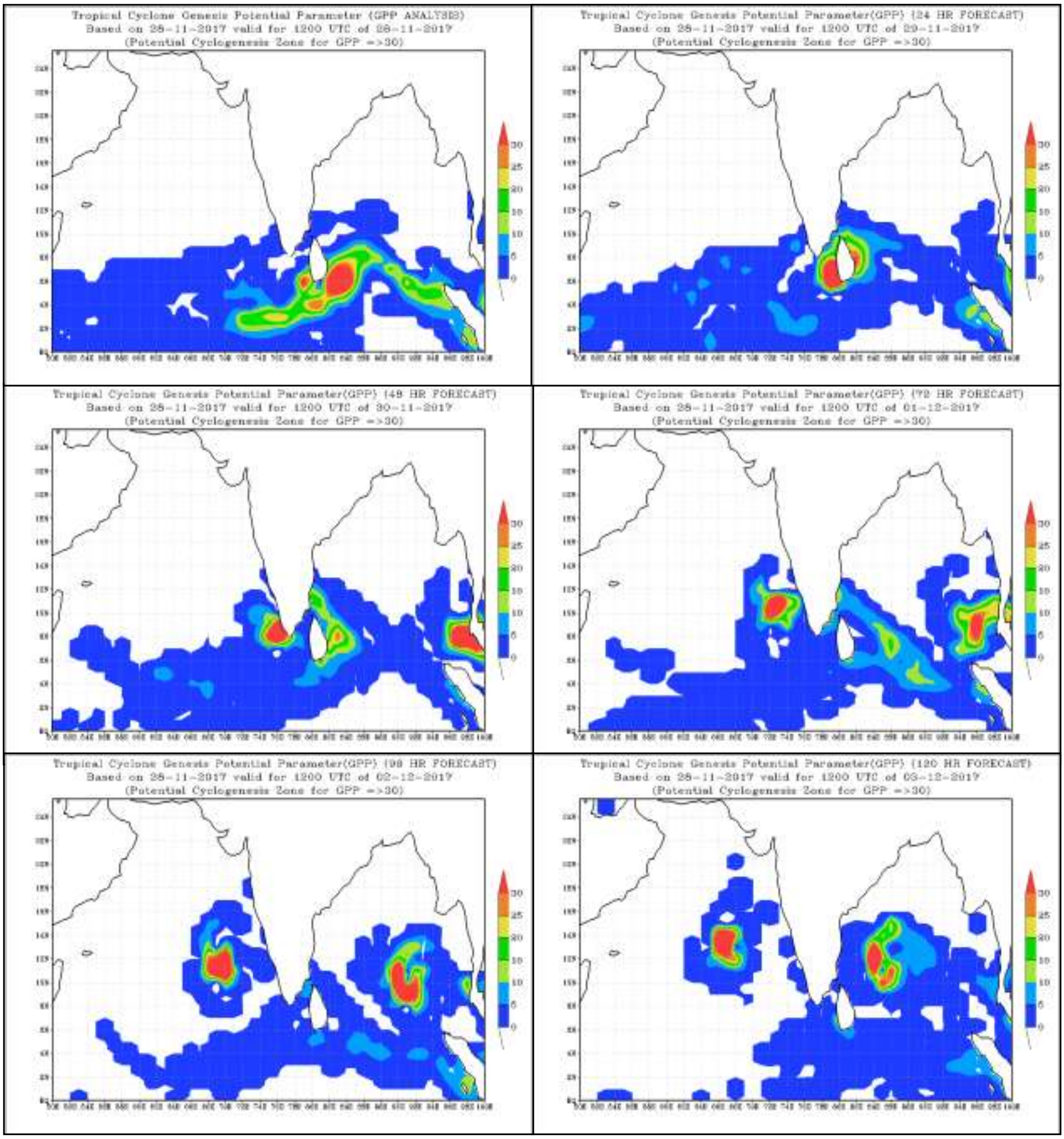


Fig. 17 (d): GPP analysis and forecast based on 1200 UTC of 28th November.

The analysis based on 0000 UTC of 29th indicated a potential zone of cyclogenesis over southwest BoB & Sri Lanka moving westwards till 30th and west-northwestwards thereafter reaching eastcentral Arabian Sea on 4th December. The cyclogenesis was predicted well but with reduced area gradually. At the same time it was showing another potential zone from south Andaman Sea.

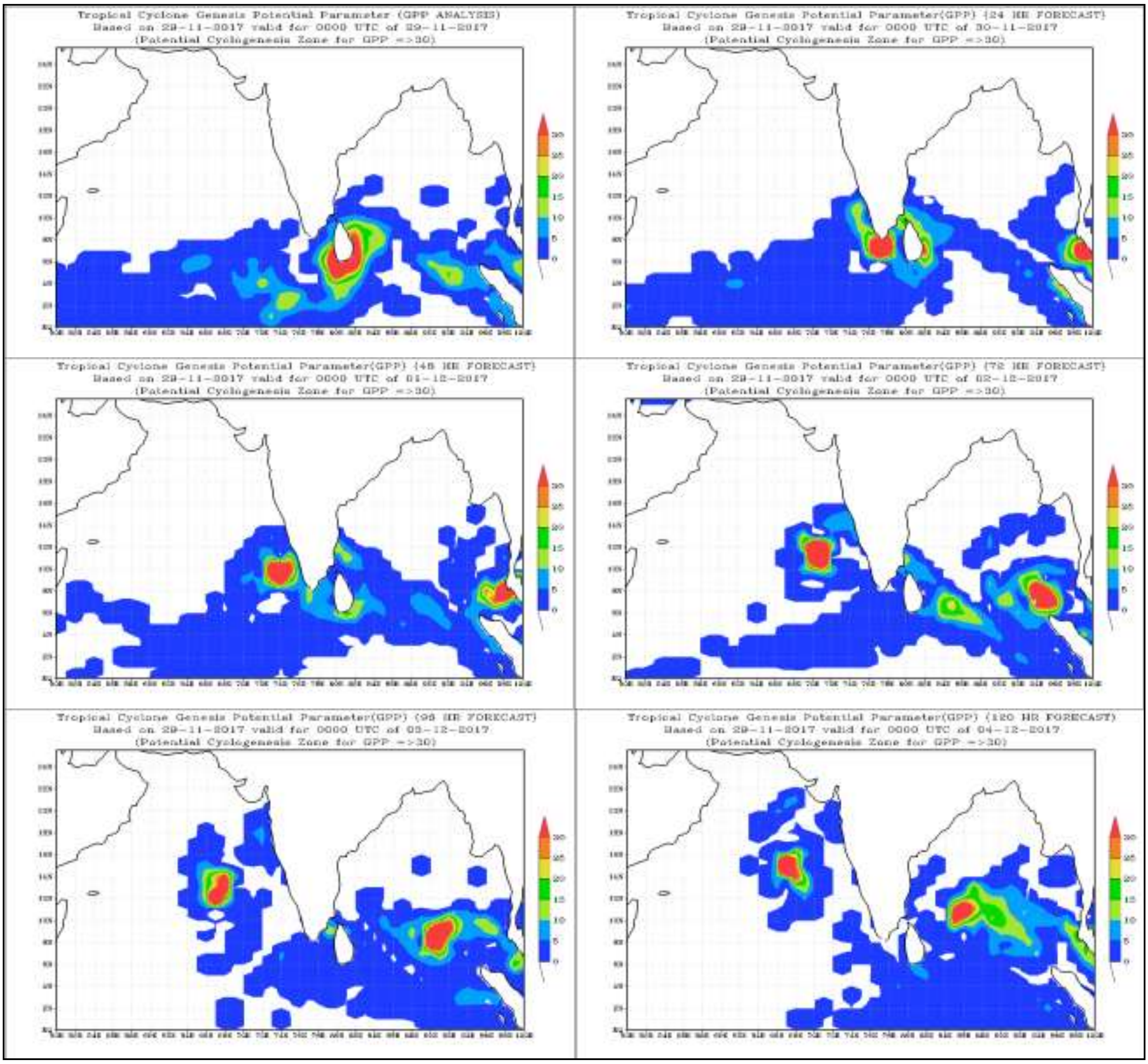


Fig. 17 (e): GPP analysis and forecast based on 0000 UTC of 29th November.

The analysis and forecast field based on 1200 UTC of 29th indicated a significant zone over Comorin on 29th which moved northwestwards and persisted over southeast Arabian Sea till 3rd Dec. becoming insignificant on 4th. It also indicated another potential zone for cyclogenesis over Andaman Sea on 30th moving west-northwestwards and reaching southwest BoB off south Andhra Pradesh coast on 4th.

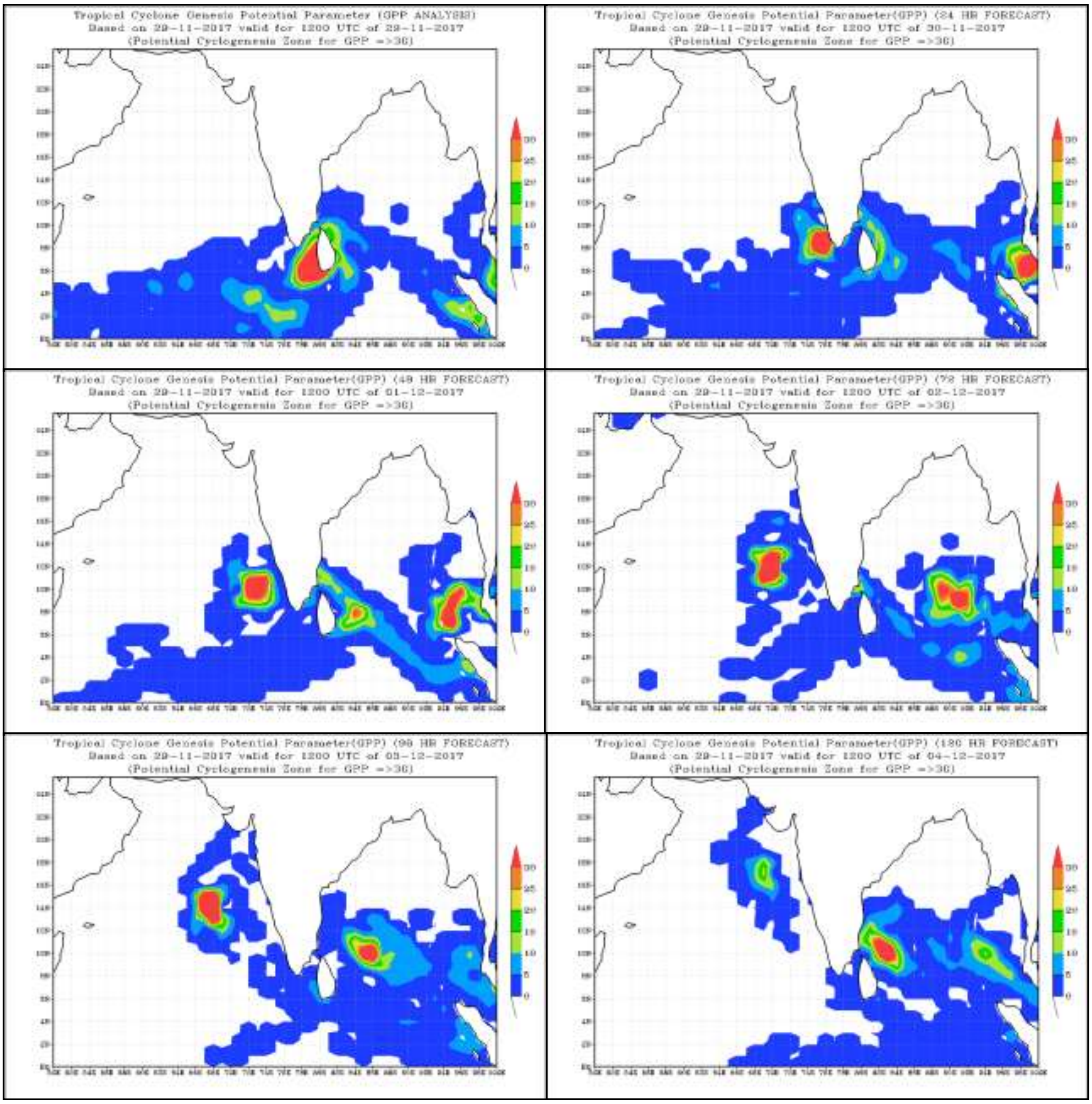


Fig.17 (f) : GPP analysis and forecast based on 1200 UTC of 29th November.

The analysis based on 0000 UTC of 30th indicated a potential zone of cyclogenesis over Comorin Area on 30th moving west-northwestwards till 3rd December, north-northeastwards from 4th onwards and weakening over eastcentral AS on 5th December. At the same time, it was showing another zone moving westward from south Andaman Sea and reaching southwest Bay off north Tamilnadu based on 6th December.

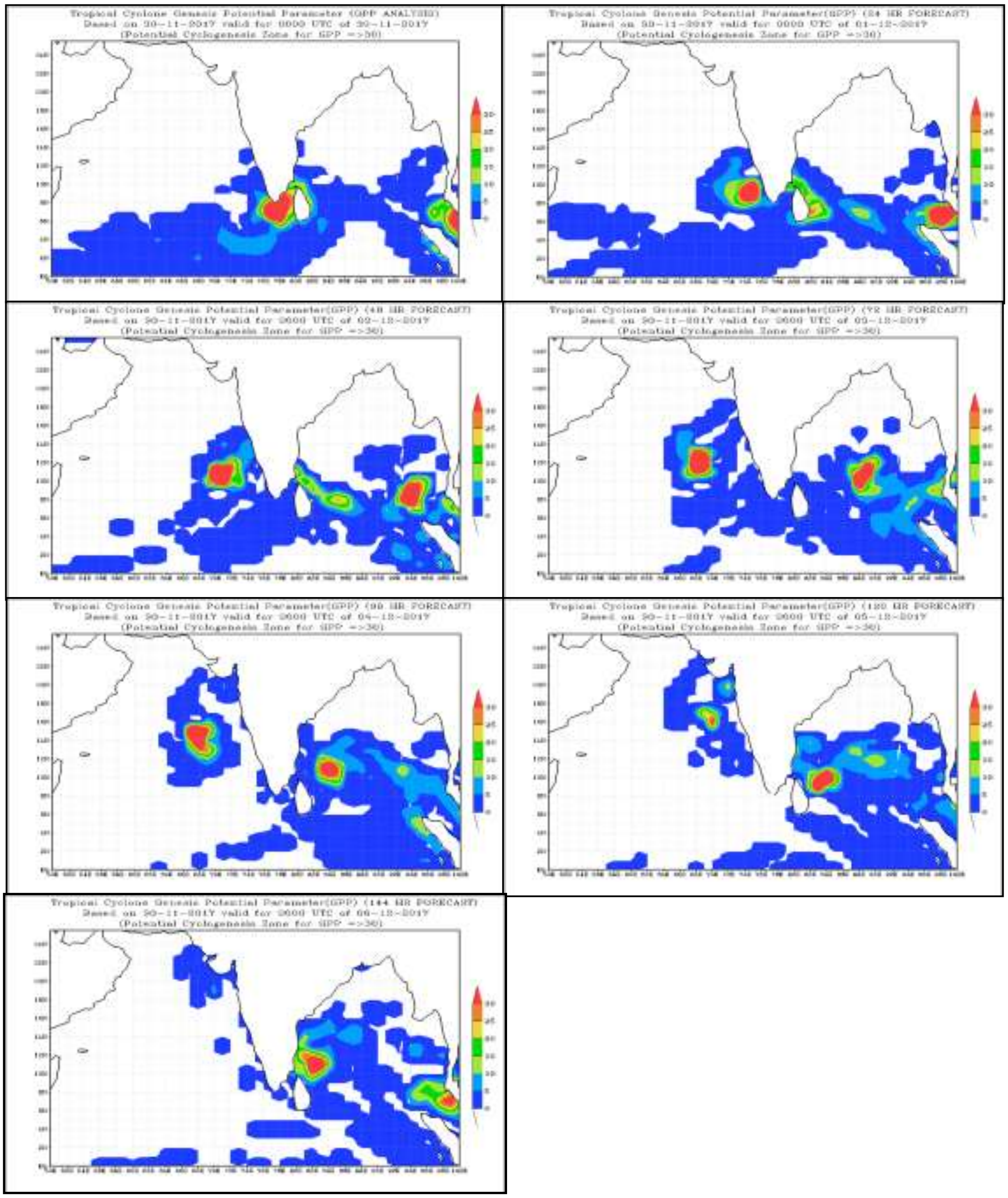


Fig. 17 (g): GPP analysis and forecast based on 0000 UTC of 30th November

Area Average GPP:

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 developed system is that average GPP ≥ 8.0 .Based on 0000 UTC analysis of 30th, the model predicted favourable GPP for next 96 hours (i.e. upto 4th December) and weakening thereafter during next 12 hours (by 1200 UTC of 4th December). The model underestimated the intensity of system beyond 96 hours. The system started weakening from 0000 UTC of 4th but maintained cyclonic storm (≥34 Kts) intensity till 0600 UTC of 5th.

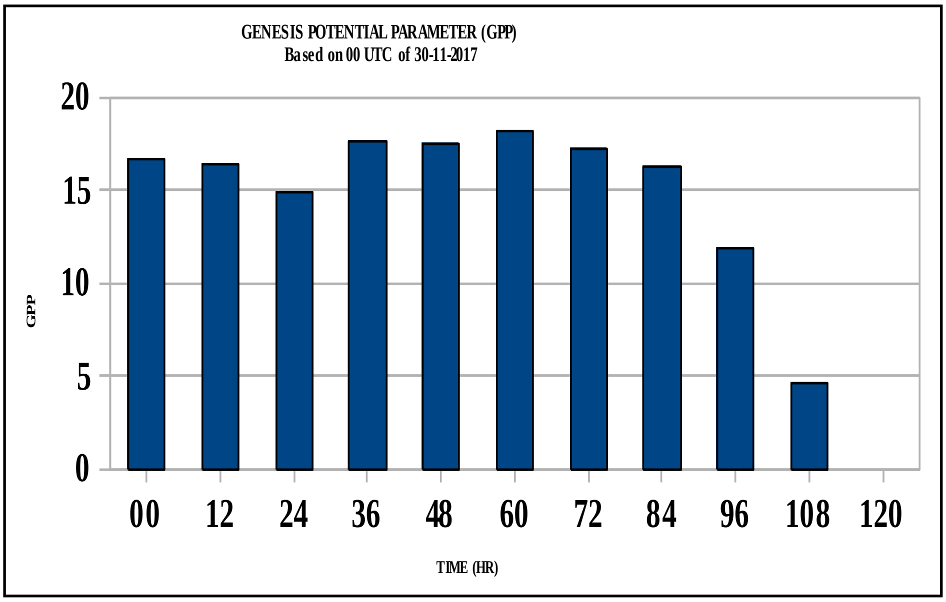


Fig. 18: Area average analysis and forecasts of GPP based on 0000 UTC of 30th November, 2017

However, the product based on 0000 UTC of 30th Nov. was made available by the time the system was already a cyclonic storm. According to NWP Division, the calculation of GPP is valid for open sea only and the GPP shows over estimation over land and land locked sea areas.

It has been observed that Ocean Heat Content (OHC) was one of the most important parameter for cyclogenesis and intensification/weakening. The currently used GPP however does not take into consideration the OHC and is based on other Gray parameters derived from IMD GFS model analysis and forecast. As the performance of GFS model was not satisfactory, the GPP derived from it could not meet the requirement.

9.2 Track prediction by NWP models

9.2.1. Track prediction by Deterministic models

Track prediction by various NWP models is presented in Fig.19. Based on initial conditions of 0000 UTC of 30th November, all models were predicting west-northwestwards movement with weakening over eastcentral AS. The models were not unanimous about the time of weakening. The models and MME indicated northeastward recurvature also. Only UKMO indicated movement towards Gujarat.

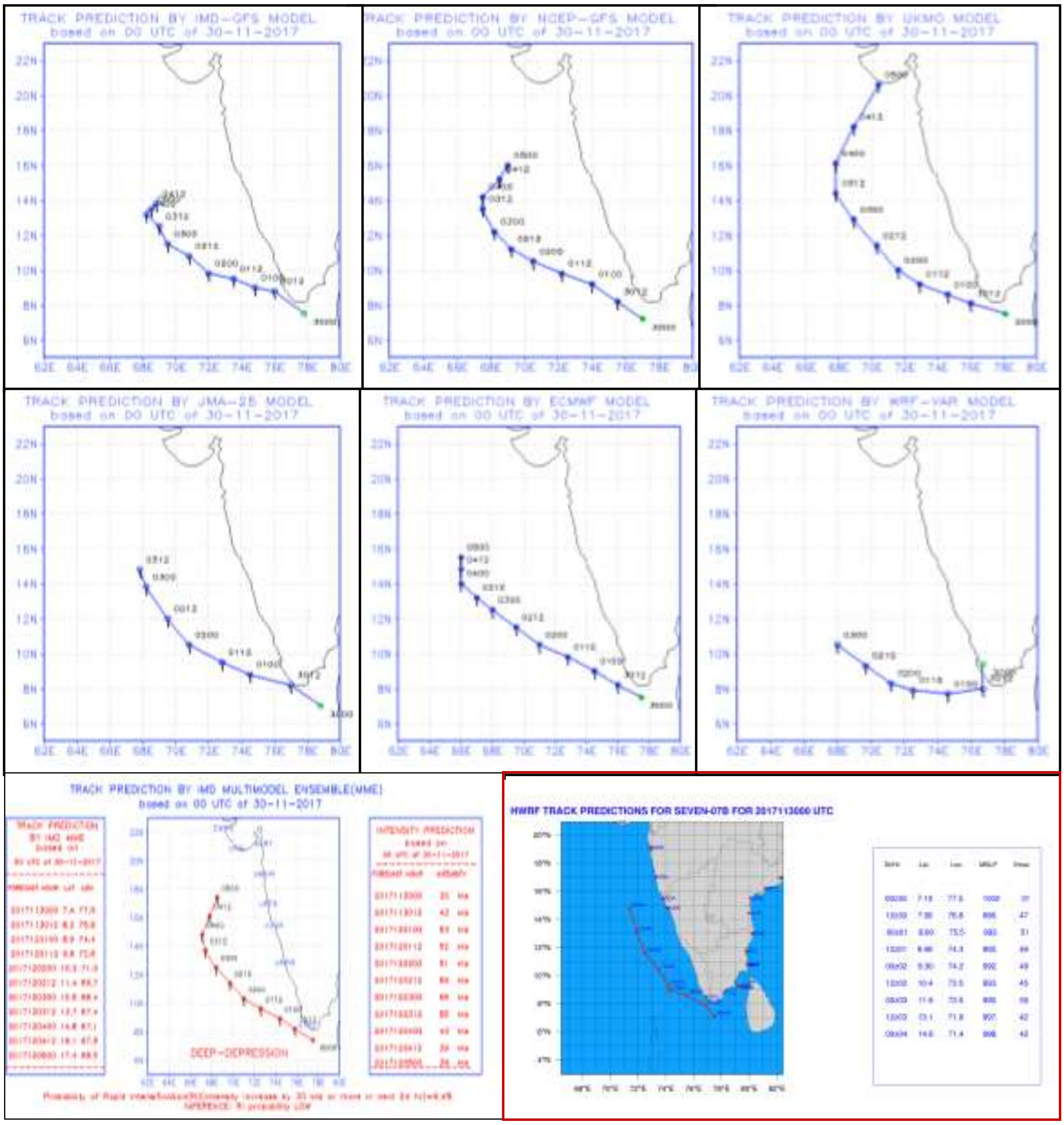


Fig. 19 (a): NWP model track forecast based on 0000 UTC of 30th November

Based on the initial conditions of 0000 UTC of 1st December, NCEP GFS indicated landfall near Dahanu, north Maharashtra in the afternoon of 5th December. All other models indicated weakening of system over eastcentral AS around 1200 UTC of 5th with JMA indicating weakening of system at 1200 UTC of 4th, HWRF at 0000 UTC of 5th and WRF VAR at 0000 UTC of 4th. All models except WRF-VAR and HWRF indicated movement towards south Gujarat-north Maharashtra coast.

