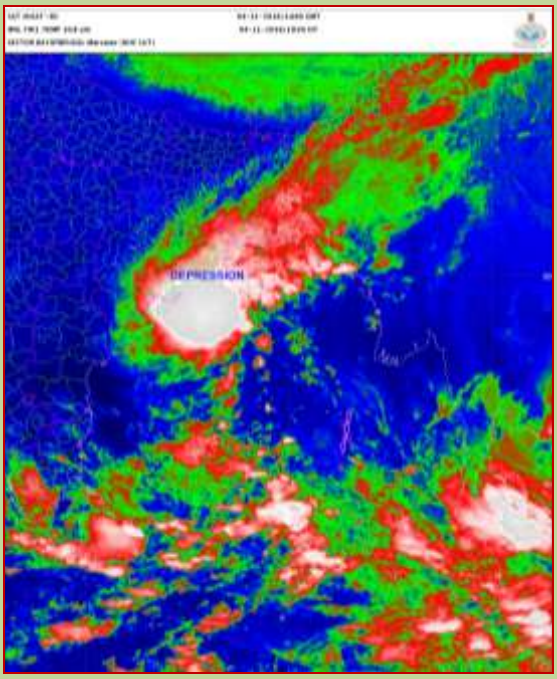
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Depression over the Bay of Bengal (02-06 November 2016): A Report



INSAT-3D enhanced colored IR imagery

Cyclone Warning Division

India Meteorological Department

New Delhi

November 2016

Depression over the Bay of Bengal
(02-06 November 2016)

1. Introduction

A low pressure area developed over south Andaman Sea and neighbouhood in the morning of 1st November 2016. Moving northwestwards, it lay as a well marked low pressure area over region in the morning of 2nd. It further moved northwestwards and concentrated into a **depression (D)** in the midnight of **2nd** and lay centered over central and adjoining southeast BoB at 1800 UTC of 2nd near latitude 12.7^{0}N and longitude 88.0^{0}E. It moved initially west-northwestwards and then northwestwards to westcentral BOB till the evening of 4th November. Thereafter, it recurved east-northeastwards and reached southeast Bangladesh coast close to Kutubdia in the afternoon of 6th near latitude 21.6^{0}N and longitude 91.9^{0}E. It weakened into a well marked low pressure area over southeast Bangladesh and adjoining northeast BOB in the evening of 6th.The observed track of the depression is shown in Fig.1. The salient features of the system are as follows.

(i) It was second consecutive recurving system in the post-monsoon season (October-December, 2016) after cyclonic storm (CS) 'Kyant'. While CS 'Kyant' had anticlockwise recurvature, this depression had clockwise recurvature.

(i) It also dissipated near the coast under the influence of high vertical wind shear, dry air incursion into the system from northwest and low ocean heat content over north BOB.

(ii) After recurvature from 4th midnight, the system moved faster with a speed of 25 kmph in east-northeast direction till 6th morning. The faster movement was due to the trough in westerlies prevailing in the middle tropospheric levels which was mainly steering the system.

(iii) Lowest estimated central pressure (ECP) was 1000 hPa with a pressure drop of 4 hPa.

(iv) The depression travelled a distance of about 1610 km during its life period.

(v) The life period of depression was 90 hours.

(vi) Genesis of depression over southeast BOB was predicted 72 hours in advance (on 30th October itself).

(vii) Though the system was moving towards east coast of India till 4th midnight, no Cyclone Warning/Alert was issued for any coastal state of India due to accurate prediction of its track towards Bangladesh.

(viii) The movement of system towards Bangladesh coast was predicted well in advance from the first Bulletin (84 hours in advance of reahing Bangladesh coast).

(ix) IMD issued regular bulletins to WMO/ESCAP Panel member countries, National & State Disaster Management Agencies, general public, media and social networking sites since inception of the system over BOB.

Brief life history, characteristic features and associated weather along with performance of NWP and operational forecast of IMD are presented and discussed in following sections.

2. Monitoring of Depression

The depression was monitored & predicted continuously since its inception by IMD. The best track parameters of the systems are presented in Table 1**.** The track of the system is presented in Fig.1. Throughout its life cycle, the system was monitored mainly with satellite, buoy, ship and coastal observations. Various national and international NWP models and dynamical-statistical models including IMD's and NCMRWF's global and meso-scale models, dynamical statistical models for genesis and intensity were utilized to predict the genesis, track and intensity of the system. 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.

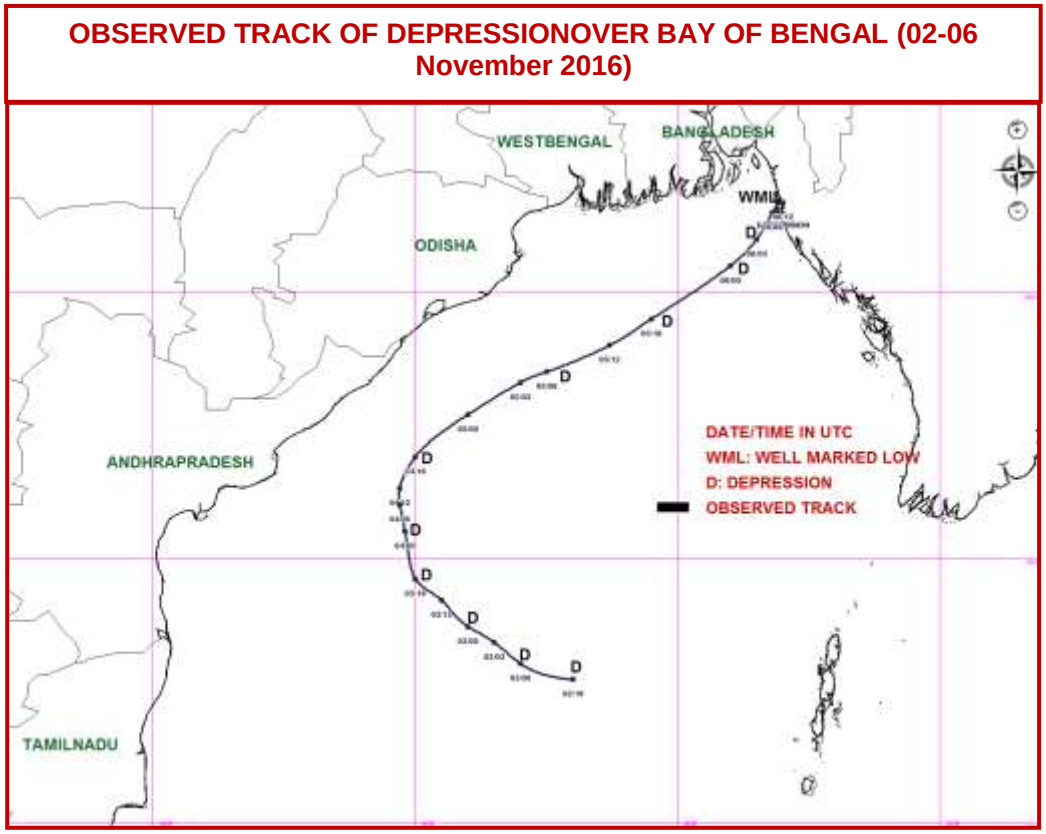


Fig.1 Observed track of depression over BoB during 02-06 October 2016

3. Brief life history

3.1. Genesis

In association with active inter-tropical convergence zone (ITCZ), a low pressure area formed over south Andaman Sea and neighbourhood at 0300 UTC of 1st November. It persisted over the area and became a well marked low pressure area at 0300 UTC of 2nd. On 2nd November, the large scale dynamical and thermodynamical features became gradually favourable. At 1800 UTC of 2nd, the vertical wind shear was 10-20 kts (moderate), upper level divergence was 40×10^{-5} s^{-1}, lower level convergence was 15×10^{-5} s^{-1} and relative vorticity at 850 hPa was around 150×10^{-6} s^{-1}. Sea surface temperature was 29-30^{0}C. The ocean thermal energy was about 60- 80 KJ/cm^2 around the system centre over central BOB. According to satellite imagery, a low level cyclonic circulation lay over south Andaman Sea and adjoining southeast BOB on 1st and it became a vortex

with T1.0 at 0300 UTC of 02 Nov. 2016 over the southeast BOB. The associated convection gradually organized on 2nd. Broken low/medium clouds with embedded intense to very intense convectioin lay over BOB between latitude 12.0^{0}N to 20.0^{0}N and longitude 83.0^{0}E to longitude 90.0^{0}E at 1800 UTC of 2nd. Intensity of system was T 1.5 at 1800 UTC of 2nd. The convection showed banding pattern at the time of genesis, covering 0.3 in logarithmic spiral. The lowest cloud top temperature was about -85^0 C Under these favourable conditions, the system concentrated into a depression and lay centered at 1800 UTC of 2nd Nov. 2016 over central and adjoining southeast BOB near latitude 12.7^{0}N and longitude 88.0^{0}E.

Table 1: Best track positions and other parameters of the depression over BOB during 02-06 October, 2016

Date	Time (UTC)	Centre lat.^{0} N/ long.^{0} E	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
02/11/2016	1800	12.7/88.0	1.5	1004	25	4	**D**
03/11/2016	0000	13.0/87.0	1.5	1004	25	4	D
	0300	13.4/86.5	1.5	1004	25	4	D
	0600	13.7/86.0	1.5	1004	25	4	D
	1200	14.2/85.5	1.5	1004	25	4	D
	1800	14.6/85.0	1.5	1004	25	4	D
04/11/2016	0000	15.5/84.8	1.5	1002	25	4	D
	0300	16.0/84.7	1.5	1002	25	4	D
	0600	16.0/84.7	1.5	1000	25	4	D
	1200	16.3/84.7	1.5	1000	25	4	D
	1800	16.9/85.0	1.5	1000	25	4	D
05/11/2016	0000	17.7/86.0	1.5	1000	25	4	D
	0300	18.3/87.0	1.5	1000	25	4	D
	0600	18.5/87.0	1.5	1000	25	4	D
	1200	19.0/88.7	1.5	1000	25	4	D
	1800	19.5/89.5	1.5	1000	25	4	D
06/11/2016	0000	20.5/91.0	1.5	1000	25	4	D
	0300	21.0/91.5	1.5	1000	25	4	D
	0600	21.5/91.8	1.5	1002	25	4	D
	0900	21.6/91.9	1.5	1003	25	3	D
	1200	**Well Marked Low Pressure Area over southeast Bangladesh & adjoining northeast Bay of Bengal**					

3.2. Intensification

At 0300 UTC of 4th, the depression lay over westcentral BOB. The upper tropospheric ridge ran along 17.0^0 N. Winds were southeasterly over the region of the depression. The vertical wind shear increased during past 24 hours and was about 15-25 kts (moderate to high) around the system centre. It was increasing towards north and west, becoming more than 30 knots to the north of 18^{0}N. The upper level divergence was about 20x10^{-5} s^{-1}, the lower level convergence was about 15x10^{-5} s^{-1} around the system

centre and the relative vorticity was around $150x10^{-6}$ s^{-1}. MJO Index was in phase 4 with amplitude more than 1. Sea surface temperature was 29-30^{0}C and the ocean thermal energy was about 60- 80 KJ/cm^2 around the system centre over westcentral BOB. Though the thermodynamical parameters, lower vorticity and upper level divergence were favourable, the system did not intensify due to high vertical wind shear. Similar condition continued throughout its life. However, from 5th onwards,

The convection continued to show curved banding pattern with the bands approaching the centre from northeast till 5th Nov. 2016. At 0300 UTC of 5th, the depression lay over westcentral and adjoining northwest BOB. The intensity of the system was T 1.5. The lowest cloud top temperature was about -91.0^0 C. Convection got disorganised in past 24 hours due to dry air incursion from southwest sector at middle level. The incursion of warm moist air to the core of system also decreased gradually. The sea surface temperature was 29-30^0 C. The ocean thermal energy was about 60- 80 KJ/cm^2 around the system centre over westcentral BOB becoming less than 50 KJ/cm^2 over north BOB. As the system moved northeastwards, it experienced more unfavourable conditions. At 0300 UTC of 6th, the intensity of the system was C.I.1.5. Associated broken low/medium clouds with embedded moderate to intense convectioin lay over northeast BOB, east Bangladesh, Tripura, Manipur and intense to very intense convection lay over Mizoram & adjoining Myanmar. The lowest cloud top temperature wass about -75.0^0 C. The convection showed further disorganisation during past 12 hours. The vertical wind shear was about 20-30 kts (high) around the system centre. The upper level divergence was about $5x10^{-5}$ s^{-1} near the system centre, the lower level convergence was about $20x10^{-5}$ s^{-1} to the northeast of the system centre.The relative vorticity was around $100x10^{-6}$ s^{-1}. Sea surface temperature was 29-30^0 C and the ocean thermal energy was less than 50 KJ/cm^2 over north BOB. Under these prevailing conditions, the system moved northeastwards and gradually weakened into a well marked low pressure area at 0900 UTC of 6th over southeast Bangladesh and adjoining northeast BOB. Typical INSAT 3D imageries are presented in Fig.2. The water vapour imageries and total precipitable imageries during 2nd to 6th Nov are presented in Fig. 3 and Fig. 4 respectively.

