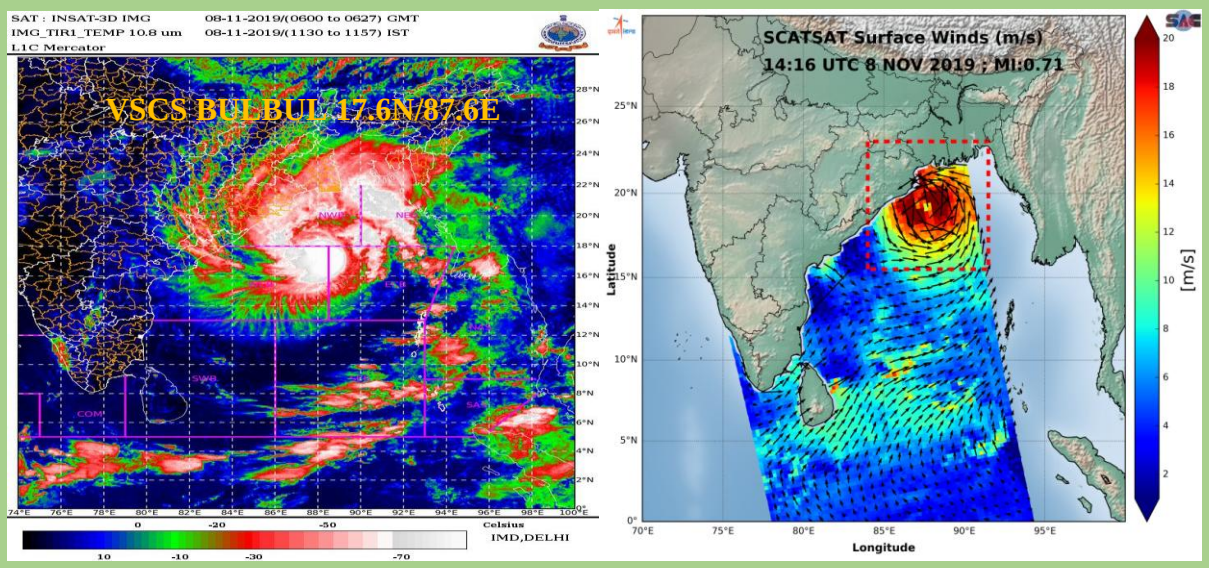
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Very Severe Cyclonic Storm "BULBUL" over the Bay of Bengal (05th – 11th November 2019): A Report



INSAT-3D enhanced colored IR imagery (06 UTC) & SCATSAT surface winds of 8th November, 2019

Cyclone Warning Division

India Meteorological Department

New Delhi

Very Severe Cyclonic Storm "BULBUL" over the Bay of Bengal
(05-11 November 2019)

1. Introduction

The Very Severe Cyclonic Storm (VSCS) "BUL BUL" originated from the remnant of Severe Tropical Storm 'MATMO' (28th October - 2nd November) over west Pacific Ocean that emerged into north Andaman Sea. It formed as a low pressure area over north Andaman Sea in the early morning (0000 UTC) of 04th November. It lay as a well marked low pressure area (WML) over north Andaman Sea & neighbourhood in the afternoon (0900 UTC) of 04th November. Moving west-northwestwards, under favourable environmental conditions it concentrated into a Depression (D) over east central and adjoining southeast Bay of Bengal (BoB) in the early morning (0000 UTC) of 05th November. Moving nearly west-northwestwards, it intensified into a deep depression (DD) over east central and adjoining southeast BoB in the early morning (0000 UTC) of 06th November. It moved north- northwestwards and intensified into cyclonic storm "BUL BUL" in the late night (1800 UTC) of 06th November over eastcentral and adjoining southeast BoB. Continuing to move north-northwestwards it further intensified into a severe cyclonic storm (SCS) in the evening of 07th November (1200 UTC) over westcentral and adjoining eastcentral BoB. Moving nearly northwards, it further intensified into a VSCS in the early morning (0000 UTC) of 08th November over westcentral and adjoining eastcentral BoB. It continued to move nearly northwards until the afternoon (0900 UTC) of 09th November and then started to re-curve northeastwards from the evening (1200 UTC) of the same day. Subsequently, it weakened into an SCS and crossed West Bengal coast, close to Sunderban Dhanchi Forest near 21.55°N/88.0°E during the night (1500 to 1800 UTC) of 09th November as SCS with maximum sustained surface wind speed of 110-120 kmph gusting to 135 kmph. Continuing to move northeastwards, it weakened into a CS over coastal Bangladesh & neighbourhood in the early morning (0000 UTC) of 10th November. It then moved east-northeastwards, weakened into a DD over coastal Bangladesh & neighbourhood in the same afternoon (0900 UTC) and into a depression in the early morning (0000 UTC) of 11th November over southeast Bangladesh & adjoining Tripura and into a WML over southern parts of Tripura & neighbourhood in the morning hours (0300 UTC) of 11th November. The observed track of the system during 05th – 11th November is presented in **Fig.1a**. Best Track parameters associated with the system are presented in **Table1**.

2. Salient Features:

The salient features of the system were as follows:

i. It was the third Cyclonic Storm developing over the Bay of Bengal this year and the second in severe category after the Extremely Severe Cyclonic Storm 'FANI' over the Bay of Bengal, during 2019, against the normal (1891-2018) of 4 per year.

ii. It was the third severe cyclonic storm crossing West Bengal coast in November during 1891-2018. During the past (1891 – 2018), a total of 22 intense low pressure systems had genesis as Depression over the eastcentral BoB in the month of November [**Fig.2 (a**)]. Out of this, only 7 systems intensified into severe cyclone stage and above. [**Fig.2 (b**)]. Among these, 4 of them exhibited northeastward re-

curving track, similar to VSCS 'BUL BUL' and moved towards west Bengal – Bangladesh – Myanmar coasts. The remaining 3 made landfall over north Andhra Pradesh coast, south Andhra Pradesh coast and Tami Nadu coast.

iii. At the same time, there was another intense low pressure system, Viz., Extremely Severe Cyclonic Storm 'MAHA' over the Arabian Sea (AS) during 30th October – 7th November **(Fig. 1b)**. Considering the data during satellite era (1961 onwards), simultaneous occurrence of two VSCSs, one each over the BoB & AS happened twice, in the past. (a) In October 2018 with development of VSCS Luban over AS (06-15 October) and VSCS Titli (08-13 October) over BoB and (b) in November 1977, viz. (i) Bay of Bengal Cyclonic Storm (14-20 Nov., 1977) which crossed Andhra Pradesh coast near Chirala on 19th Nov. and (ii) Bay of Bengal VSCS (09-23rd Nov., 1977) which crossed Tamil Nadu coast close to south of Nagapattinam on 12th Nov. and then emerged into Arabian Sea, made a looping track, intensified into an SCS, weakened thereafter and crossed Karnataka coast to the north of Mangaluru on 29th Nov. as a depression. (**Fig.2**)

iv. It had a brief westward track initially, followed by a nearly northward and then northeastward re-curving track prior to landfall with length of 1644 km. It was mainly steered by the winds at the periphery of an anticyclone in middle & upper tropospheric levels to the northeast of the system centre.

v. It did not exhibit any rapid intensification during its life cycle. Gradual intensification occurred as the system gained Latitude. Favourable vertical wind shear environment, poleward outflow aided by the anti-cyclone to the northeast of the system along with high Sea Surface Temperatures (29 - 30ºC), aided the system to mature into a VSCS.

vi. The peak MSW of the cyclone was 135-145 kmph (75 knots) gusting to 160 kmph during 0600 UTC of 08th November to 1200 UTC of 09th November over the westcentral and adjoining northwest BoB. The lowest estimated central pressure was 976 hPa during 1200 UTC of 08th November to 0000 UTC of 09th November.

vii. BUL BUL weakened slightly prior to crossing (from 0300 UTC of 09th November onwards) the Sunderban Delta owing to increased vertical wind shear and Land interaction.

viii. The system crossed West Bengal coast close to Sunderban Dhanchi Forest near 21.55°N/88.5°E between 1500 UTC and 1800 UTC of 09th November, 2019 with maximum sustained wind speed of 110-120 kmph gusting to 135 kmph.

ix. The system maintained the severe cyclonic storm intensity, for 4 more hours after crossing and subsequently maintained the cyclonic storm intensity for subsequent 09 hours over the land, owing to its proximity with sea water surrounding the Deltaic zone.

x. The life period (D to D) of the system was 144 hours (06 days) against long period average (LPA) (1990-2013) of 140 hours (5 days & 20 hrs) for VSCS categories over the BoB during post monsoon season.

xi. It moved slower as 12 hour average translational speed was about 11.2 kmph against LPA (1990-2013) of 14.3 kmph for VSCS category over north Indian Ocean.

xii. The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 8.55 X10^2 knots, 5.21 X 10^4

knots^2 and 3.35 X10^6 knots^3 respectively against long period average during 1990-2013 of 5.28 X10^2 knots, 8.6 X 10^4 knots^2 and 2.8 X10^6 knots^3 respectively.

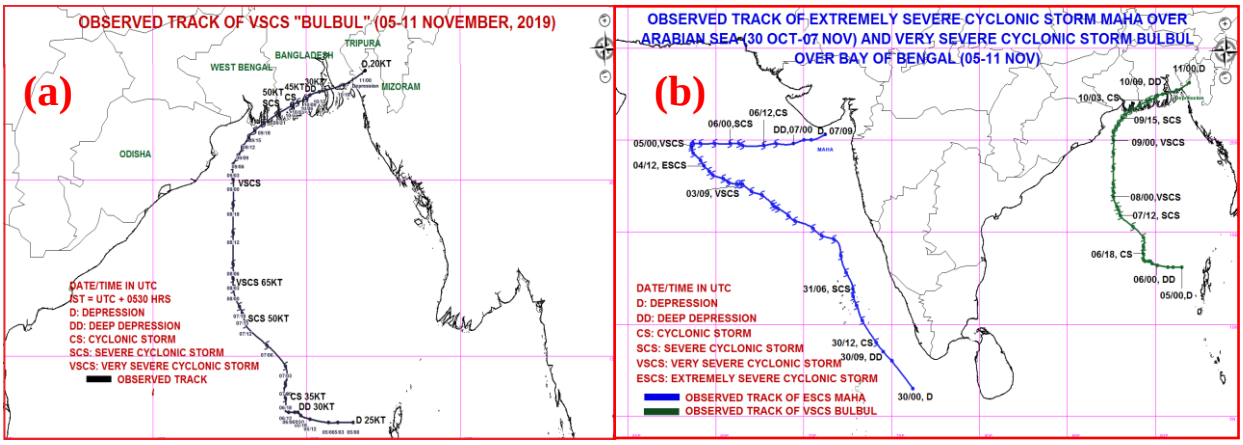


Fig.1: (a) Observed track of VSCS 'BUL BUL' over the Bay of Bengal (05-11 November, 2019) and (b) observed tracks of extremely severe cyclonic storm Maha (30 Oct-07 Nov) and VSCS Bulbul (05-11 Nov)

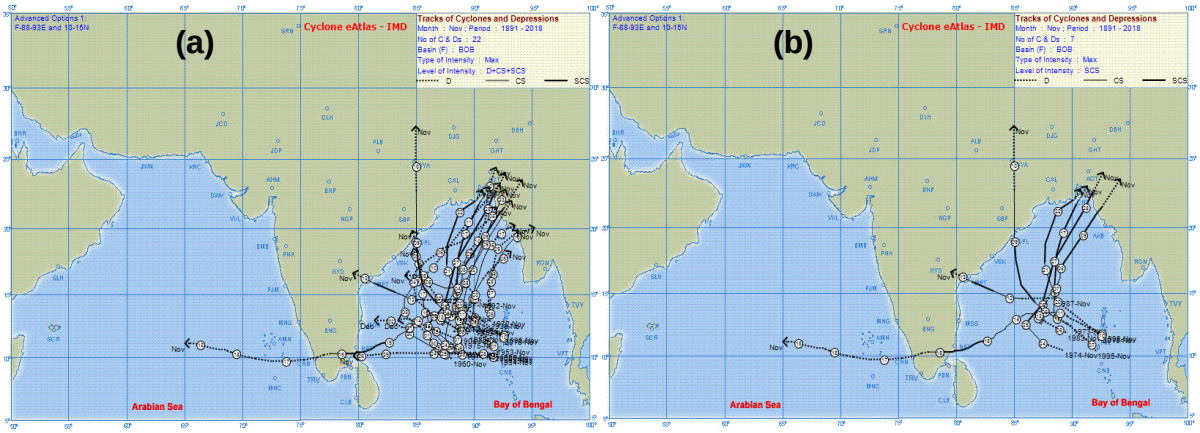


Fig.2: (a) Past tracks of severe cyclonic storms forming over the BoB of similar genesis and (b) and those intensified into Severe Cyclonic Storms in the month of November (1891-2018)

3. Brief life history

3.1. Genesis

It originated from the remnant of severe Tropical Storm 'MATMO' (28th October - 2nd November) over west Pacific Ocean that emerged into north Andaman Sea. This remnant developed into an LPA over north Andaman Sea in the early morning (0000 UTC) of 04th November and into a WML over north Andaman Sea & neighbourhood in the afternoon (0900 UTC) of 04th November.

3.2. Intensification and movement

At 0300 UTC of 5th November, the sea surface temperature (SST) was about 29-30°C around the system. The tropical cyclone heat potential (TCHP) was 60-80 KJ/cm^2 around the system center and was increasing along the forecast track to 80-100 KJ/cm^2. The low level relative vorticity was 70 X10^{-5}s^{-1} to the south of system centre. The lower level convergence was about 10 x10^{-5} s^{-1} around the system centre and the upper level divergence was about 20 x10^{-5} s^{-1} to the southwest of system center. The vertical wind shear was 10-15 knots over the system area and along the forecast track. The upper

tropospheric ridge roughly ran along 15°N and lay to the north of the system area. Under these favourable conditions, the system intensified into a depression over eastcentral and adjoining southeast BoB and north Andaman Sea near 13.1°N /91.0°E.

At 0000 UTC of 6th November, the SST was about 29-30°C around the system and TCHP was 80-100 KJ/cm^2 around the system center. The low level relative vorticity increased and was about 150 X10^{-5}s^{-1} to the south of the system centre. The lower level convergence was about 10 x10^{-5} s^{-1} around the system centre and the upper level divergence was about 20 x10^{-5} s^{-1} to the southwest of system center. The vertical wind shear was moderate (15-20 knots) over the system area. The ridge roughly ran along 15°N to the north of the system. Under these favourable conditions, the system moved nearly westwards and intensified into a deep depression near 13.4°N/89.7°E.

At 2300 UTC of 6th, similar sea conditions prevailed. The vertical wind shear was moderate (15-20 knots) over the system area and it was increasing becoming high (20-25 knots) along the forecast track. The low level relative vorticity was about 150 X10^{-5}s^{-1} to the south of the system centre. The lower level convergence was about 20 X10^{-5} s^{-1} around the system centre and the upper level divergence was about 30 X10^{-5} s^{-1} to the southwest of system center. The ridge roughly ran along 15°N to the north of the system area. Under these conditions, the system moved northwestwards and intensified into a CS over eastcentral and adjoining southeast BoB near 13.8°N/89.3°E.

At 1200 UTC of 7th, similar sea conditions prevailed. The low level relative vorticity increased and was about 200 X10^{-5}s^{-1} to the south of system centre. The lower level convergence was about 20 x10^{-5} s^{-1} close to the system centre and the upper level divergence was about 30 x10^{-5} s^{-1} around the system center. The vertical wind shear was moderate (15-20 knots) over the system area and was high (20-25 knots) to the west of system centre. The upper tropospheric ridge ran roughly along 20°N over the BoB. The anticyclonic circulation over North Thailand steered the system north-northwestwards. At the same time, an upper tropospheric trough in westerlies was also approaching towards the system. As a result from 9th onwards, the system was expected to recurve northeastwards from 9th onwards and after recurvature, it was expected to experience high vertical wind shear and colder sea. Under these conditions, the system moved intensified into an SCS and lay centered over westcentral and adjoining eastcentral BoB near latitude 15.9°N/88.0°E.