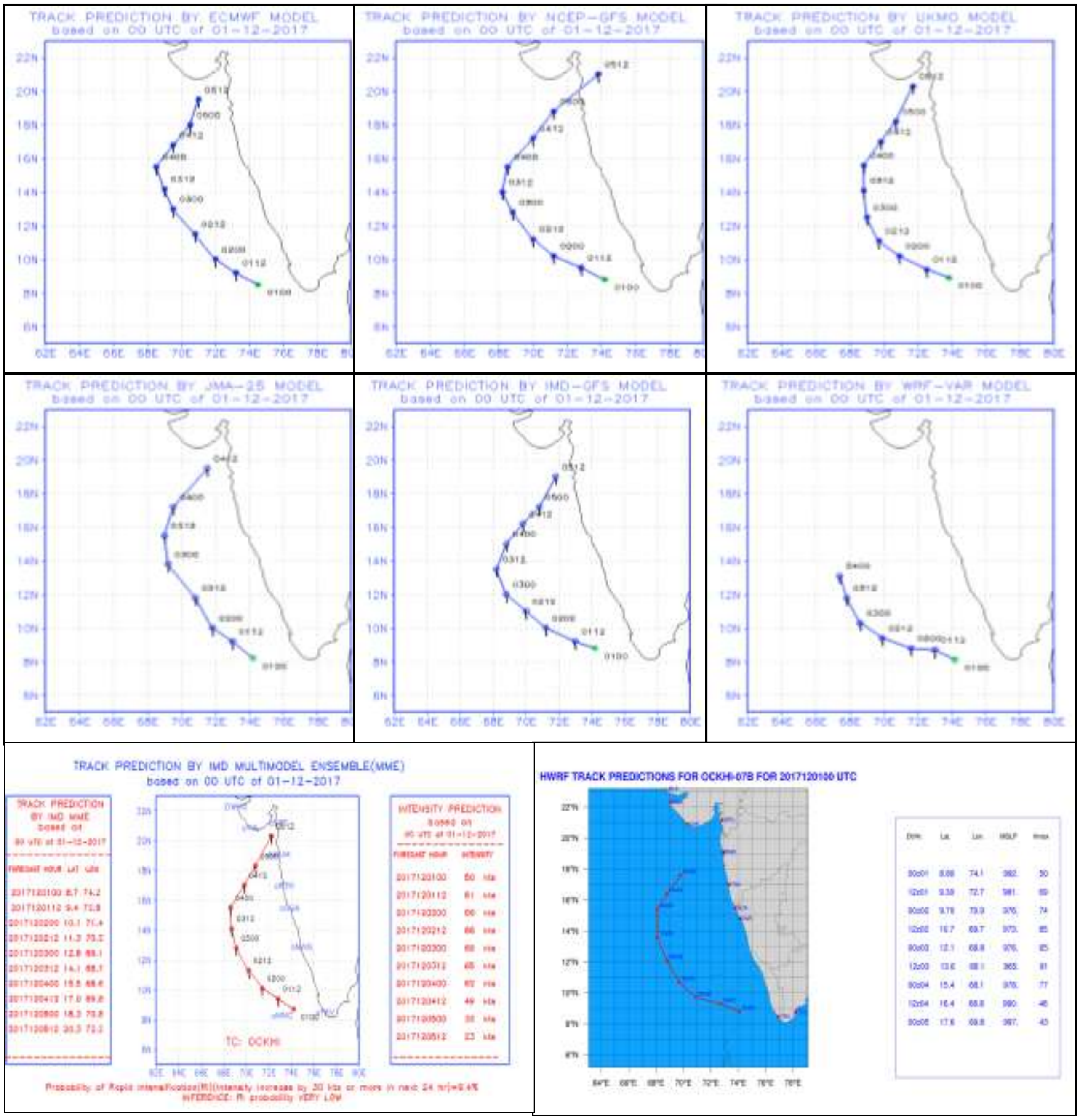


Fig. 19 (b): NWP model track forecast based on 0000 UTC of 1st December

Based on the initial conditions of 0000 UTC of 2nd December, NCEP GFS, ECMWF and MME indicated weakening of system over eastcentral BoB. All other models including UKMO, JMA, IMD GFS indicated landfall of system between Mumbai and Dahanu over north Maharashtra between 0800 to 1200 UTC of 5th. HWRF however indicated landfall near Surat around 0300 UTC of 5th December.

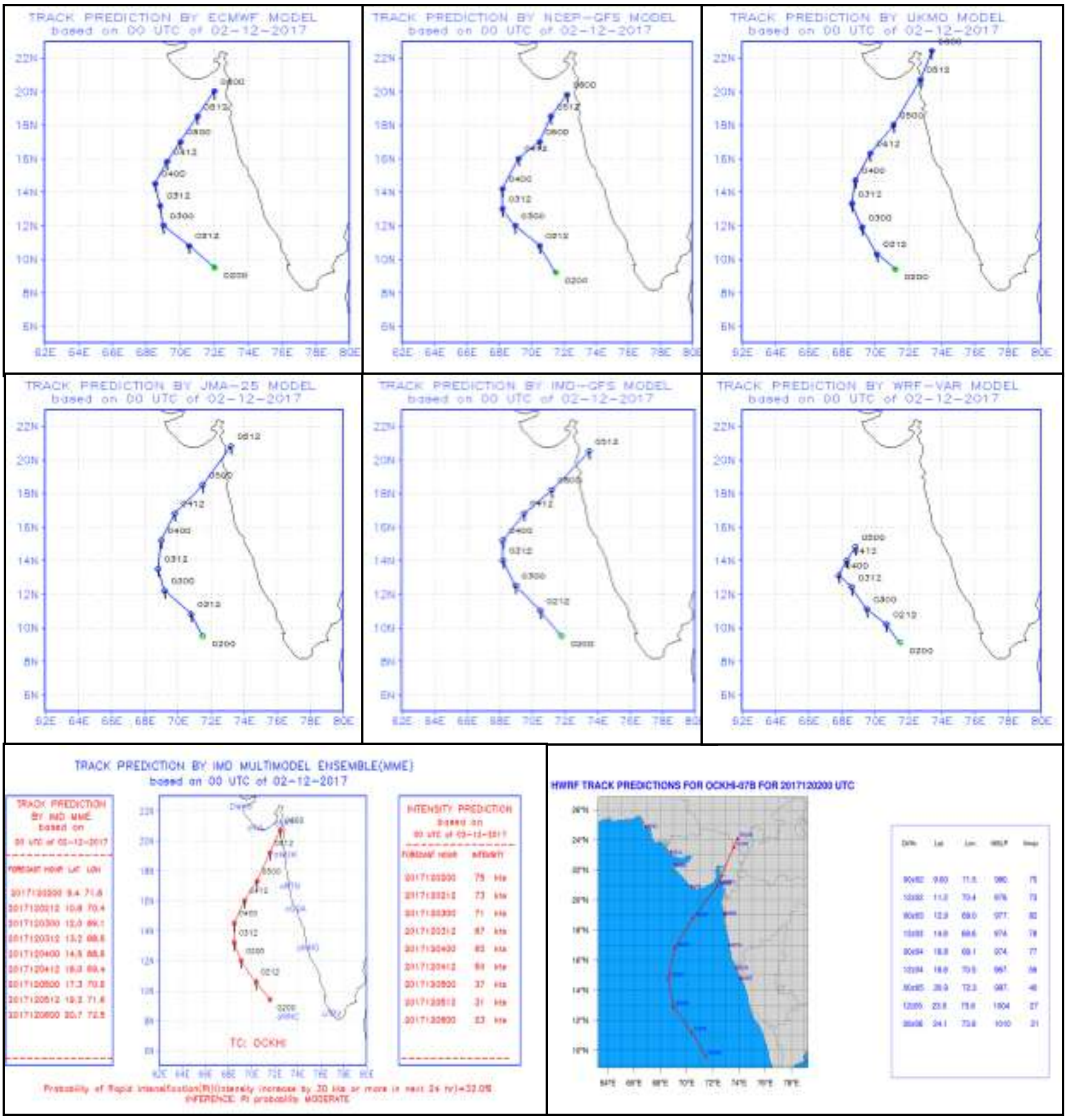


Fig. 19 (c): NWP model track forecast based on 0000 UTC of 2nd December

Based on the initial conditions of 0000 UTC of 3rd December, all models except WRF-VAR and IMD GFS indicated landfall between Surat and Dahanu around night of 5th December.

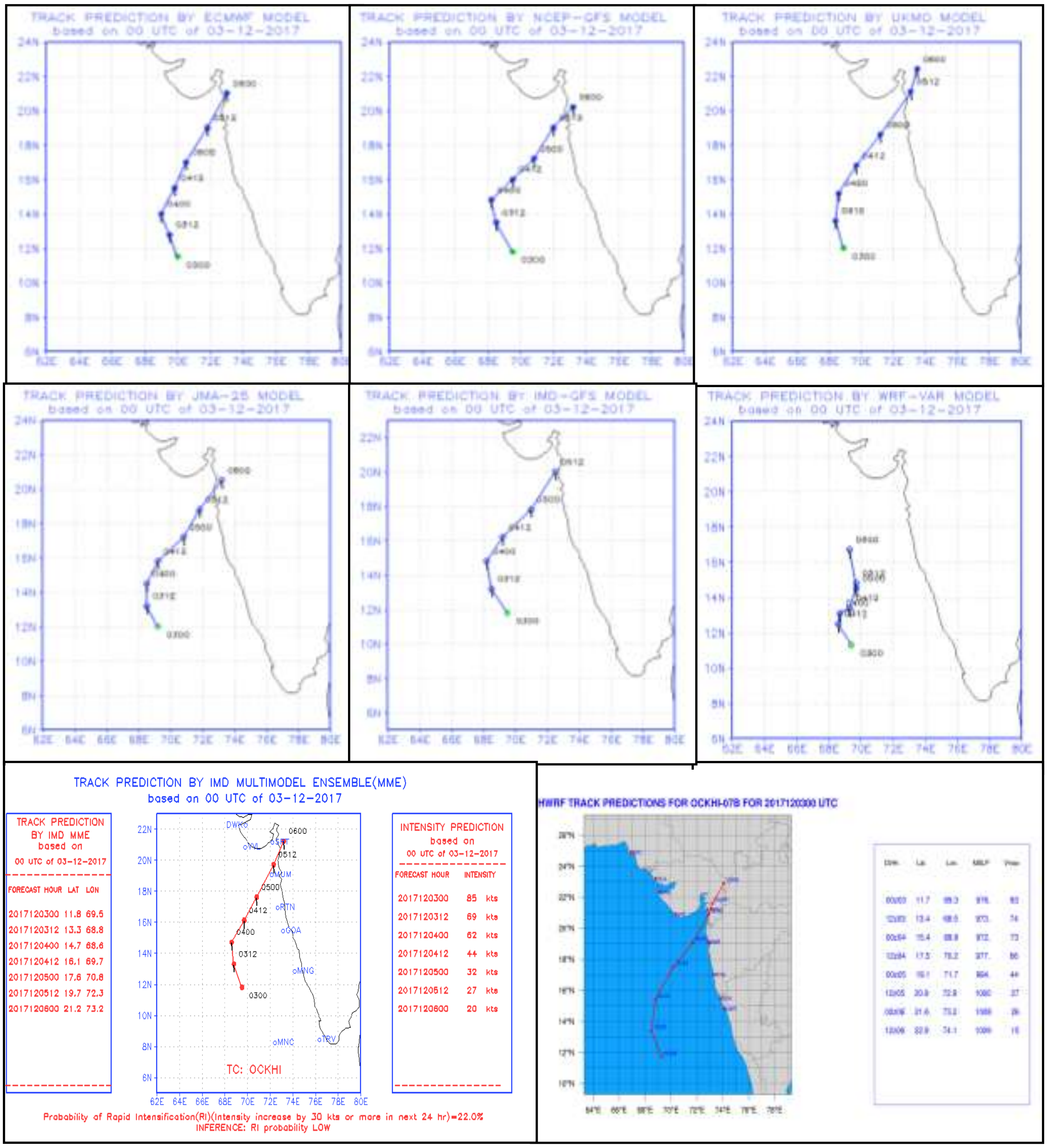


Fig. 19 (d): NWP model track forecast based on 0000 UTC of 3rd December

Based on the initial conditions of 0000 UTC of 4th December, all models except WRF-VAR and HWRF indicated landfall between Surat and Dahanu around night of 5th December. HWRF indicated landfall near to east of Veeraval.

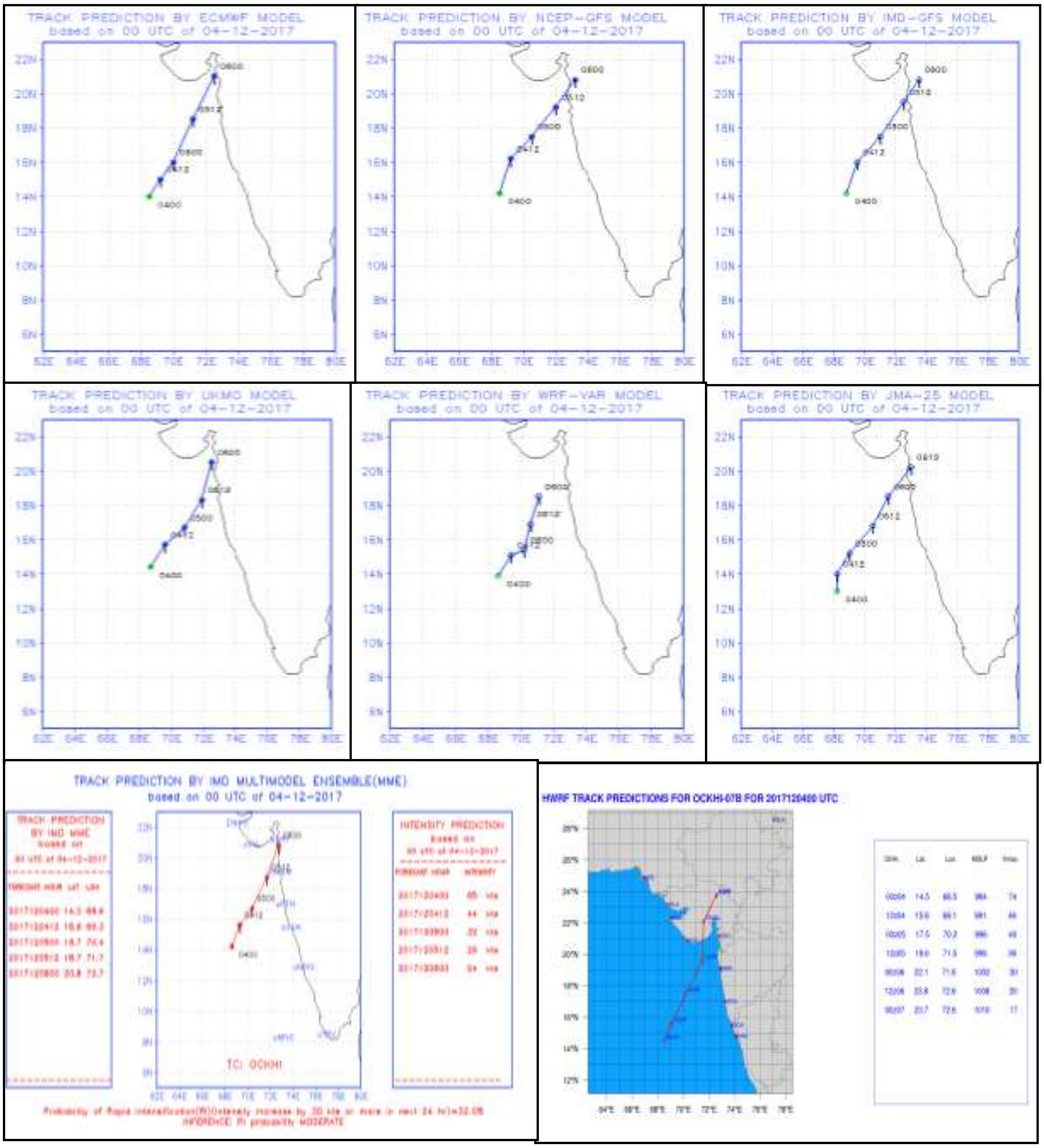


Fig. 19 (e): NWP model track forecast based on 0000 UTC of 3rd December

Based on the initial conditions of 0000 UTC of 5th December, all models except HWRF indicated weakening over eastcentral AS close to south Gujarat and north Maharashtra coast between Surat and Dahanu. HWRF indicated landfall over Gujarat to the east of Veeraval.

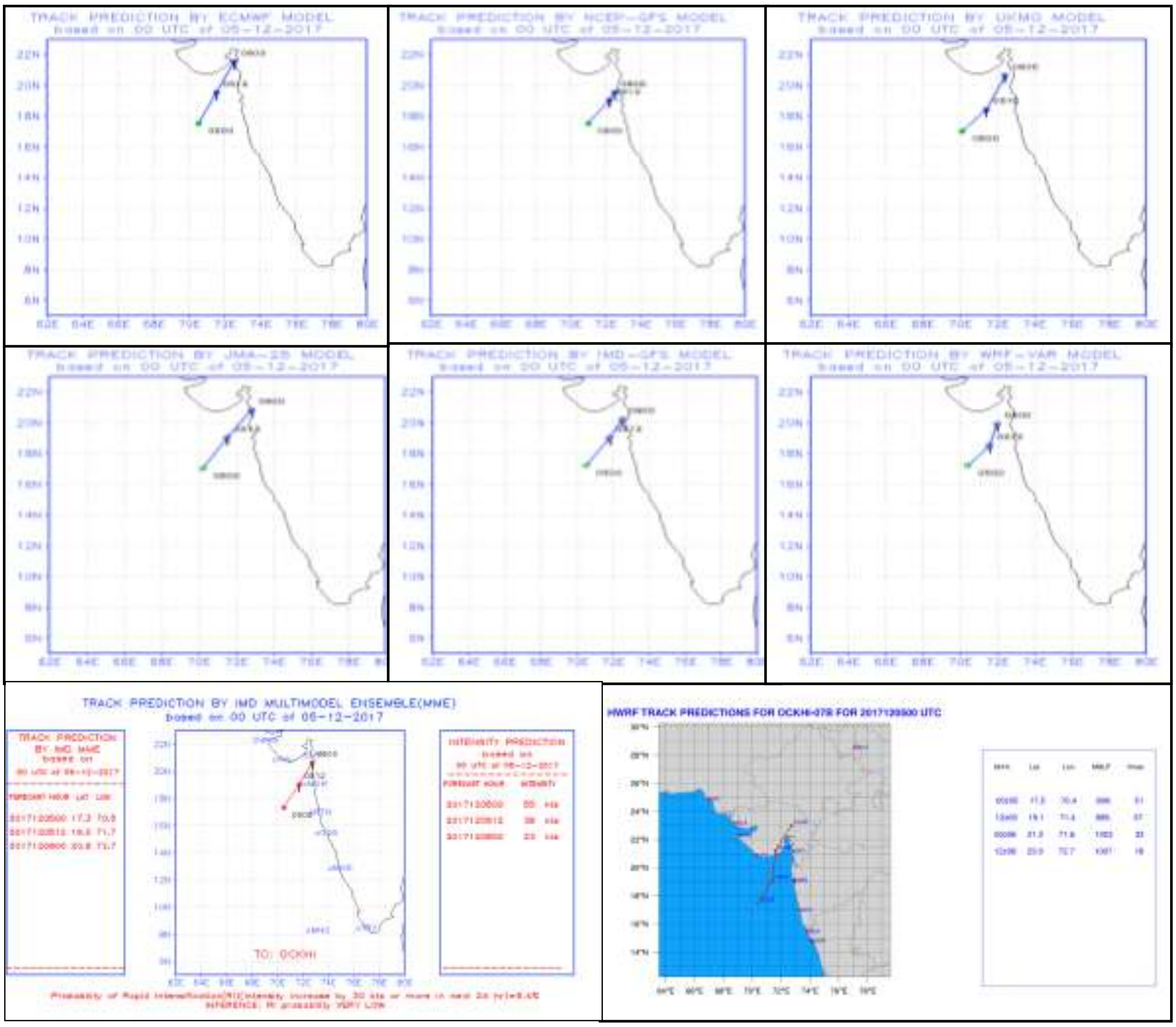


Fig. 19 (f): NWP model track forecast based on 0000 UTC of 3rd December

Hence to conclude all the models except WRF-VAR were indicating movement towards north Maharashtra and south Gujarat coast. Most of the models were indicating gradual weakening over eastcentral and adjoining northeast AS close to south Gujrat & North Maharashtra coasts. Most of the models indicated weakening around night of 5th December.

Composite forecast track based on various initial conditions by MME and observed track is presented in Fig.20. It is seen that MME could predict the northeastward recurvature and movement towards Gujarat coast and weakening of system over eastcentral AS from initial conditions of 0000 UTC & 1200 UTC of 1st December onwards. However it had westward bias in predicting the point of recurvature during initial days (30th Nov & 1st Dec).