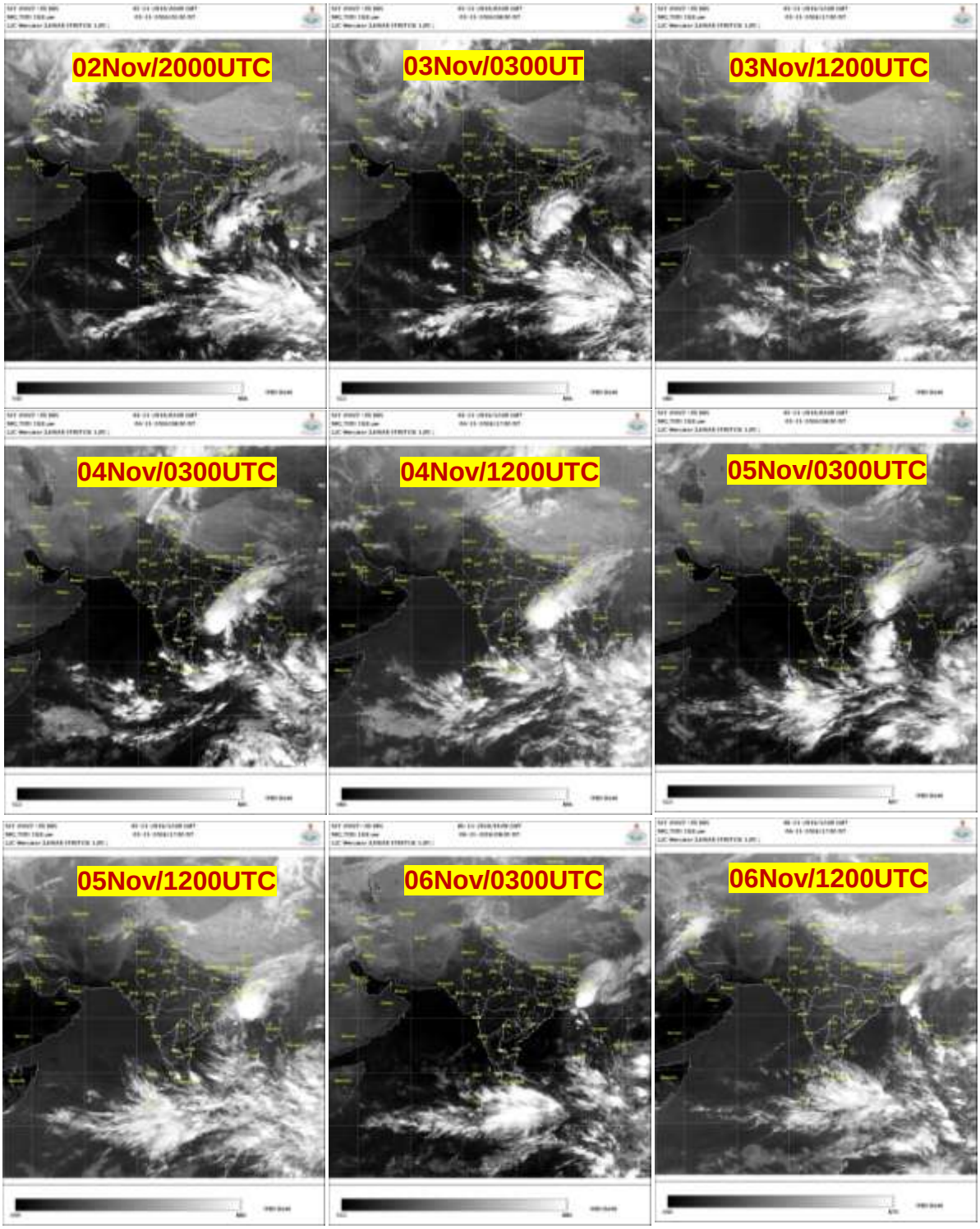


Fig.2a: Typical INSAT-3D IR imageries during 02-06 Nov 2016

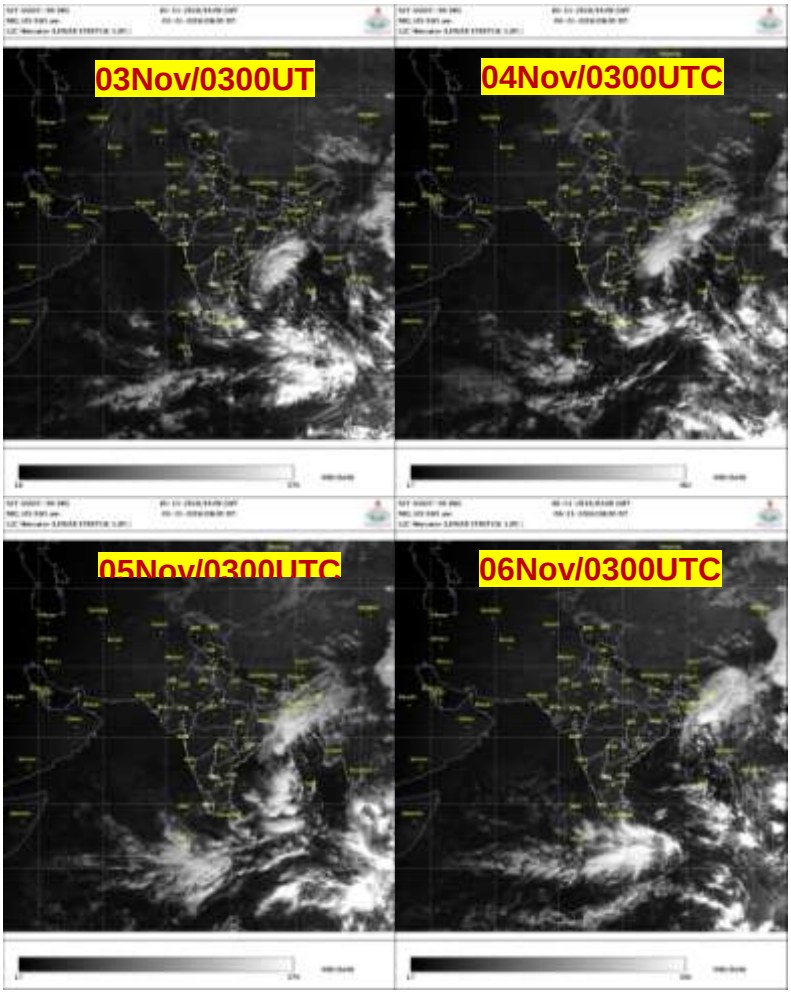


Fig.2b: Typical INSAT-3D visible imageries at 0300 UTC of 02-06 Nov 2016

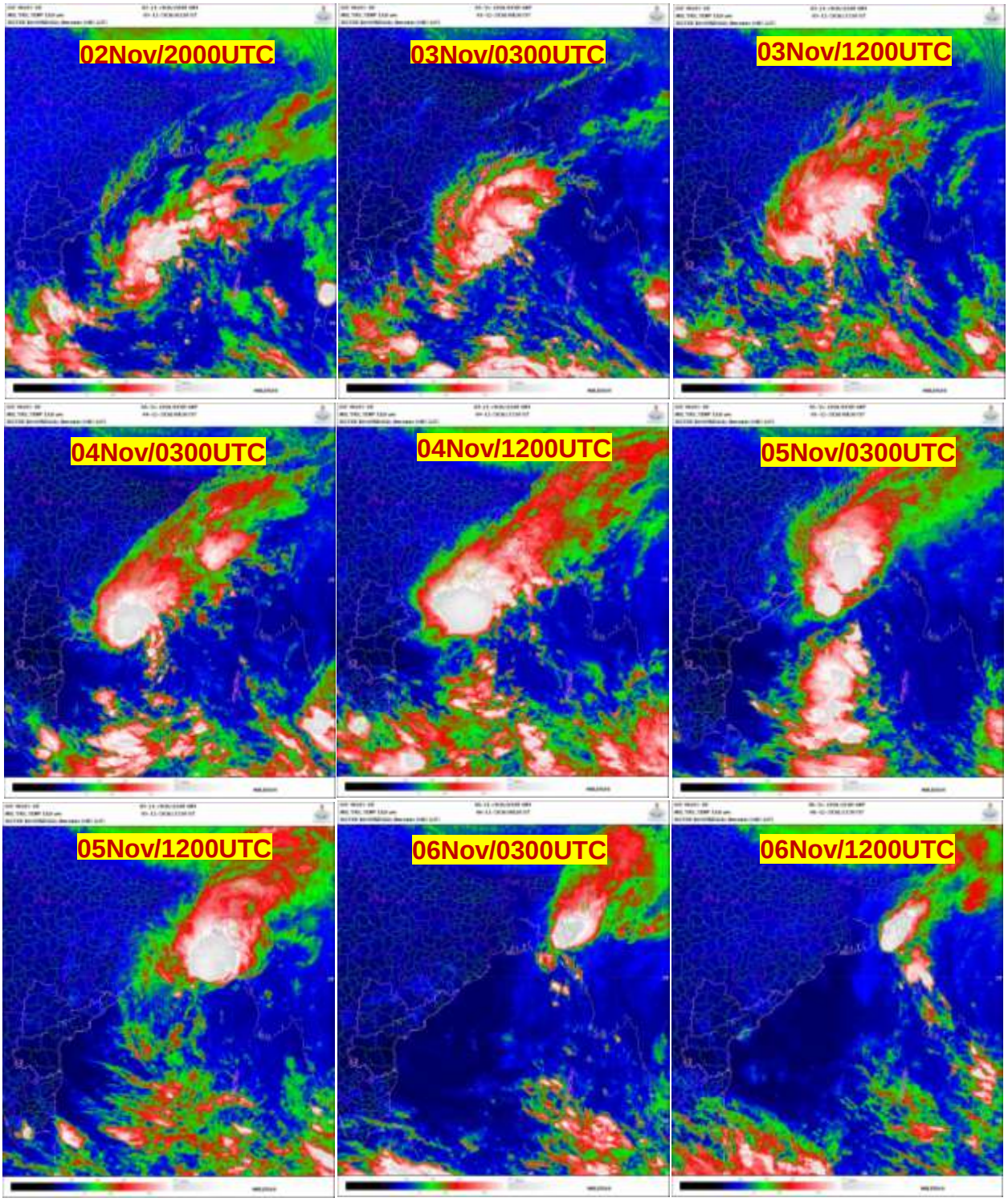


Fig.2c: Typical INSAT-3D enhanced colored imageries during 02-06 Nov 2016

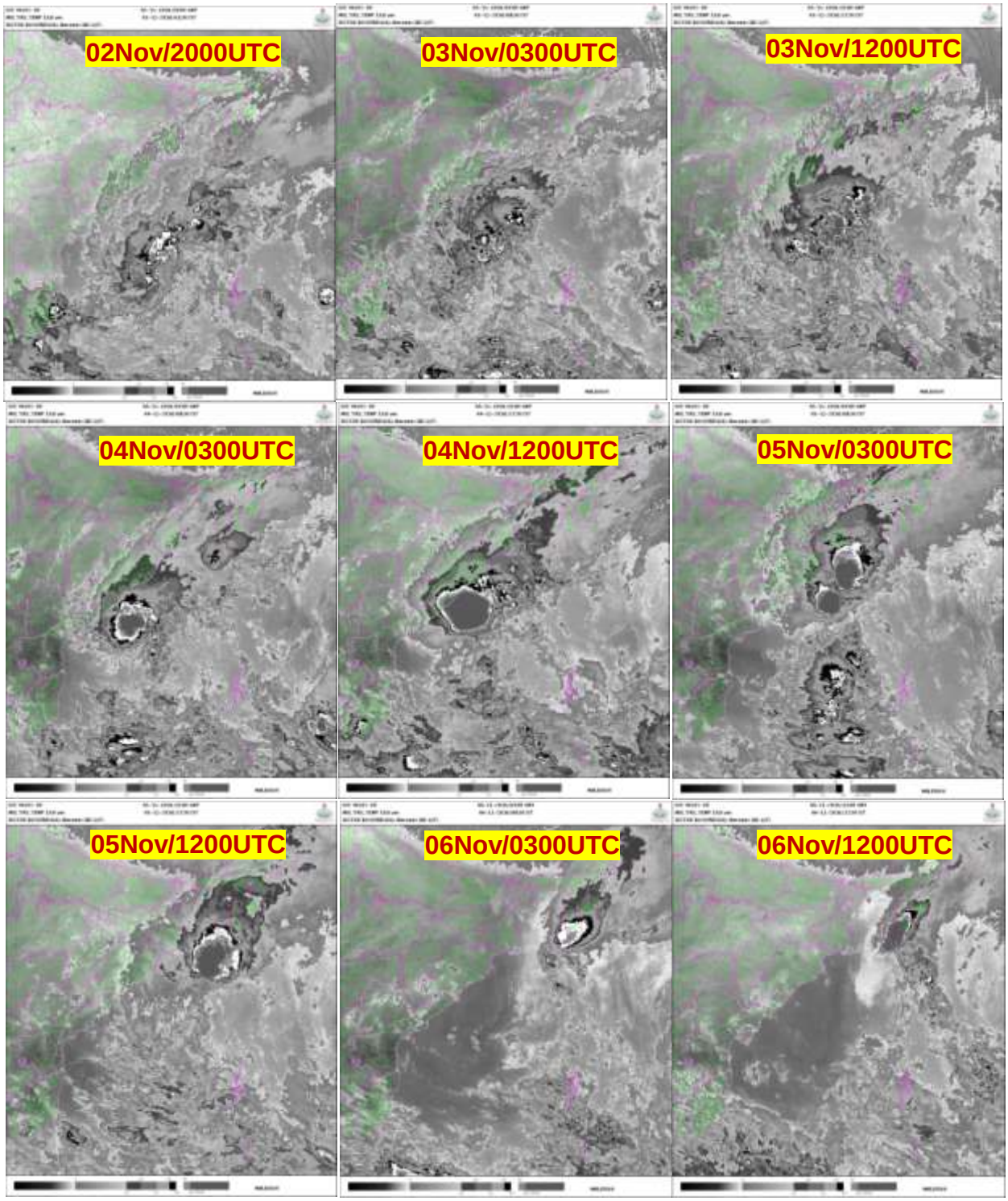


Fig.2d: Typical INSAT-3D cloud top brightness temperature imageries during 02-06 Nov 2016