At 0000 UTC of 8th, similar sea conditions persisted. The low level relative vorticity was about 200 X10^{-5}s^{-1} to the south of the system centre. The lower level convergence was about 20 x10^{-5} s^{-1} close to the system centre. The upper level divergence increased and was about 40 x10^{-5} s^{-1} around the system center. The vertical wind shear was moderate (15-20 knots) over the system area and was about 20-25 knots to the west of the system centre. The ridge ran roughly along 20°N over Bay of Bengal region in association with anticyclonic circulation centered over North Thailand. Under these conditions, the system moved north-northwestwards and intensified into a VSCS over westcentral and adjoining eastcentral BoB near latitude 16.9°N/87.6°E.

At 0300 UTC of 9th, similar sea conditions persisted. The low level relative vorticity was about 200 X10^{-5}s^{-1} around the system entre. The lower level convergence was about 30 x10^{-5} s^{-1} around the system centre. The upper level divergence increased was about 20 x10^{-5} s^{-1} around the system center. The vertical wind shear was high (20-25 knots) north-northwest of system centre. The ridge ran roughly along 20°N over the Bay of Bengal region in association with anticyclonic circulation centered over North Thailand. Under these conditions, the system moved north-northwestwards and weakened slightly over northwest BoB near latitude 20.4°N/87.6°E.

At 1500 UTC of 9th, the TCHP was <50 KJ/cm^2. SST was 27-29°C over the system area. The low level relative vorticity was around 250 X10^{-5}s^{-1} around the system centre. The lower level convergence was about 20 x10^{-5} s^{-1} and the upper level divergence was

about 40-50 $x10^{-5}$ s^{-1} around the system centre. The vertical wind shear increased and was high (25-30 knots) to the north-northwest of the system centre and was also further increasing along the forecast track becoming high along West Bengal – Bangladesh coasts. The ridge ran roughly along 21°N over the BoB region. The system was lying to the north of the upper tropospheric ridge. Under the influence of southwesterly winds prevailing to the north of ridge, the system moved northeastwards and lay over northwest BoB near 21.4°N/88.3°E. It weakened into an SCS, under the influence of high vertical wind shear, low TCHP and land surface interactions. Continuing to move northeastwards, it crossed West Bengal coast close to Sunderban Dhanchi forest near 21.55°N/88.5°E during 1500 to 1800 UTC of 9th November.

At 0000 UTC of 10th, the low level relative vorticity further decreased and was around 200 $X10^{-5}s^{-1}$ to southwest of the system centre. The lower level convergence was about 20 $x10^{-5}$ s^{-1} to the south of system centre and the upper level divergence is about 40 x 10^{-5} s^{-1} to the southwest of system centre. The vertical wind shear was high (25-30 knots) over the system centre. The ridge ran along 21°N over BoB region. Under these conditions, it further weakened into a CS over coastal Bangladesh and neighborhood near 22.1°N /89.5°E.

At 0900 UTC of 10th, the low level relative vorticity further decreased and was around 100 $X10^{-5}s^{-1}$ around the system centre. The lower level convergence also decreased and was about 20 $x10^{-5}$ s^{-1} to the southeast of the system centre and the upper level divergence remained the same and was about 30 $x10^{-5}$ s^{-1} to the southeast of the system centre. The vertical wind shear was high (30-40 knots) over the system centre. The system was lying underneath the mid-latitude westerlies. Hence, the system moved east-northeastwards under the influence of west-southwesterly winds in the mid and upper tropospheric levels. Under these conditions, it further weakened into a DD over coastal Bangladesh and neighborhood near 22.4°N /90.1°E.

At 0000 UTC of 11th, the low level relative vorticity further decreased and was around 50 $X10^{-5}s^{-1}$ around the system centre. The lower level convergence also decreased and was about 5 $X10^{-5}$ s^{-1} to the southeast of the system centre and no upper level divergence prevailed over the system. The vertical wind shear was high (40 knots) over the system centre. Mid-latitude westerlies prevailed over the system. Moving east-northeastwards, it further weakened into a Depression over southeast Bangladesh and adjoining south Tripura near 23.1°N / 91.9°E and into a WML over south Tripura and neighbourhood at 0300 UTC of 11th.

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm, 'BUL BUL' over Bay of Bengal during 05 - 11 Nov, 2019.

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
05/11/2019	0000	13.1	91.5	1.5	1004	20	03	**D**
	0300	13.1	91.0	1.5	1003	25	03	D
	0600	13.1	90.7	1.5	1003	25	03	D
	1200	13.2	90.1	1.5	1003	25	03	D
	1800	13.3	89.8	1.5	1002	25	04	D
06/11/2019	0000	13.4	89.7	2.0	1001	30	05	**DD**
	0300	13.4	89.6	2.0	1001	30	05	DD
	0600	13.4	89.4	2.0	1001	30	05	DD
	1200	13.5	89.3	2.0	1000	30	06	DD

	1800	13.8	89.3	2.5	998	35	07	**CS**
07/11/2019	0000	14.2	89.3	2.5	998	35	07	CS
	0300	14.7	89.3	2.5	998	35	07	CS
	0600	15.3	88.7	2.5	996	40	08	CS
	0900	15.5	88.4	3.0	995	45	09	CS
	1200	15.9	88.0	3.0	994	45	10	CS
	1500	16.2	87.9	3.0	992	50	12	**SCS**
	1800	16.4	87.8	3.5	989	55	15	SCS
	2100	16.6	87.7	3.5	986	60	18	SCS
08/11/2019	0000	16.9	87.6	4.0	983	65	21	**VSCS**
	0300	17.2	87.6	4.0	982	65	22	VSCS
	0600	17.6	87.6	4.0	980	70	24	VSCS
	0900	18.1	87.6	4.0	980	70	24	VSCS
	1200	18.5	87.6	4.0	976	75	28	VSCS
	1500	19.2	87.7	4.0	976	75	28	VSCS
	1800	19.3	87.6	4.0	976	75	28	VSCS
	2100	19.6	87.7	4.0	976	75	28	VSCS
09/11/2019	0000	20.0	87.6	4.0	976	75	28	VSCS
	0300	20.4	87.6	4.0	980	70	24	VSCS
	0600	20.6	87.8	4.0	982	70	22	VSCS
	0900	20.9	87.9	4.0	982	70	22	VSCS
	1200	21.2	88.1	4.5	982	70	22	VSCS
	1500	21.4	88.3	4.5	986	60	18	**SCS**
	Crossed West Bengal Coast close to Sunderban Dhanchi forest near 21.55°N/88.5°E during 1500 to 1800 UTC of 9th November.							
	1800	21.6	88.6		990	60	18	SCS
	2100	21.9	89.1		996	50	12	SCS
10/11/2019	0000	22.1	89.5		998	45	10	**CS**
	0300	22.2	89.7		1000	40	08	CS
	0600	22.3	90.0		1000	40	08	CS
	0900	22.4	90.1		1002	30	06	**DD**
	1200	22.5	90.4		1002	30	05	DD
	1800	22.7	91.2		1002	30	05	DD
11/11/2019	0000	23.1	91.9		1004	20	03	**D**
	0300	Well marked Low pressure area over south Tripura & neighborhood						

The TPW imageries during 5th-10th November, 2019 are presented in **Fig.3**. These imageries indicate continuous warm and moist air advection from the southern sector into the system, till 7th November. From 8th onwards, the supply of warm moist air gradually reduced.

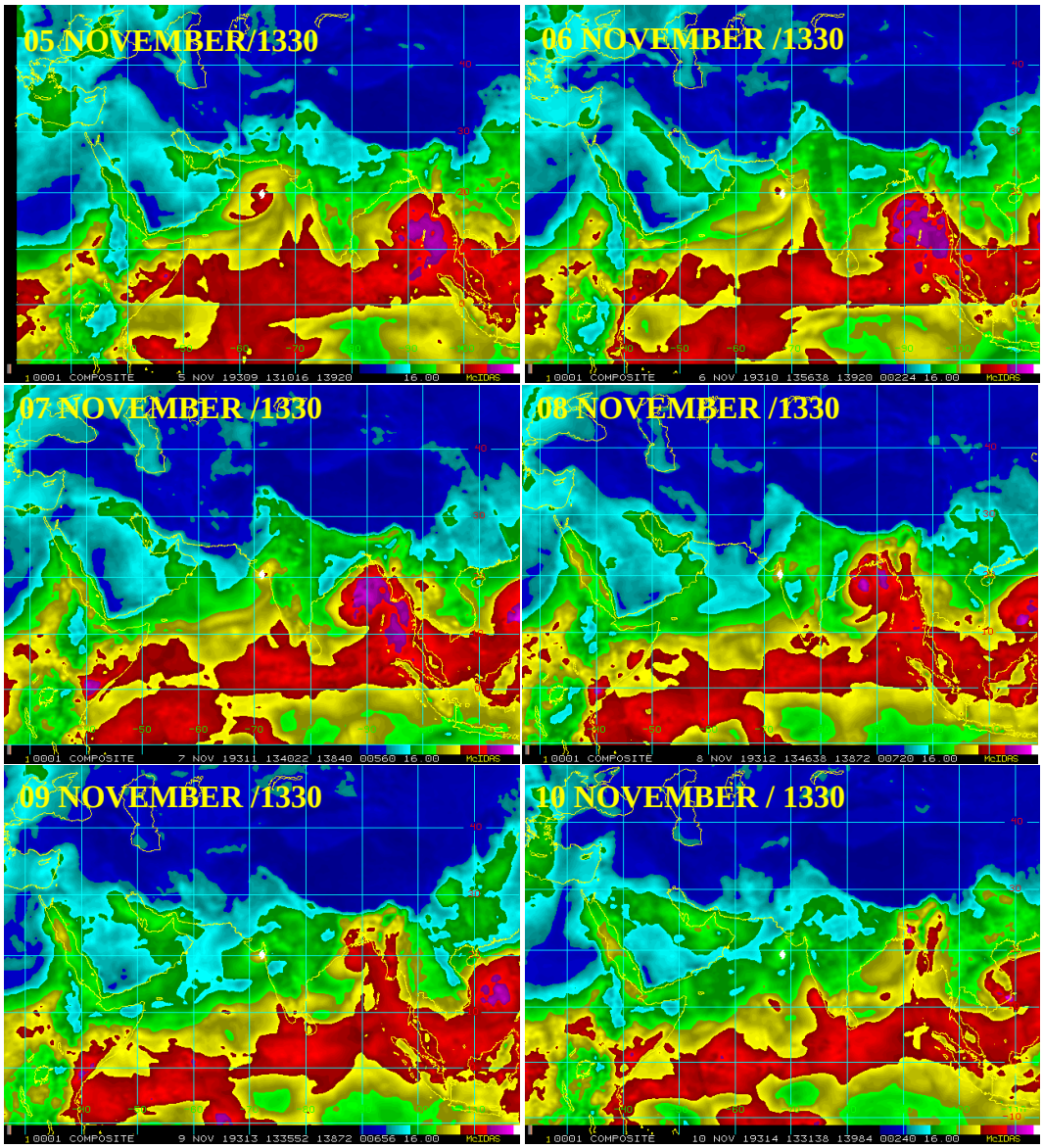


Fig. 3: Total Precipitable Water (TPW) imageries during VSCS BULBUL (05th-10th November, 2019)

The mean vertical wind shear (VWS) speed & direction in the layer 200 to 850 hPa and 500 to 850 hPa is presented in **Fig.4**. The mean wind shear around the system between 500 to 850 hPa levels remained moderate (around 20 knots) throughout the life cycle. However, in the layer between 200 to 850 hPa, it remained moderate till 6th November and thereafter, it increased gradually becoming high from 6th November onwards. The direction of mean VWS in the layer 200 to 850 hPa wind and 500 to 850 hPa was southwesterly during the period. It caused the convective cloud mass to be sheared to the northeast of the system centre.

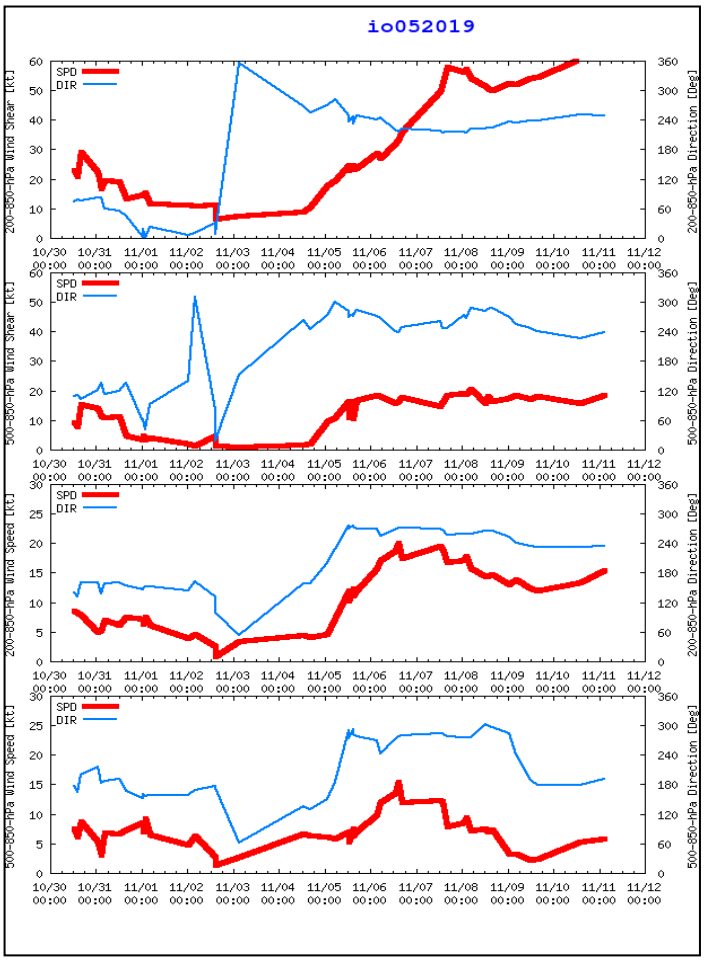


Fig.4 Wind shear and wind speed in the layers between 200 to 850 hPa and 500 to 850 hPa around the VSCS BULBUL (05-11 NOVEMBER, 2019)

From **Fig.4**, it is seen that from the genesis stage, the mean deep layer winds between 200-850 hPa levels steered the system initially northwestwards till 1200 UTC of 5th November and then northeastwards. Thus, the mean wind speed direction as represented in Fig. 4 couldn't explain the movement of the system. Actually, northeastwards movement started from 9th/0600 UTC onwards. The twelve hourly movement of VSCS Bulbul is presented in **Fig.5a**. The 12 hourly average translational speed of the cyclone was about 11.2 kmph and hence the cyclone was moving slower against the normal speed of 14.3 kmph.

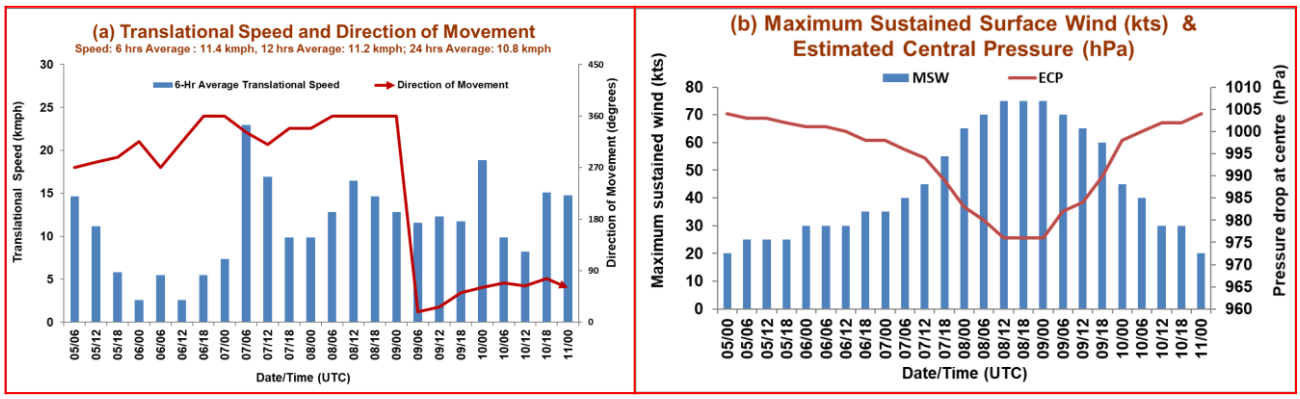


Fig.5: (a) Translational speed & direction of movement and (b) maximum sustained wind speed during life cycle of Bulbul

3.3 Maximum Sustained Surface Wind speed and estimated central pressure

The lowest estimated central pressure and the maximum sustained wind speed are presented in **Fig.5b**. The lowest estimated central pressure had been 976 hPa during 8th/1200-9th/0000 UTC. The estimated maximum sustained surface wind speed (MSW) was 75 knots during the same period with pressure drop of 28 hPa. Rapid intensification was seen during 8th/0000 UTC to 8th/1200 UTC. After landfall, the system also weakened rapidly during 10th/0000 to 10th/1800 UTC.