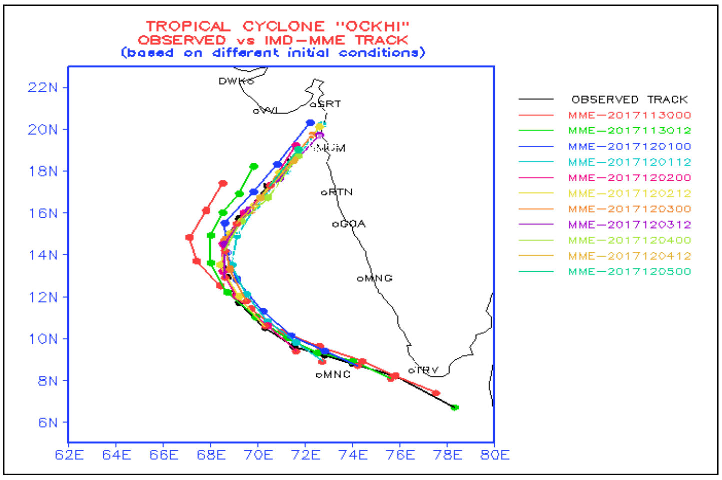


Fig. 20: Observed track and forecast tracks by MME based on initial conditions of 0000 & 1200 UTC during 30th November to 05th December

9.2.2. Track Prediction by Ensemble Prediction System:

The probabilistic and deterministic track forecast by UK Meteorological Office (UKMO) & European Centre for Medium Range Weather Forecasts (ECMWF) and consolidated forecast by these centres based on initial conditions of 0000 UTC of 1st December are presented in Fig. 21.

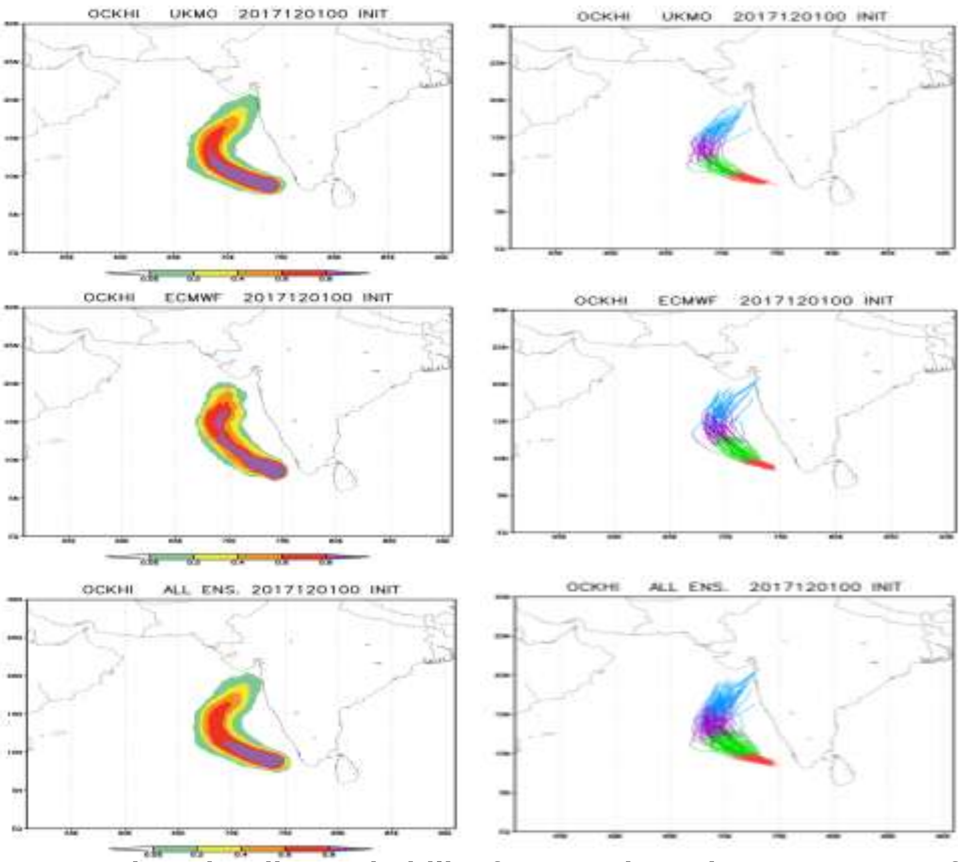


Fig.21 : EPS track and strike probability forecast based on 0000 UTC of 1st December

Based on initial conditions of 0000 UTC of 1st December, all EPS models predicted initial west-northwestwards movement and north-northeastwards recurvature thereafter with weakening over eastcentral AS.

The probabilistic and deterministic track forecast by ECMWF based on initial conditions of 1200 UTC of 1st December are presented in Fig. (a). 60-80 % members indicated north-northwestwards movement of system, followed by north-northeastwards recurvature with dissipation over eastcentral AS. Based on initial conditions of 0000 UTC of 2nd, all members were unanimous about track, however 5-20% members indicated weakening over eastcentral AS off south Maharashtra coast or north Gujarat coast (Fig. 21 (b)).

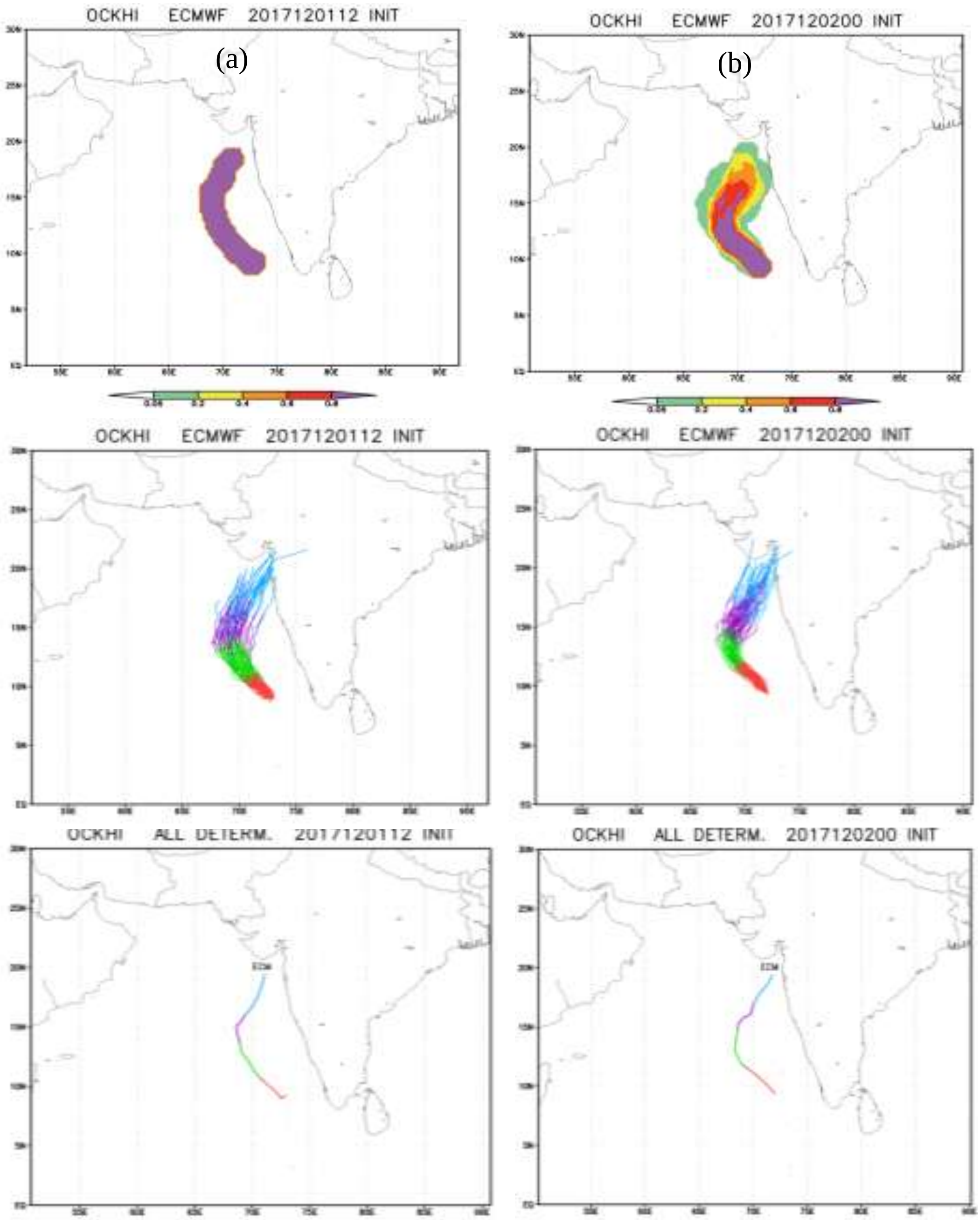


Fig.21 (b) : EPS track and strike probability forecast based on 1200 UTC of 1st December and 0000 UTC of 2nd December

9.2.3. Track forecast by NCMRWF Models

(a) NCMRWF Unified Model

The track forecast by NCMRWF Unified Model (NCUM) based on initial conditions of 0000/1200 UTC during 29th November to 5th December is presented in Fig. 22(a) From 30th onwards, the model predicted initial west-northwestward movement with northeastwards recurvature towards south Gujarat-north Maharashtra coast. On 29th & 30th, it indicated dissipation over sea. The forecast based on initial conditions of 1st, 2nd & 5th December indicated movement towards south Gujarat & north Maharashtra coast (Fig. 22 (a).

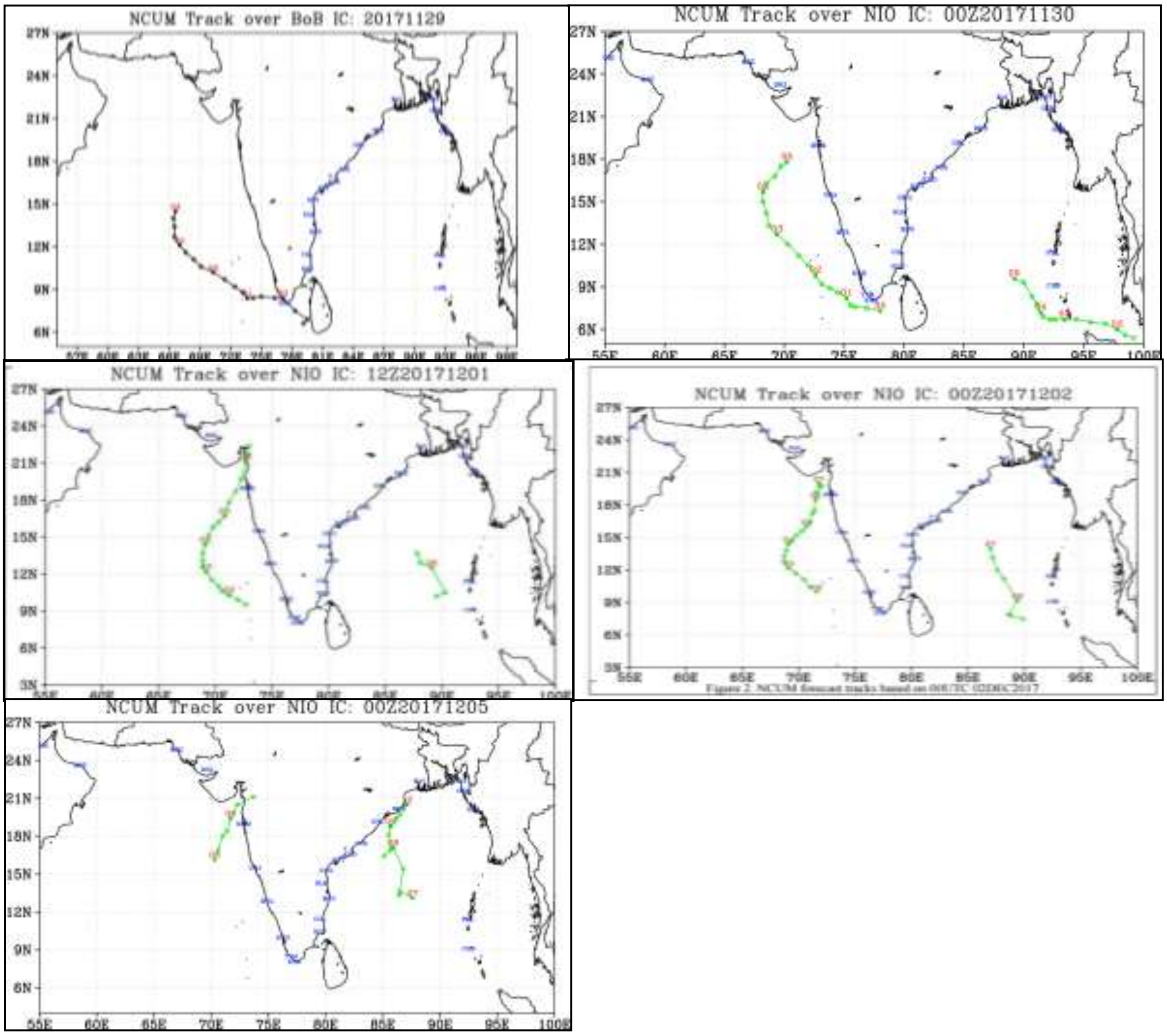


Fig. 22 (a): Track forecast by NCUM Models

(b) Met Office Global & Regional Ensemble Prediction System (MOGREPS)

The MOGREPS forecast tracks based on 0000 UTC of 29th predicted that the system will cross the Indian coast near Kanyakumari and emerge in Arabian Sea. The system would track northwestwards (>80% probability) and then there was some probability (40-60%) that the system would recurve and track towards Gujarat (Fig. 22 (b))..

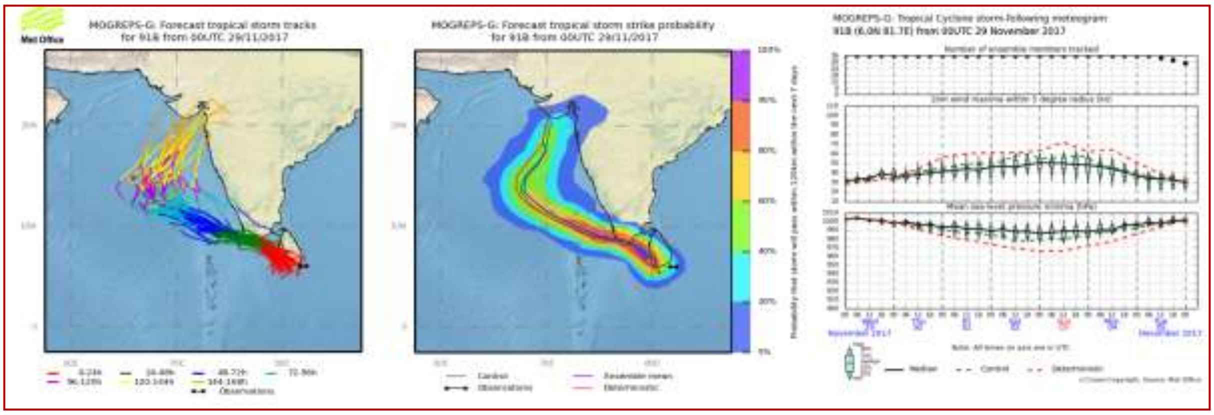


Fig. 22 (b): Track Prediction by MOGREPS models based on 0000 UTC of 29th November

The MOGREPS forecast tracks based on 0000 UTC of 2nd November predicted that TC Ockhi will move northeastwards (>80% probability), will recurve northeastwards (>80% probability) and cross the Indian coast near Gujarat Maharashtra border (Fig. 22 (c)).

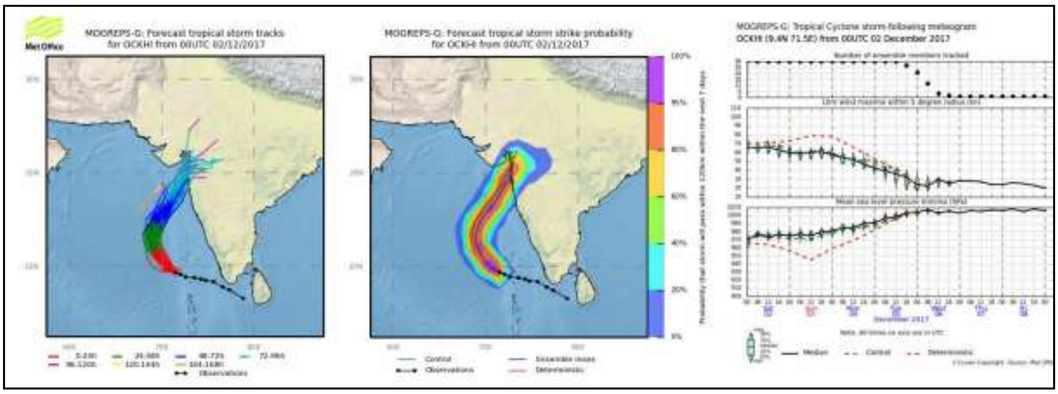


Fig. 22 (c): Track Prediction by MOGREPS models based on 0000 UTC of 2nd December

As per the MOGREPS forecast tracks based on 0000 UTC of 5th December, the system would track northeastwards (>80% probability) towards Maharashtra coast (Fig. 22 (d)).

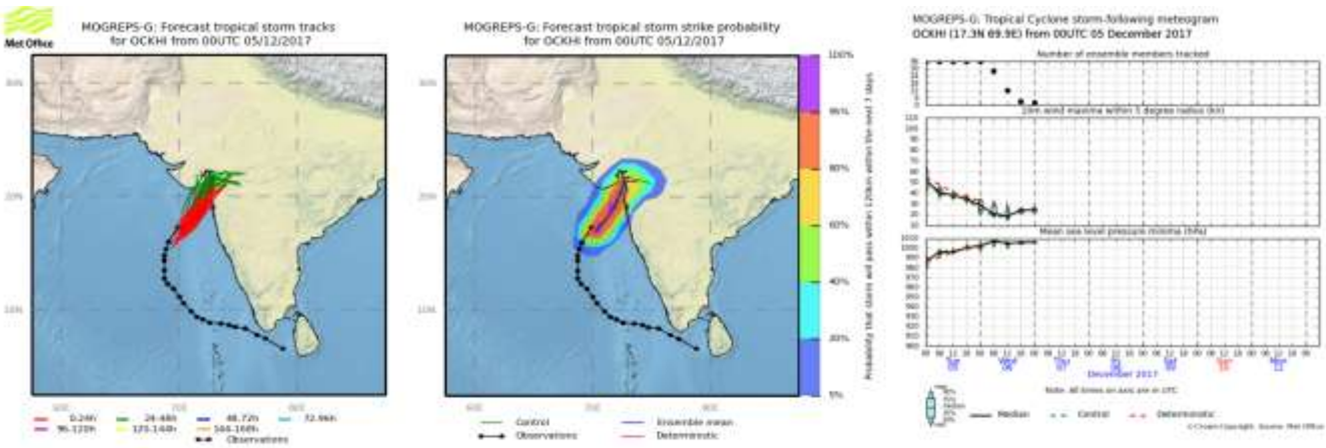


Fig. 22 (g): Track Prediction by MOGREPS models based on 0000 UTC of 5th December

9.3 Track 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 6. The average cross track errors (CTE) and along track errors (ATE) are presented in Table 7 (a-b). From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors of MME were the least for 12, 24 and 36 hours lead period. It was lowest in case of for 48 to 96 hrs and NEPS and NCUM for 108 and 120 hrs respectively.

Table 6. Average track forecast errors (Direct Position Error (DPE)) in km

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
IMD-GFS	51(11)	68(10)	98(9)	117(8)	123(7)	145(6)	211(5)	218(4)	190(3)	407(2)
IMD-WRF	59(11)	115(10)	166(9)	226(8)	271(7)	278(6)	-	-	-	-
JMA	70(11)	70(10)	85(9)	103(8)	148(7)	215(6)	304(5)	-	-	-
NCEP-GFS	60(11)	65(10)	75(9)	110(8)	91(7)	104(6)	131(5)	203(4)	259(3)	301(2)
UKMO	42(11)	63(10)	76(9)	122(8)	146(7)	173(6)	187(5)	191(4)	203(3)	294(2)
ECMWF	58(11)	69(10)	64(9)	62(8)	86(7)	100(6)	90(5)	139(4)	201(3)	329(2)
IMD-HWRF	58(21)	99(20)	130(18)	180(16)	234(14)	251(12)	279(10)	251(8)	-	-
IMD-MME	29(11)	44(10)	58(9)	86(8)	100(7)	112(6)	118(5)	147(4)	169(3)	187(2)
NCUM	82 (13)	122(12)	129(11)	121(10)	144(9)	180(8)	155(7)	155(6)	178(5)	169(3)
NEPS	90(7)	134(6)	178(6)	217(5)	211(5)	208(4)	187(4)	157(3)	148(3)	

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

Table 7 (a). Average cross-track forecast errors (CTE) in km

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
IMD-GFS	32	33	40	54	72	106	164	203	171	366
IMD-WRF	28	49	87	138	177	216	-	-	-	-
JMA	32	24	54	81	117	165	234	-	-	-
NCEP-GFS	33	23	28	51	38	53	96	179	233	279
UKMO	19	32	43	66	76	101	113	112	87	114
ECMWF	43	37	58	51	62	55	48	77	146	315
IMD-HWRF	99	150	191	221	278	282	276	279	-	-
IMD-MME	20	24	40	52	58	59	52	86	112	161
NCUM	54	65	59	68	74	84	77	84	130	154
NEPS	63	75	100	123	144	145	147	102	94	

Table 7 (b). Average along-track forecast errors (ATE) in km

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
IMD-GFS	30	54	84	99	92	86	125	78	76	178
IMD-WRF	47	97	110	140	156	144	-	-	-	-
JMA	54	57	50	58	87	133	184	-	-	-
NCEP-GFS	39	57	66	87	73	76	67	85	106	100
UKMO	34	50	58	93	110	128	138	154	176	257
ECMWF	30	53	19	28	51	76	67	109	117	92
IMD-HWRF	35	46	48	80	92	132	158	84	-	-
IMD-MME	14	34	38	64	73	86	89	117	112	83
NCUM	51	112	108	91	103	138	119	116	111	105
NEPS	54	65	59	68	74	84	77	84	130	154

Above tables show that DPE was largely contributed by CTE for 12-36 hrs, 108 to 120 hrs and ATE by 48-96 hrs for most of models & MME except HWRF. ATE was less than CTE for all lead times in case of HWRF.

9.4. Intensity forecast error

The intensity forecast errors of IMD-SCIP model and HWRF model are shown in Table 8. The errors by IMD-HWRF were less as compared to IMD-SCIP upto 36 hours lead period and beyond that errors in intensity forecast by SCI{P model were less.

Table-8 Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of SCIP model (Number of forecasts verified is given in the parentheses)

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
IMD-SCIP (AAE)	8.3 (11)	11.8 (10)	13.1 (9)	13.3 (8)	12.4 (7)	9.7 (6)	10.4 (5)	15.3 (4)	13.7 (3)	7.5 (2)
HWRF (AAE)	7.2 (21)	9.2 (20)	7.8 (18)	16.8 (16)	13.0 (14)	11.3 (12)	12.9 (10)	8.3 (8)		
IMD-SCIP (RMSE)	10.0	13.7	15.0	16.7	14.7	11.2	12.2	17.9	14.8	9.9
HWRF (RMSE)	9.3	10.7	10.2	19.8	17.6	14.4	15.8	11.6		

The figure in parenthesis indicates the No. of observations verified.