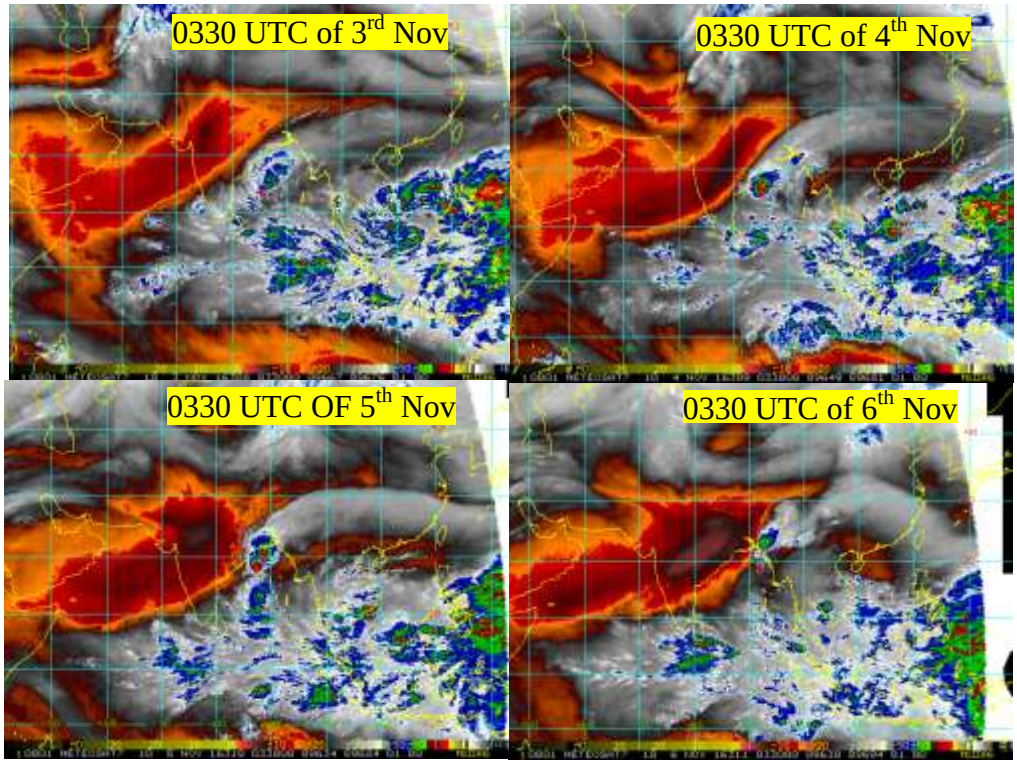


Fig.3: Water Vapour Imagery during 3rd to 6th November 2016

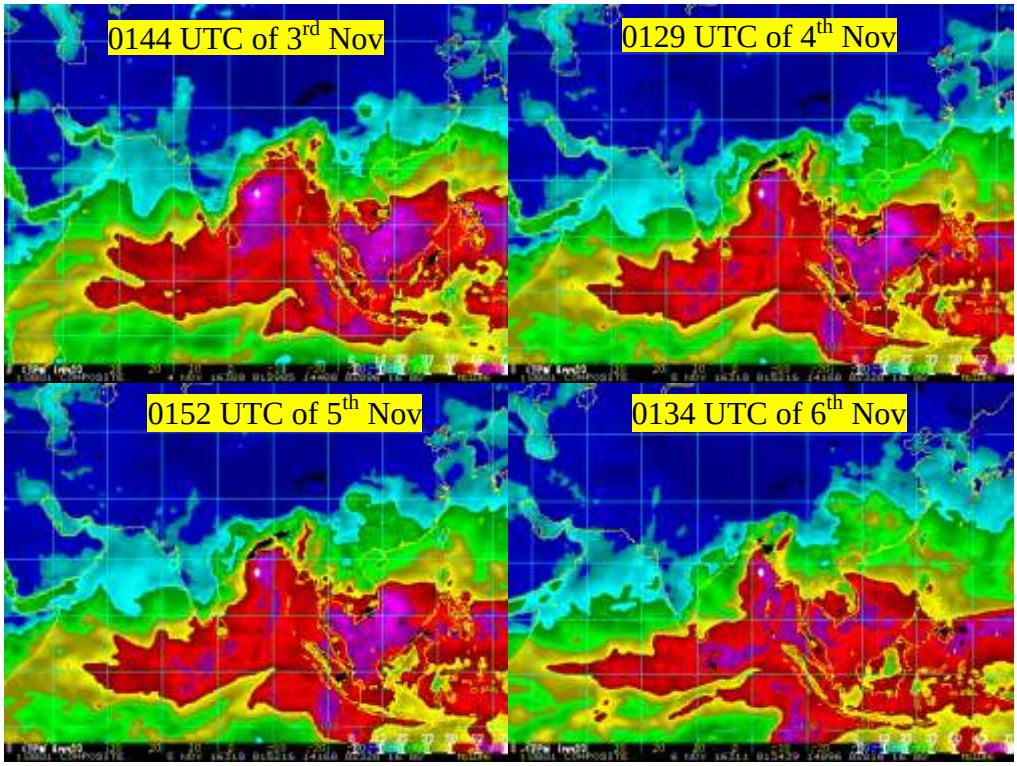


Fig.4: Total Precipitable Water Vapour Imagery during 3rd to 6th November 2016

3.3 Speed and direction of Movement

At 0300 UTC of 3rd, the upper tropospheric ridge ran along 16.0^{0}N and the system was to the south of ridge. The prevailing winds in upper level were east-southeasterly and southeasterly near the system. Under its influence, the system moved west-northwestwards to northwestwards till 1800 UTC of 3rd. Thereafter the system recurved nearly northwards till 1200 UTC of 4th as it came very close to the ridge during this period and the upper level winds were nearly southerly. From 1800 UTC of 4th, the system transitioned to the north of ridge and recurved northeastwards under the influence of southwesterly winds in upper level under the influence of mid-latitude trough in westerlies. A trough in mid-tropospheric westerlies ran along 80.0^{0}E and to the north of 17.0^{0}N till 0000 UTC of 5th November. This helped in steering the system northeastwards from 1800 UTC of 4th. Initially the system moved with an average speed of 10-15 kmph. At 0300 UTC of 5th, the trough in mid-latitude westerlies ran along 86.0^{0}E and to the north of 20.0^{0}N and under its influence, the system moved faster with an average speed of 25 kmph. The system slowed down after 0600 UTC of 6th and moved with an average speed of 5 kmph when it reached near the coast due to gradual weakening of the system. The system had a track length of about 1610 km during its life period. The wind speed in middle and deep layer around the system centre is presented in Fig.5.

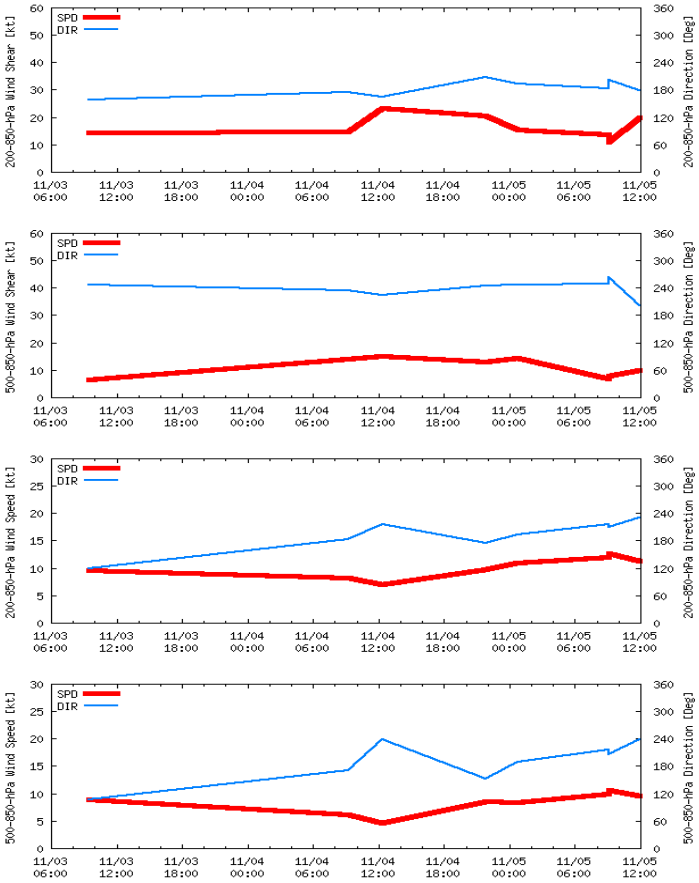


Fig.5(a)Wind shear (i) between 850 and 200 hPa levels & (ii) between 850 and 500 hPa levels and mean wind speed & direction within 850 to 500 hPa levels and 850 to 200 hPa levels around the system during 3rd to 6th Nov.

The 12 hrs translational speed and direction of the system are shown in Fig.5(b). It indicates that the system moved initially west-northwestwards, then recurved gradually and finally moved east-northeastwards. The translational speed gradually decreased becoming minimum around 1200 UTC of 4th Nov. and then increased gradually as it moved northeastwards under the influence of the mid-latitude westerly trough. Comparison of Fig.5a and Fig.5b indicate that the depression was steered by 200-850 hPa mean layer wind.

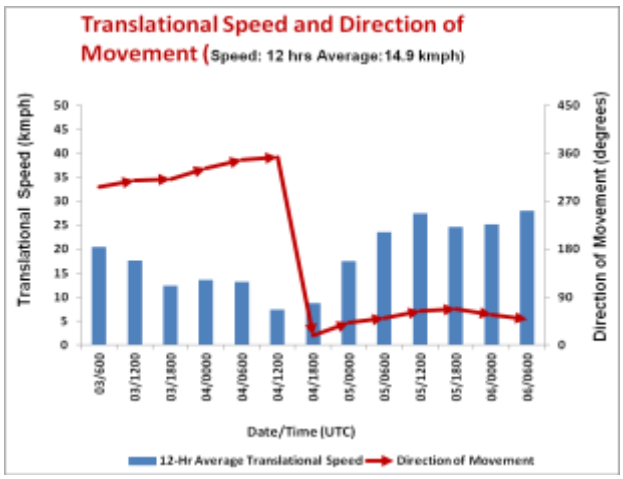


Fig.5(b). 12 hrly average translational speed and direction of depression (3-6 Nov. 2016).

4. Climatological aspects

Considering the area of genesis (+/- 2^0 around the genesis point), the cliamtological tracks of the cyclonic disturbances during 1891-2015 are presented in Fig.7. It indicates that climatologically, only 20% of the tracks recurved towards northeast and remaining moved northwestwards. All the systems generating over this 2^{0}x2^{0}block dissipated over the Sea. Out of five systems, two intensified into cyclonic storms.