4. Monitoring of VSCS, 'BULBUL'

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the genesis of the cyclone was indicated about 12 days prior to the formation of depression over the BoB on 05th November. First information about possible cyclogenesis over Eastcentral BoB during later half of week (01-06 November) with low probability (01-33%) was indicated in the extended range outlook issued by IMD on 24th October 2019. Thus, the track of severe tropical storm MATMO was monitored and chances of its remnant emerging into the Indian Sea and likely intensification was predicted continuously from 24th October onwards by IMD.

The cyclone was monitored mainly with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites and available ships & buoy observations in the region. As the system came closer enough (within 400 km from the coast) to Odisha – West Bengal coasts, the Doppler weather RADARs of IMD along the east coast, viz., Gopalpur, Paradip & Kolkata were utilised for monitoring the system. Various numerical weather prediction models developed by Ministry of Earth Sciences (MoES) institutions and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the cyclone. A digitized forecasting system of IMD was utilized for analysis and comparison of various models' guidance, decision making process and warning product generation.

4.1. Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D and 3DR imageries. Satellite imageries of international geostationary satellites Meteosat-8 & SCATSAT and microwave & high resolution images of polar orbiting satellites DMSP, NOAA series, TRMM, Metops were also considered. Typical INSAT-3D visible/IR imageries, enhanced colored imageries and cloud top brightness temperature imageries are presented in **Fig.6**. The system showed curved band pattern during genesis and growth stage upto the intensity of CS. It has central dense overcast (CDO) pattern during SCS stage. It showed sheared pattern after landfall.

At 1200 UTC of 04th, the current intensity of the system was T 1.0. Broken low to medium clouds with embedded intense to very intense convection lay over North Andaman Sea and adjoining eastcentral BoB and adjoining Andaman Islands between latitude 08.0°N & 16.0°N and longitude 86.0°E to 93.0°E. The minimum CTT was -93°C.

At 1500 UTC of 04th, the current intensity of the system was T1.0. Broken low to medium clouds with embedded intense to very intense convection lay over North Andaman Sea and adjoining eastcentral BoB and adjoining Andaman Islands between latitude 08.0°N & 16.0°N and longitude 89.5°E & 92.5°E. The minimum CTT was -93°C.

At 0300 UTC of 05th November, 2019, clouds showed shear pattern. Current intensity of the system was T 1.5. Broken low to medium clouds with embedded intense

to very intense convection lay over eastcentral and adjoining southeast BoB between latitude 10.5°N & 15.5°N and longitude 85.5°E to 92.0°E. The minimum CTT was -93°C.

At 0000 UTC of 06th, the current intensity of the system is T 2.0. Broken low to medium clouds with embedded intense to very intense convection lay over eastcentral and adjoining southeast BoB between latitude 11.0°N & 19.5°N and longitude 85.5°E & 93.5°E. The minimum CTT was -93°C.

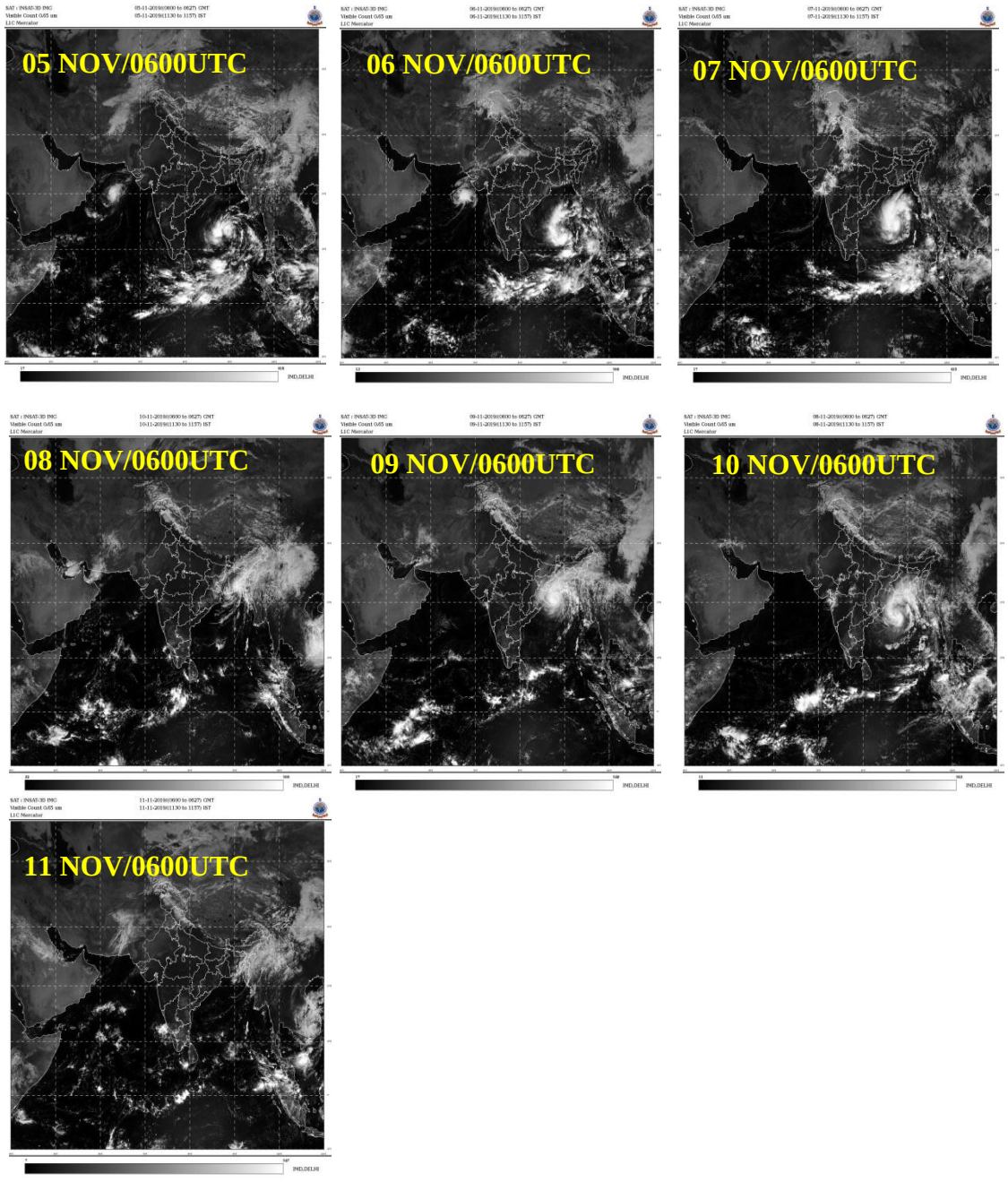


Fig. 6a: INSAT-3D visible imageries during life cycle of VSCS BULBUL (05th-11th November, 2019)

At 1800 UTC of 06th, current intensity of the system was T2.5. Broken low to medium clouds with embedded intense to very intense convection lay over eastcentral and adjoining southeast BoB between latitude 11.5°N & 17.0°N and longitude 87.0°E & 91.5°E. The minimum CTT was -93°C.

At 1200 UTC of 07th November, 2019, current intensity of the system was T3.0. Broken low to medium clouds with embedded intense to very intense convection lay over eastcentral and adjoining westcentral BoB between latitude 12.0°N & 21.0°N and longitude 84.5°E & 92.0°E. The minimum CTT was -93°C.

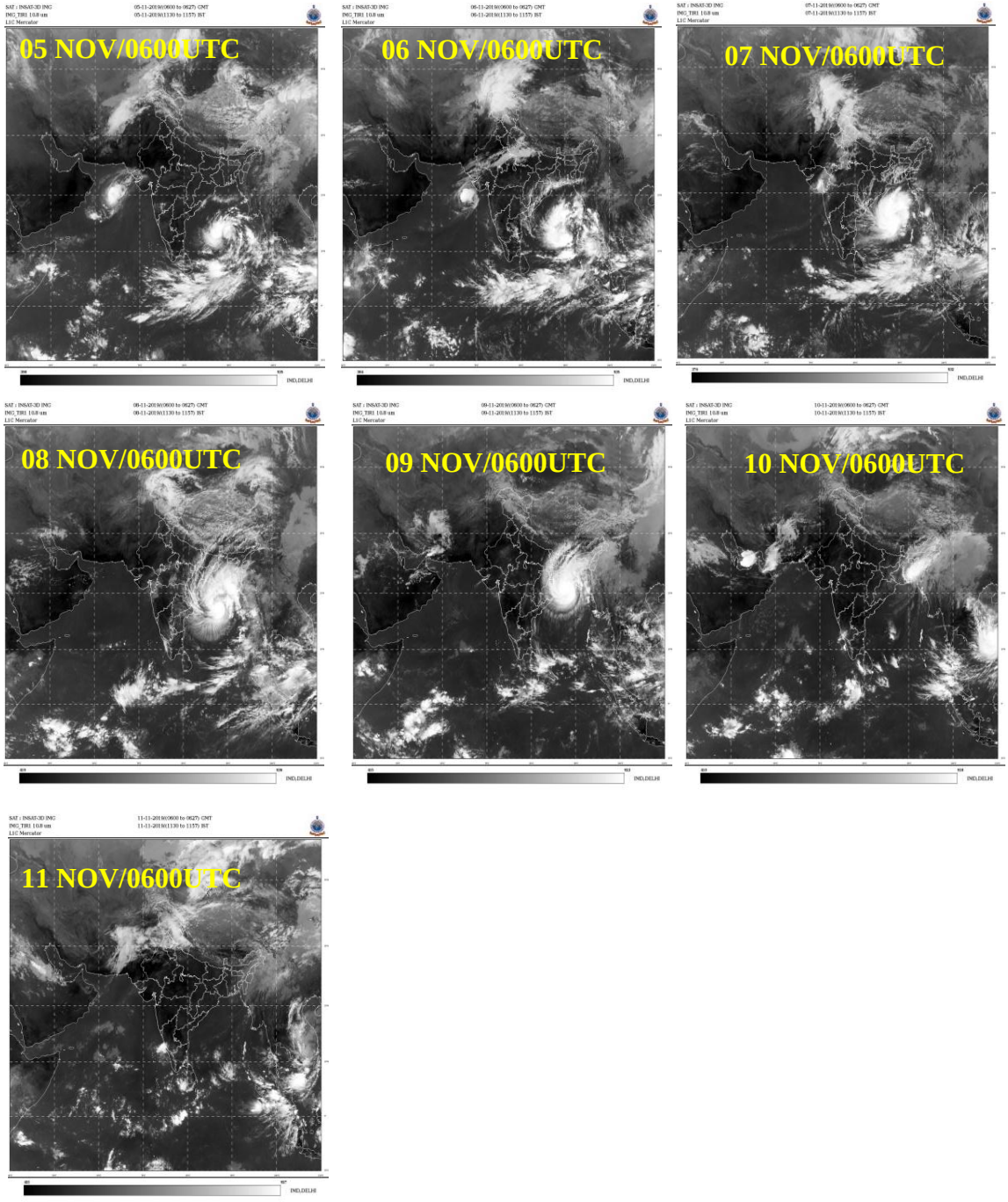


Fig. 6b: INSAT-3D IR imageries during life cycle of VSCS BULBUL (05th-11th November, 2019)

At 0000 UTC of 08th, current intensity of the system was T4.0. Broken low to medium clouds with embedded intense to very intense convection lay over eastcentral

and adjoining westcentral BoB between latitude 14.0°N & 21.0°N and longitude 85.0°E & 90.0°E. The minimum CTT was -93°C.

At 1800 UTC of 09th, broken low to medium clouds with embedded intense to very intense convection lay over northwest and adjoining westcentral BoB, north of latitude 21.87°N and west of longitude 88.92°E. The minimum CTT was -78°C.

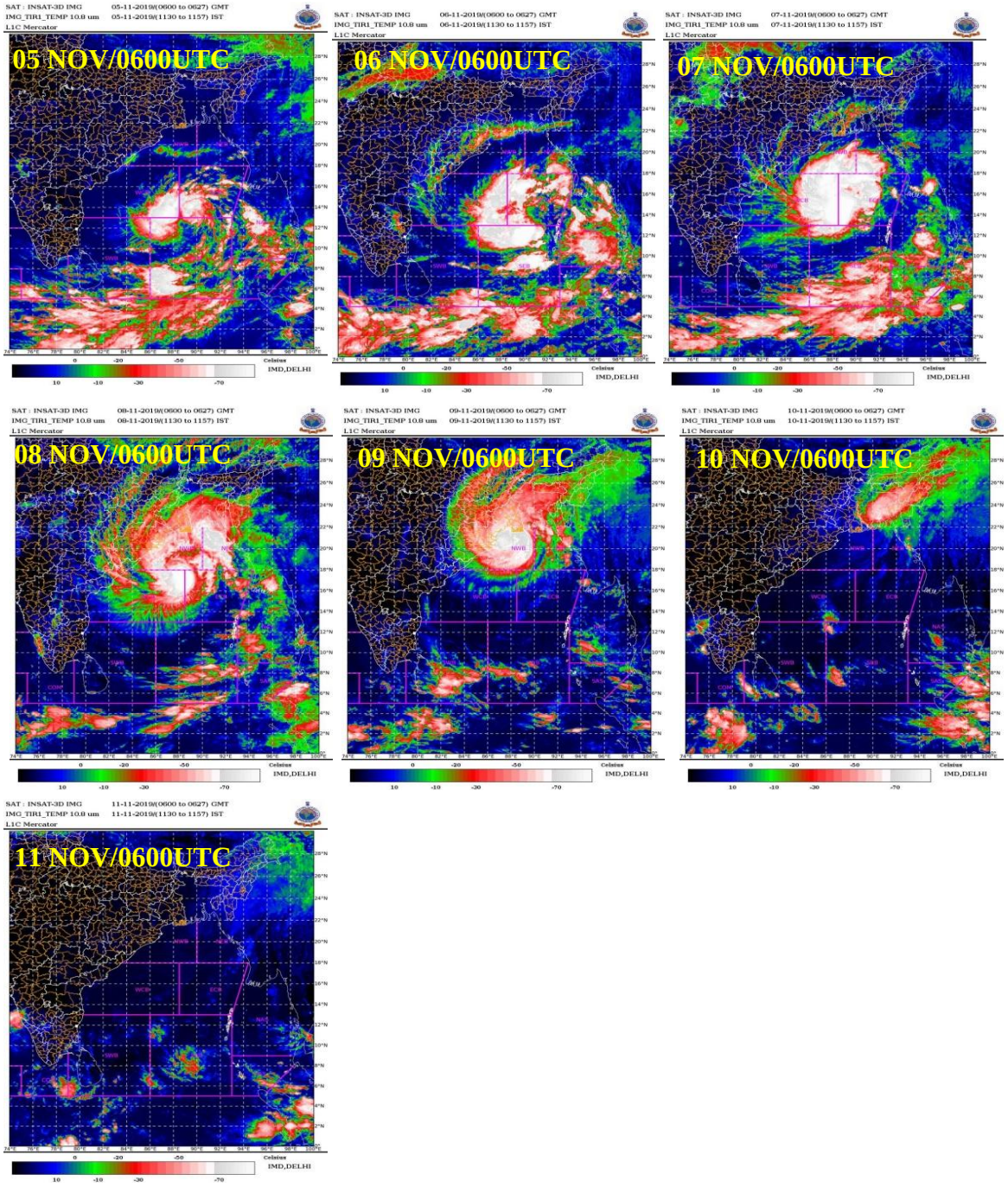


Fig. 6c: INSAT-3D enhanced colored imageries during life cycle of VSCS BULBUL (05th-11th November, 2019)

At 0000 UTC of 10th, broken low to medium clouds with embedded intense to very intense convection lay over southwest Bangladesh and adjoining northwest BoB between

latitude 21.5°N & 23.5°N and longitude 88.2°E & 90.4°E. The minimum CTT was -80°C.