Intensity forecast skill by IMD-HWRF is presented in Table 9.

Table-9 Intensity forecast Skill by IMD-HWRF Model

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr
Skill in AAE	1.3 (21)	31.5 (20)	67.2 (18)	51.5 (16)	71.9 (14)	83.2 (12)	84.2 (10)	90.4 (8)
Skill in RMSE	12 (21)	32.2 (20)	62.0 (18)	51.2 (16)	68.3 (14)	81.5 (12)	84.3 (10)	88.6 (8)

The figure in parenthesis indicates the No. of observations verified.

The operational intensity versus predicted intensity by SCIP model and HWRF model are presented in Fig 23. IMD SCIP all along underestimated the intensity of the system. HWRF could pick up the intensity upto 36 hours lead period and beyond 96 hours lead period. For period between 48 hours to 90 hours, there was large error in intensity prediction.

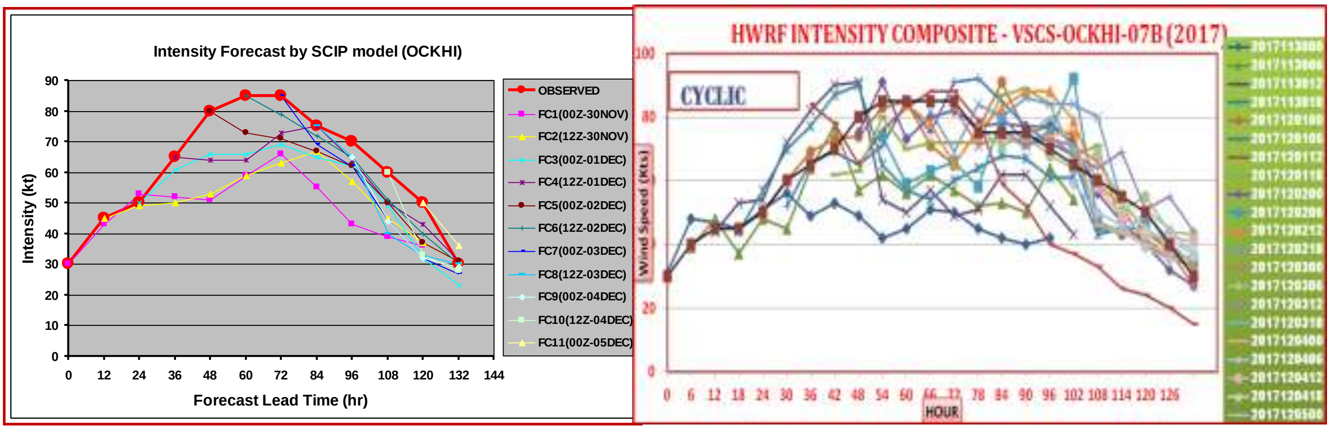


Fig. 23. Operational Intensity vs predicted intensity by SCIP Model and HWRF model

9.4. Heavy rainfall forecast by models

9.4.1. Heavy rainfall forecast by HWRF model

The forecast rainfall swaths by HWRF model are presented in Fig.24. HWRF predicted heavy rainfall over Tamil Nadu, Kerala and Karnataka on 30th November. On 1st, it predicted light to moderate rainfall over Tamil Nadu and Kerala. From 2nd onwards, it predicted light to moderate rainfall over Goa, Maharashtra and Gujarat. The error in rainfall prediction was mainly due to track forecast error of the model.

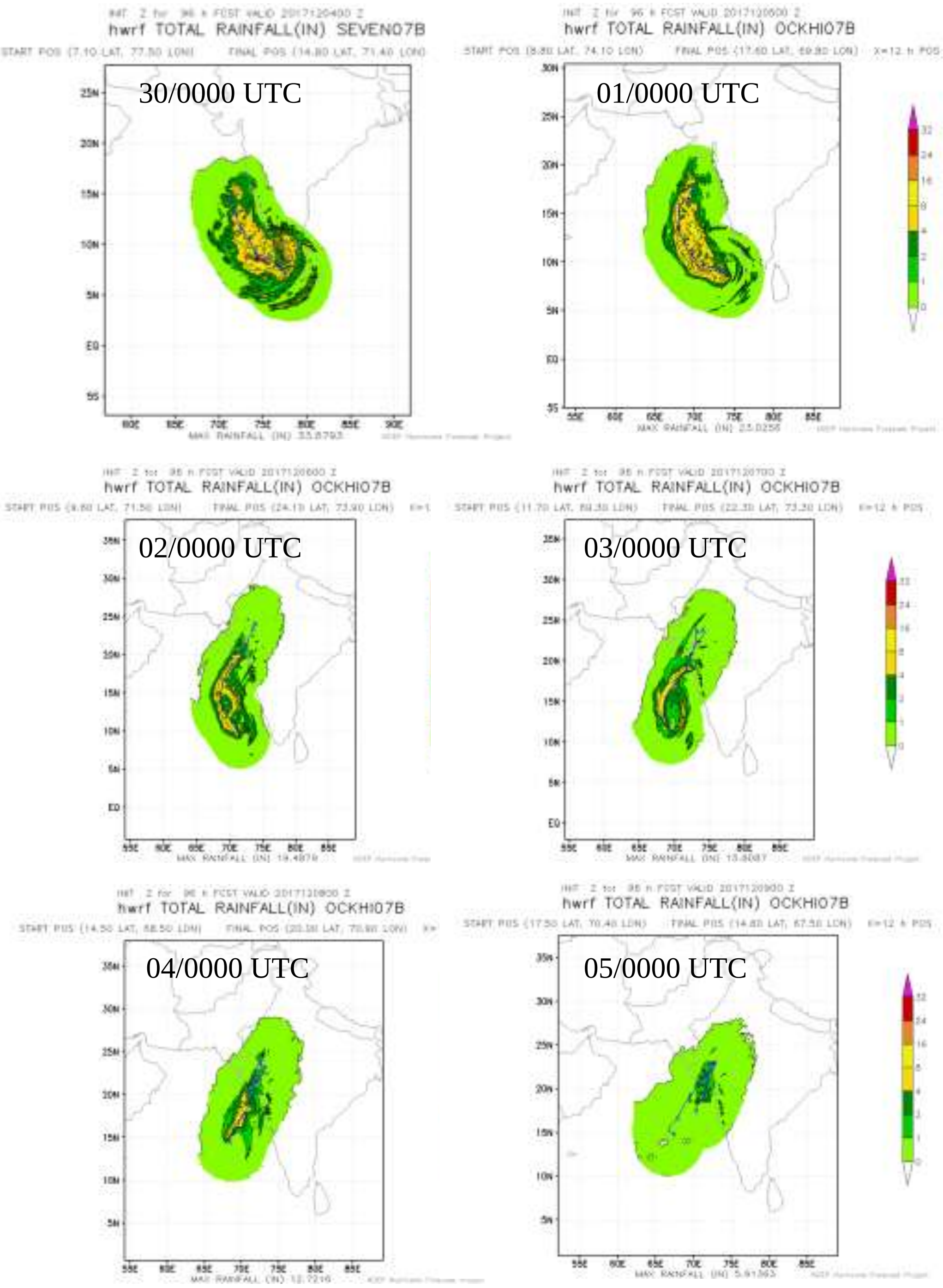


Fig.24: Heavy rainfall forecast by HWRF based on initial conditions of 0000 UTC of 30th November to 5th December, 2017.

9.4.2. Heavy rainfall forecast by IMD GFS model

Rainfall forecast upto 120 hours by IMD GFS model based on 0000 UTC observations of 29th November to 5th December is presented in Fig. 25.

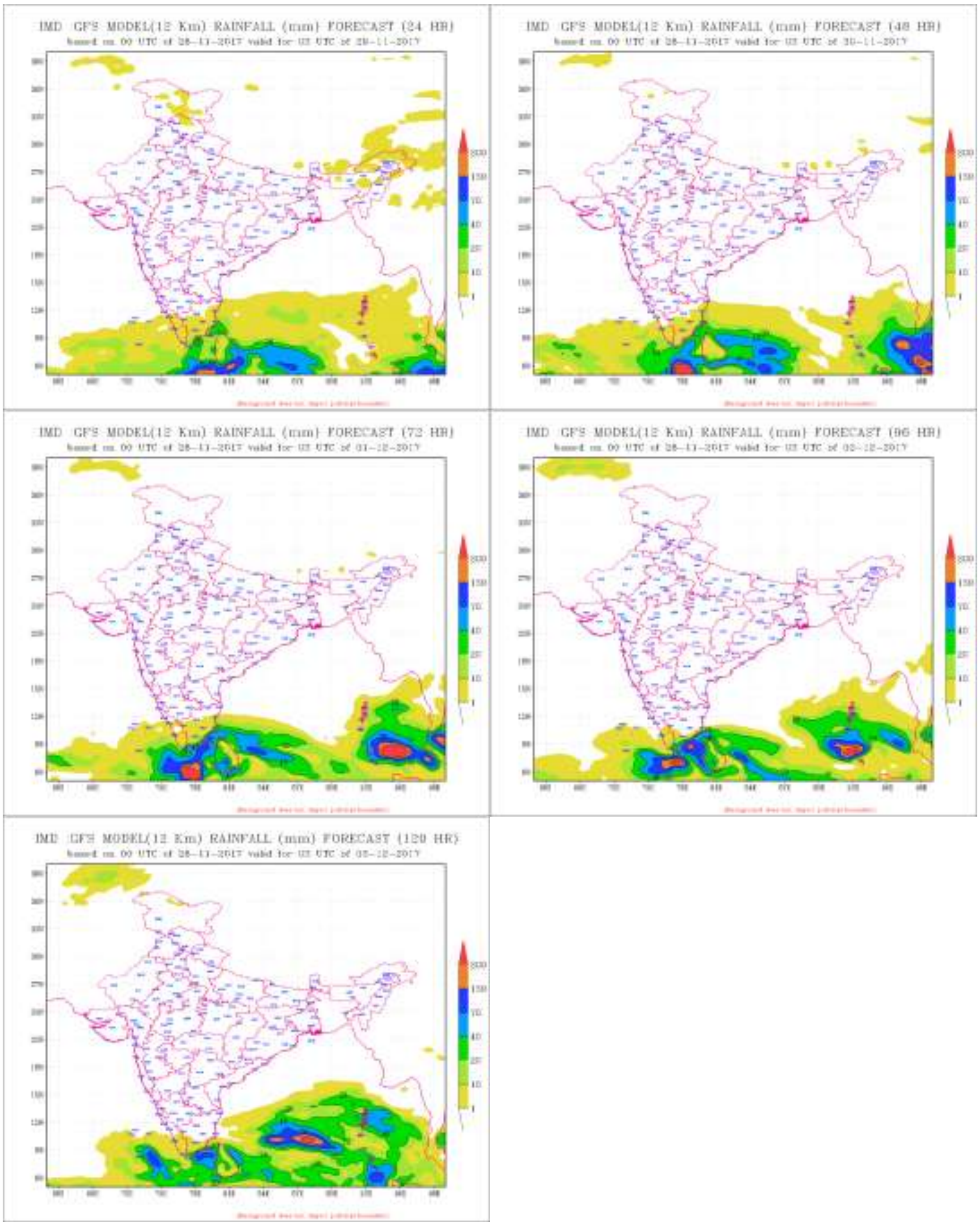


Fig 25 (a) IMD : GFS MODEL Rainfall forecast based on 000UTC of 28th November 2017

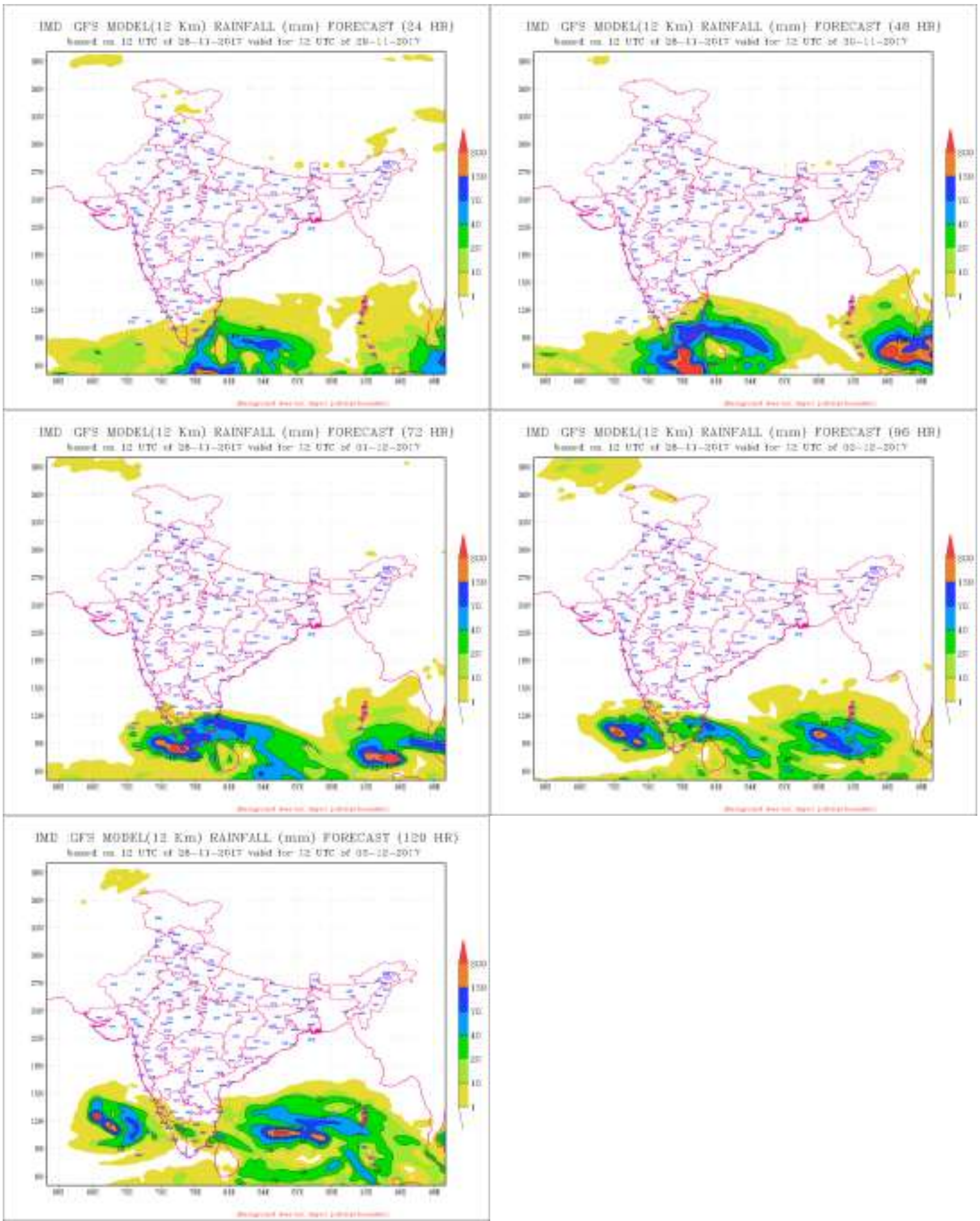


Fig 25 (b) IMD : GFS MODEL Rainfall forecast based on 1200UTC of 28th November 2017

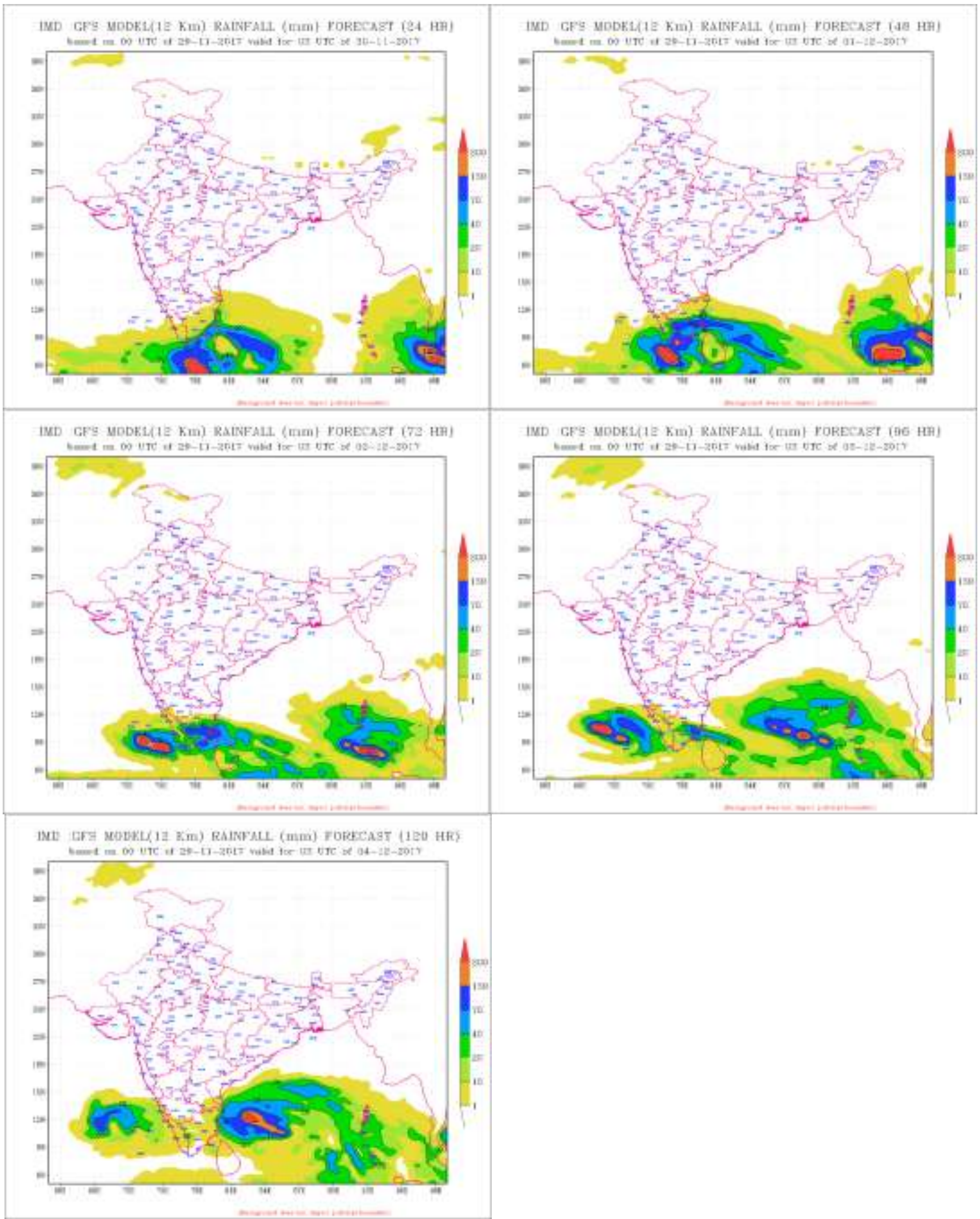


Fig 25 (c) IMD GFS MODEL Rainfall forecast based on 0000UTC of 29th November c17

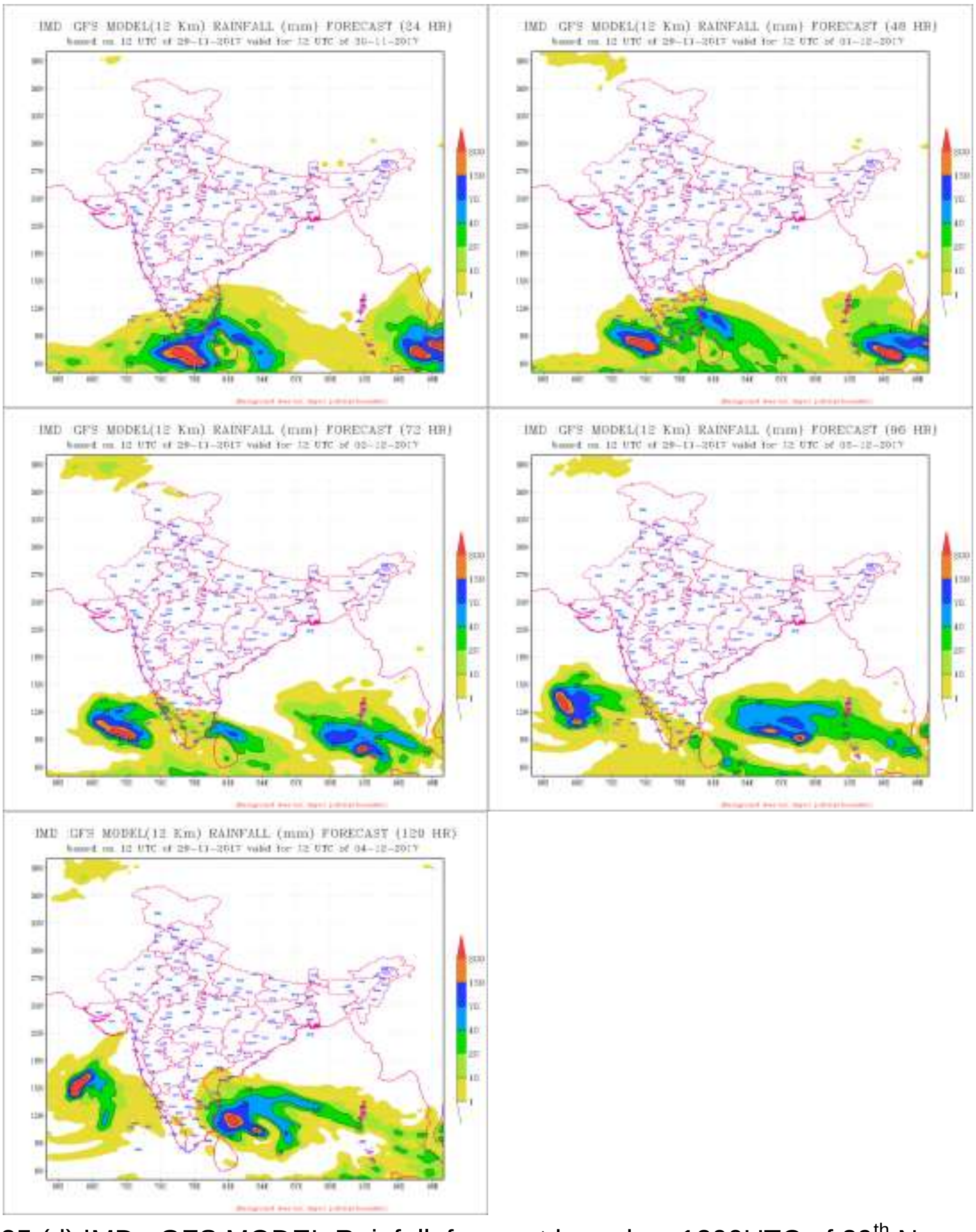


Fig 25 (d) IMD : GFS MODEL Rainfall forecast based on 1200UTC of 29th November 2017