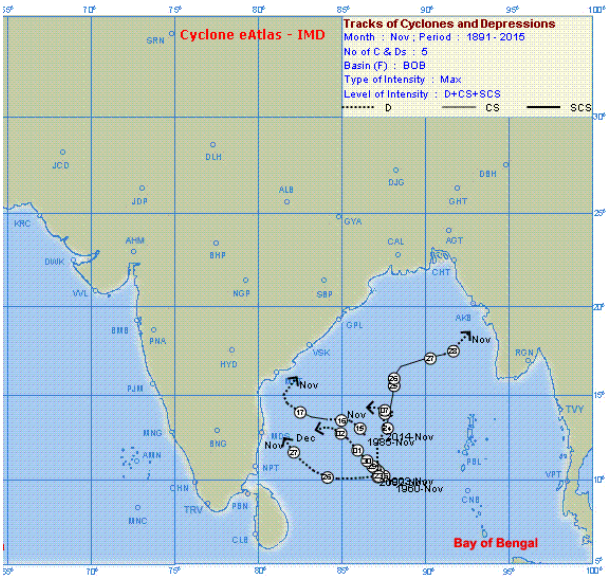


Fig6. Climatological tracks of TCs forming within +/- 2^0 around the genesis point during 1891-2015.

Dynamical features

IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels are presented in Fig.8. IMD GFS analysis based on 0000 UTC of 2nd Nov., picked up development of a low over southeast BOB with circulation extending upto mid-tropospheric level. At 200 hPa, a ridge ran along lat. 15^0N.

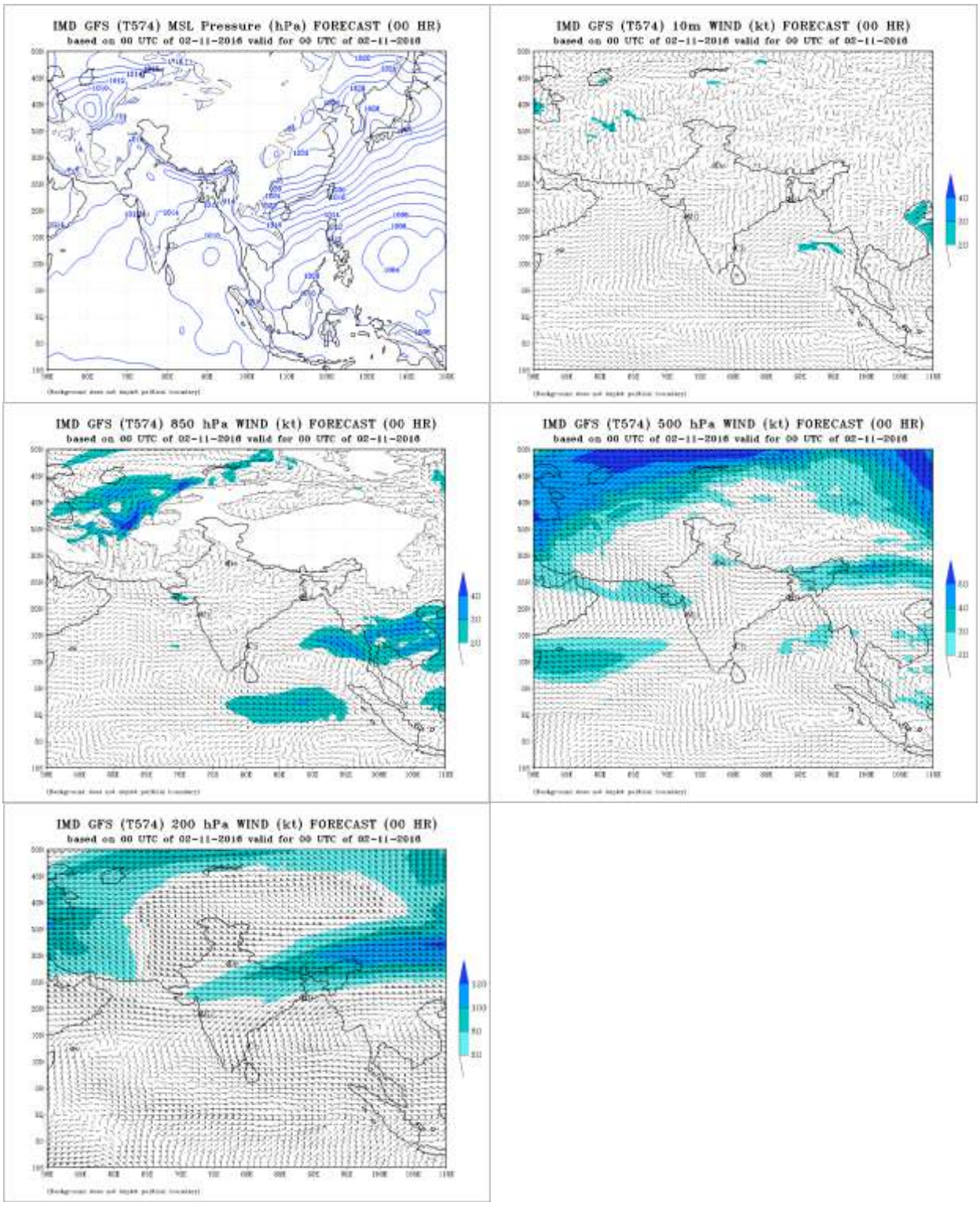


Fig. 8a: IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 2nd November

IMD GFS analysis based on 0000 UTC of 3rd Nov., indicated west-northwestward movement of the system with intensification into a depression over southwest BOB extending upto mid-tropospheric level.

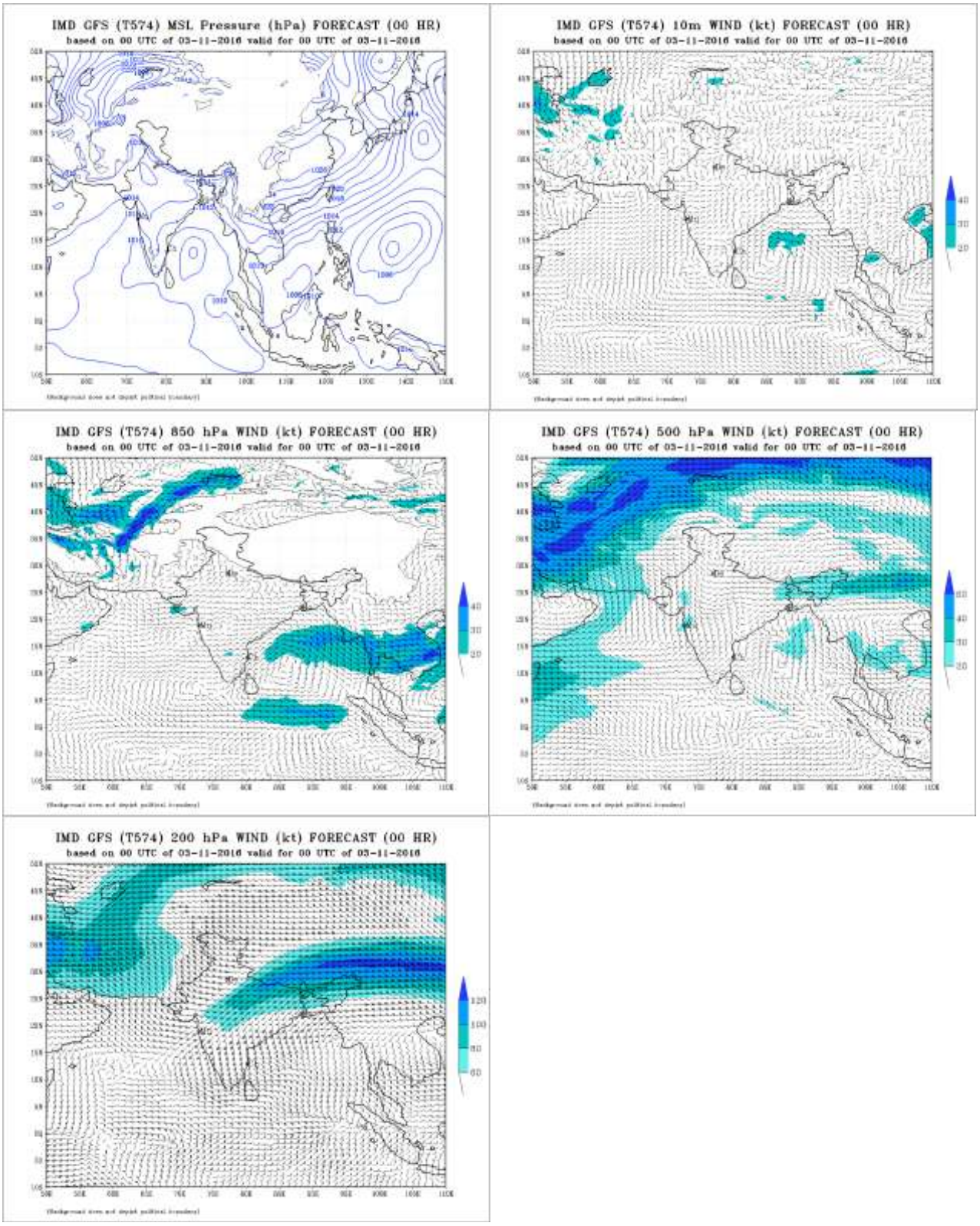


Fig. 8b: IMD GFS analysis of MSLP, 10m wind and winds at 850, 500 & 200 hPa levels based on 0000 UTC of 3rd November

IMD GFS analysis based on 0000 UTC of 4th Nov., indicated northward movement of the system with further intensification over westcentral BOB extending upto mid-tropospheric level. A trough in mid-tropospheric level ran along long. 80^0E to the north of 15^0N, suggesting the recurvature of the system to northeastwards.

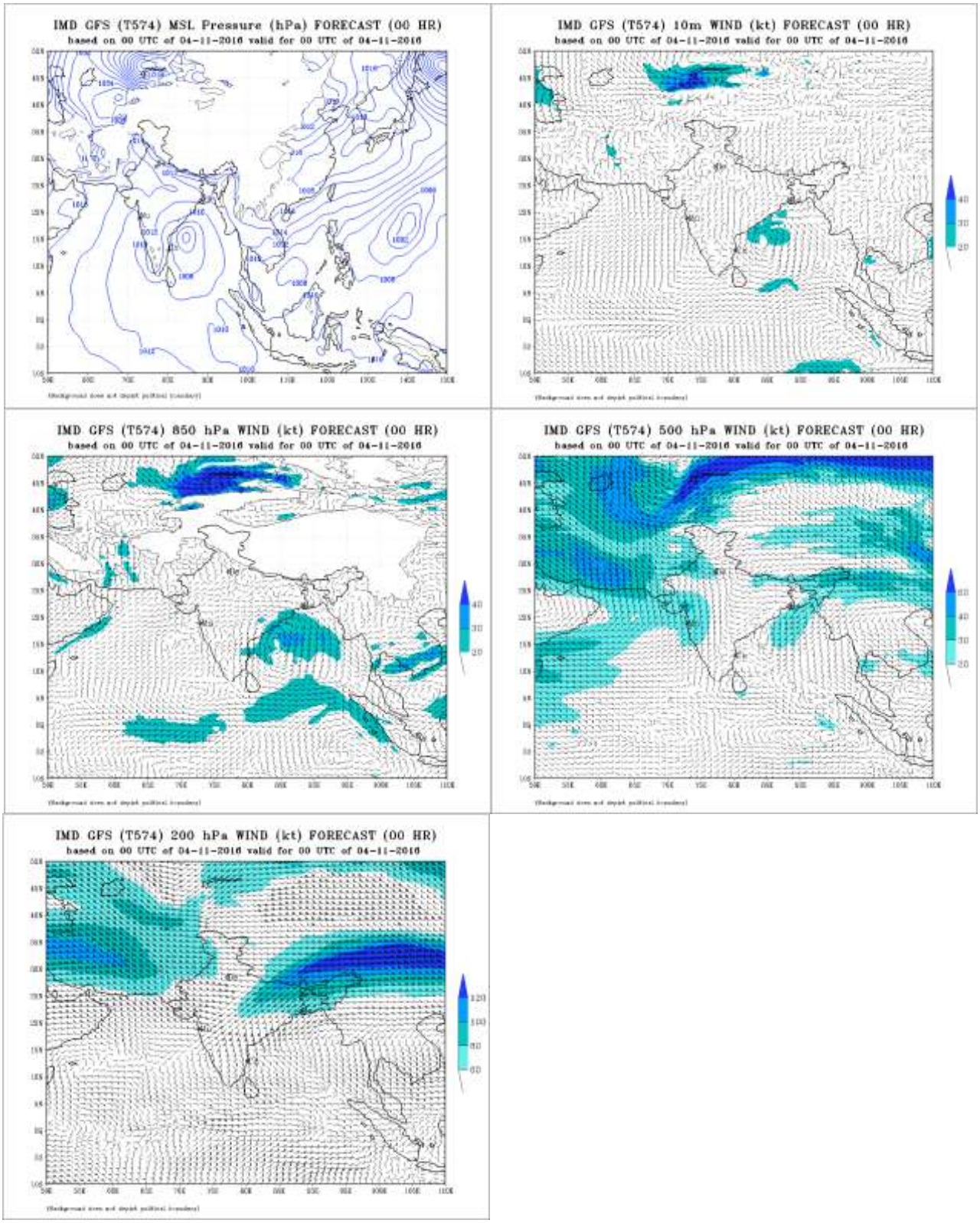


Fig. 8c: IMD GFS analysis of MSLP, 10m wind and winds at 850 and 500 hPa levels based on 0000 UTC of 4th November

IMD GFS analysis based on 0000 UTC of 5th Nov., indicated east-northeastward recurvature of the system over westcentral BOB under the influence of the trough in westerly running along 85^0E to the north of 15^0N.