At 0900 UTC of 10th, broken low to medium clouds with embedded intense to very intense convection lay over Bangladesh and adjoining extreme northeast BoB, Tripura, North Mizoram, Manipur, south Assam, Meghalaya and neighborhood. The minimum CTT was -65°C.

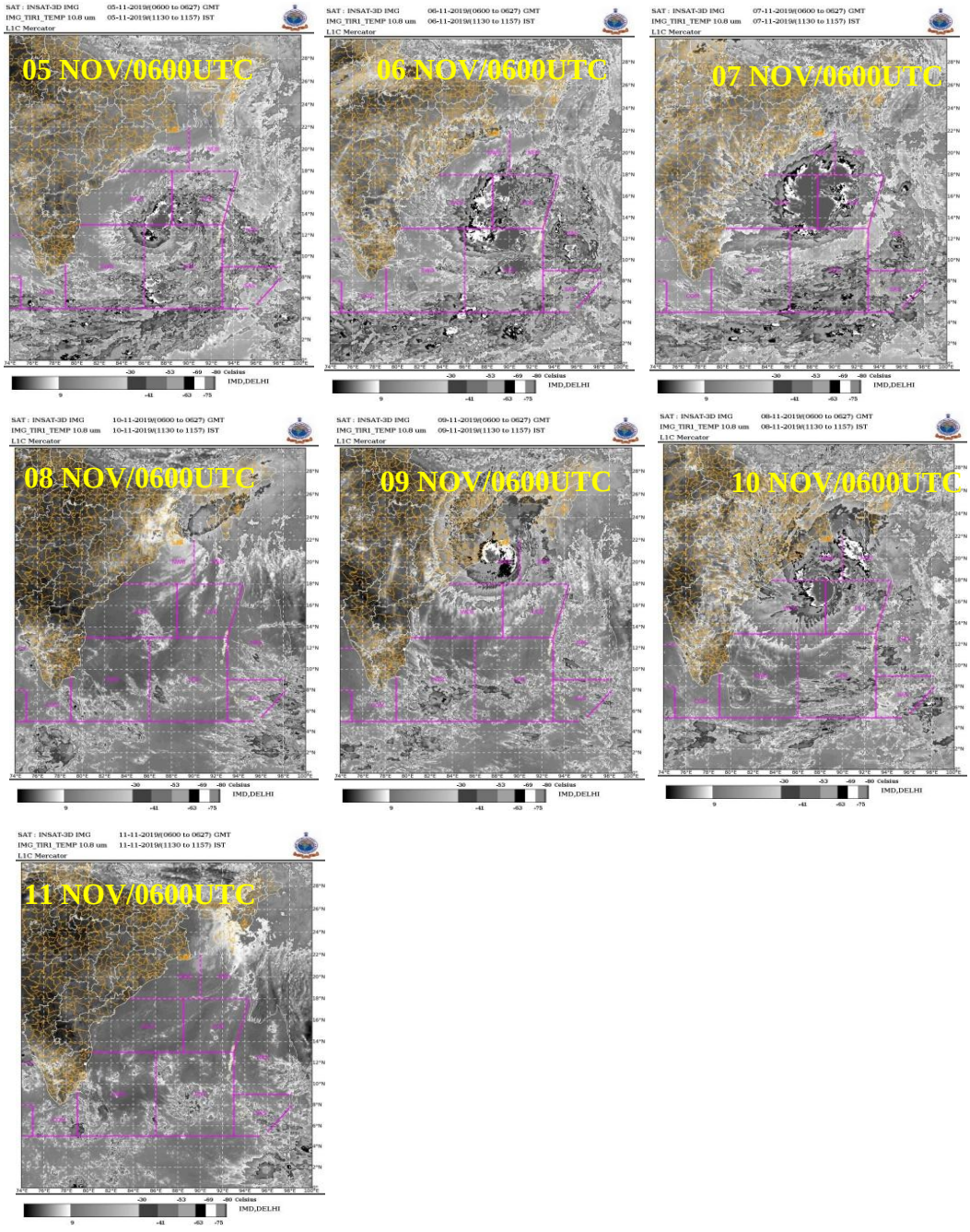


Fig. 6d: INSAT-3D cloud top brightness imageries during life cycle of VSCS BULBUL (05-11th November, 2019)

At 0000UTC of 11th November, scattered low to medium clouds with embedded isolated weak convection lay over southeast Bangladesh and adjoining Tripura & neighborhood.

At 0300UTC of 11th November, scattered low to medium clouds with embedded isolated weak convection lay over south east Bangladesh and adjoining Tripura and neighborhood.

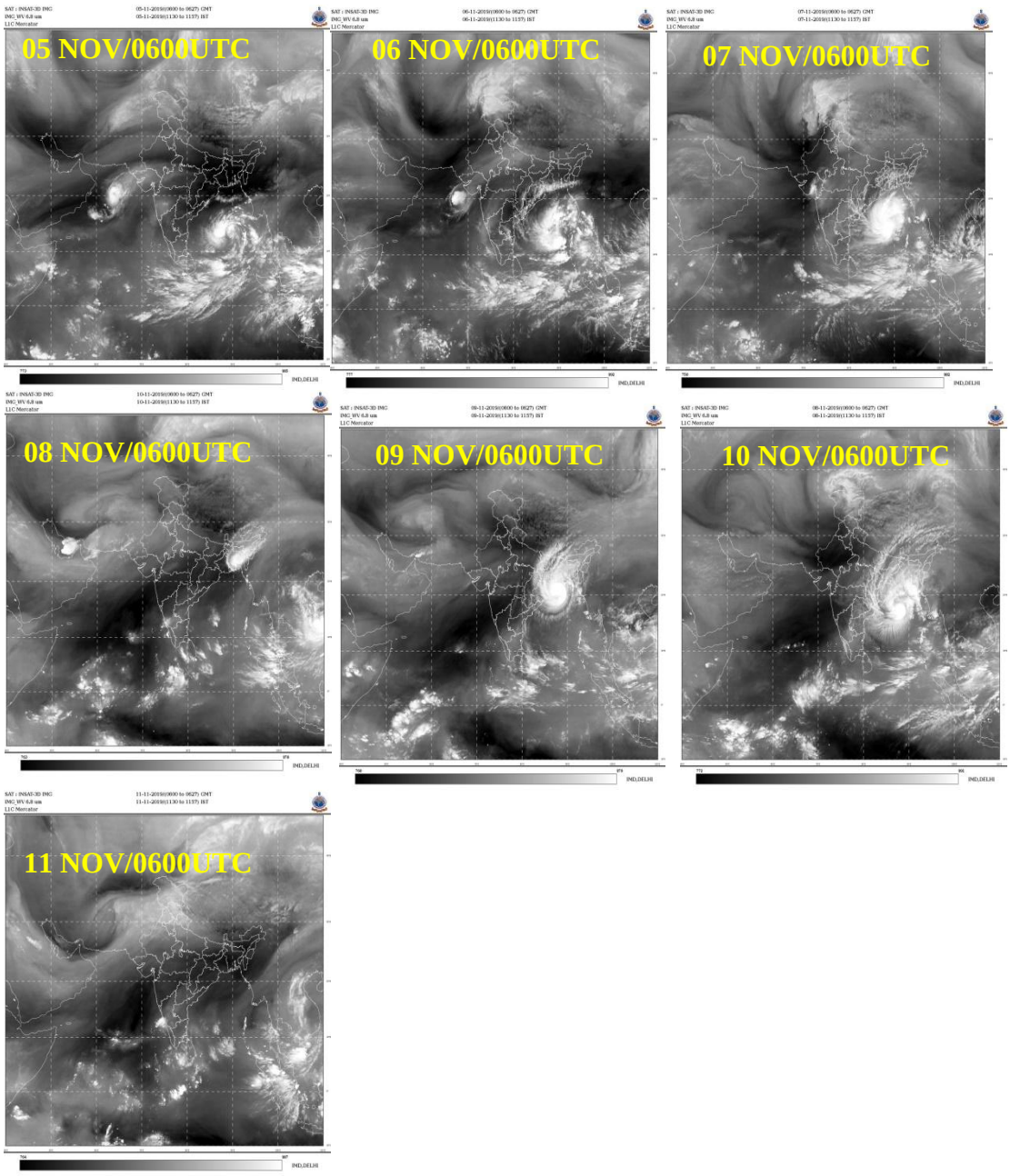


Fig. 6e: INSAT-3D Water Vapor imageries during life cycle of VSCS BULBUL (05th-11th November, 2019

Typical SCAT SAT imageries during 4th- 7th November are presented in Fig. 6f. The circulation centre was correctly picked up by ASCAT imageries. Matching Index M.I. > 0.6 was seen for all the imageries indicating the potential to intensify into a CS.

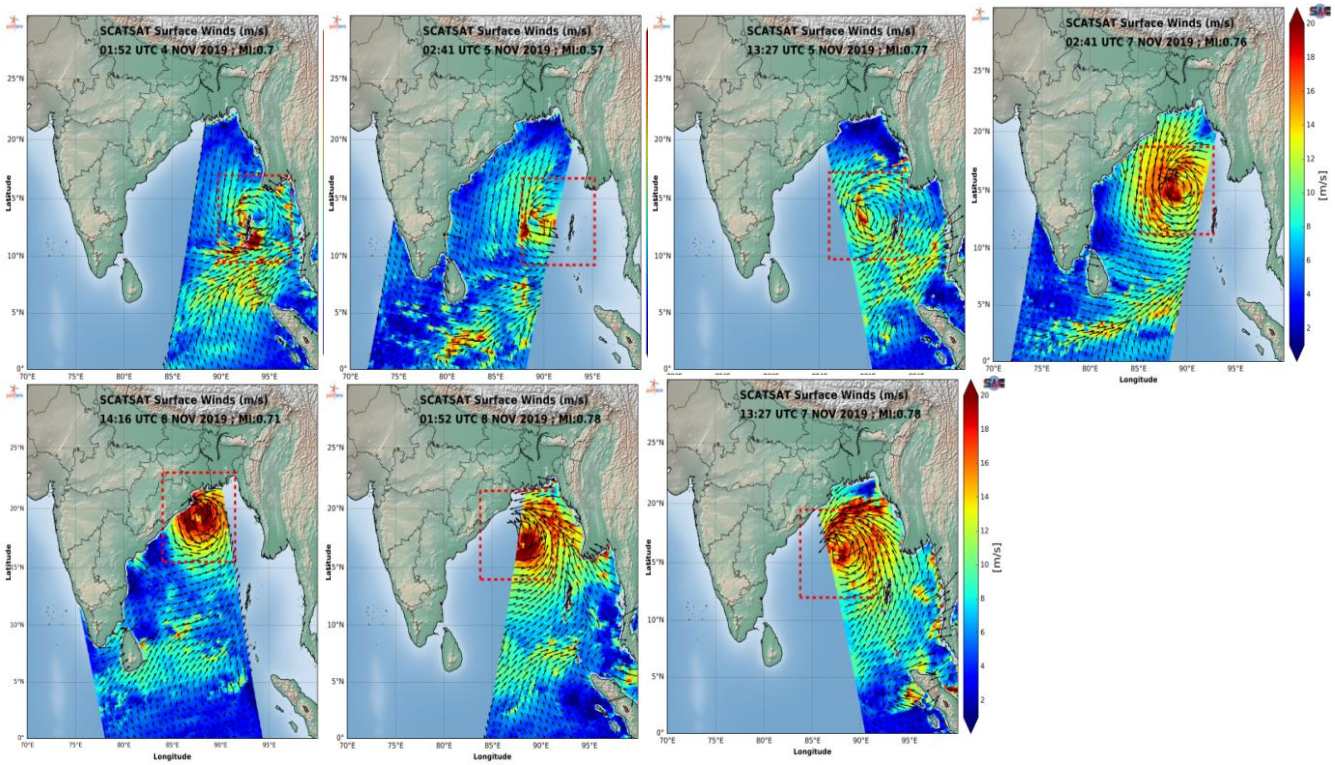


Fig. 6f: SCATSAT imageries during 4th-7th Nov in association with VSCS Bulbul

ASCAT imageries during 5th-8th November are presented in Fig. 6g. Circulation centre was correctly picked up, however ASCAT has limitations wrt estimation of intensity beyond 50 kts.

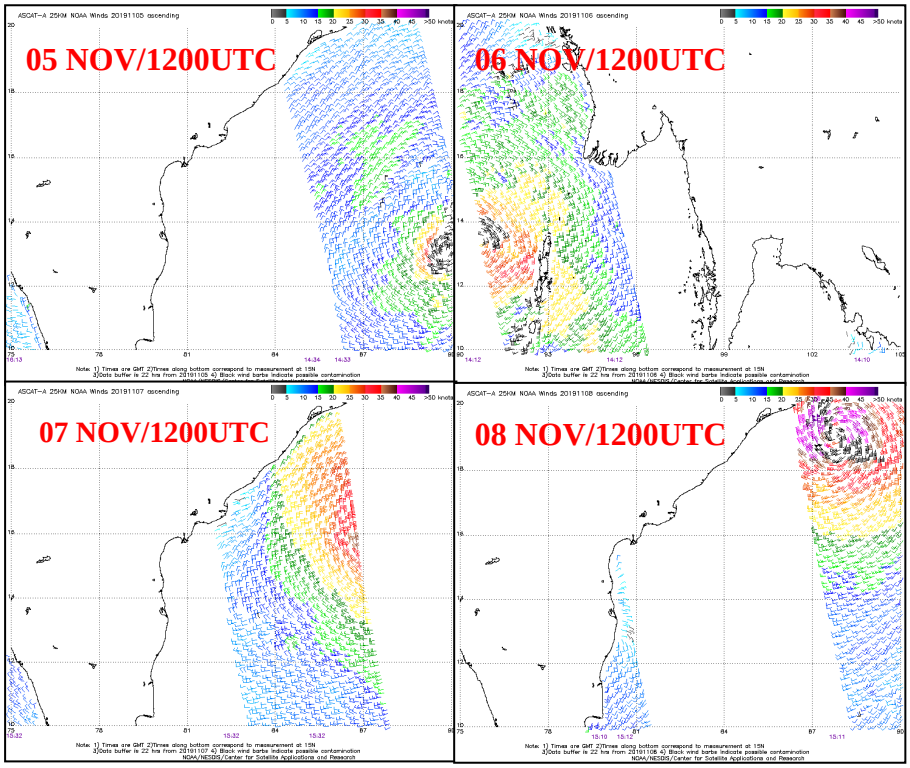


Fig. 6g: ASCAT imageries during 5th-8th November in association with VSCS BULBUL

4.2 Features observed through Radar

The VSCS Bulbul was tracked by DWRs Paradeep, Gopalpur and Kolkata during it's movement along the east coast of India over northwest BoB. Typical DWR imageries from these radars are presented in Fig. 7.