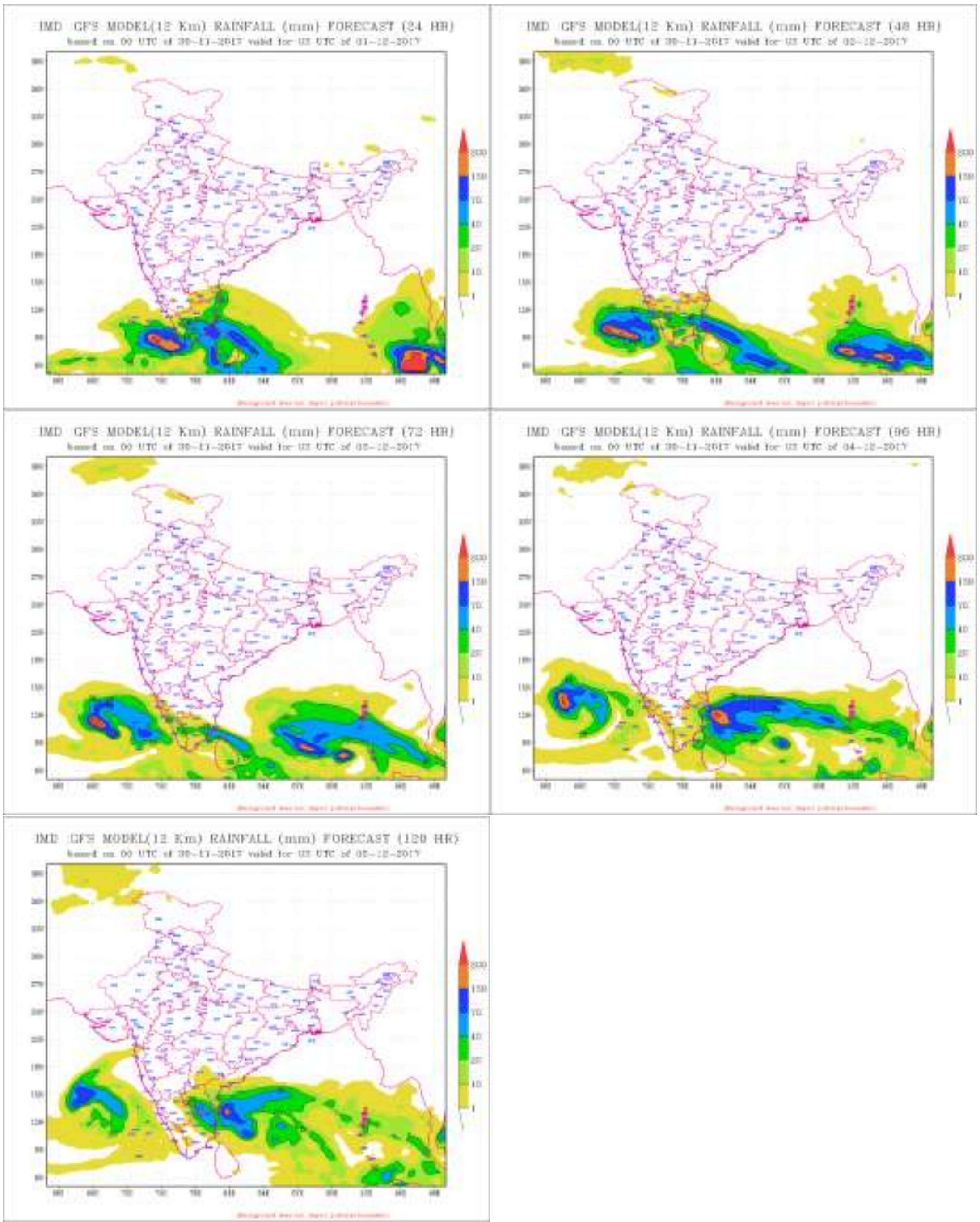


Fig 25 (e) IMD : GFS MODEL Rainfall forecast based on 0000UTC of 30th November 2017

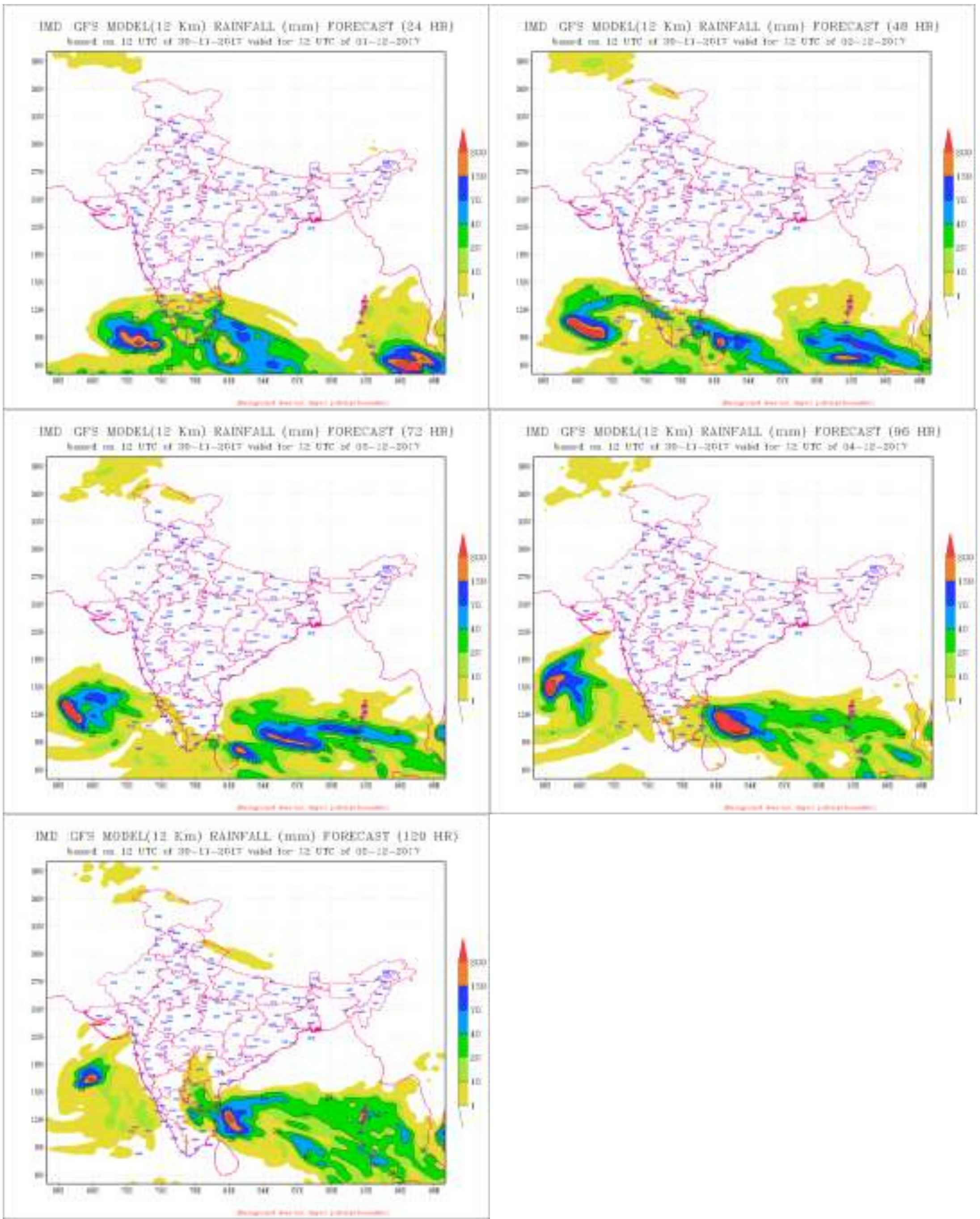


Fig 25 (f) IMD : GFS MODEL Rainfall forecast based on 1200UTC of 30th November 2017

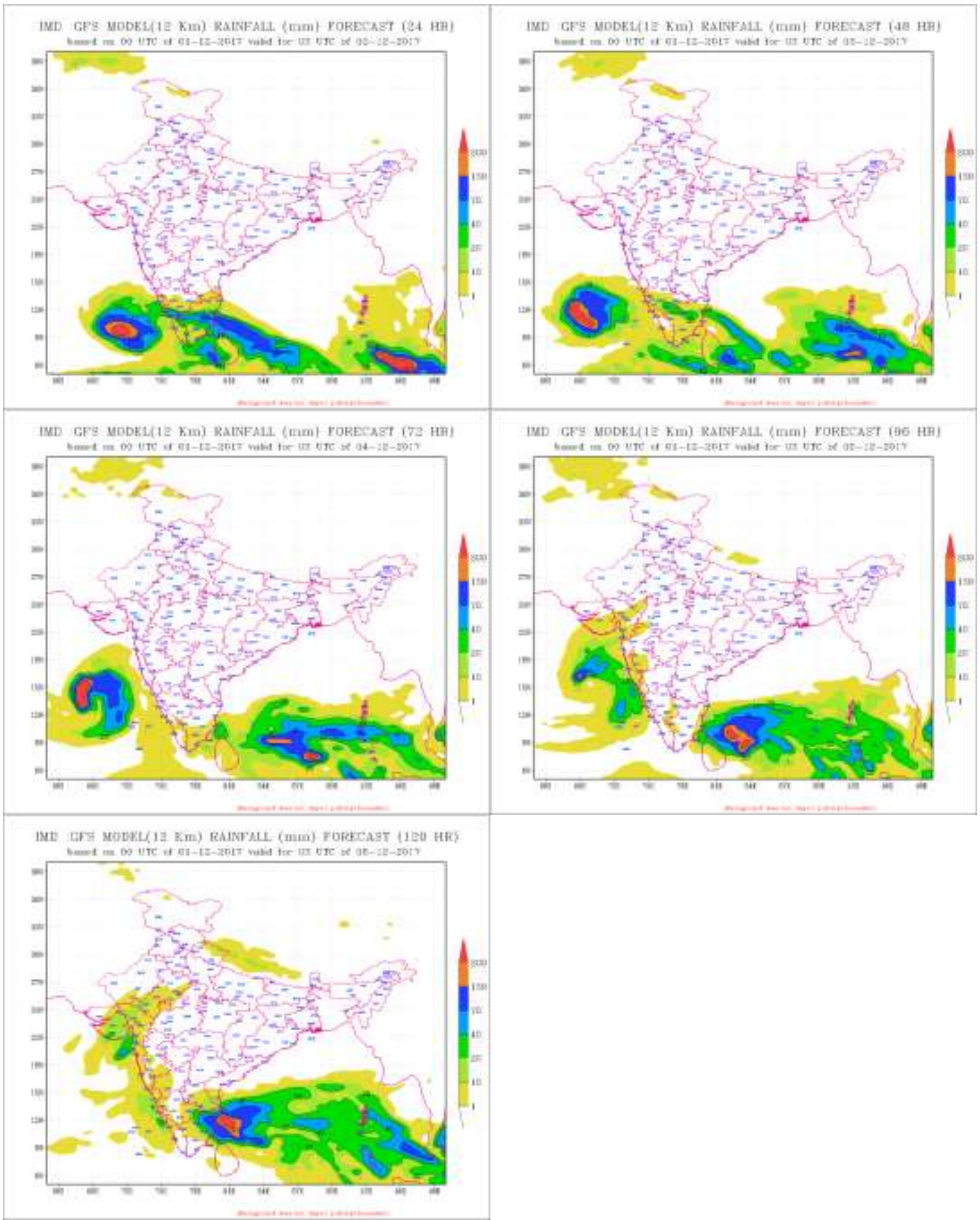


Fig 25 (g): IMD GFS MODEL Rainfall forecast based on 0000UTC of 1st December 2017

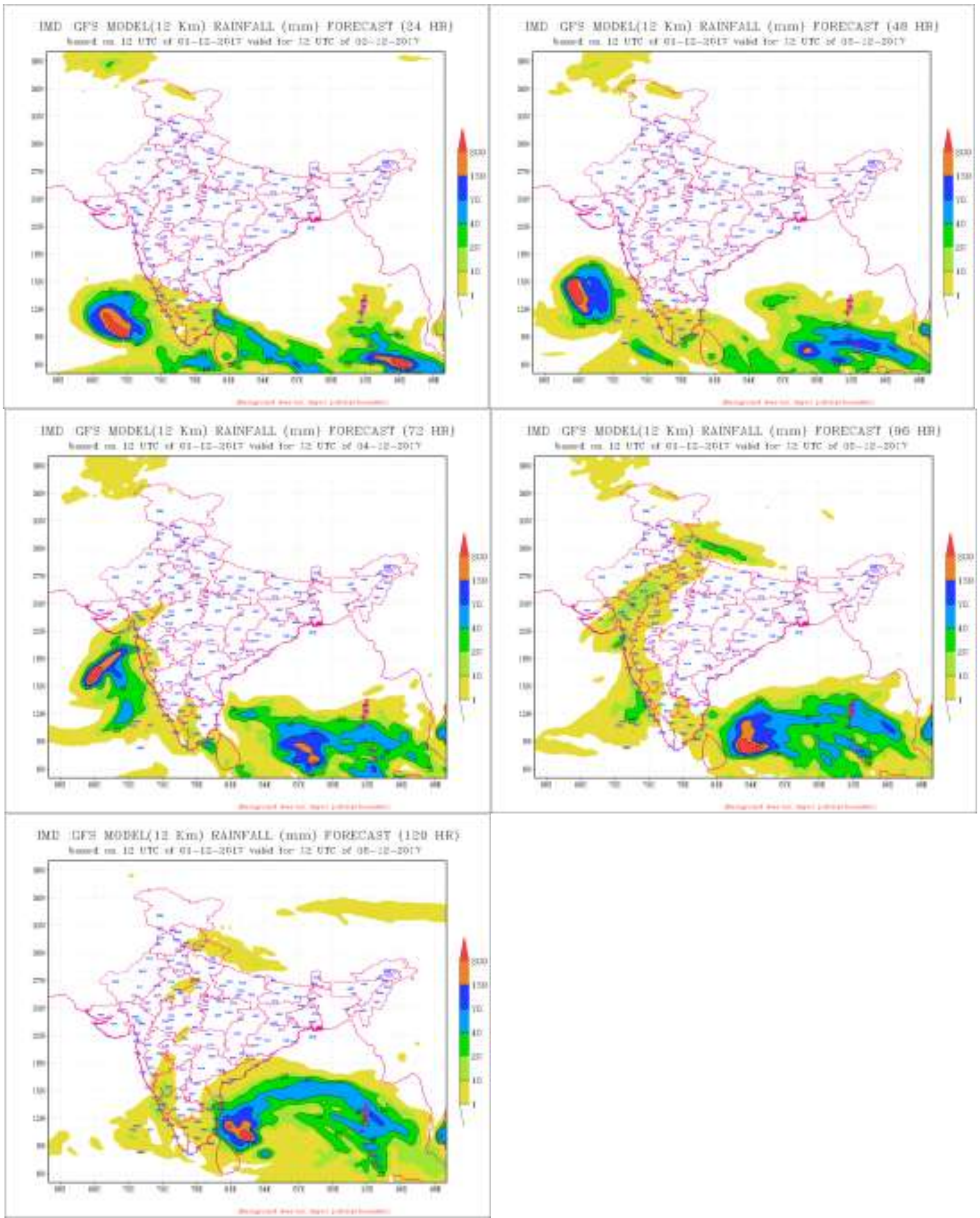


Fig 25 (h): IMD GFS MODEL Rainfall forecast based on 1200UTC of 1st December 2017

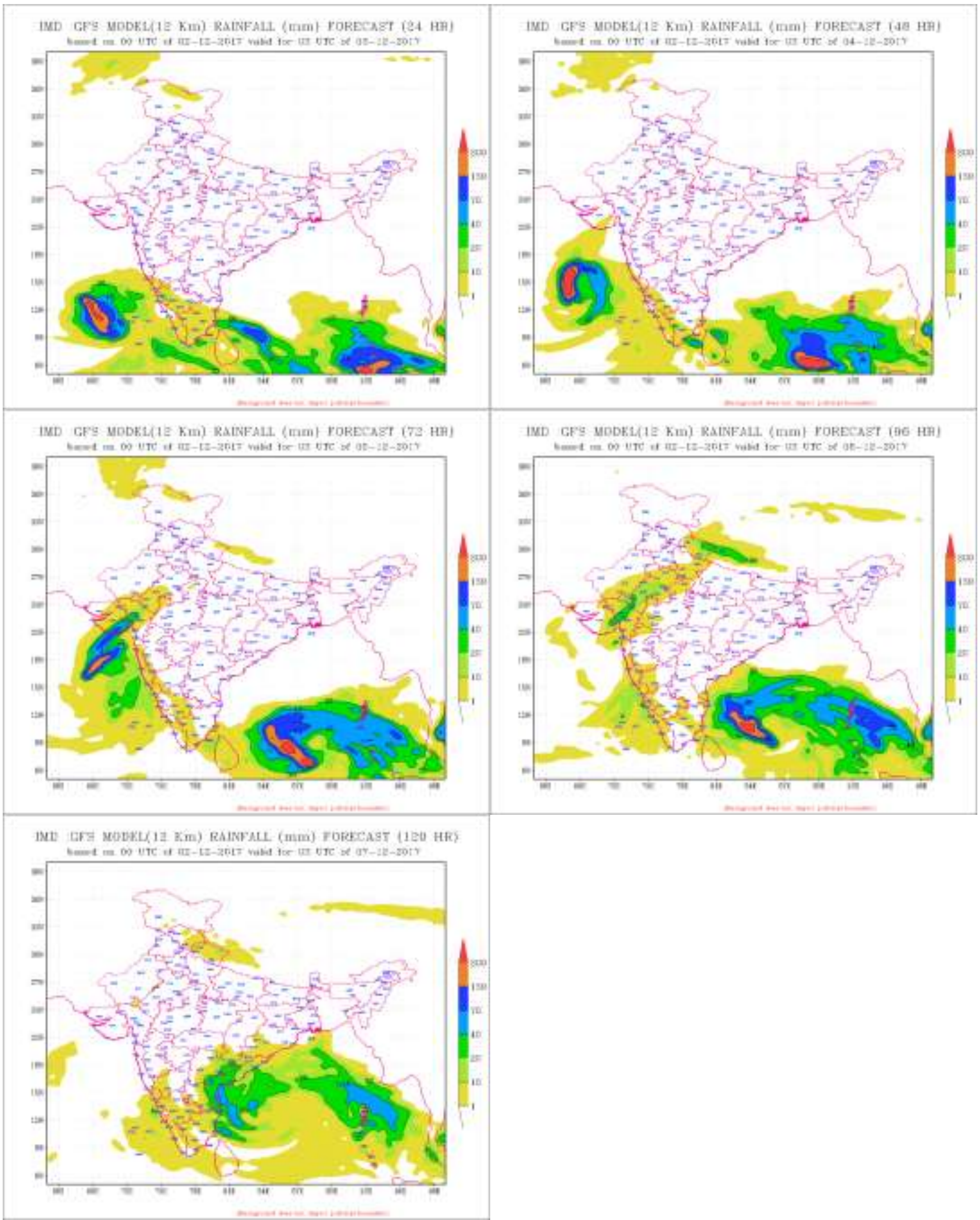


Fig 25 (i) IMD GFS MODEL Rainfall forecast based on 0000UTC of 2nd December 2017

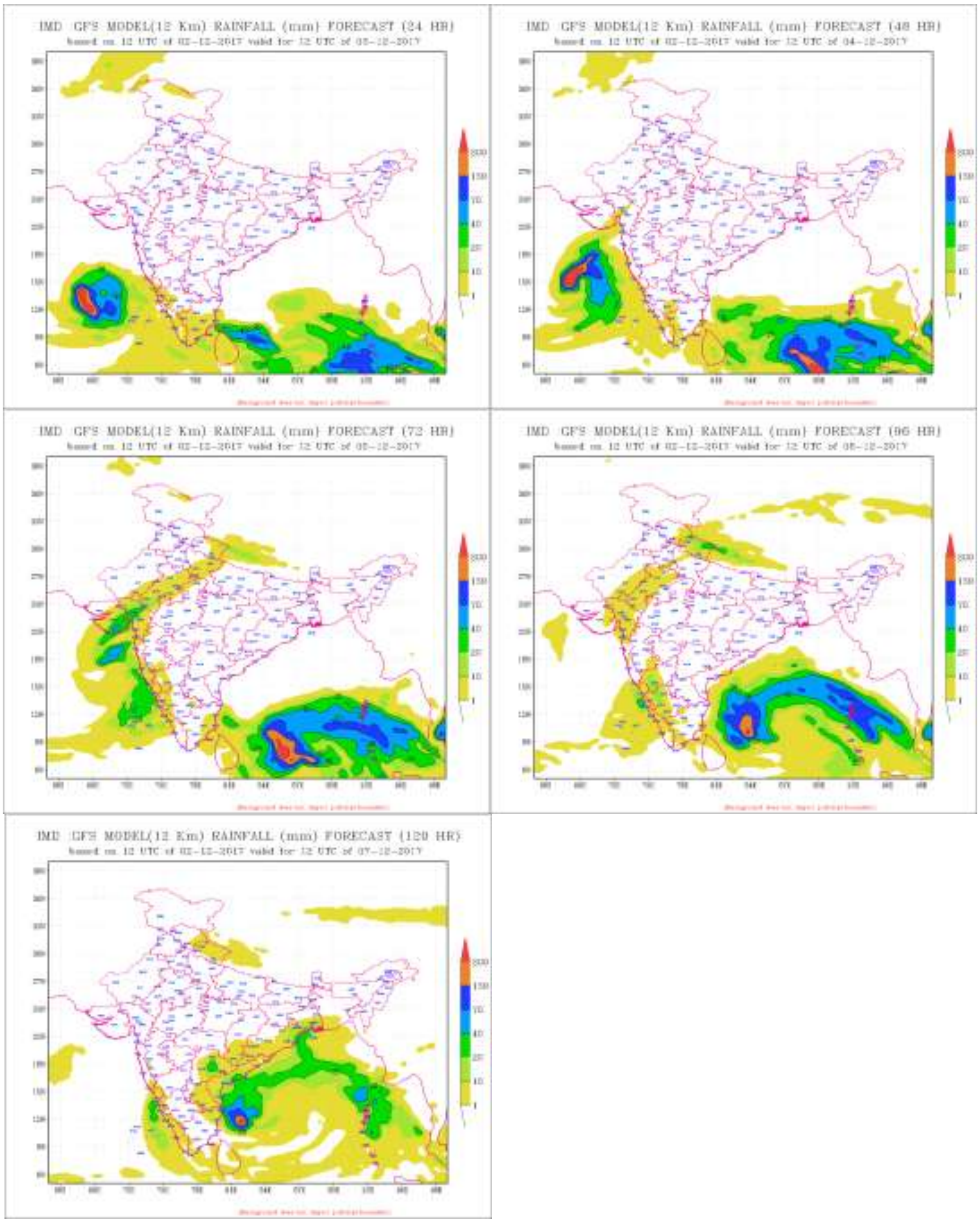


Fig 25 (j): IMD GFS MODEL Rainfall forecast based on 1200UTC of 2nd December 2017