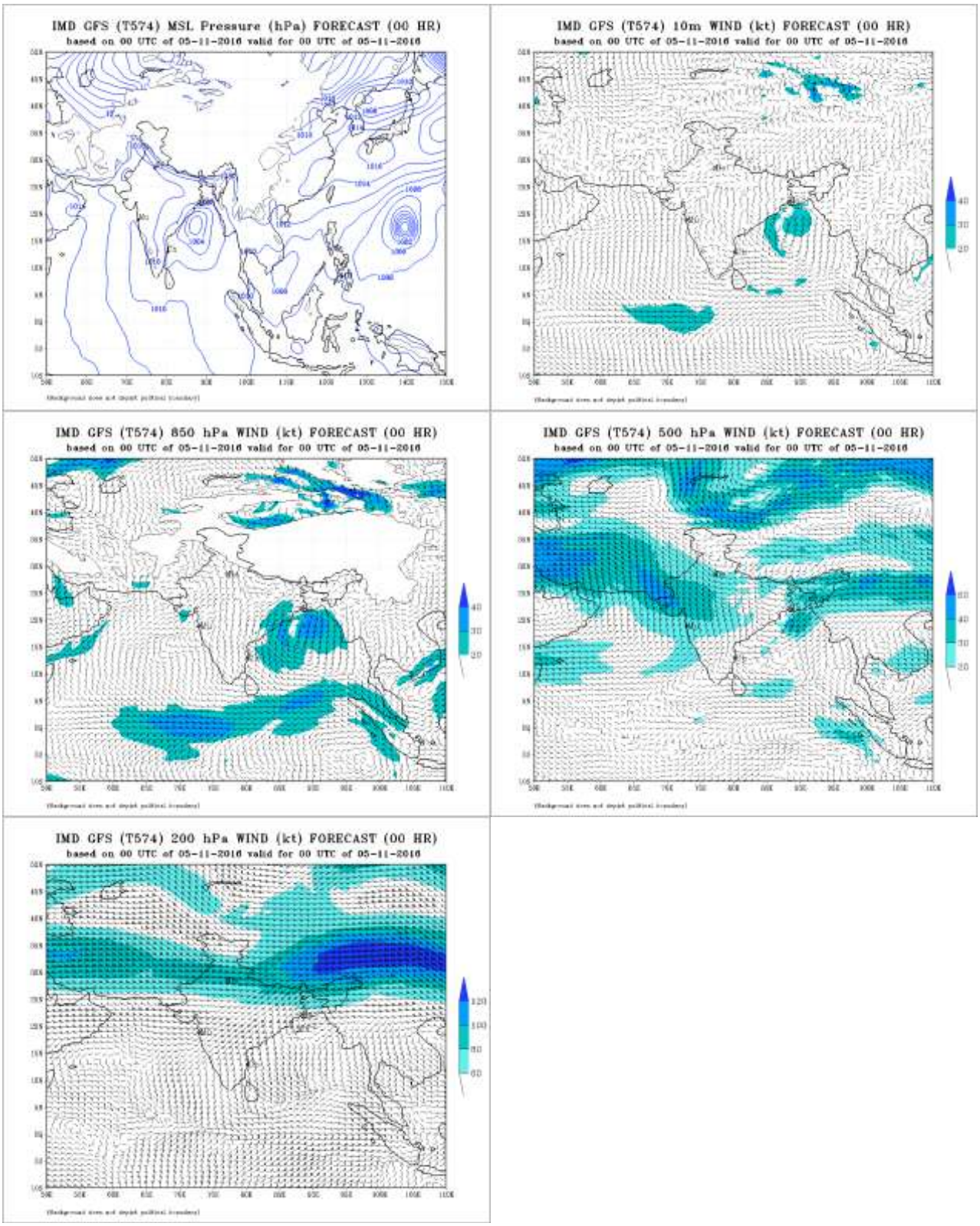


Fig. 8d: IMD GFS analysis of MSLP, 10m wind and winds at 850 and 500 hPa levels based on 0000 UTC of 5th November

IMD GFS analysis based on 0000 UTC of 6th Nov indicated weakening of the system over northeast BOB.

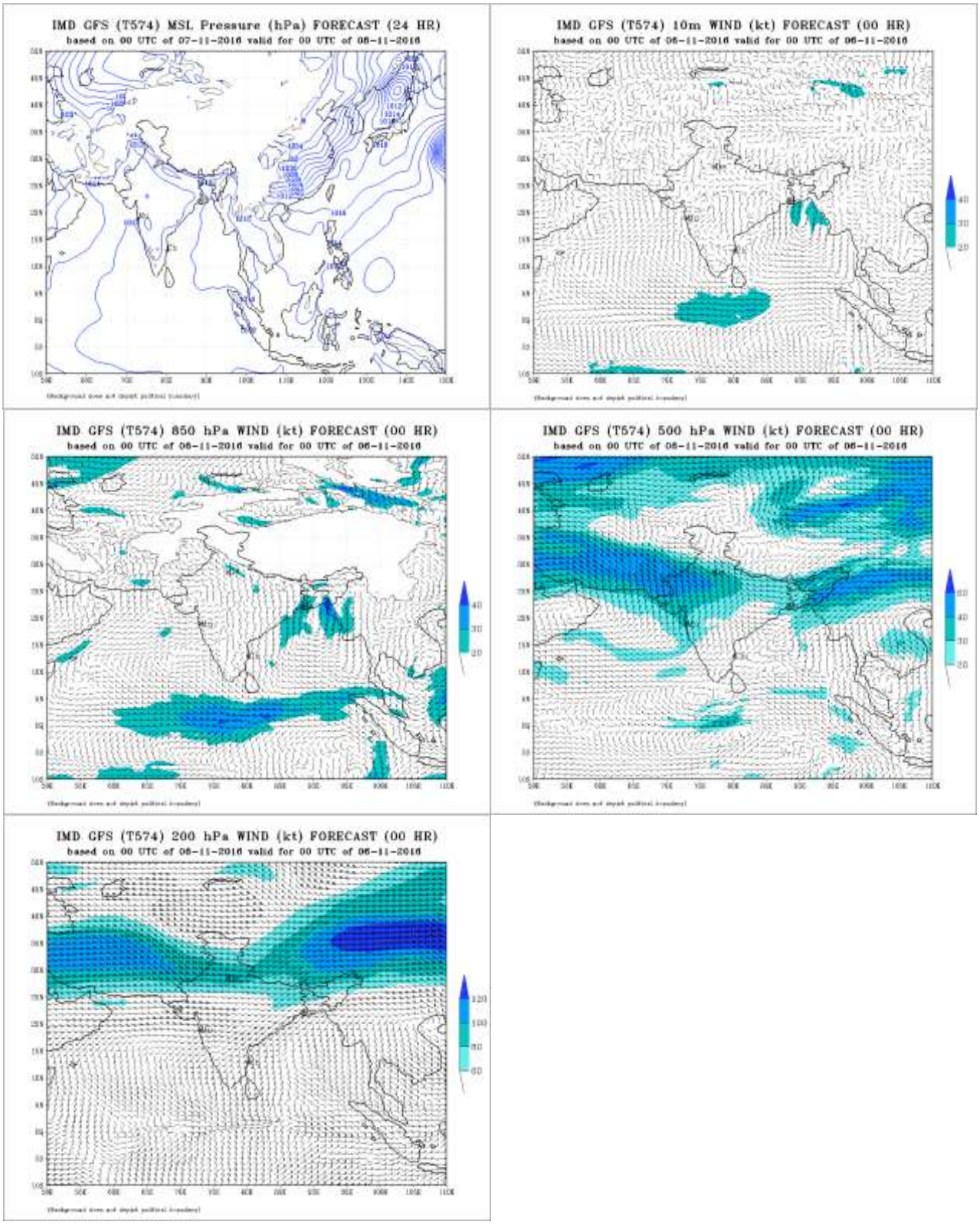


Fig. 8e: IMD GFS analysis of MSLP, 10m wind and winds at 850 and 500 hPa levels based on 0000 UTC of 6th Novembe

Thus the IMD-GFS model could detect the genesis, track and weakening over the sea.

7. Bulletins issued by IMD

7.1 Bulletins issued by Cyclone Warning Division, New Delhi

IMD continuously monitored, predicted and issued bulletins giving track positions based on 00, 03, 06, 12 and 18 UTC observations till the system weakened into a low pressure area. The graphical display of the observed track was uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in) regularly. The prognostics and diagnostics of the systems were described in the RSMC bulletins.

Table-2a: Bulletins issued by Cyclone Warning Division, New Delhi

SN	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	19	1. IMD's website 2. FAX and e-mail to Control Room NDM, Cabinet Secretariat, Minister of Sc. & Tech, Secretary MoES, DST, HQ Integrated Defence Staff, DG Doordarshan, All India Radio, DG-NDRF, Indian Navy, IAF, Chief Secretary-Kerala, Karnataka, Andhra Pradesh, Tamil Nadu, West Bengal, Odisha, Mizoram, Arunachal Pradesh, Assam, Manipur and Tripura.
2	RSMC Bulletin	9	1. IMD's website 2. All WMO/ESCAP member countries through GTS and E-mail. 3. Indian Navy, IAF by E-mail
3	SMS based bulletin	10,835	SMS through (i) IMD network for disaster managers (1595) & (ii) IMD's public registration using Department of Electronics and Information Technology network (9240) (once daily and twice on 6th Nov.) and (iii) Kisan Portal for farmers (21,42,990).
4	Bulletins through Social Media	Once daily	Cyclone Warnings were uploaded on Social networking sites like Face book and Tweeter once daily during the life cycle of system.

Bulletins issued by Area Cyclone Warning Centres and Cyclone Warning Centres of IMD in association with the system are given in Table 2 b

Table-2b: Bulletins issued by ACWC Chennai/ACWC Kolkata/CWC Bhubaneswar/ CWC VZK

S.No.	Type of Bulletin Number	No. of Bulletins issued by			
		ACWC Chennai	ACWC Kolkata	CWC Bhubaneswar	CWC VZK
1.	Sea Area Bulletins	14	22	-	-
2.	Coastal Weather Bulletins	10	14	14	13
3.	Fishermen Warnings issued	20	30	24	12
4.	Port Warnings	10	32	22	10
5.	Heavy Rainfall Warning	7	06	10	02
6.	Gale Wind Warning	NIL	NIL.	08	03
7.	Information & Warning issued to State Government and other Agencies	7	05	23	23
8.	SMS	24	NIL	1600	110

8. Realized Weather:

8.1 Rainfall:

Even though the system did not cross the Indian coast, the sheared convective cloud mass caused rainfall at many places with isolated heavy rainfall over north coastal Andhra Pradesh, coastal Odisha, coastal West Bengal, south Assam, Tripura and Mizoram for one day each. The depression also caused widespread rainfall with isolated heavy to very heavy falls over Bangladesh on 6th. Realized rainfall ≥ 7cm over Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, Gangetic West Bengal, Odisha and Puducherry during 4th-7th November is presented below:

4 Nov. 2016:
Gangetic West Bengal: Contai-7
Puducherry: Kangeyam-7, Rameswaram-7

5 Nov. 2016:
Assam : Karimganj-9, ,
Odisha: Tirtol and Paradip-10 each, Marsaghai -9, Astaranga-8, Derabisi,Chandbali, Garadapur-8 each, Balikuda, Kendrapara, Kujanga and Rajkanika-7

6 Nov. 2016:
Assam & Meghalaya: B.P Ghat-9 and Karimganj-9 each, Halflong-7
Nagaland, Manipur, Mizoram & Tripura: Arundhutinagar-13, Khowai-12, Agartala Airport, Kailashahar Airport-12 each, Kamalpur-11, Bishalgarh-11, Udaipur, Gokulpur-10 each, Belonia, Sonamura-9 each, Sabroom-8, Aizwal-7

7 Nov. 2016:
Assam & Meghalaya: B.P.Ghat-13, Halflong-10, Karimganj-8, Lumding-7
Nagaland, Manipur, Mizoram & Tripura: Gokulpur, Udaipur, Amarpur, Bishalgarh-11 each, Khowai-10, Wokha, Kailashahar airport, Belonia-8 each, Chhamonu, Jharnapani-7

9. Damage due to system

No damage was reported by any coastal state of India and Bangladesh.

10. Performance of operational NWP models

IMD operationally runs a regional models, WRF for short-range prediction and one Global model T574L64 for medium range prediction (7 days). The WRF-Var model is run at the horizontal resolution of 27 km, 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25^{o} S to 45^{o} N long 40^{o} E to 120^{o} E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 23 km. The boundary conditions are updated at every six hours interval.

Global models are also run at NCMRWF. These include GFS (23 km) and unified model (17 km) adapted from UK Meteorological Office. An important component common to both the deterministic and ensemble model is that they do not use any TC relocation in the analysis.