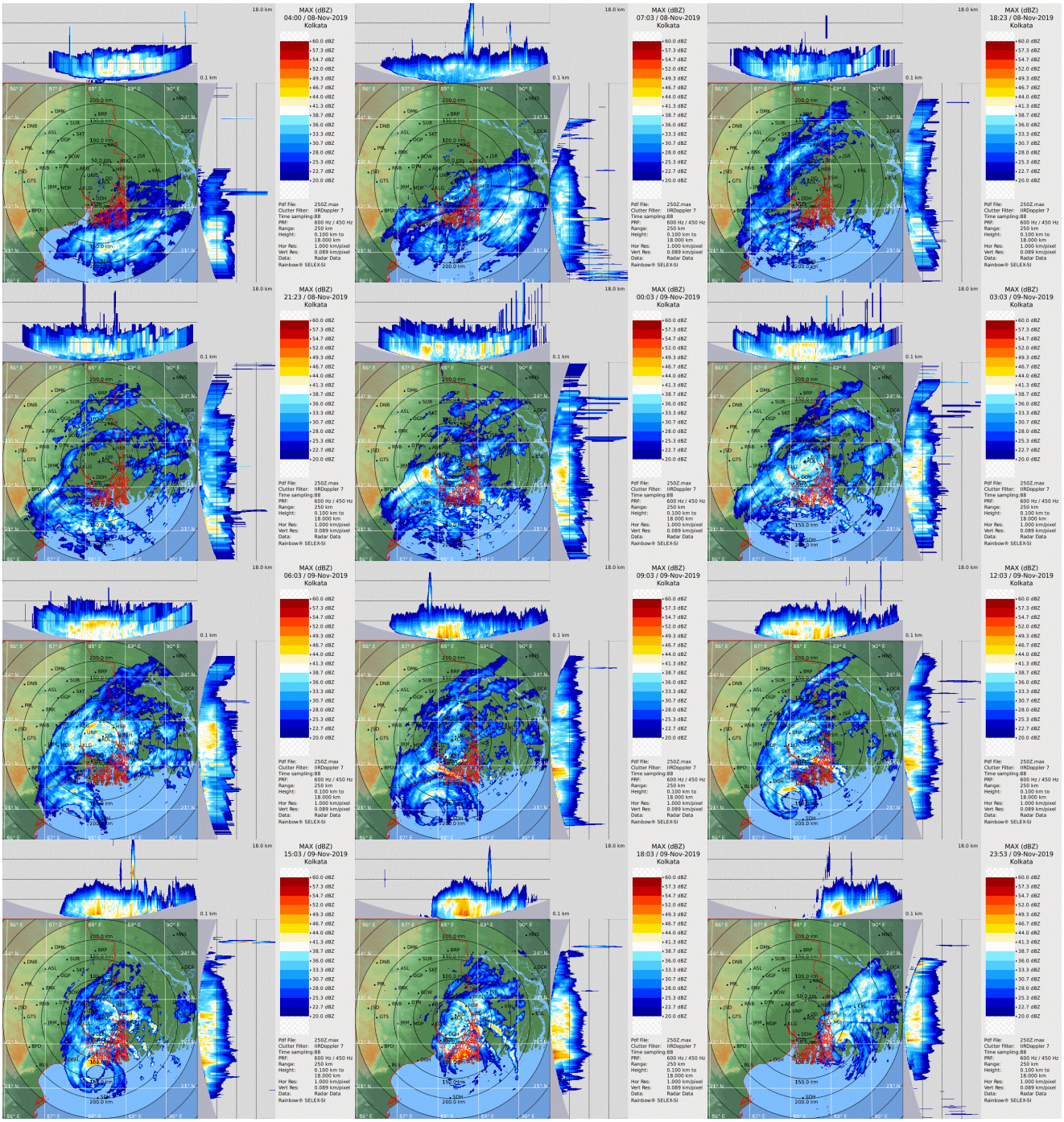


Fig.7(i): Radar imageries from DWR Kolkata during 8th-9th November for VSCS BULBUL

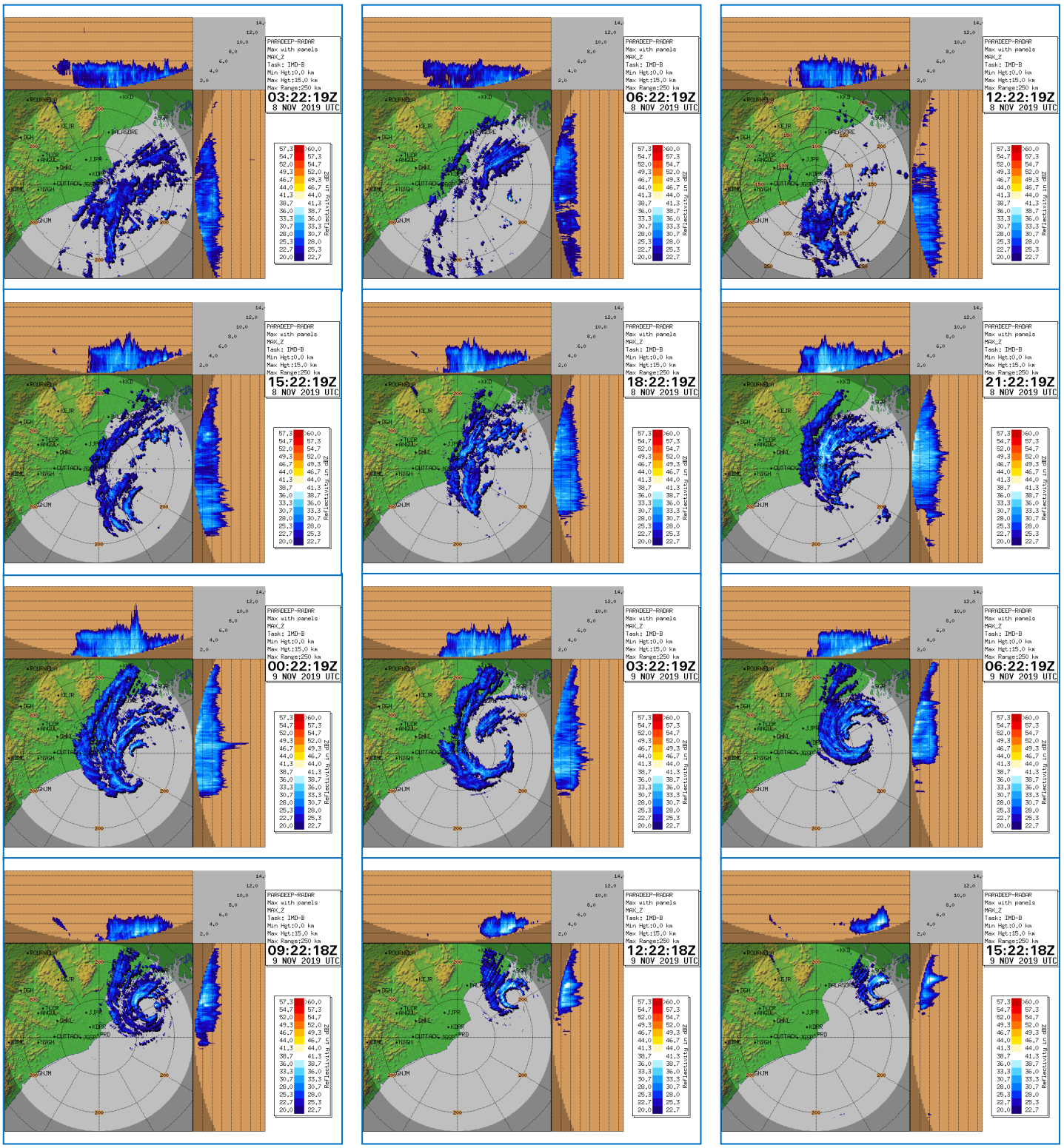


Fig.7(ii): Radar imageries from DWR Paradeep during 8th – 9th November for VSCS BULBUL

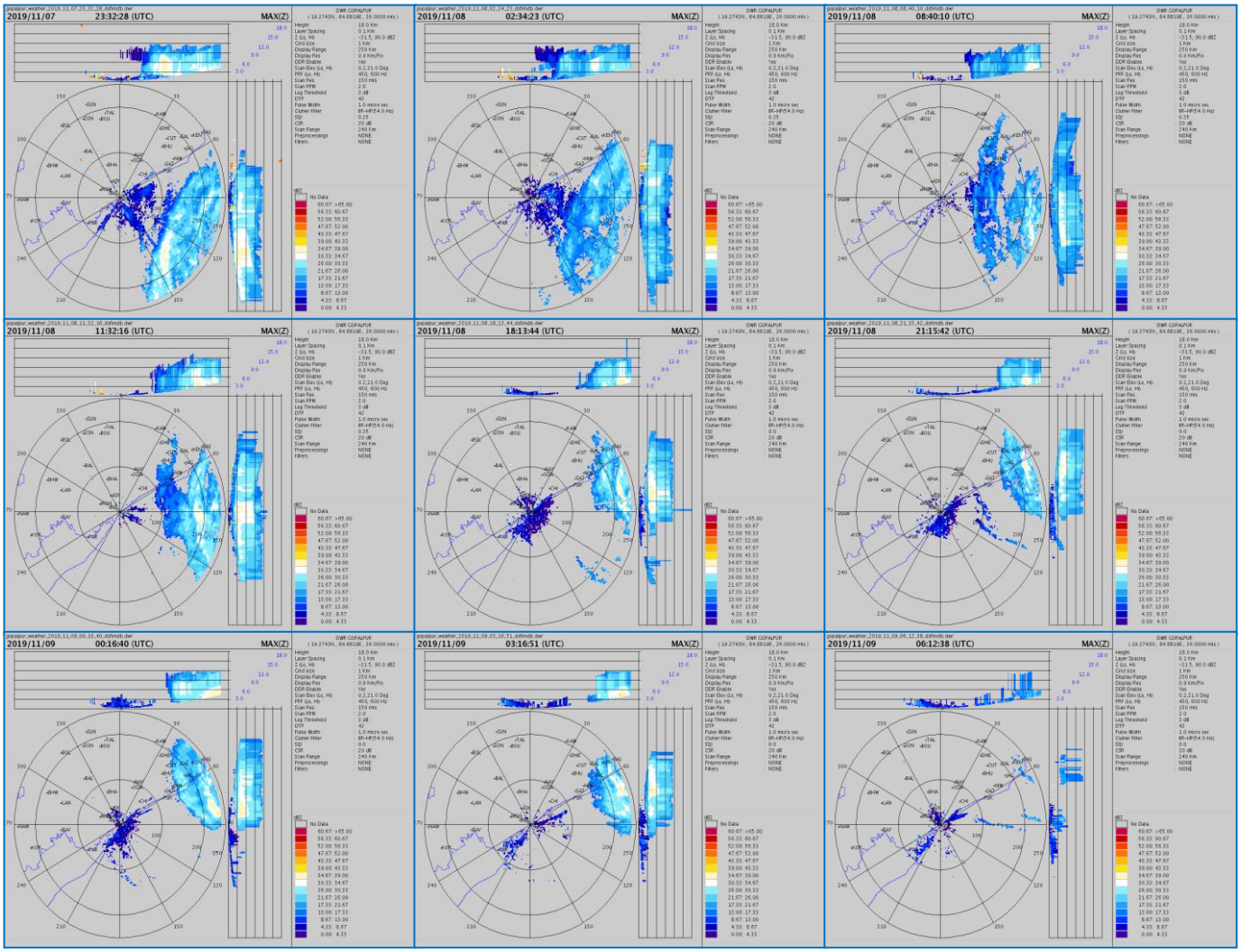


Fig7(iii): Radar imageries from DWR Gopalpur during 7th – 9th November for VSCS BULBUL

5. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa level during 05th-11th November are presented in Fig.8. GFS (T1534) analysis based on 0000 UTC of 5th November, indicated an LPA over north Andaman Sea. Actually cyclogenesis had occurred at 0000 UTC.

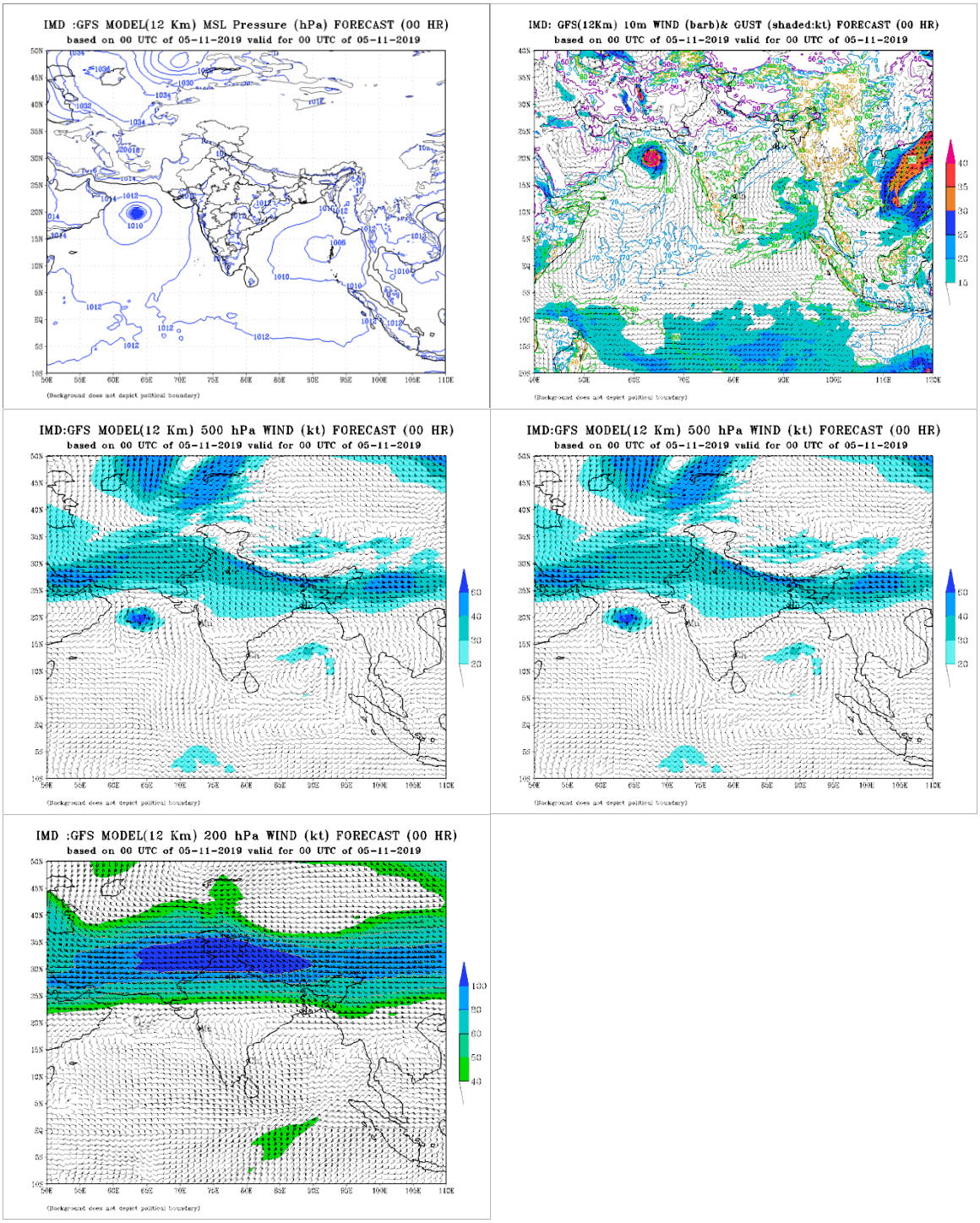


Fig. 8(a): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 5th November 2019

IMD GFS analysis field based on 0000 UTC of 6th indicated a deep depression over southeast BoB near 12ºN/89ºE with circulation extending upto 500 hPa level. Synoptically, the system lay as a DD near 13.4ºN/89.7ºE.