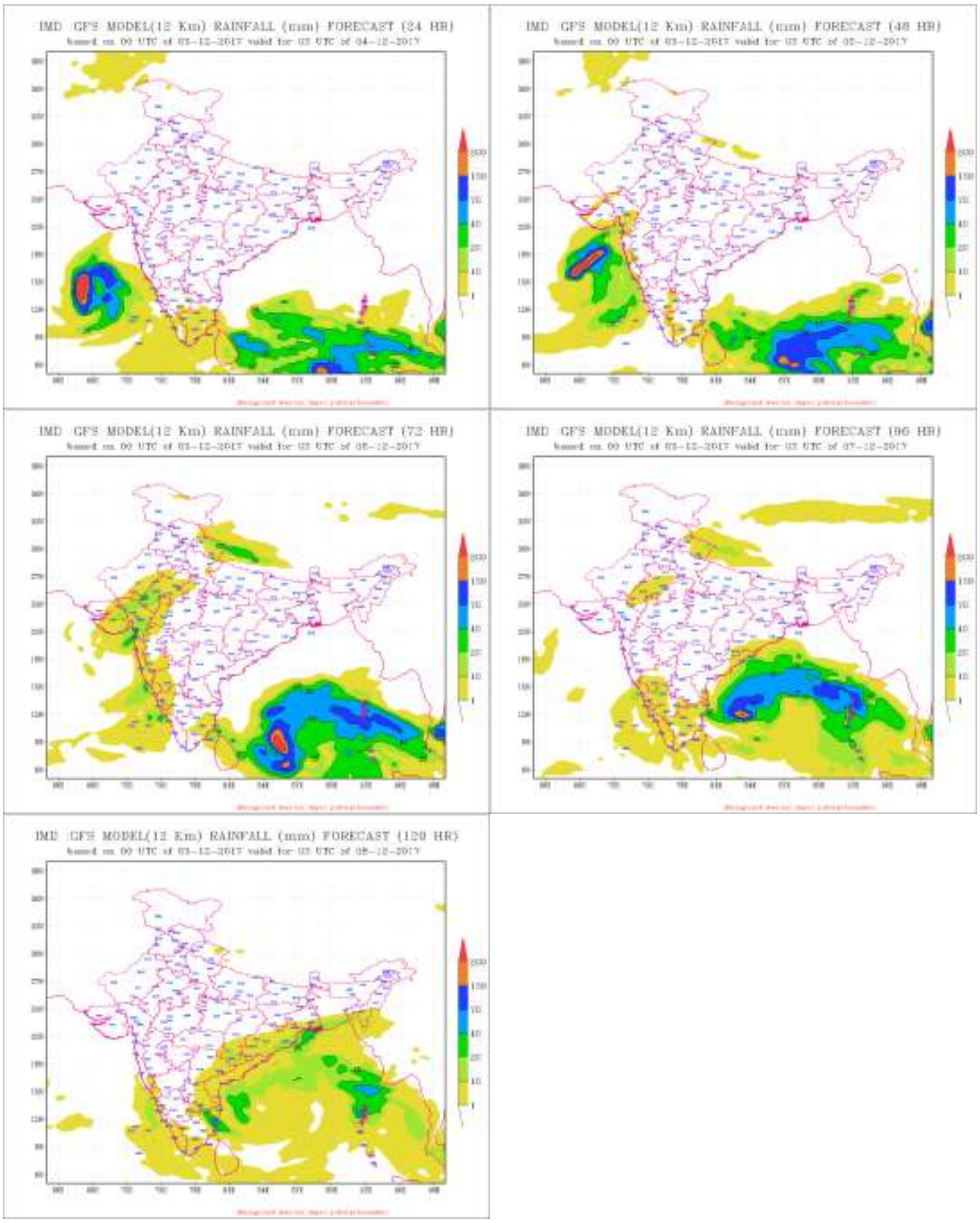


Fig 25 (k) IMD GFS MODEL Rainfall forecast based on 0000UTC of 3rd December 2017

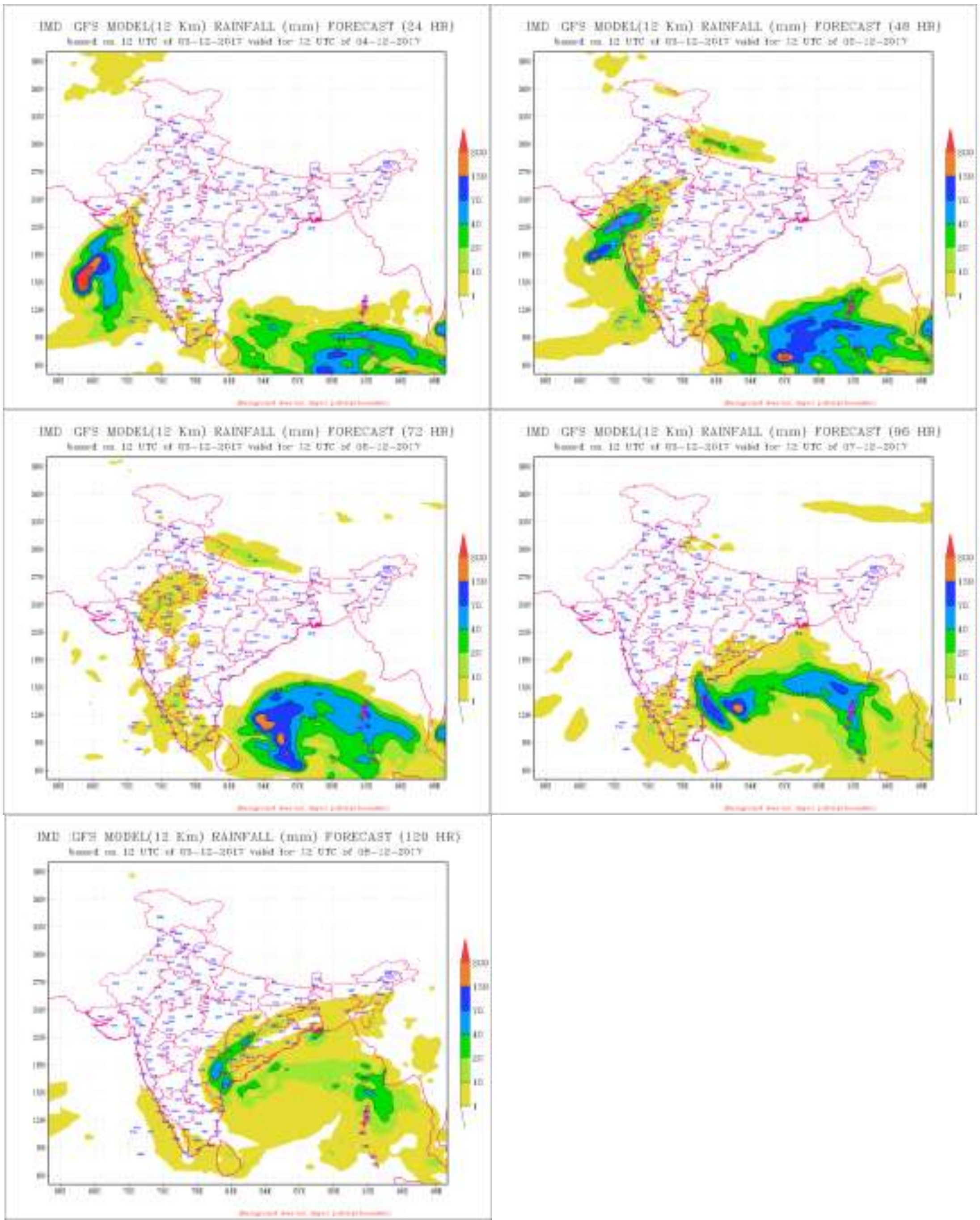


Fig 25 (l): IMD GFS MODEL Rainfall forecast based on 1200UTC of 3rd December 2017

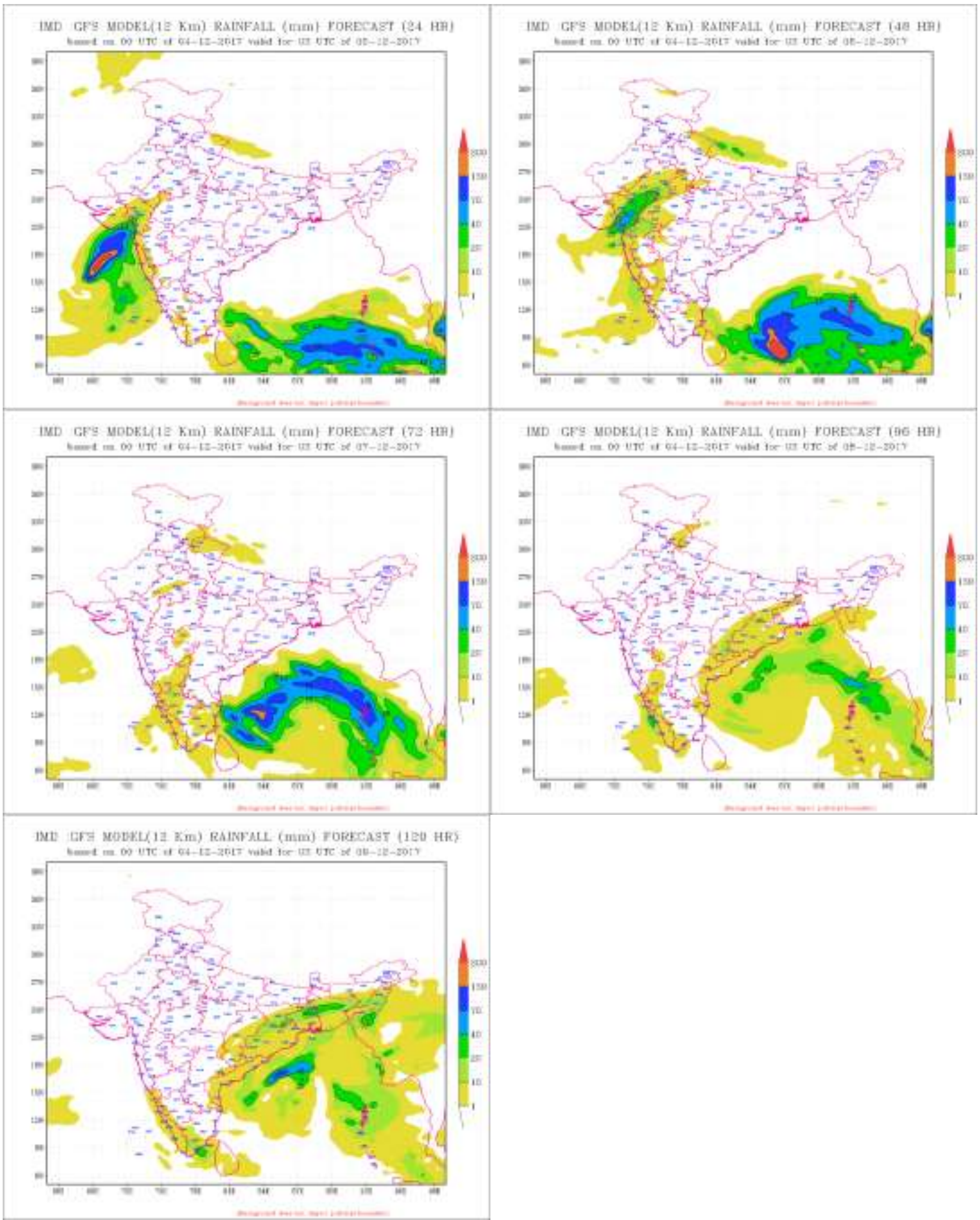


Fig 25(m): IMD GFS MODEL Rainfall forecast based on 0000UTC of 4th December 2017

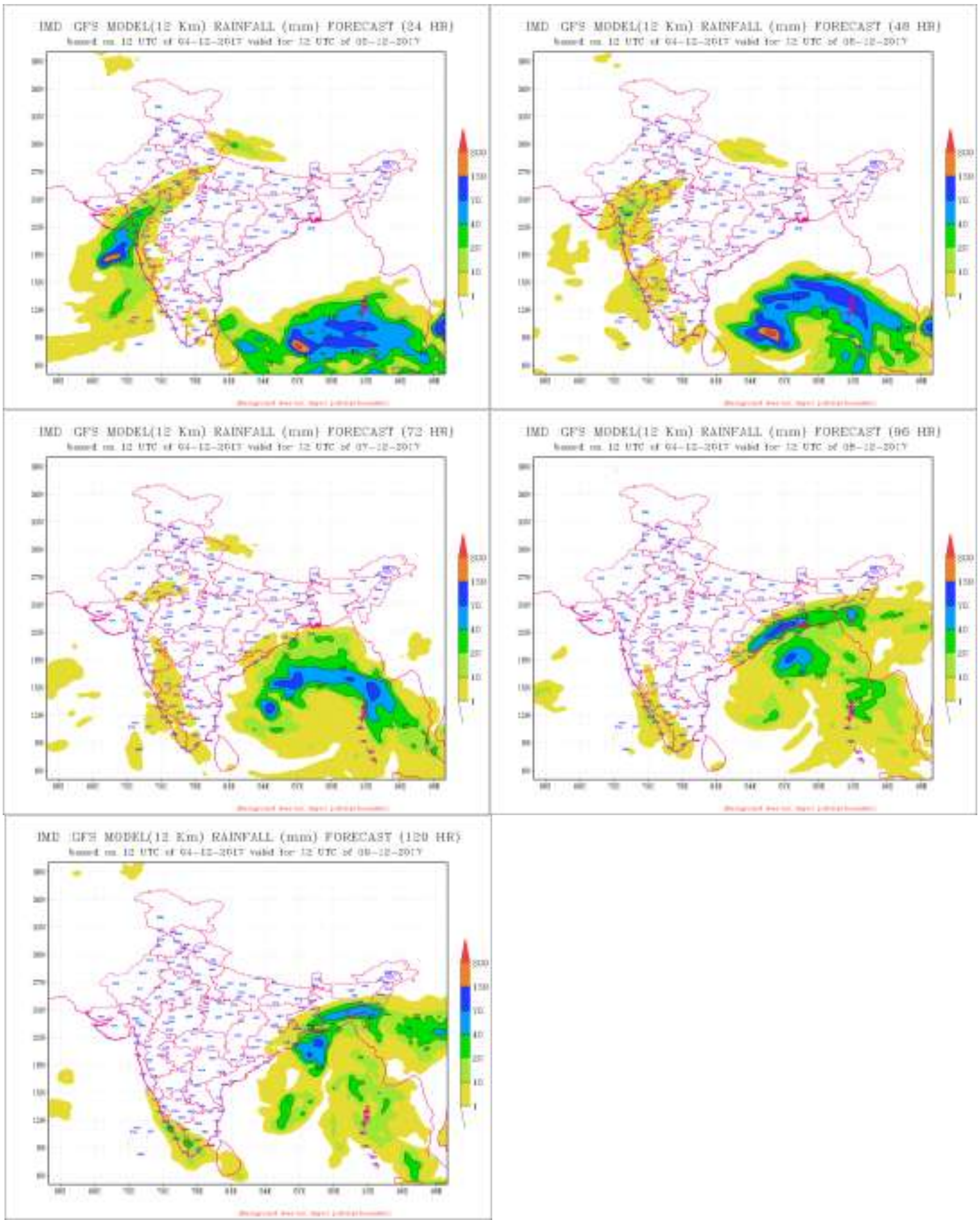


Fig 25 (n) IMD GFS MODEL Rainfall forecast based on 1200UTC of 4th December 2017

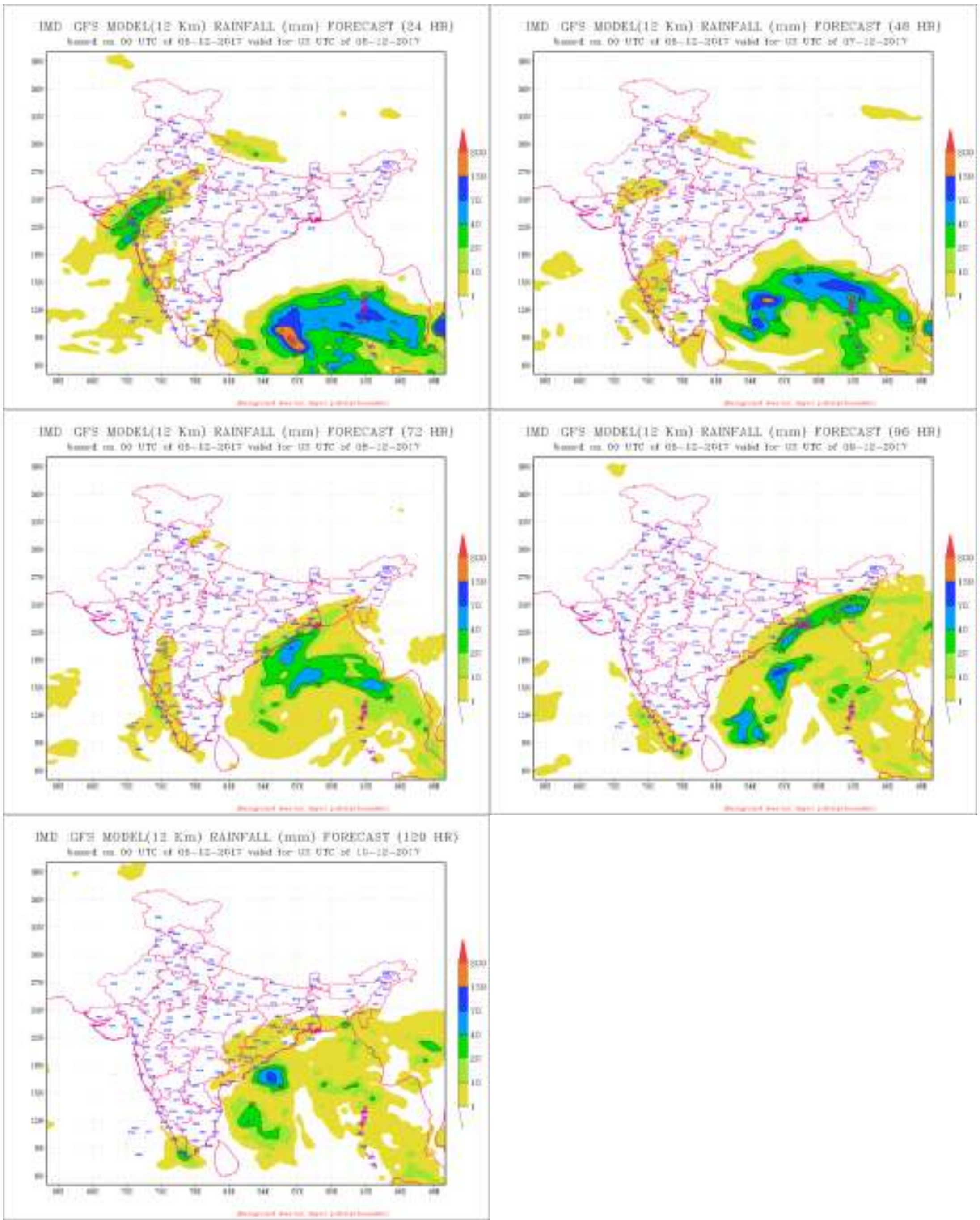


Fig 25 (o): IMD GFS MODEL Rainfall forecast based on 0000UTC of 5th December 2017

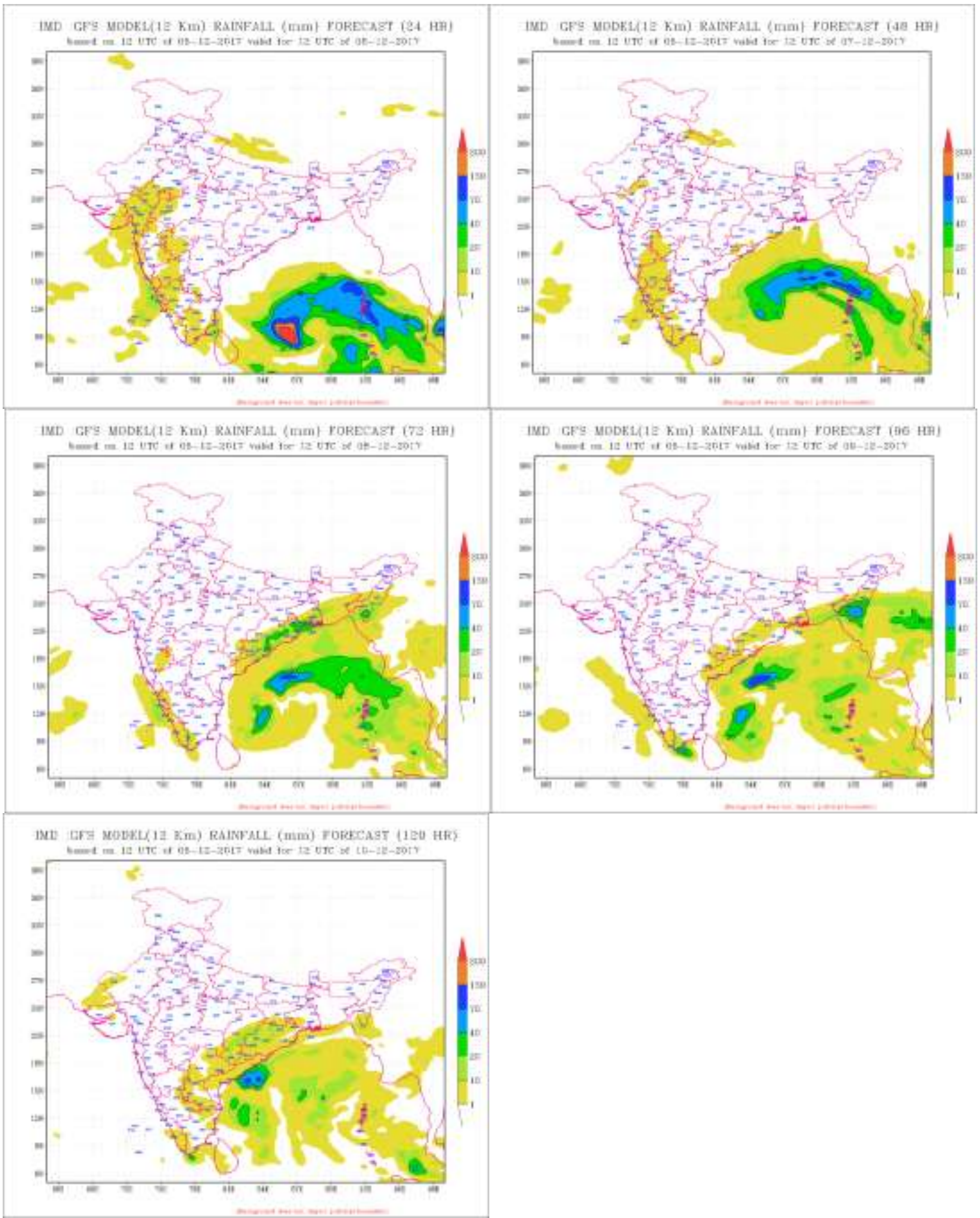


Fig 25 (p): IMD GFS MODEL Rainfall forecast based on 1200UTC of 5th December 2017

9.4.3. Heavy rainfall forecast by IMD WRF model

Rainfall forecast by IMD WRF based on 0000 & 1200 UTC during 28th -30th November is presented in Fig. 26.