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 for cyclone are presented and discussed.

10.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for the system

Figure 9 (a-f) shows the predicted zone of cyclogenesis. Grid point analysis and forecasts of GPP indicate the formation of cyclone over southwest BOB 120 hrs before its formation. Hence, it showed over estimation of intensity. Since all low pressure systems do not intensify into cyclones, it is important to identify the potential of intensification (into cyclone) of a low pressure system at the early stages (T No. 1.0, 1.5, 2.0) of development. Conditions for: (i) Developed system: Threshold value of average

GPP ≥ 8.0 and (ii) Non-developed system: Threshold value of GPP < 8.0. The analysis and forecasts of GPP showed that GPP ≥ 8.0 (threshold value for intensification into cyclone) based on 00 UTC of 1st November and 2nd November 2016 indicated its potential to intensify into a cyclone (over estimated) at early stages of development. However, the updated analysis and forecasts of GPP based on 00 UTC of 2nd November to 5th November 2016 showed weakening of the system.

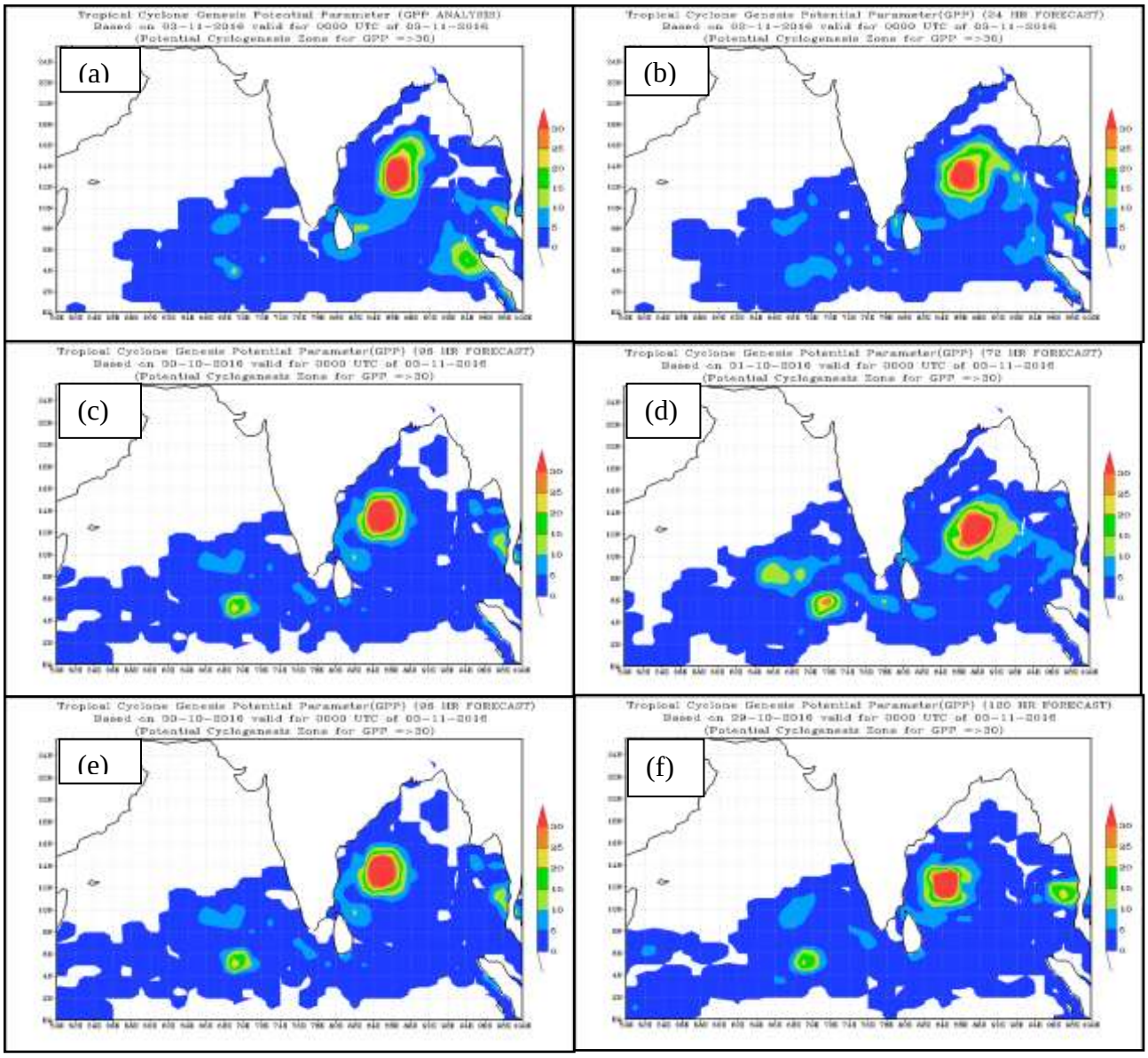


Figure 9 (a-f): Predicted zone of cyclogenesis based on 0000 UTC of 29th Oct. to 3rd Nov. for 0000 UTC of 3rd Nov2016.

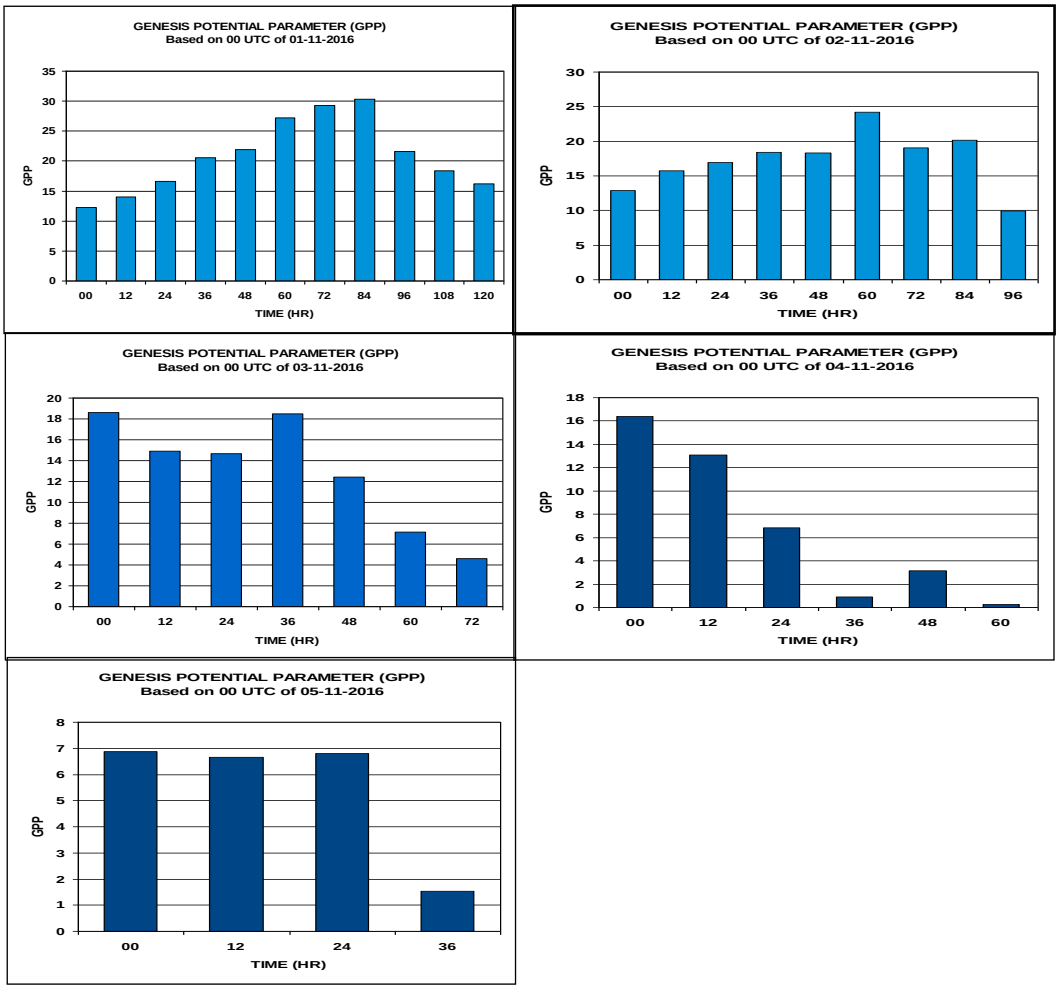


Fig. 10. Area average analysis and forecasts based on 1st-5th Nov 2016

GPP indicated weakening of the system from 5th November onwards based on initial conditions of 3rd, 4th and 5th November.

10.2 Track prediction by NWP models

Track prediction by various NWP models is presented in Fig.11. Based on initial conditions of 0000 UTC of 3rd Nov, IMD GFS, WRF-VAR, ECMWF and JMA showed dissipation over sea. NCEP GFS and HWRF predicted northward recurvature and landfall over southwest Bangladesh. UKMO (at 0900 UTC of 6th Nov.) and MME predicted landfall over southeast Bangladesh near Chittagong (at 0000 UTC of 7th Nov.). In addition JMA and WRF predicted looping tracks. Most of the models predicted northeastwards recurvature.

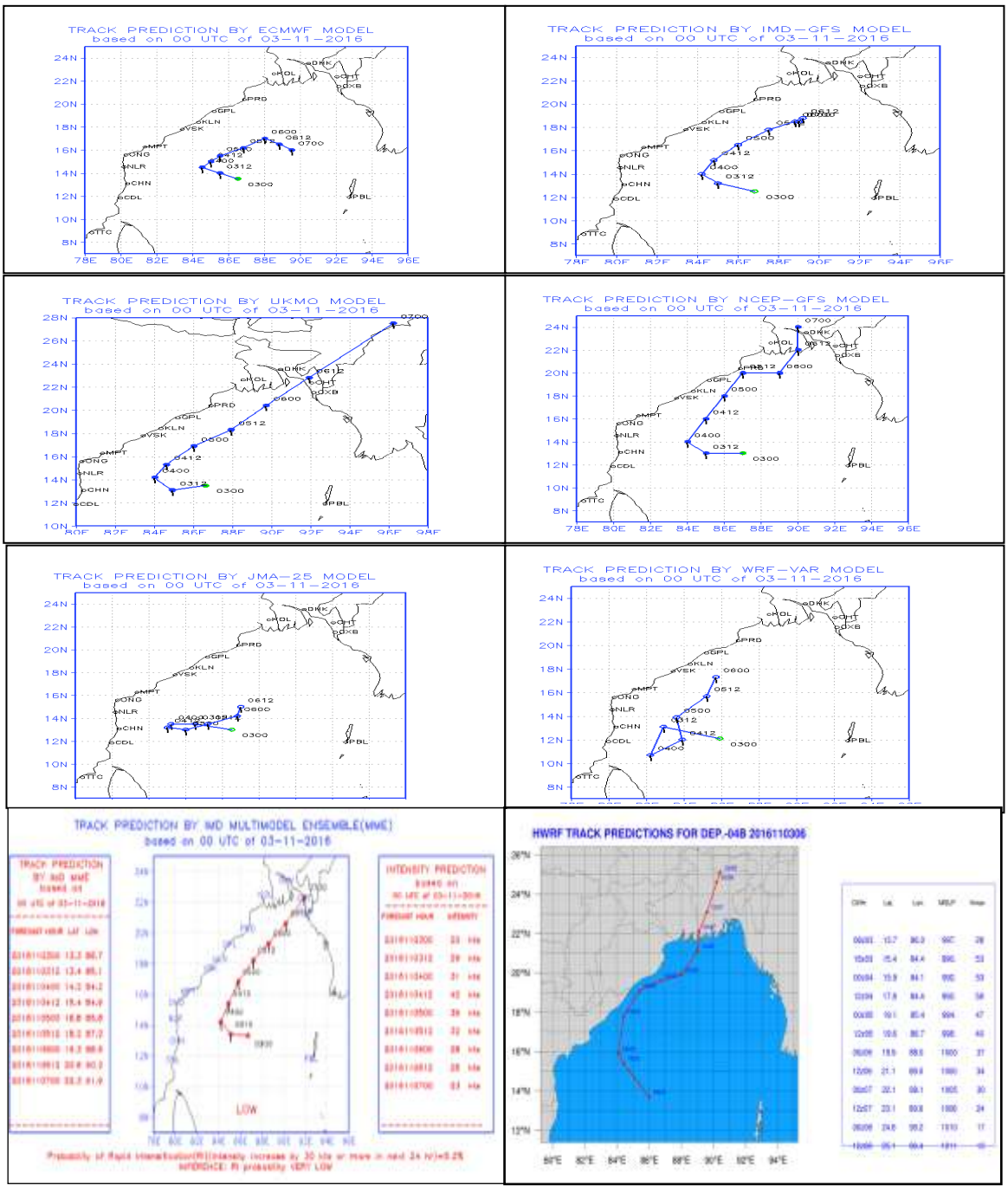


Fig. 11a. Track prediction by NWP models based on 0000 UTC of 3rd Nov. 2016

Based on initial conditions of 0000 UTC of 4th Nov ECMWF, WRF-VAR and JMA showed dissipation over sea. NCEP GFS, MME and HWRF predicted northward recurvature and landfall over southwest Bangladesh. UKMO (at 1800 UTC of 6th Nov.) over southeast Bangladesh. Most of the models suggested movement of cyclone close to east coast of India, northeast recurvature and landfall over Bangladesh. WRF predicted looping track.