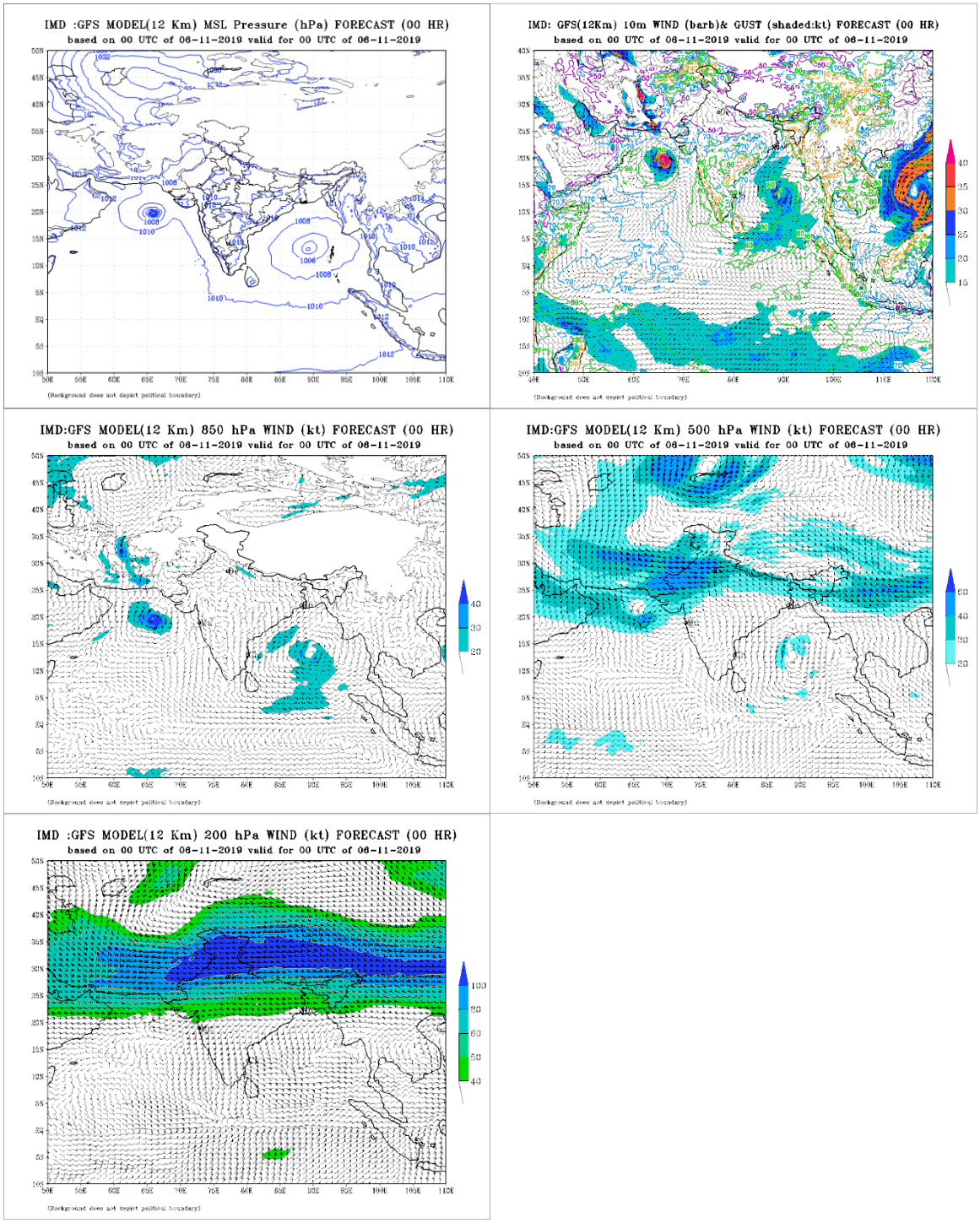


Fig. 8(b): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 6th November 2019

IMD GFS analysis field based on 0000 UTC of 7th November indicated a CS near 14.5ºN/89.5ºE with circulation extending upto 500 hPa level. Synoptically, the system lay as a CS near 14.2ºN/89.3ºE.

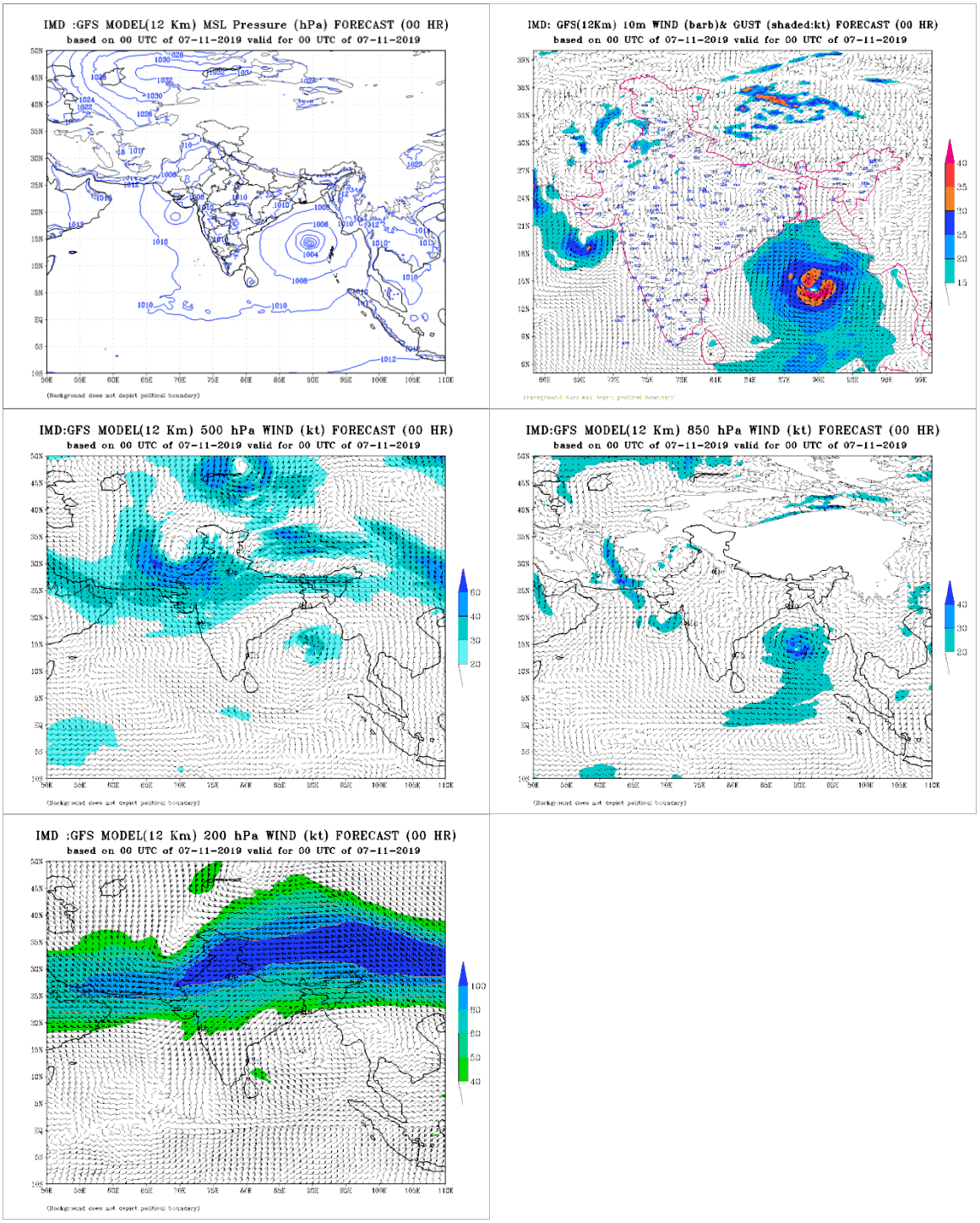


Fig. 8(c): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 7th November 2019

IMD GFS analysis field based on 0000 UTC of 8th November indicated further intensification of the system into a VSCS near 17.5ºN/87.5ºE with circulation extending upto 500 hPa level. Synoptically, the system lay as a VSCS near 16.9ºN/87.6ºE.

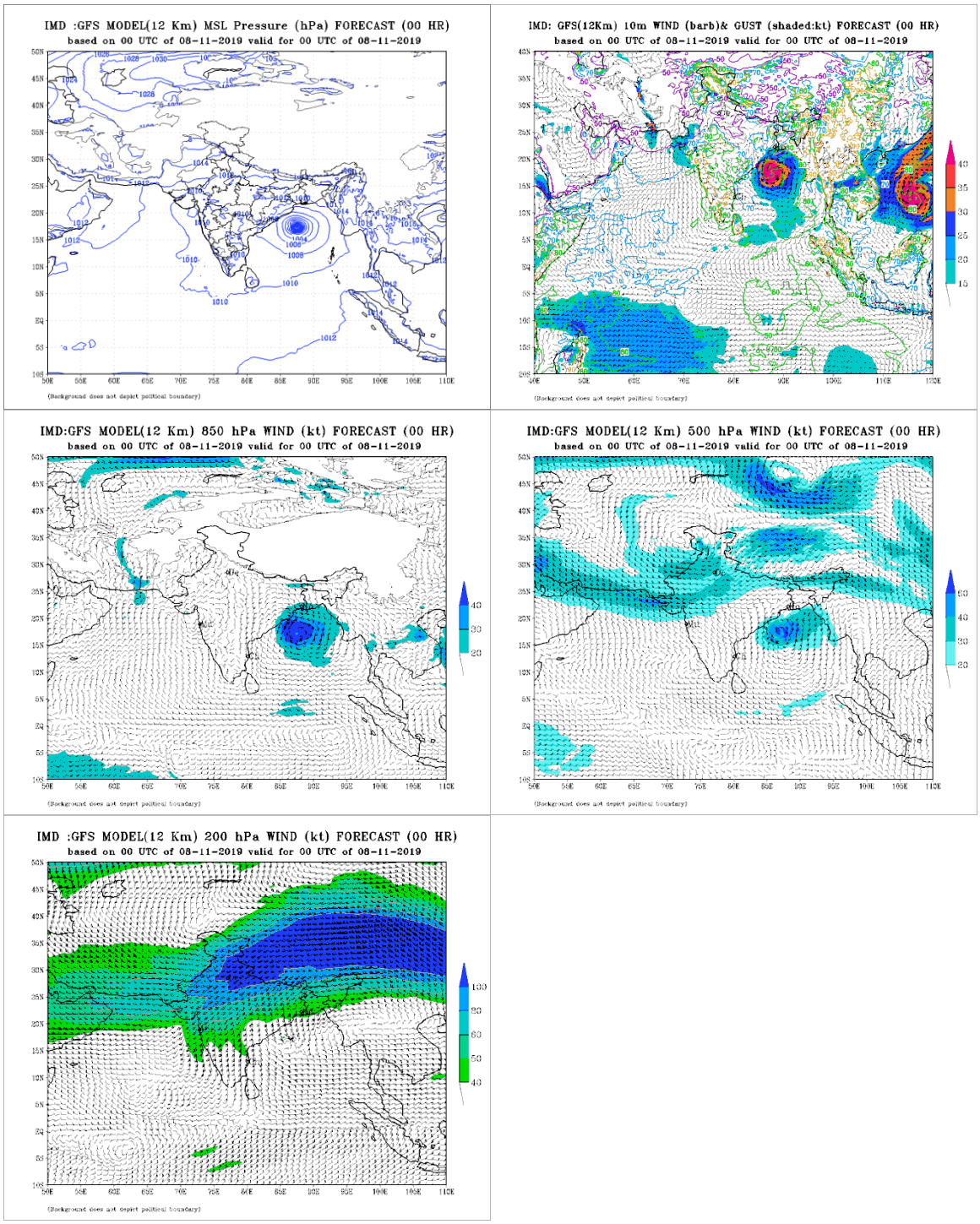


Fig. 8(d): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 8th November 2019

IMD GFS analysis field based on 0000 UTC of 9th November indicated movement of the system as VSCS towards Odisha-West Bengal coasts near 19.5ºN/87.5ºE with circulation extending upto 200 hPa level. Synoptically, the system lay as a VSCS near 20.0ºN/87.6ºE.

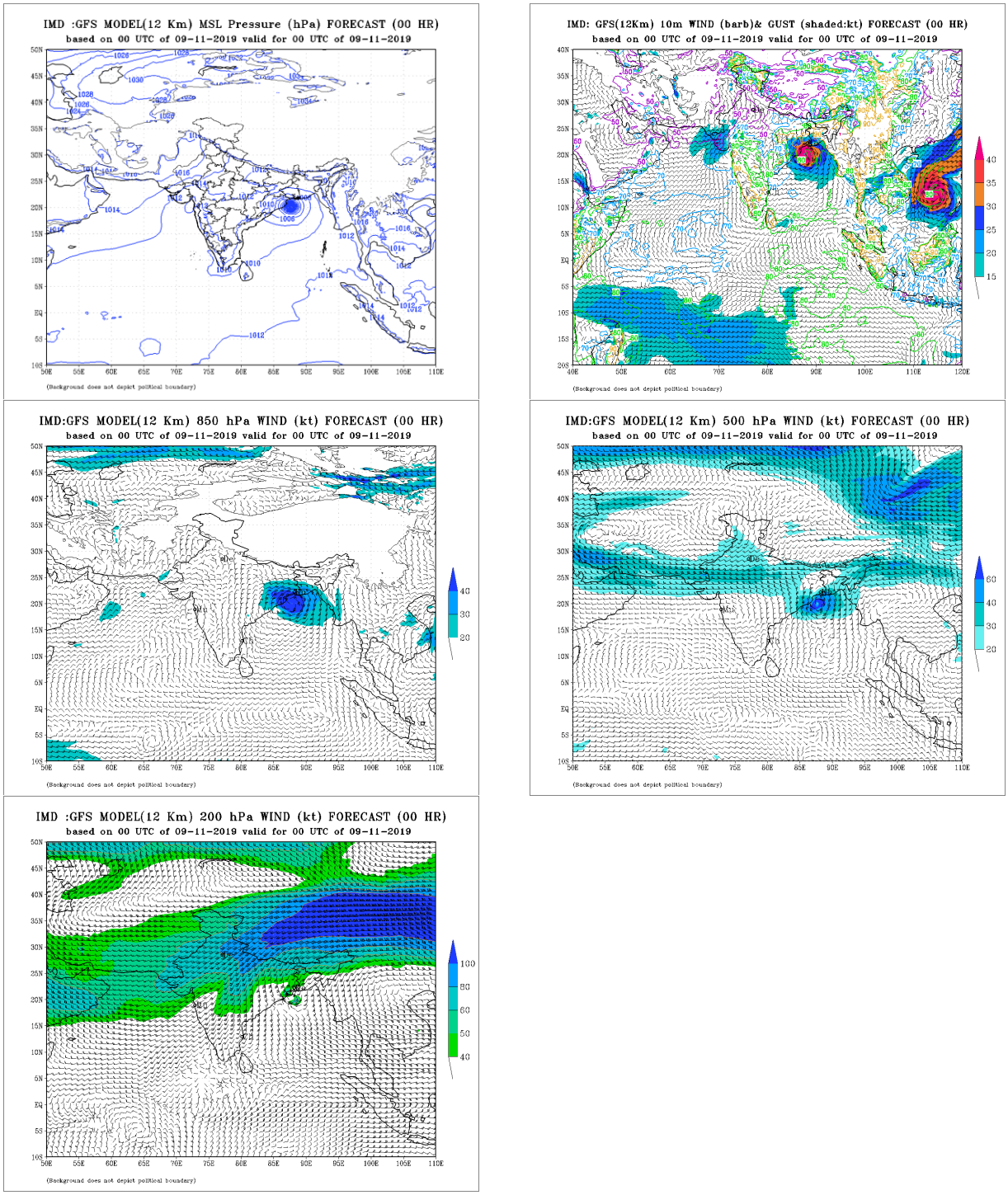


Fig. 8 (e): IMD GFS (T 1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 9th November 2019

IMD GFS analysis field based on 0000 UTC of 10th November indicated the system crossing West Bengal-Bangladesh coasts near 22.5ºN/89.0ºE. Actually, the system crossed West Bengal coast close to Sunderban Dhanchi forest near 21.55°N/88.5°E during 1500 to 1800 UTC of 9th November and 0000 UTC of 10th, it lay near 22.1ºN/89.5ºE.