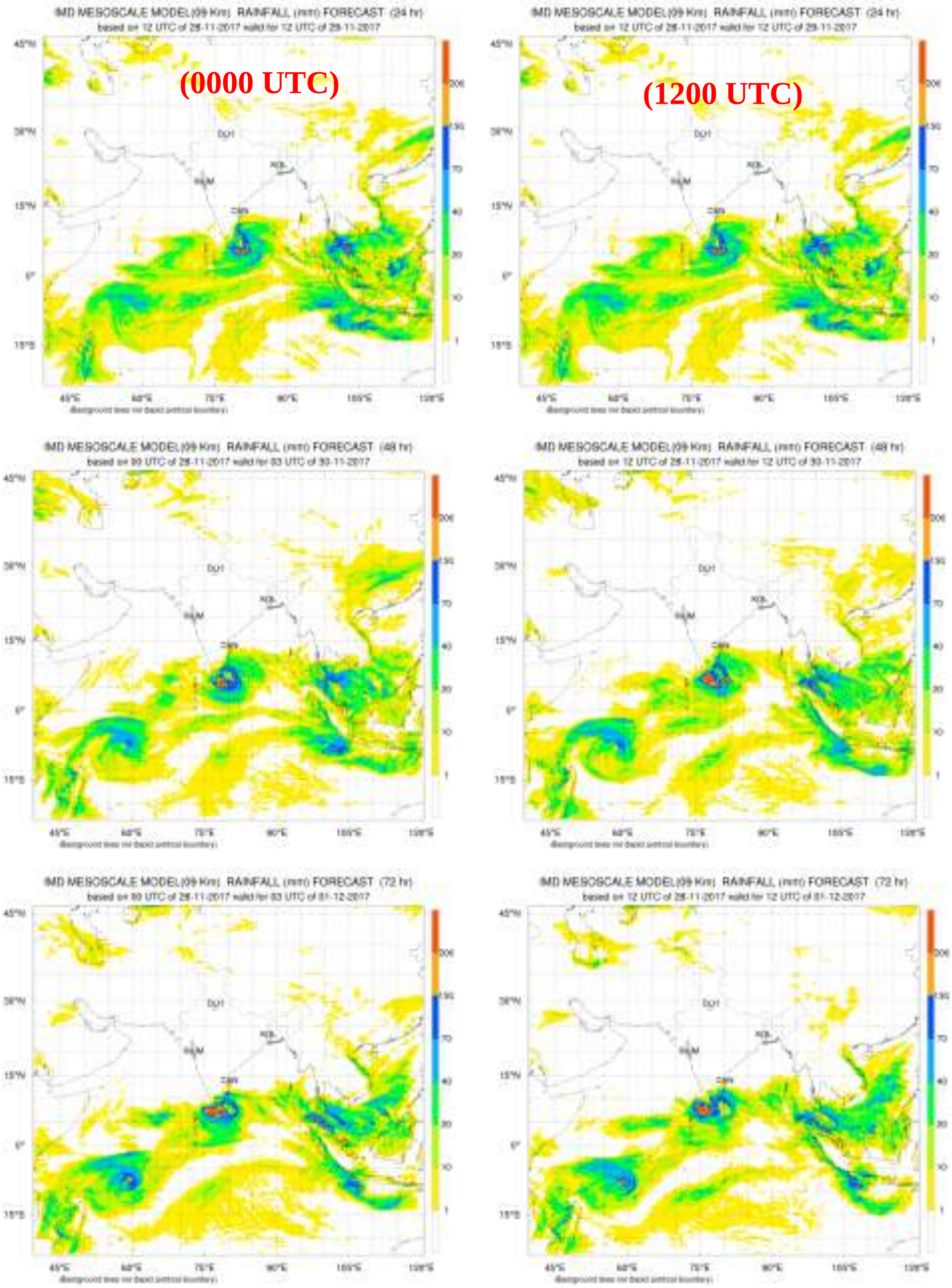


Fig 26 (a) IMD WRF MODEL Rainfall forecast based on 0000UTC and 1200UTC of 28th November 2017

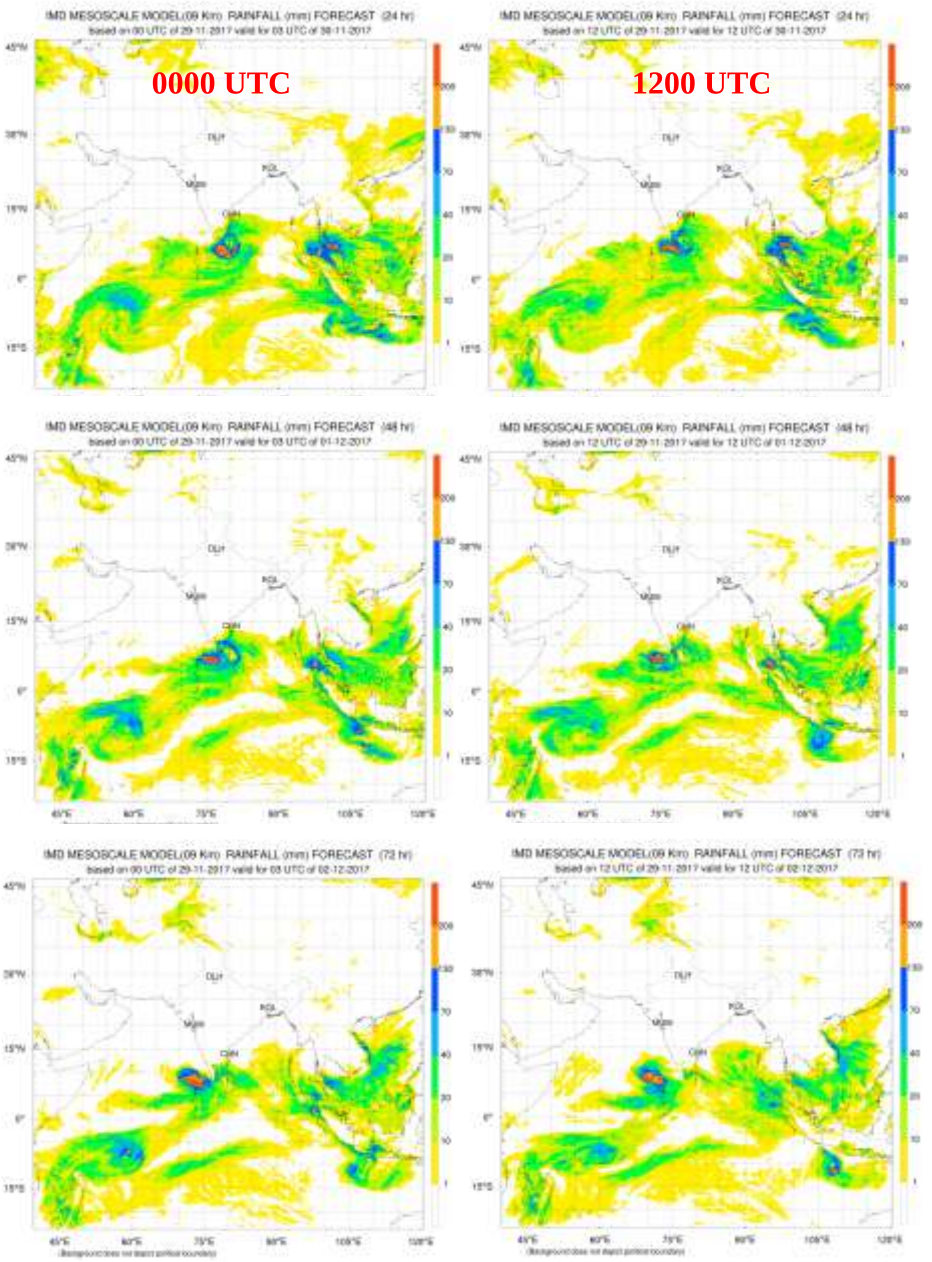


Fig 26 (b) IMD WRF MODEL Rainfall forecast based on 0000UTC and 1200UTC of 29h November 2017

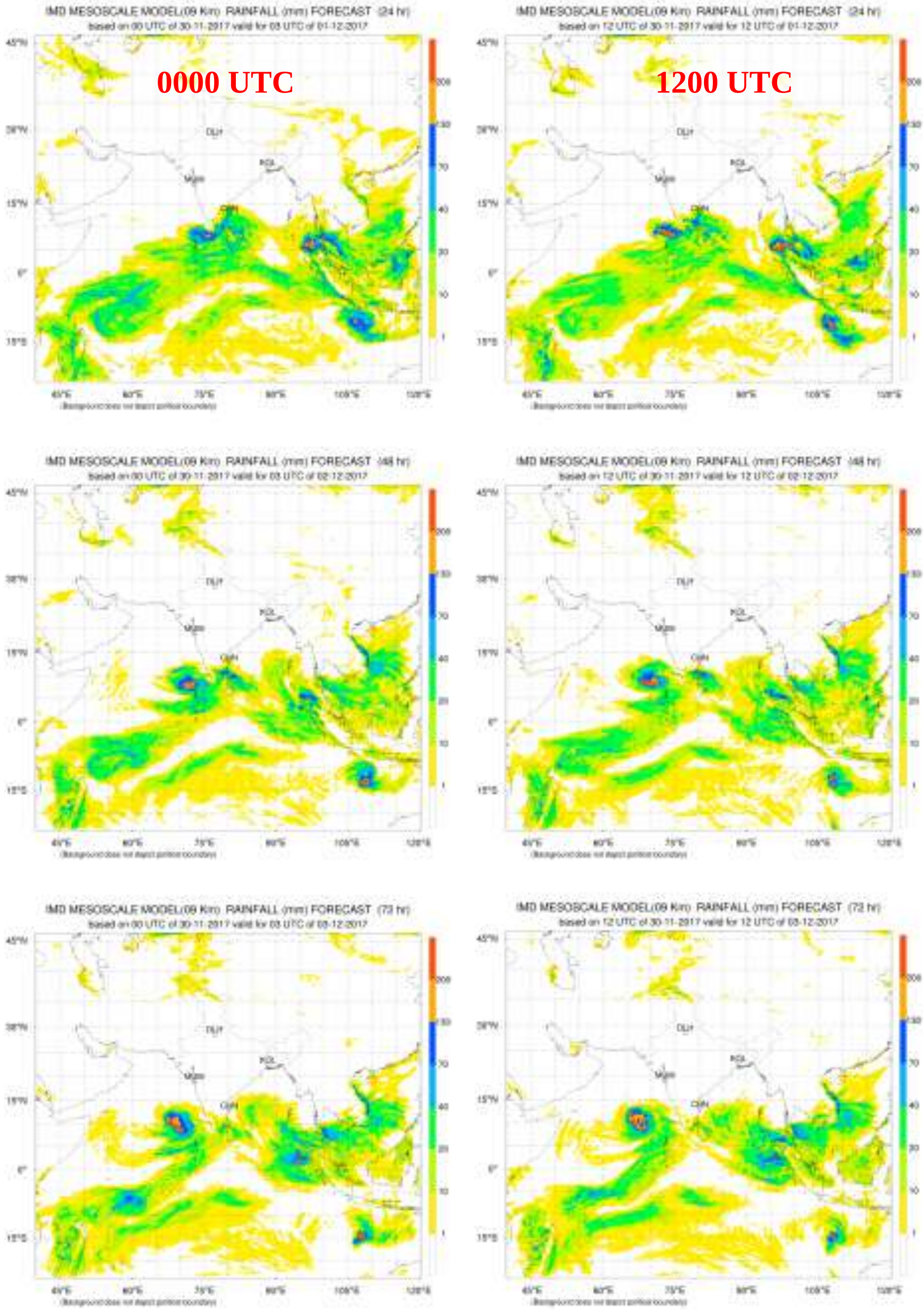


Fig. 26 (c): IMD WRF MODEL Rainfall forecast based on 0000UTC and 1200UTC of 30th November 2017

9.5 Storm surge forecast

IMD predicted storm surge forecast based on guidance from Indian National Centre for Ocean Information Services (INCOIS) Advance Circulation (ADCIRC) model and Indian Institute of Delhi. First warning of storm surge of height about 1.0 m above astronomical tides likely to inundate low lying areas of Lakshadweep Islands was issued on 1700 hrs IST of 30th.

10. Operational Forecast Performance

10.1 Operational Genesis forecast

- The first information regarding formation of depression during next 48-72 hours (i.e. 29th onwards) was issued on 28th November in the Tropical Weather Outlook issued at 1200 hours IST. The system developed into a depression in the forenoon of 29th.
- In the first bulletin based on 1150 IST of 29th Nov, IMD, New Delhi indicated the west-northwestward movement of system and its emergence into Comorin area by 30th. It was also mentioned that the system would intensify further. The system emerged into Comorin Area during night of 29th and intensified into Deep Depression in the early hrs (0230 IST) of 30th and into Cyclonic Storm in the forenoon (0830 IST) of 30th Nov. 2017.

10.2 Cyclone Warning

- As the deep depression after crossing over southern Sri Lanka unusually intensified into a cyclone Ockhi in 12 to 24 hrs from 29th November morning over Comorin Sea, the cyclone specific advisory was only issued from 30th Nov at 1155 hrs IST as per the protocol for south Tamil Nadu, South Kerala and Lakshadweep
- However, cyclone watch/alert could not be issued due to unusual rapid intensification over the Comorin Sea.
- It is quite different from cases of cyclone intensification that happens over central part of Bay of Bengal and Arabian Sea. In those cases, usual provision of issuing cyclone alert/watch normally exists as per SOP.
- In this case, cyclone warning was to be issued directly on 30th morning only to enhance already initiated actions taken by respective state Govt. based on the regular bulletins issued by IMD since 29th November forenoon.

10.3 Track Forecast

- The west northwestward movement towards Lakshadweep was predicted in the first bulletin itself issued at 0830 hrs IST of 29th Nov.
- The observed and first forecast track with cone of uncertainty issued for (a) Kerala, Tamil Nadu, Lakshadweep based on 0000 UTC of 30th Nov 2017 and (b) Gujarat coast are shown in **Fig.27 and 28 respectively.**
- The track forecast error for 12, 24, 48 and 72 hrs lead period were 52.4, 77.2, 111.9 and 189.6 km respectively, which is significantly less than the average track forecast errors of 59.7, 97.2, 149.1 and 202.8 km during last five years (2012-16). The track forecast skill was about 45%, 61%, 76% and 69% for 12, 24, 48 and 72 hrs lead period respectively, which are higher than the long period average (LPA) during 2012-16 for 12 and 24 hrs lead period (**Fig. 29**).

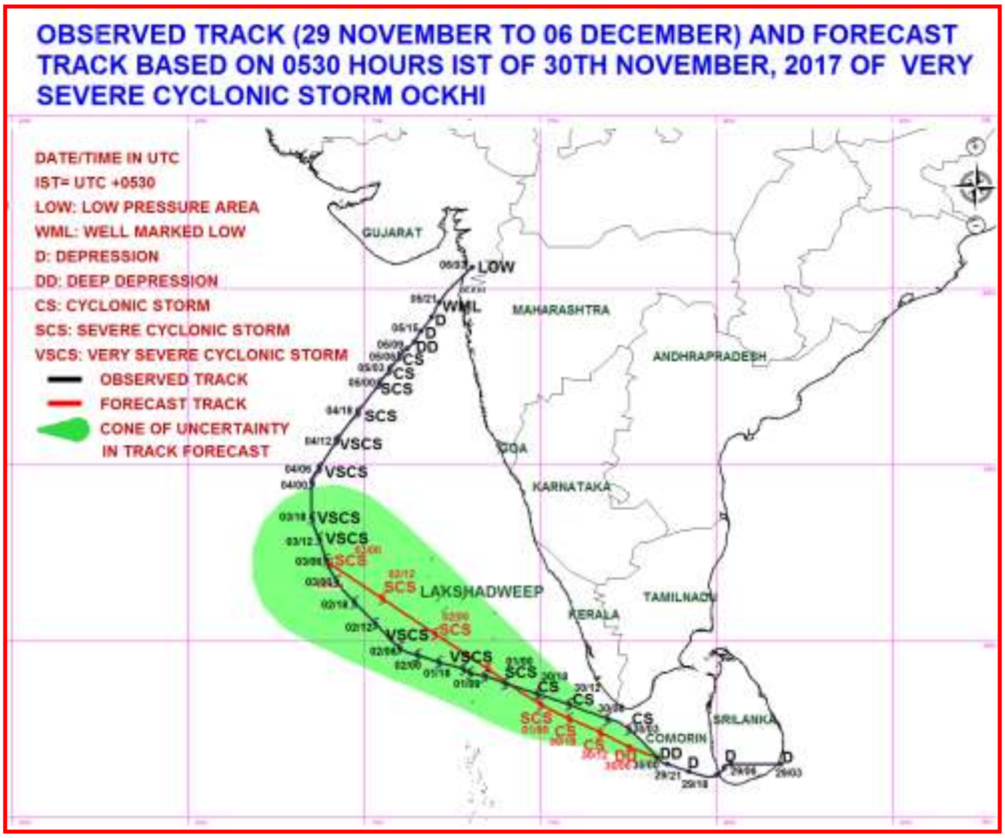


Fig.27: Observed and forecast track with cone of uncertainty issued for Kerala, Tamil Nadu, Lakshadweep

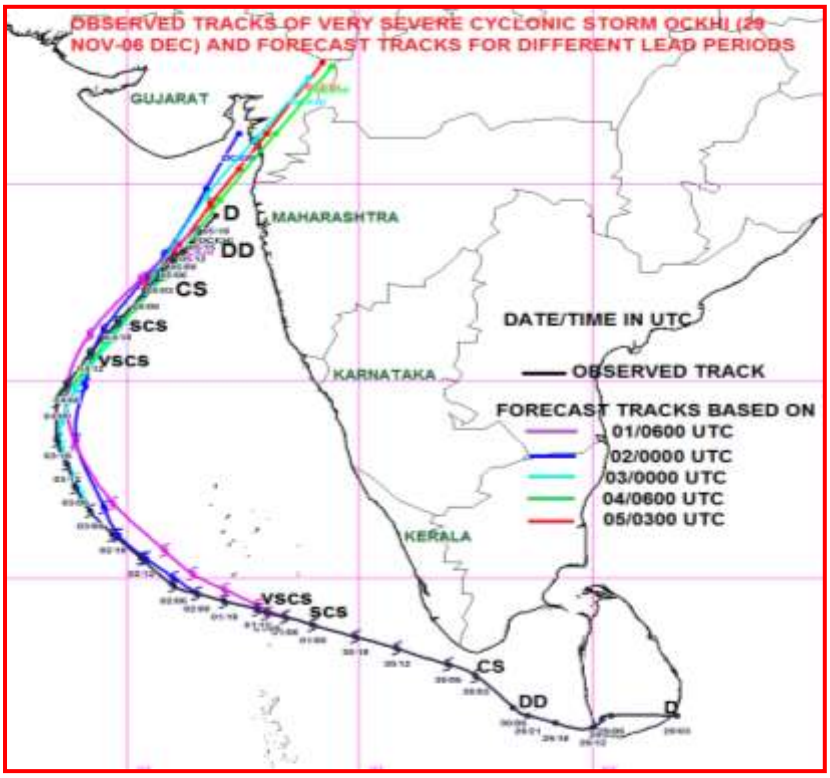


Fig.28: Typical graphical products displaying observed and forecast track for movement towards Gujarat coast

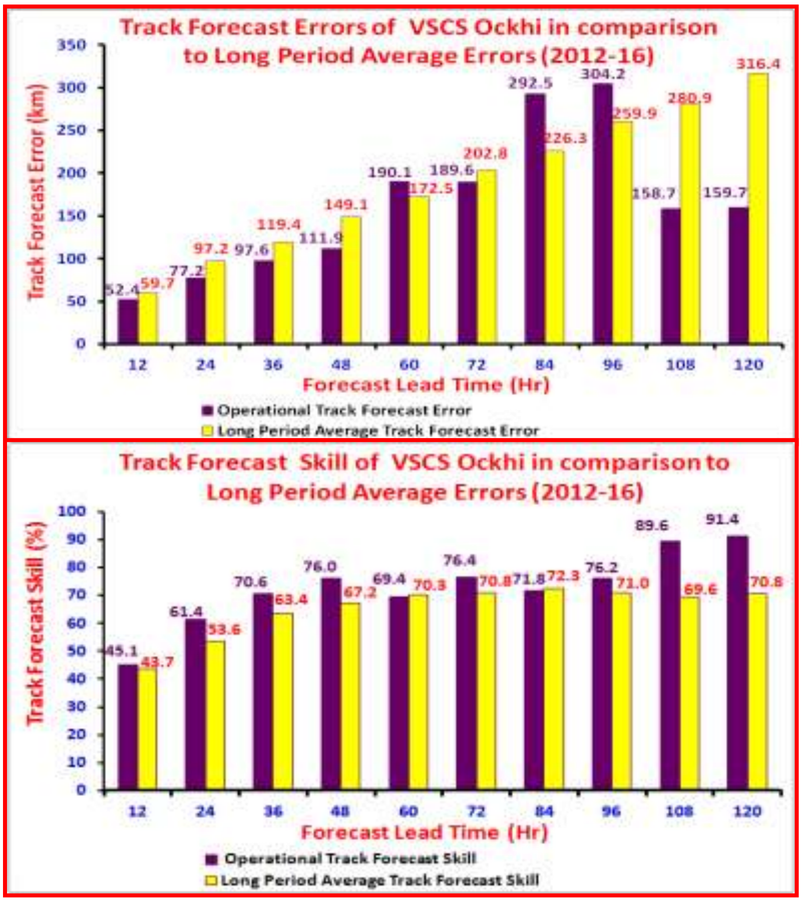


Fig.29: Track Forecast Errors and Skill of VSCS Ockhi

10.4 Intensity Forecast

- First wind warning for 45-55 kmph gusting to 65 kmph for south Kerala, south Karnataka and Lakshadweep was first issued at 1150 hrs IST of 29th November.
- It was increased gradually with expected intensification of the system
- Thiruvananthapuram recorded 62 kmph in gustiness at 1300 IST of 30th Nov. The threshold wind speed of 45 kmph was recorded over Thiruvananthapuram from 1230 IST of 30th Nov. Onwards**.**
- Maximum wind 120-130 kmph gusting to 145 kmph prevailed over northern parts of Lakshadweep
- First wind warning for 40-50 kmph gusting to 60 kmph for south Gujarat and north Maharashtra coast on 5th Dec. was first issued at 1700 hrs IST and 1930 hrs IST of 2nd Dec. The actual wind along these coasts has been 30-40 kmph.
- The absolute intensity (wind) forecast error for 12, 24, 48 and 72 hrs lead period were 5.4, 7.0, 13.5 and 16.4 knots against the LPA of 6.5, 10.7, 15.5 and 16.3 knots respectively. The skill in absolute intensity (wind) forecast for 12, 24, 48 and 72 hrs lead period was 26.6, 48.4, 61.0 and 75.7% against the LPA of 18.2, 35.2, 55.7 and 66.8% respectively. (**Fig. 30**).