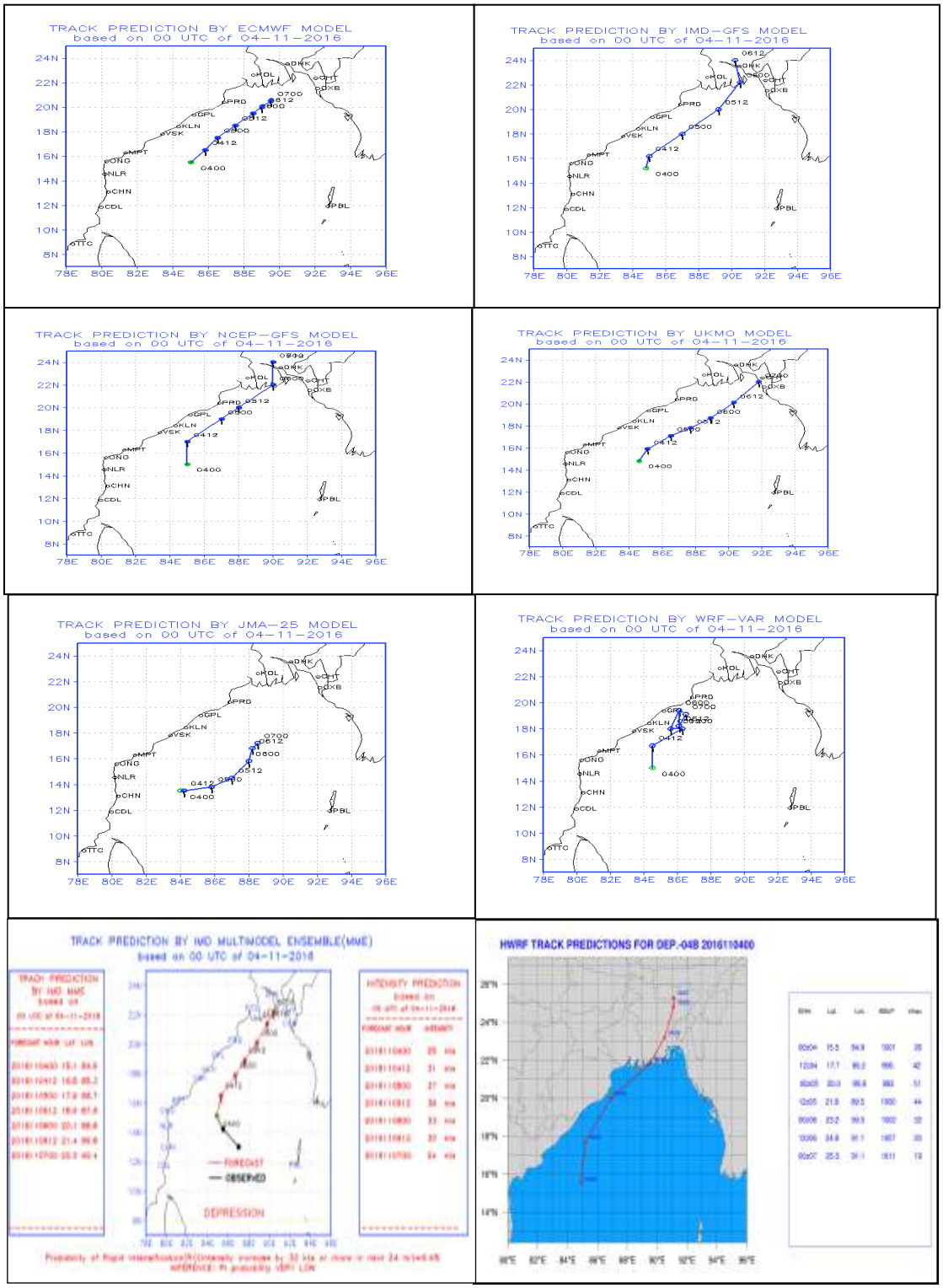


Fig.11 b. Track prediction by NWP models based on 0000 UTC of 4th Nov. 2016

Based on initial conditions of 0000 UTC of 5th Nov, ECMWF, UKMO, WRF-VAR and JMA showed dissipation over sea. All others including NCEP GFS, UKMO, MME and HWRF predicted northward recurvature and landfall over southwest Bangladesh.

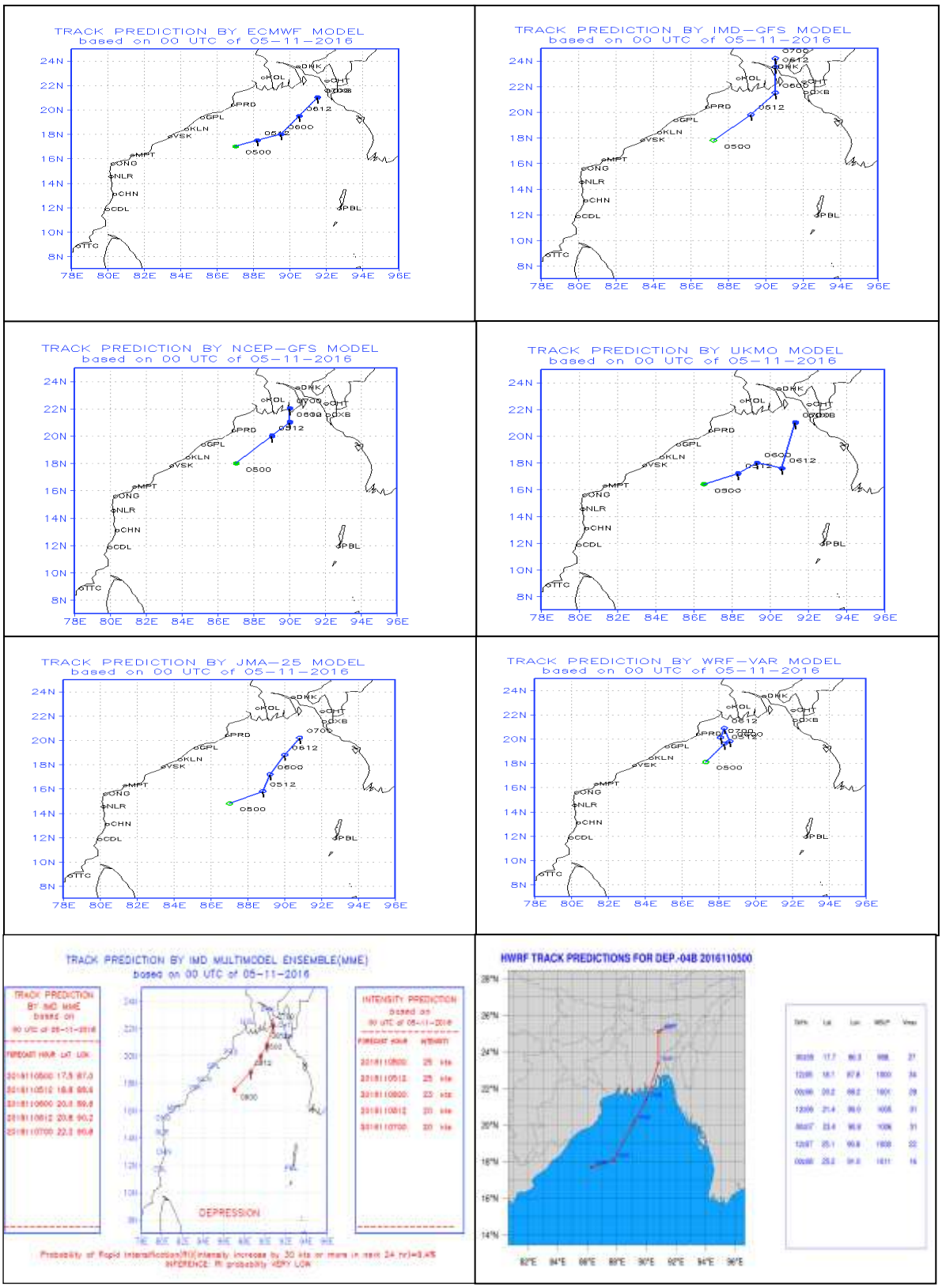


Fig. 11c. Track prediction by NWP models based on 0000 UTC of 5th Nov. 2016

Ensemble Prediction System

The probabilistic and deterministic track forecast by Meteorological service Canada (MSC), National Centre for Environment Prediction (NCEP) and consolidated forecast by both centres based on initial conditions of 1200 UTC of 4th Nov. are presented in Fig. 12. MSC predicted 5-20% strike probability over Bangladesh and NCEP members showed 40-60% strike probability over Bangladesh. All members predicted 20-40 % strike probability over Bangladesh. Individual deterministic tracks by MSC showed large variation and those by NCEP showed landfall over Bangladesh.

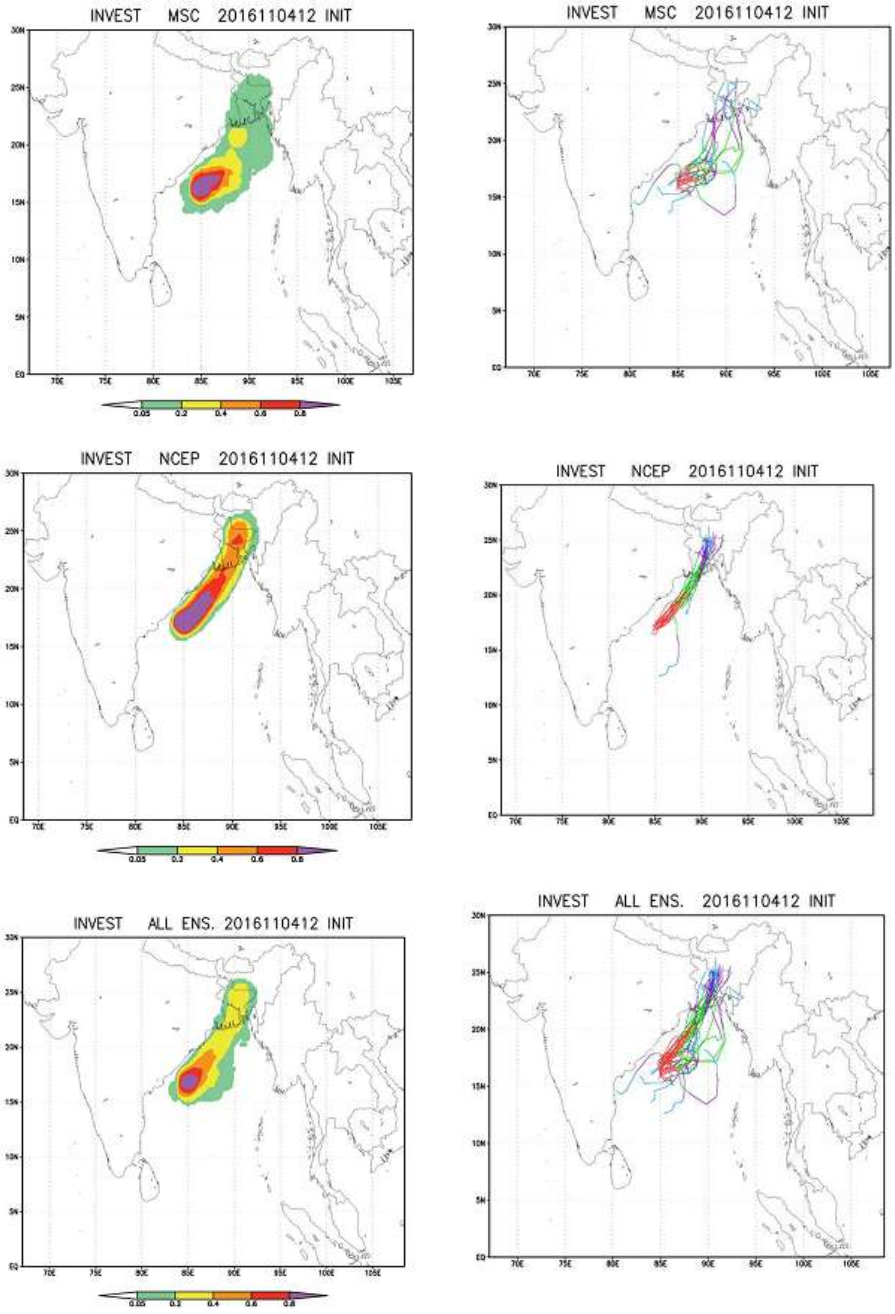


Fig. 12 (a): EPS track and strike probability forecast based on 1200 UTC of 4th Nov. 2016

Based on initial conditions of 1200 UTC of 5th Nov., MSC predicted 5-20% strike probability of landfall over Bangladesh. NCEP and all members did not pick up this system. Individual deterministic tracks showed landfall over Bangladesh.