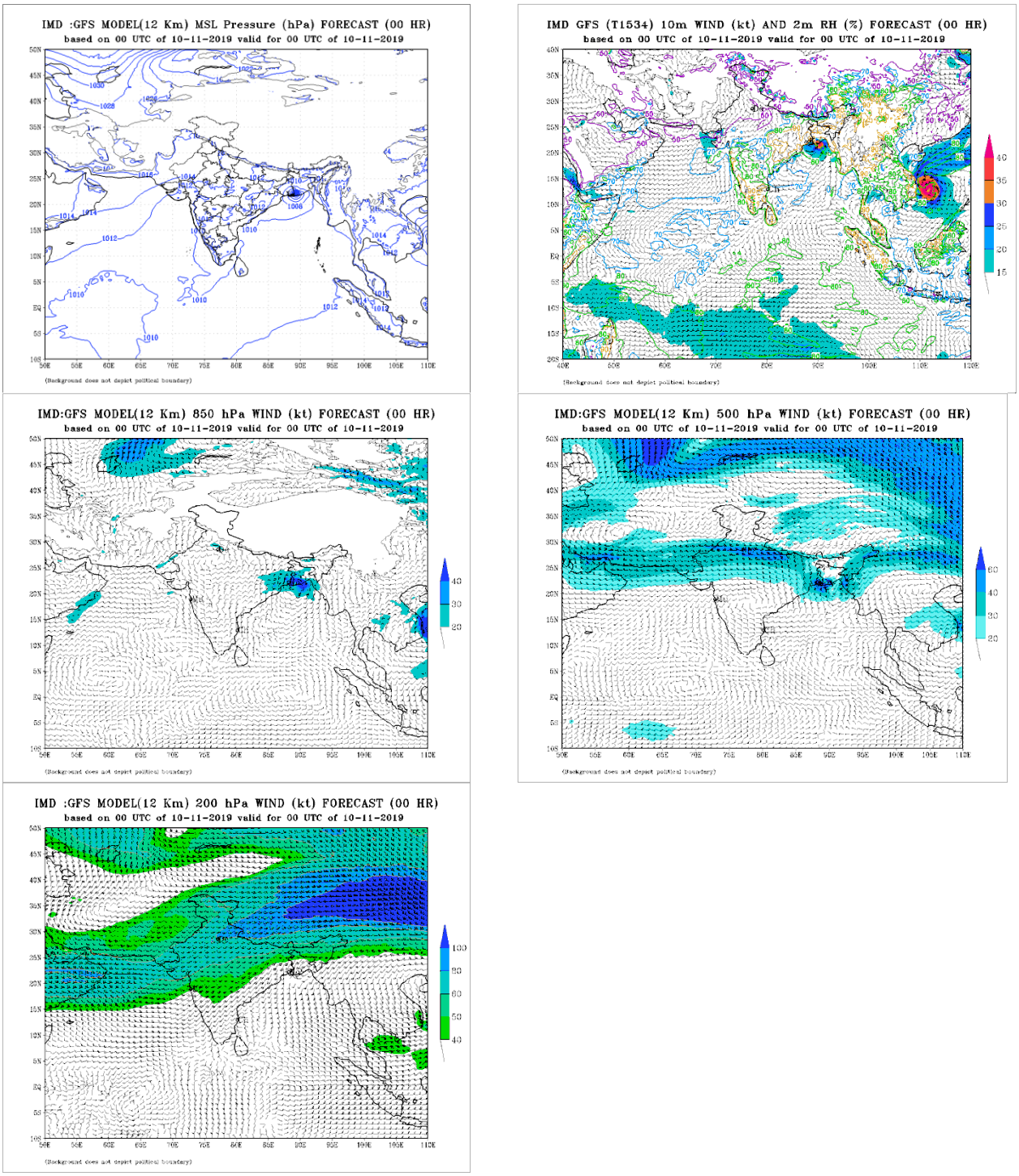


Fig. 8(f): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 10th November, 2019

6. Realized Weather:

Rainfall associated with VSCS Bulbul based on IMD-NCMRWF GPM merged gauge 24 hours cumulative rainfall ending at 0300 UTC of date is presented in **Fig.9**.

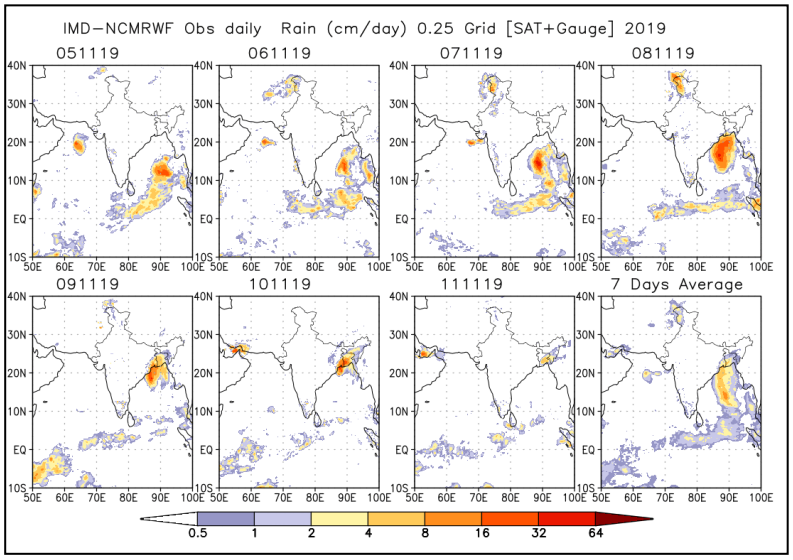


Fig.9: IMD-NCMRWF GPM merged gauge 24 hr cumulative rainfall (cm) ending at 0830 IST of date during 05th – 11th November and 7 days average rainfall (cm/day)

It indicates occurrence of heavy to very heavy rainfall over eastcentral BoB on 5th November, heavy to very heavy & extremely heavy falls over eastcentral BoB on 6th, over central and adjoining northwest BoB on 7th and heavy to very heavy rainfall over northwest & adjoining westcentral BoB off Odisha – West Bengal coasts on 8th November. As the system reached further close to Odisha- West Bengal coasts on 8th & 9th, the following rainfall amounts were reported by meteorological observatories in Odisha and west Bengal during the past 24 hours ending at 0300 UTC of 09th,10th & 11th November:

Realised rainfall in cm (≥ 7 cm) ending at 0300 UTC of date-

9th November

Odisha

Paradip-16, Chandbali-15, Rajkanika-14, Tirtol & Balipatna-10 each and Bhadrak-7.

West Bengal

Digha-7.

10th November

Odisha

Bhograi-9

West Bengal

Dhapa -21, Canning-19, Joka -16, Cantai & Jora Bridge -13, Kakdwip- 12, Ultadanga & Positional Astronomy Centre, IMD -11 each, Newmarket, Ballygunge, Patuli, Behala, Dumdum, Digha & Haldia-10 each, Alipore & Barrackpur -9 each, Mominpur & Palmer Bridge -8 each, Shibpur -7 (Other than Canning & Kakdwip, all other places are in Kolkata).

After crossing the coast & weakening, it caused isolated heavy rains over Tripura for a day.

11th November

Tripura

Sabroom – 8

7.1 Maximum sustained wind

Realised Max sustained wind speed (MSW) recorded on 09.11.19:

Kolkata (Alipore) reported MSW of 60 kmph at 2230 IST on 09.11.19 and at 0015 IST on 10.11.19; Digha reported 45-50 kmph during 1940-1945 IST on 09.11.19

7.2 Realised storm surge:

No damaging storm surge report over West Bengal coast during the time of crossing. Also it was the period of low astronomical tide, when the system crossed coast.

8. Damage due to VSCS BULBUL

(A) West Bengal (as reported by media):

It caused widespread damage in the coastal districts of East Midnapore, North and South 24 Parganas due to gale wind speed & heavy rainfall and in the adjoining districts of Gangetic West Bengal due to heavy rain and squally winds.

i) Affected districts: North and South 24 Parganas and east Medinipur were the most affected; other affected districts were Kolkata, Howrah, Hooghly and Nadia
ii) Casualties: Total 13; North 24 Parganas-6, South 24 Parganas-3, east Medinipur-2, Kolkata & East Burdwan 1 each.
iii) No. of people affected: 4,65,000
iv) House damaged: 60,000 No.
v) Extensive damage to Mangrove forest in Sunderban Delta, cultivation of flowers, vegetable, paddy crops and pan field in the affected districts.
vi) Disruption of electricity by uprooting of many electric poles, electric transformer in coastal belt of east Medinipur, North and south 24 Parganas districts. 1050 no of mobile towers affected also in the said area.
vii) Some area of Howrah district experienced water logging.

As a pre-cautionary measure, the Airport operations were cancelled in the Kolkata international Airport for a period of 12 hours on 9th November.

(B) Odisha (Based on media reports & inputs from various meetings conducted by the State Government agencies):

Five districts such as Jagatsinghpur, Kendrapada, Bhadrak Balasore and Mayurbhanj have been mostly affected due to cyclone 'Bulbul'. District of Jajpur was also affected to some extent. Early warnings were issued for different sector and state government has taken proper safety measures for which there are no human casualty though in some newspaper has mentioned one human death due to wall collapse. As many as 8218 persons were evacuated in 5 districts namely Jagatsinghpur, Kendrapada, Bhadrak, Balasore and Mayurbhanj districts and placed in 91 shelters.

As per initial report, about 5500 houses have been damaged due to cyclone. As per preliminary estimation, nearly 3 lakh hectare of crop area including horticulture crops have been affected out of which about 2 Lakh hectare have suffered crop loss to the extent of 33% and above. Many trees and some communication and electric poles fallen especially in four districts namely Jagatsinghpur, Kendrapada, Bhadrak and Balasore.

Loss of livestock and Poultry: As per preliminary report, 11 large animals, 5 small animals and 50 poultry birds have been lost due to the cyclone.

Apart from the above, Fishing operations were affected over the Deep Sea areas of the BOB during 5^{th} – 7^{th} November and over the coastal areas of Odisha & West Bengal on 8^{th} & 9^{th} November.

9. Performance of operational NWP models

IMD operationally runs a regional model, WRF for short-range prediction and one Global model T1534 for medium range prediction (10 days). The WRF-VAR model is run at the horizontal resolution of 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. 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 (e) 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 VSCS Bulbul are presented and discussed.

9.1 Prediction of cyclogenesis (GPP) for BULBUL

Predicted zone of cyclogenesis based on 0000 UTC of 1^{st}-6^{th} November for 6^{th} November is presented in Fig.10. The model could predict cyclogenesis zone correctly about 120 hrs in advance. 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. It also indicated potential for intensification of the system into a Cyclonic storm based on initial condition of 00 & 12 UTC of 5^{th}-6^{th} November onwards. Area average analysis of GPP is shown in Fig.11.

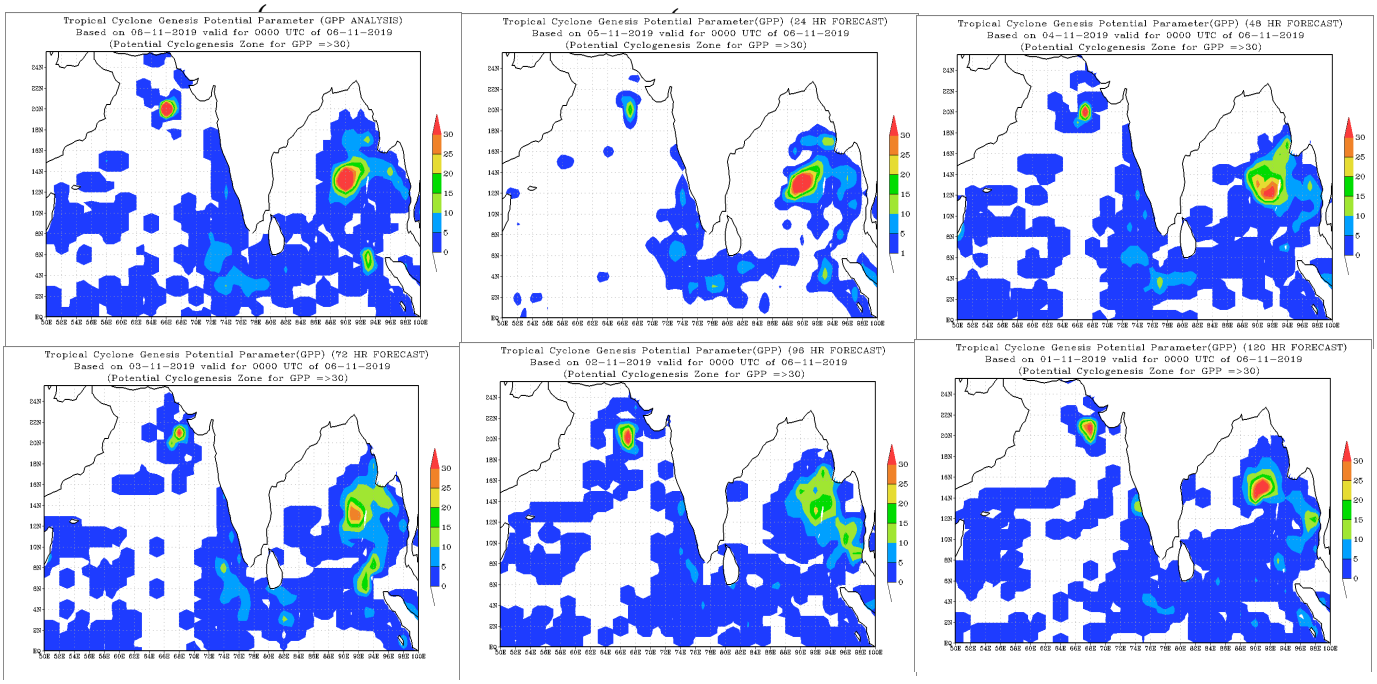


Fig.10: Predicted zone of Cyclogenesis based on 0000 UTC from 01-06 November 2019

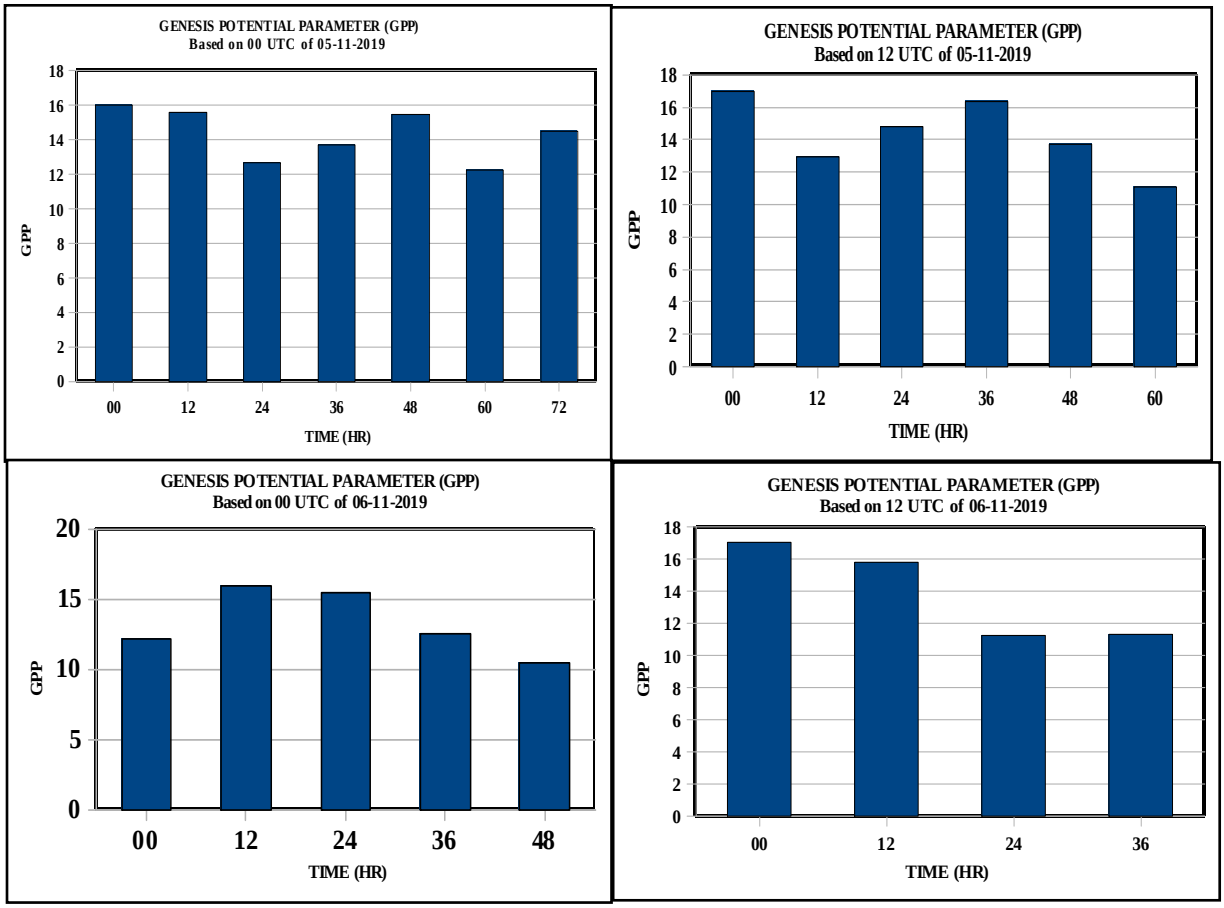


Fig.11 Area average analysis and forecasts of GPP based on 0000 and 1200 UTC of 5th and 6th November, 2019

9.2 Track prediction by NWP models

Track prediction by various NWP models is presented in **Fig.12**. Based on initial conditions of 0000 UTC of 5th November, only UKMO and IMD GFS were indicating landfall near Bangladesh coast. All other models were indicating weakening over sea.