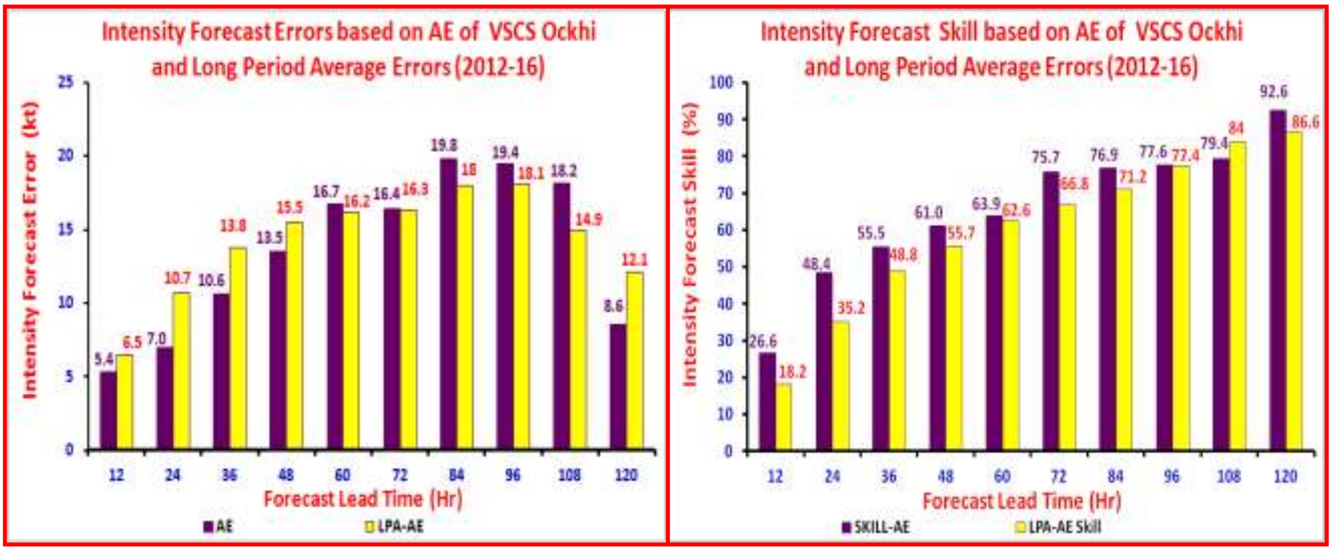


Fig. 30: Absolute Error (AE) of intensity forecast and skill of IMD for VSCS Ockhi

10.5. Adverse weather warning verification

The verifications of adverse weather warning heavy rainfall, gale wind and storm surge warning issued by IMD at 0300 UTC during 30th November to 6th December are presented in Table 10-12. It is found that all the three types of adverse weather were predicted accurately and well in advance.

- Heavy rainfall warning for south Kerala, south Tamil Nadu and Lakshadweep was first issued at around noon of 28th November for occurrence during next 72 hours.
- Heavy rainfall warning for south coastal Gujarat was first issued at 1700 hrs IST of 2nd December for occurrence on 5th December.
- Heavy rainfall warning for north coastal Maharashtra was first issued at 1330 hrs IST of 2nd December for occurrence from 4th night during subsequent 48 hours.
- It caused isolated heavy rainfall over south Tamil Nadu on 28th and 29th and scattered heavy to very heavy rainfall and isolated extremely heavy rainfall over south Tamil Nadu on 30th Nov. and 1st & 2nd Dec. It caused isolated heavy rainfall over south Kerala on 29th Nov. and 1st Dec. and heavy to very heavy rainfall on 30th Nov. It caused heavy to very heavy rainfall over Lakshadweep on 01st and 2nd Dec. There was heavy rainfall over north coastal Maharashtra and adjoining south coastal Gujarat on 5th Dec.

Table – 10 Verification of Heavy Rainfall Warning

<table>
<tr><th>Date/Time of issue (base time) (hours IST)</th><th>Heavy rainfall warning for the date</th><th>Realised 24-hour heavy rainfall ending at 0300 UTC of date</th></tr>
<tr><td>29.11.2017
1150 (0830)</td><td>• Heavy to very heavy rainfall at isolated places over south Tamil Nadu during next 48 hours.
• Heavy rainfall at isolated places during next 24 hours and isolated heavy to very heavy rainfall during subsequent 24 hours over south Kerala.
• Heavy to very heavy rainfall at isolated places over Lakshadweep islands on 1st and 2nd December.</td><td rowspan="4"><u>27 November 2017</u>

Tamil Nadu & Puducherry: Rameswaram-14, Chembarabakkam-12, Chembarambakkam ARG-11, Chennai & Sirkali-10 each, Kancheepuram-9, Vedaranyam-8, Poonamalle ARG, Kolapakkam ARG, Chidambaram, Poonamallee, Anaikaranchatram, Kollid and Anna University-7 each.
South Interior Karnataka:-Imangala ARG-100
Kerala:-Kollam RLY-7

<u>28 November 2017</u>
Kerala:-Piravam-7

<u>29 November 2017</u>
Tamilnadu & Puducherry:-Nannilam-7

<u>30 November 2017</u>
Tamil Nadu & Puducherry: Vallam, Thuckalay and Pondicherry-7 each
Kerala: Aryankavu-15

<u>1 December 2017</u>
Tamil Nadu & Puducherry: Papanasam (District: Tirunelveli)-45, Manimutharu-38, Mylaudy-19, Thenkasi-17, Thuckalay, Pechiparai, Gudalur & Bhoothapandy-16 each, Watrap-15, Maniyachi, Eraniel & Colachel-14 each, Nagercoil, Kodaikanal & Coonoor PTO-13 each, Kuzhithurai, Srivilliputhur, Satankulam, Shencottah, Ayikudi, Coonoor, Samayapuram & Srivaikuntam-12 each, Ottapadiram, Tiruchendur & Kovilpatti AWS-11 each, Tuticorin, Ambasamudram, Uttamapalayam & Kanyakumari-10</td></tr>
<tr><td>30.11.2017
1200 (0830)</td><td>• Heavy to very heavy rainfall at isolated places over south Tamil Nadu & south Kerala during next 24 hours and isolated heavy falls over interior Tamil Nadu and Kerala during subsequent 24 hours.
• Heavy to very heavy rainfall at a few places and isolated extremely heavy falls over Lakshadweep area during next 48 hours.</td></tr>
<tr><td>01.12.2017
1130 (0830)</td><td>• Heavy to very heavy rainfall at a few places and isolated extremely heavy falls (>20 cm) over Lakshadweep area during next 24 hours and isolated heavy to very heavy falls during subsequent 24 hours.
• Heavy rainfall at isolated places over Kerala during next 24 hours.</td></tr>
<tr><td>02.12.2017
1130 (0830)</td><td>• Heavy to very heavy rainfall at a few places and isolated extremely heavy falls (>20 cm) over north Lakshadweep Islands during next 24 hours and isolated heavy to very heavy falls during subsequent 24 hours. Isolated heavy to very rainfall over south Lakshadweep Islands during next 24 hours.
• Heavy rainfall at isolated places over Kerala during next 24 hours.</td></tr>
</table>

<table>
<tr>
<td>03.12.2017
1130 (0830)</td>
<td>• Heavy rainfall at isolated places over south Gujarat on 05th December.</td>
<td rowspan="3">each, Radhapuram, Polur, Kovilpatti, Madavaram AWS, Sankarankoil & Sattur-9 each, Arani, Sivaganga, Sivagiri, Uthiramerur, Rajapalayam, Anna University, Grand Anaicut, Uthagamandalam, Chembarabakkam & DGP Office-8 each and Musiri, Vadipatti, K.Paramathi, Karur, Vilathikulam, Anna UTY ARG, Lalgudi, Ambur, Padalur, Panchapatti, Mayanur, Thamaraipakkam, K Bridge, Cholavaram, Nanguneri, Periyakulam, Kalugumalai & Chennai(N)-7 each
Kerala: Aryankavu-26, Myladumpara AGRI-12, Varkala & Punalur-9 each and Trivandrum AERO &, Neyyattinkara-8 each
Lakshadweep: Minicoy-19.

<u>2 December 2017</u>
Tamil Nadu & Puducherry: Sathanur Dam-23, Sirkali-19, Chidambaram & Anaikaranchatram (Kollid)-18 each, Chidambaram AWS-17, Virudachalam & Chengam-15 each, Gingee-14, Mylam AWS & K.M.Koil-14 each, Tirukoilur, Vilupuram, Coonoor PTO & Karaikal-13 each, Cuddalore, Sethiathope & Tiruvannamalai-12 each, Pondicherry-11, Mayanur, Paramathivelur & Polur-10 each, Parangipettai, Kallakurichi, Kodavasal, Nagapattinam, Vanur, Mayiladuthurai, Sankarapuram,& Eraniel, Jayamkondam, Rayakottah, Neyveli AWS, Kuzhithurai, Ariyalur & Tindivanam-9 each, Tiruvaiyaru, Tozhudur, Srimushnam, Valangaiman, Tiruvarur, Ulundurpet, Papanasam (District: Thanjavur) &, Kothagiri-8 each and Harur, Panruti, Needamangalam, Thuckalay, Uthangarai, Nagercoil, Arani</td>
</tr>
<tr>
<td>04.12.2017
1200 (0830)</td>
<td>• Gujarat: Light to moderate rainfall at a few places over Saurashtra and south Gujarat region on 4th December. Light to moderate rainfall at most places with heavy rainfall at isolated places over Saurashtra and south Gujarat region on 05th December and light to moderate rainfall over Gujarat region at many places on 6th December (upto around noon).
• Maharashtra: Light to moderate rainfall at a few places over north Konkan including Mumbai on 4th December. Light to moderate rainfall at most places with isolated heavy rainfall is also over north Konkan on 5th December.</td>
</tr>
<tr>
<td>05.12.2017
1150 (0830)</td>
<td>• Gujarat: Light to moderate rainfall at most places with heavy rainfall at isolated places over Saurashtra and south Gujarat region till the morning of 6th December, 2017 (Valsad, Surat, Navsari, Bharuch, Dang, Tapi, Amreli, Gir- Somnath, Bhavnagar, Diu, Daman, Dadra, and Nagar Haveli districts) and light to moderate rainfall over Gujarat region at many places during subsequent 12 hours.
• Maharashtra: Light to moderate rainfall at most places with isolated heavy rainfall is also over north Konkan till the morning of 6th December, 2017 (Palghar, Thane, Raigarh, Greater Mumbai, Dhule, Nandurbar, Nashik, Jalgaon, Ahmednagar and Pune districts).</td>
</tr>
</table>

06.12.2017 1150 (0830)	• Heavy rainfall over Nicobar Islands and rainfall at many places over Andaman Islands during next 2 days • Rainfall at many places over north Andhra Pradesh and south Odisha during 7th to 9th December, 2017 with isolated heavy falls on 8th and 9th.	& Attur-7 each. **Kerala:** Trivandrum AERO-8 and Perinthalamanna & Angadipuram-7 each **Lakshadweep:** Minicoy-14 **3 December 2017** **Tamil Nadu & Puducherry:** Tiruvarur-14, Pandavaiyar Head & Kodavasal-13 each, Valangaiman & Nannilam-12 each, Nagapattinam-11, Needamangalam, Kumbakonam, & Karaikal-9 each, Thiruthuraipoondi, Aduthurai AWS & Tiruvadanai-8 each and Thiruvidaimaruthur-7 **6 December 2017** **Konkan & Goa:** Dahanu-10, Talasari & Colaba-8 each and Palghar AGRI-7 **Gujarat Region:** Umergam & Vapi-9 each and Pardi, Waghai, Vansda & Gandevi ARG-7 each

Table 11. Verification of Gale/Squally Wind warning

Date/Time of issue (base time) (hours IST)	Gale wind warning	Recorded wind speed
29.11.2017 1150 (0830)	• Squally winds reaching 45-55 kmph gusting to 65 kmph along and off South Tamil Nadu and South Kerala during next 48 hours and over Lakshadweep Islands and adjoining sea areas on 01st and 02nd December.	Tamil Nadu & Kerala: 65-75 kmph gusting to 75 kmph. Thiruvananthapuram recorded 62 kmph in gustiness at 1300 IST of 30th Nov. Lakshadweep reported 65 knots. South Gujarat & north Maharashtra coasts: 10-20 kts on 5th to 6th morning.
30.11.2017 1200 (0830)	• Gale wind speed reaching 65-75 kmph gusting to 85 kmph along & off South Kerala during next 48 hours and along & off south Tamilnadu during next 24 hours. • Squally winds speed reaching 55-65 kmph gusting to 75 kmph along & around Lakshadweep Islands during next 12 hours and increase thereafter with wind speeds becoming 80-90 kmph gusting to 100 kmph from tonight, the 30th November 2017.	
01.12.2017 1130 (0830)	• Gale winds speed reaching 110-120 kmph gusting to 130 kmph over & around Lakshadweep Islands during next 24 hours and gradual decrease thereafter. • Squally wind speed reaching 45-55 kmph gusting to 65 kmph along & off Kerala during next 24 hours and along & off Karnataka coast during next 24 hours.	

02.12.2017 1130 (0830)	• Gale winds speed reaching 100-110 kmph gusting to 120 kmph over & around north Lakshadweep Islands during next 24 hours and gradual decrease thereafter. Gale winds speed reaching 70-80 kmph gusting to 90 kmph south Lakshadweep Islands during next 12 hours and gradual decrease thereafter. • Squally wind speed reaching 45-55 kmph gusting to 65 kmph along & off Kerala coast during next 24 hours and along & off Karnataka coast during next 48 hours.	
03.12.2017 1130 (0830)	• Squally winds speed reaching 50-60 kmph gusting to 70 kmph over & around north Lakshadweep Islands during next 12 hours and gradual decrease thereafter. • Squally wind speed reaching 45-55 kmph gusting to 65 kmph along & off north Maharashtra and South Gujarat coasts from 4th night to 6th December 2017 morning.	
04.12.2017 1200 (0830)	• Squally wind speed reaching 50-60 kmph gusting to 70 kmph along & off north Maharashtra and South Gujarat coasts from today, the 4th night to 6th December 2017 morning.	
05.12.2017 1150 (0830)	• Squally wind speed reaching 50-60 kmph gusting to 70 kmph along & off north Maharashtra and South Gujarat coasts during next 24 hours.	
06.12.2017 1150 (0830)	• Squally winds speed reaching 40-50 kmph gusting to 60 kmph over and around Nicobar Islands during next 24 hours and decrease thereafter. • Squally winds speed reaching 40-50 kmph gusting to 60 kmph to prevail along and off Andhra Pradesh and south Odisha coasts from 7th evening to 9th December morning and decrease thereafter.	

Table 12. Verification of Storm Surge Forecast issued by IMD

First warning of storm surge of height about 1.0 m above astronomical tides likely to inundate low lying areas of Lakshadweep Islands was issued on 1700 hrs IST of 30th.

Date/Time of issue (base time) (hours IST)	Storm Surge Forecast	Estimated storm surge
29.11.2017 1150 (0830)	NIL	1 m over Lakshadweep Islands
30.11.2017 1200 (0830)	NIL	
01.12.2017 1130 (0830)	Storm surge of about 1 meter above astronomical tides to inundate low lying areas of Lakshadweep Islands.	

02.12.2017 1130 (0830)	Storm surge of about 1 meter above astronomical tides to inundate low lying areas of north Lakshadweep Islands during next 24 hrs and storm surge of about 0.5 metre above astronomical tides to inundate low lying areas of south Lakshadweep Islands during next 12 hrs.
03.12.2017- 06.12.2017 1130 (0830)	NIL

11. Bulletins issued by IMD

11.1 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 upto 120 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 different 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, Cabinet Secretariat, HQ Integrated Defence Staff, Doordarshan, All India Radio, Indian Railways, Indian Navy, IAF, concerned states like- Tamil Nadu, Kerala, Goa, Maharashtra, Karnataka, Gujarat, and Union Territory of Lakshadweep, Daman & Diu, Dadra Nagar Haveli. The bulletin also contained the suggested action for disaster managers and general public. 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.

- **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 bulletins were issued by the cyclone warning division at New Delhi and cyclone warning centres of IMD at Chennai, Meteorological Centre, Thiruvananthapuram, Goa, Area Cyclone Warning Centre Mumbai and Cyclone Warning Centre Ahmedabad 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.

Statistics of bulletins issued by Cyclone Warning services of IMD in association with the very severe cyclonic storm Ockhi are given in **Table 13**

Table 13: Bulletins issued by Cyclone Warning Division, IMD, New Delhi

S.N	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	54	1. IMD's website 2. FAX/ e-mail to Control Room, MHA and NDMA, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Indian Railways, Indian Navy, IAF, Chief Secretary- Tamil Nadu, Kerala, Goa, Maharashtra, Karnataka, Gujarat, Administrator, Lakshadweep, Daman & Diu, Dadra Nagar Haveli.
2	RSMC Bulletin	52	1. IMD's website 2. All WMO/ESCAP member countries through GTS and email. 3. Indian Navy, IAF by E-mail
3	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	23	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	Tropical Cyclone Vital Statistics	22	Modelling group of IMD, National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc.
5	Bulletins through SMS	At least once a day	SMS through (i) IMD network for disaster managers at national level and concerned states (ii) Department of Electronics and Information Technology

			(iii) KISAAN Portal and (iv) INCOIS
6	Bulletins through Social Media	11	Cyclone Warnings were uploaded on Social networking sites like Face book and Tweeter since inception to weakening of system (every time when there was change in intensity).
7	Press Release	10	Disaster Managers and Media by email and uploaded on website
8	Press Briefings		Regular

Table 14: Bulletins issued by ACWC Chennai, CWC Ahmedabad, MC Goa, MC Thiruvananthapuram and ACWC Mumbai

S. No.	Type of Bulletin	No. of Bulletins issued				
		ACWC Chennai	CWC Ahmedabad	MC Goa	MC Thiruvananthapuram	ACWC Mumbai
1	Port warnings	16	6	12	22	16
2	Special bulletins (including coastal weather) to AIR stations	19	9	12	27	13
3	Four stage warnings	15	4	8	13	18
4	Warning to fishermen	15	4	8	13	7
5	Special Observations	NIL	14	Nil	4	-

12. Summary and Conclusion:

It developed from a low pressure area over southwest Bay of Bengal and adjoining areas of south Sri Lanka & equatorial Indian Ocean in the forenoon of 28th November. It became a well marked low pressure area in the early morning of 29th over the same region. It further concentrated into a Depression over southwest BoB off southeast Sri Lanka coast in the forenoon of 29th Nov. Moving westwards, it crossed Sri Lanka coast after some time. Continuing it's westward movement, it emerged into Comorin area in the evening of 29th and intensified into a Deep Depression in the early hours of 30th. It further moved northwestwards and intensified into a Cyclonic Storm in the forenoon of 30th Nov. over the Comorin area. Moving west-northwestwards, it further intensified into a Severe Cyclonic Storm over Lakshadweep area in the early morning of 01st Dec. and Very Severe Cyclonic Storm over southeast AS to the west of Lakshadweep in the afternoon of 01st Dec. It then moved northwestwards and reached its peak intensity of 150-160 kmph gusting to 180 kmph in the afternoon of 2nd Dec with lowest central pressure of 976 hPa. It moved north-northwestwards for some time and then north-northeastwards and maintained its intensity till early morning of 03rd Dec. It continued to move north-northeastwards and weakened gradually. It crossed south coast of Gujarat between Surat and Dahanu as a well marked low around early morning of 6th Dec.

It was a rare cyclone with rapid intensification in genesis stage. It intensified from depression to a cyclonic storm within twenty four hours. It caused isolated heavy rainfall over south Tamil Nadu on 28th and 29th and scattered heavy to very heavy rainfall and isolated extremely heavy rainfall over south Tamil Nadu on 30th Nov. and 1st & 2nd Dec. It caused isolated heavy rainfall over south Kerala on 29th Nov. and 1st Dec. and heavy to very heavy rainfall on 30th Nov.

It caused heavy to very heavy rainfall over Lakshadweep on 01st and 2nd Dec. There was heavy rainfall over north coastal Maharashtra and adjoining south coastal Gujarat on 5th Dec. Thiruvananthapuram recorded 62 kmph in gustiness at 1300 IST of 30th Nov. Storm surge of height 1m over Lakshadweep Islands was observed on 30th.

IMD utilised all its resources to monitor and predict the genesis, track and intensification of VSCS Ockhi. The forecast of its genesis (formation of Depression) on 29th November was predicted on 28th Nov. itself. The track forecast error for 12, 24, 48 and 72 hrs lead period were 52.4, 77.2, 111.9 and 189.6 km respectively, which is significantly less than the average track forecast errors of 59.7, 97.2, 149.1 and 202.8 km during last five years (2012-16). The track forecast skill was about 45%, 61%, 76% and 69% for 12, 24, 48 and 72 hrs lead period respectively, which are higher than the long period average (LPA) during 2012-16 for 12 and 24 hrs lead period. The absolute intensity (wind) forecast error for 12, 24, 48 and 72 hrs lead period were 5.4, 7.0, 13.5 and 16.4 knots against the LPA of 6.5, 10.7, 15.5 and 16.3 knots respectively. The skill in absolute intensity (wind) forecast for 12, 24, 48 and 72 hrs lead period was 26.6, 48.4, 61.0 and 75.7% against the LPA of 18.2, 35.2, 55.7 and 66.8% respectively.

14. Acknowledgements:

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