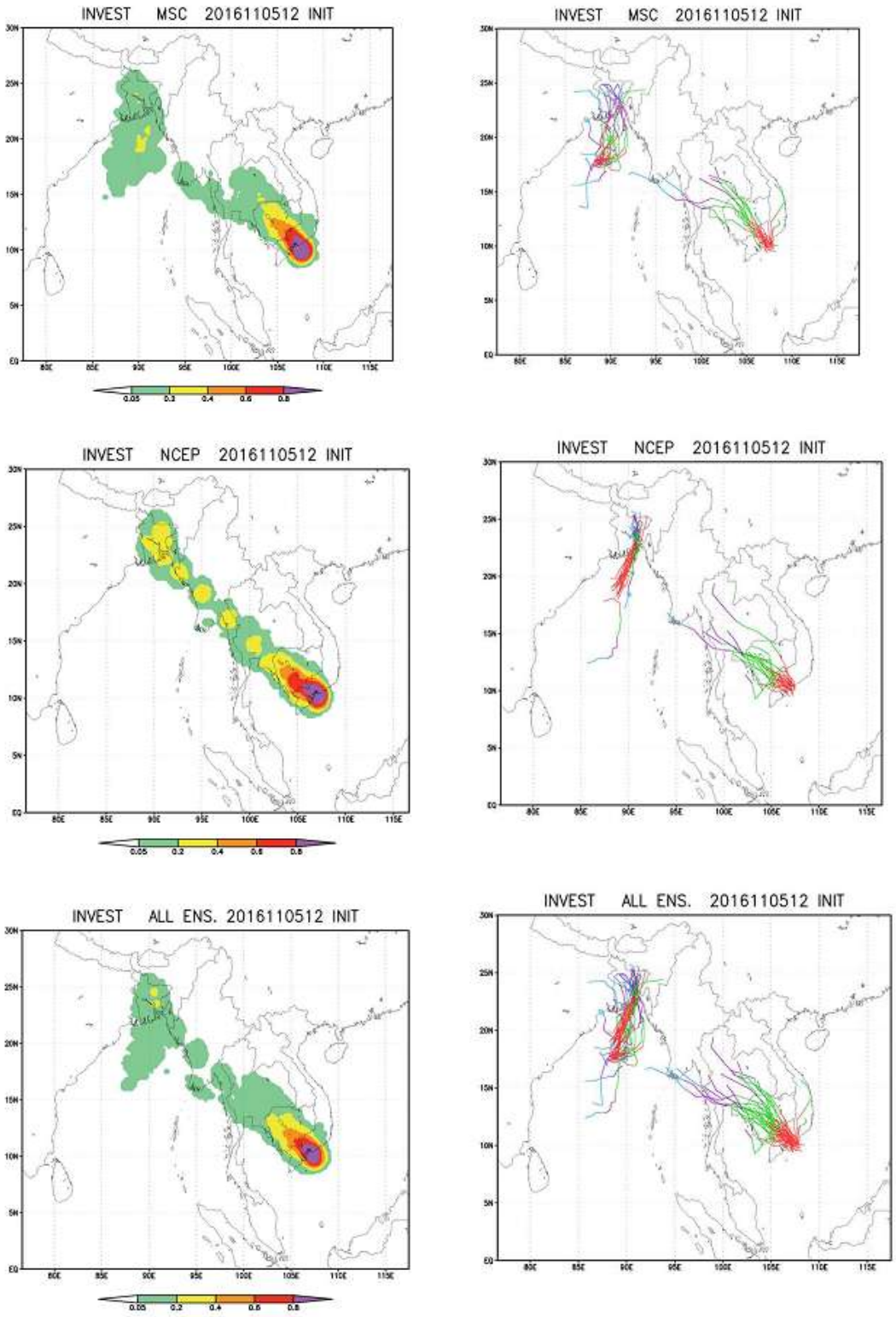


Fig.11 (a): EPS track and strike probability forecast based on 1200 UTC of 5th Nov. 2016

10.3 Track and intensity forecast errors by various NWP Models

The average track forecast errors (Direct Position Error) in km at different lead period (hr) of various models are presented in Table 3. The average cross track errors (CTE) and along track errors (ATE) are presented in Table 4 (a-b). From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors of UKMO were significantly less for all lead periods. Average track errors of IMD-MME followed by HWRF were the least for 24 hours lead period. For 48 hours lead period, average track errors were the least by NCEP GFS followed by IMD GFS and MME. For 72 hours lead period, average track errors were the least by UKMO, followed by NCEP GFS and MME.

Table 3. Average track forecast errors (Direct Position Error (DPE)) in km

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
IMD-GFS	87(3)	137(3)	123(2)	165(2)	184(1)	320(1)
IMD-WRF	145(3)	304(3)	415(2)	510(2)	522(1)	661(1)
JMA	268(3)	376(3)	461(2)	588(2)	716(1)	830(1)
NCEP-GFS	114(3)	161(3)	90(2)	115(2)	210(1)	216(1)
UKMO	135(3)	194(3)	141(2)	193(2)	115(1)	136(1)
ECMWF	105(3)	164(3)	143(2)	267(2)	370(1)	501(1)
IMD-HWRF	84(9)	114(6)	212(6)	224(4)	232(3)	359(1)
IMD-MME	64(3)	131(3)	109(2)	168(2)	181(1)	284(1)

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

Table 4 (a). Average cross-track forecast errors (CTE) in km

Lead time →	**12 hr**	**24 hr**	**36 hr**	**48 hr**	**60 hr**	**72 hr**
IMD-GFS	69	119	53	103	87	103
IMD-WRF	122	211	241	288	264	336
JMA	181	227	294	258	202	79
NCEP-GFS	88	100	70	101	201	160
UKMO	111	129	49	16	61	115
ECMWF	87	105	50	92	113	103
IMD-HWRF	10	78	127	173	191	251
IMD-MME	59	74	55	77	129	162

Table 4 (b). Average along-track forecast errors (ATE) in km

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
IMD-GFS	43	58	110	105	162	303
IMD-WRF	65	173	330	415	450	569
JMA	162	265	327	522	687	826
NCEP-GFS	64	103	34	29	60	145
UKMO	68	127	127	192	97	72
ECMWF	48	115	134	250	353	490
IMD-HWRF	77	112	168	176	164	201
IMD-MME	19	92	94	149	127	233

Above tables show that DPE was largely contributed by ATE, that is errors in speed of movement of the storm, whereas CTE shows that forecast tracks were close to the observed track.

The intensity forecasts of IMD-SCIP model and HWRF model are shown in Table 5. The probability of rapid intensification (RI) index of IMD is shown in Table 6. It correctly predicted no RI for the system.

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

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
IMD-SCIP (AAE)	3.3(3)	6.7(3)	14.0(2)	11.0(2)	7.0(1)	3.0(1)
HWRF (AAE)	14 (9)	17 (8)	15 (6)	15 (4)	11 (3)	10 (1)
IMD-SCIP (RMSE)	4.2	7.8	14.3	11.4	7.0	3.0
HWRF (RMSE)	10.9 (9)	18.5 (8)	16.5 (6)	16.0 (4)	14.4 (3)	10 (1)

( ) : No of forecasts verified

The average errors in intensity prediction by SCIP model were less for all lead periods compared to HWRF. HWRF model over-predicted the intensity of the system.

Table 8: Probability of Rapid intensification

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Intensity changes(kt) occurred in 24h
00UTC/03.11.2016	5.2 %	VERY LOW	0
00UTC/04.11.2016	9.4 %	VERY LOW	0
00UTC/05.11.016	9.4 %	VERY LOW	0

11. Operational Forecast Performance

11.1. Adverse weather forecast verification

The verifications of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Table 9-10. It is found that all the adverse weather were predicted accurately and well in advance.

Table9 : Heavy Rainfall warning issued by IMD and realized heavy rainfall

Date /Time	Warning issued	Realized heavy rainfall (7 cm or more) during past 24 hrs ending at 0830 hrs IST of date
03-11-2016/ 0830 IST	Isolated heavy rainfall over north coastal Andhra Pradesh on 4th and isolated heavy to very heavy rainfall over coastal Odisha and coastal West Bengal on 4th & 5th. Isolated heavy rainfall over Mizoram & Tripura during 4-6th and over Manipur and south Assam on 5th & 6th November.	**4 Nov. 2016:** **Gangetic west Bengal**: Contai-7 **Puducherry**: Kangeyam-7, Rameswaram-7 **5 Nov. 2016:** **Assam :** Karimganj-9, , **Odisha:** Tirtol and Paradip-10 each, Marsaghai -9, Astaranga-8, Derabisi,Chandbali, Garadapur-8 each, Balikuda, Kendrapara, Kujanga and Rajkanika-7 each, **6 Nov. 2016:** **Assam & Meghalaya**: B.P ghat-9 and Karimganj-9 each, Halflong-7, **Nagaland, Manipur, Mizoram & Tripura:** Arundhutinagar-13, Khowai-12, Agartala airport, Kailashahar airport-12 each, Kamalpur-11, Bishalgarh-11, Udaipur, Gokulpur-10 each, Belonia, Sonamura-9 each, Sabroom-8, Aizwal-7, **7 Nov. 2016:** **Assam & Meghalaya:** B.P.Ghat-13, Halflong-10, Karimganj-8, Lumding-7, **Nagaland, Manipur, Mizoram & Tripura:** Gokulpur, Udaipur, Amarpur, Bishalgarh-11 each, Khowai-10, Wokha, Kailashahar airport, Belonia-8 each, Chhamonu, Jharnapani-7 each.
04-11-2016/ 0830 IST	Isolated heavy rainfall over north coastal Andhra Pradesh on 4th and isolated heavy to very heavy rainfall over coastal Odisha and coastal West Bengal on 4th & 5th. Isolated heavy rainfall over Mizoram & Tripura during 4-6th and over Manipur and south Assam on 5th & 6th November.	
05-11-2016/ 0830 IST	Isolated heavy to very heavy rainfall on 5th and isolated heavy falls on 6th over coastal West Bengal. Isolated heavy falls over Mizoram, Tripura, Manipur, eastern Meghalaya and south Assam on 5th & 6th November.	
06-11-2016/ 0830 IST	Isolated heavy to very heavy falls over Mizoram and Tripura on 6th November. Isolated heavy falls over south Assam, Nagaland and Manipur on 6th November.	

Table 10: Wind warning issued by IMD and realized Wind		
Date /Time(IST) of issue	**Warning issued**	**Realized wind speed during past 24 hrs ending at 0830 hrs IST of date**
03-11-2016/ 0830 IST	Squally winds speed reaching 40-50 kmph gusting to 60 kmph along & off north Andhra Pradesh coast on 4th, Odisha coast on 4th & 5th and West Bengal coast from 4th to 6th Nov.	Based on coastal observation and scatterometery observations, wind speed of 40-50 kmph prevailed along and off Odisha coast on 4th and 5th November, West Bengal coast on 5th and 6th November
04-11-2016/ 0830 IST	Squally winds speed reaching 45-55 kmph gusting to 65 kmph along & off north Andhra Pradesh coast on 4th, Odisha coast on 4th & 5th and West Bengal coast from 4th to 6th Nov.	
05-11-2016/ 0830 IST	Squally winds speed reaching 45-55 kmph gusting to 65 kmph along & off north Andhra Pradesh coast during next 12 hrs, south Odisha coast on 5th and north Odisha & West Bengal coasts on 5th & 6th November.	
06-11-2016/ 0830 IST	Squally winds speed reaching 40-50 kmph gusting to 60 kmph along & off West Bengal coast during next 12 hours.	

12. Summary and Conclusion:

The system developed from a low pressure area over south Andaman Sea and neighbourhood in the morning of 1st November and concentrated into a depression in the night of 2nd over eastcentral and adjoining southeast BOB. The system followed clockwise recurving track. Though the thermodynamical parameters, vorticity and upper level divergence were favourable, the system did not intensify because of high vertical wind shear, cold air intrusion from northwest and low ocean thermal energy over north BoB. The system dissipated near southeast Bangladesh & adjoining northeast BoB

IMD utilised all its resources to monitor and predict the genesis, track and intensification of the system. The forecast of its genesis, its track, intensity, point & time of landfall, were predicted well with sufficient lead time. Its movement away from Indian coast was also predicted well in advance with high confidence.

14. Acknowledgements:

RSMC New Delhi duly acknowledges the contribution of the valuable inputs and guidance from NCMRWF, INCOIS and NIOT Chennai. The inputs from Agricultural Meteorology Division, Pune, NWP Division, ISSD and Satellite Division at IMD HQ New Delhi and Area Cyclone Warning Centre (ACWC) Chennai & Kolkata and Cyclone Warning Centre (CWC) Vishakhapatnam & Bhubaneswar are also appreciated.