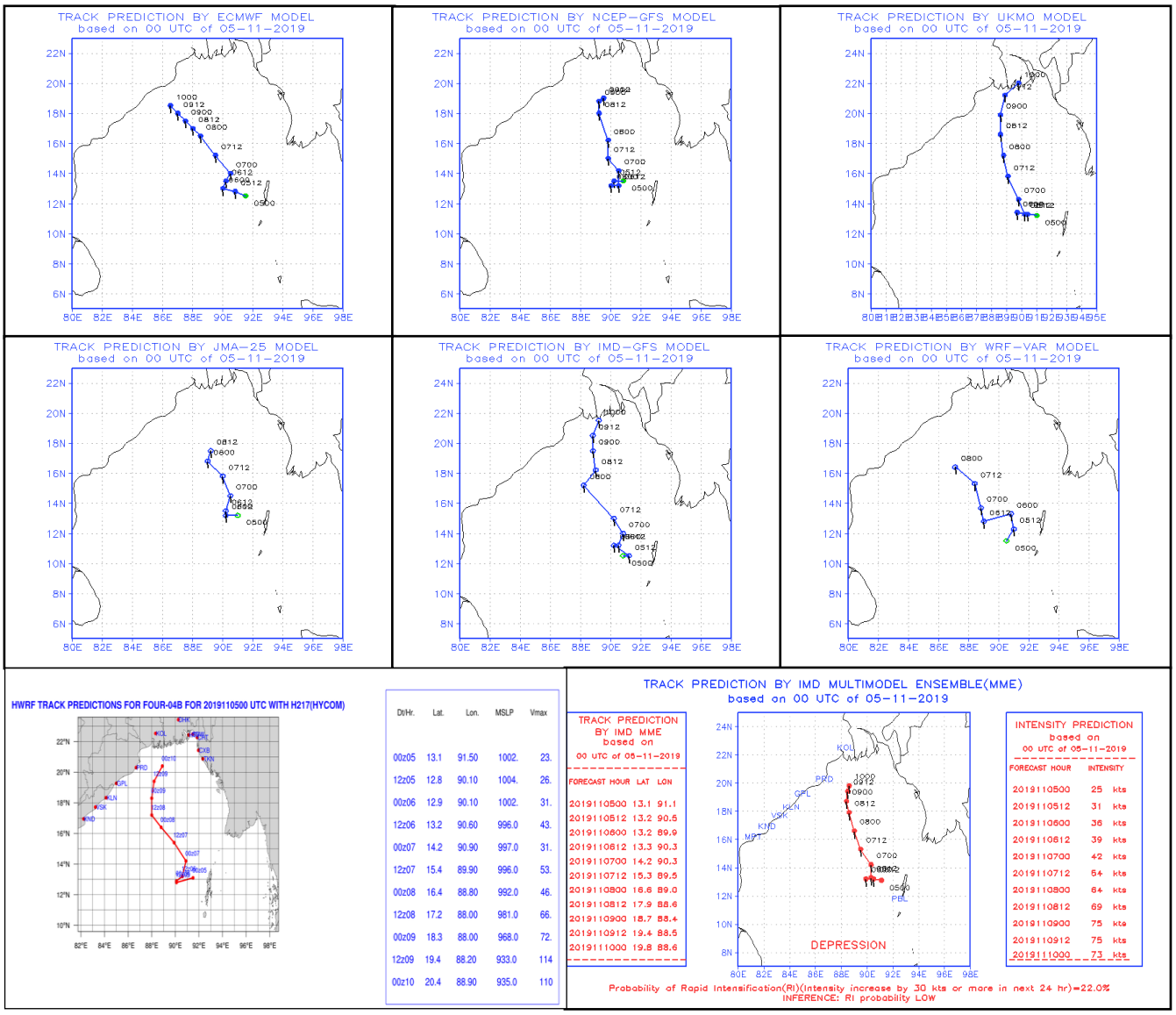


Fig. 12 (a): NWP model track forecast based on 0000 UTC of 05.11.2019

Based on initial conditions of 0000 UTC of 6th November, only UKMO and IMD GFS were indicating landfall near West Bengal - Bangladesh coasts. All other models were indicating weakening over sea.

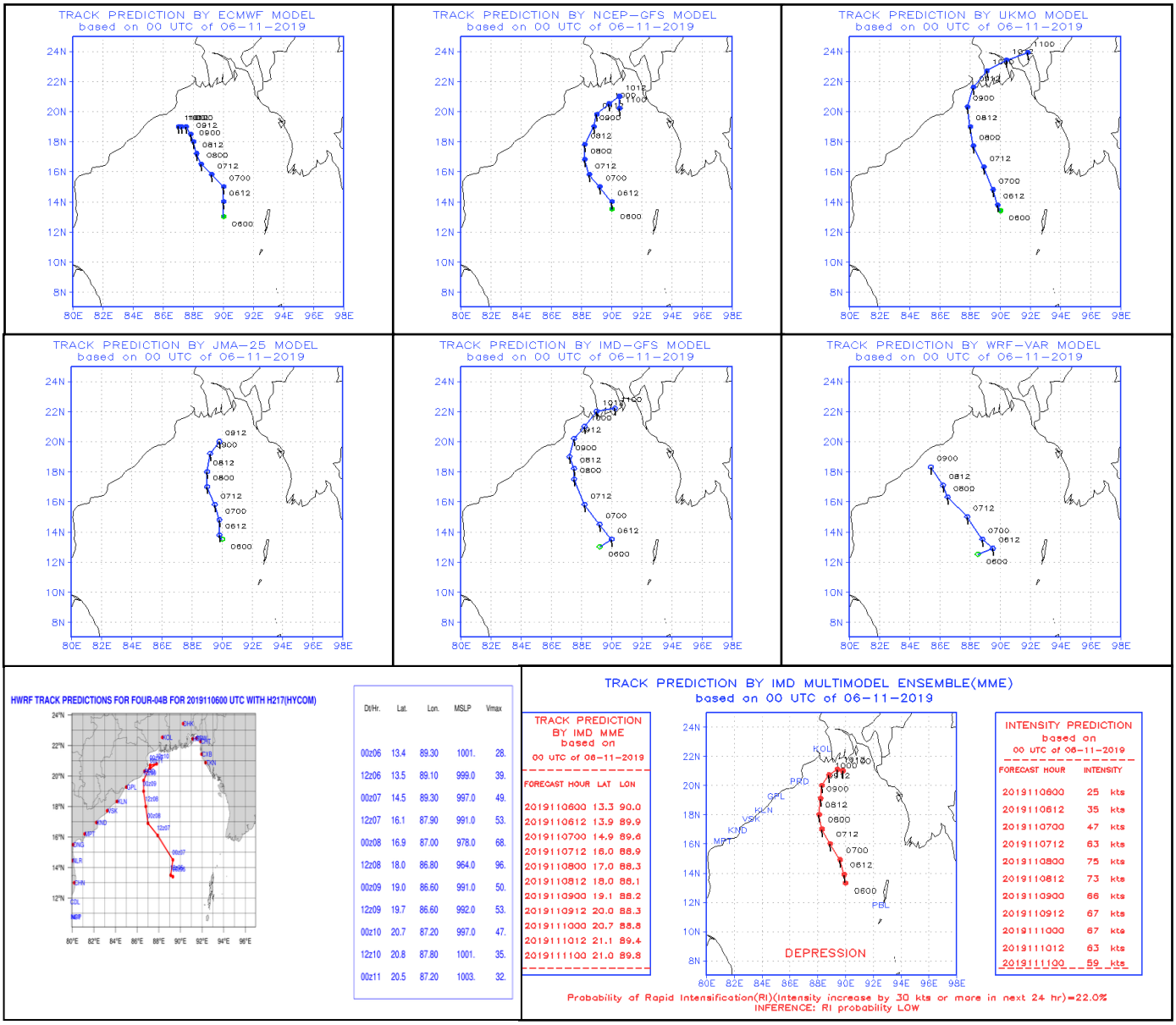


Fig. 12 (b): NWP model track forecast based on 0000 UTC of 06.11.2019

Based on initial conditions of 0000 UTC of 7th November, UKMO, IMD GFS, NCEP GFS, HWRF and MME were indicating landfall near West Bengal coast.

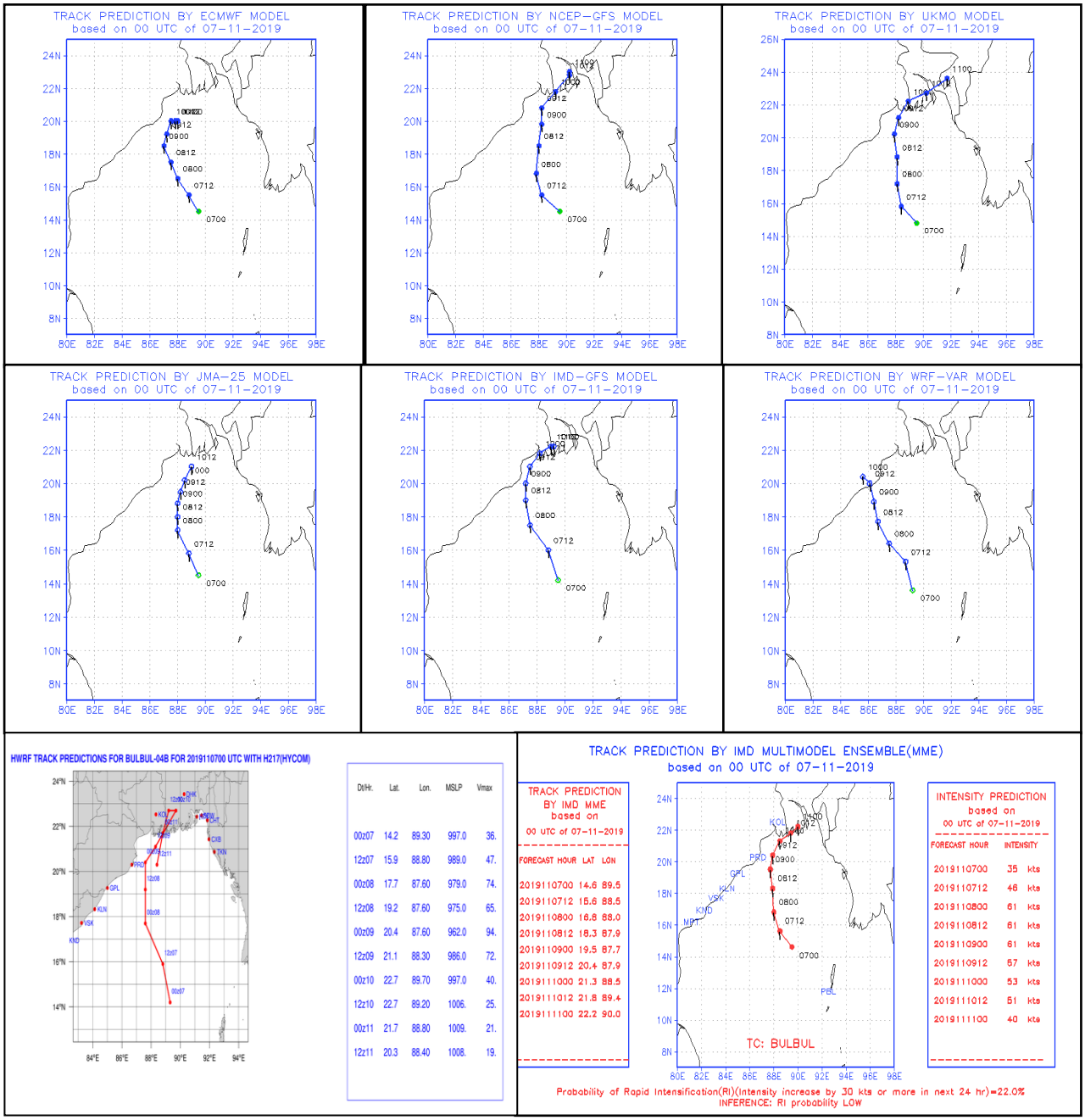


Fig. 12 (c): NWP model track forecast based on 0000 UTC of 07.11.2019

Based on initial conditions of 0000 UTC of 8th November, all models except WRF were indicating landfall near West Bengal coast.

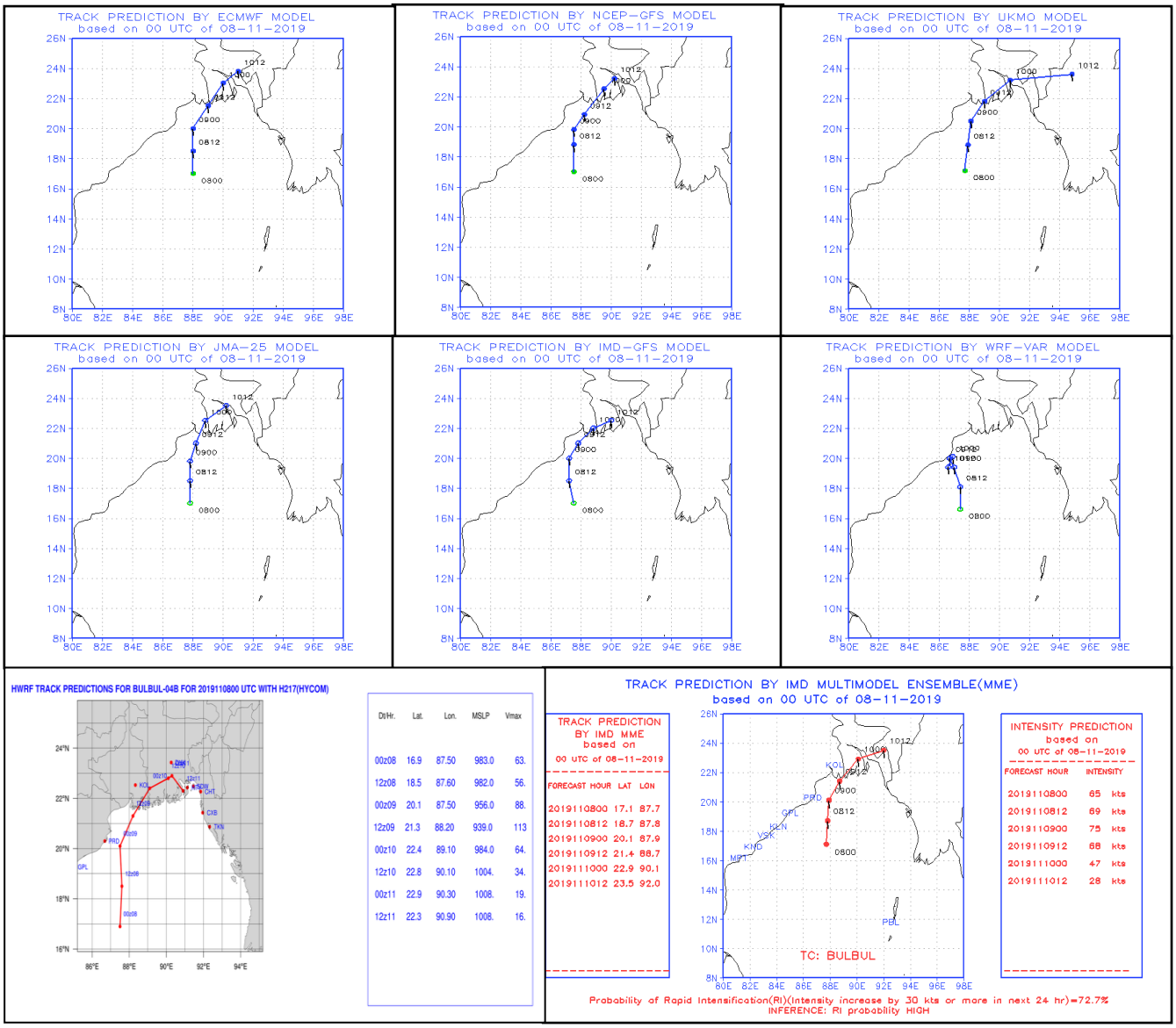


Fig. 12 (d): NWP model track forecast based on 0000 UTC of 08.11.2019

Based on initial conditions of 0000 UTC of 9th November, all models unanimously indicated landfall near West Bengal coast.

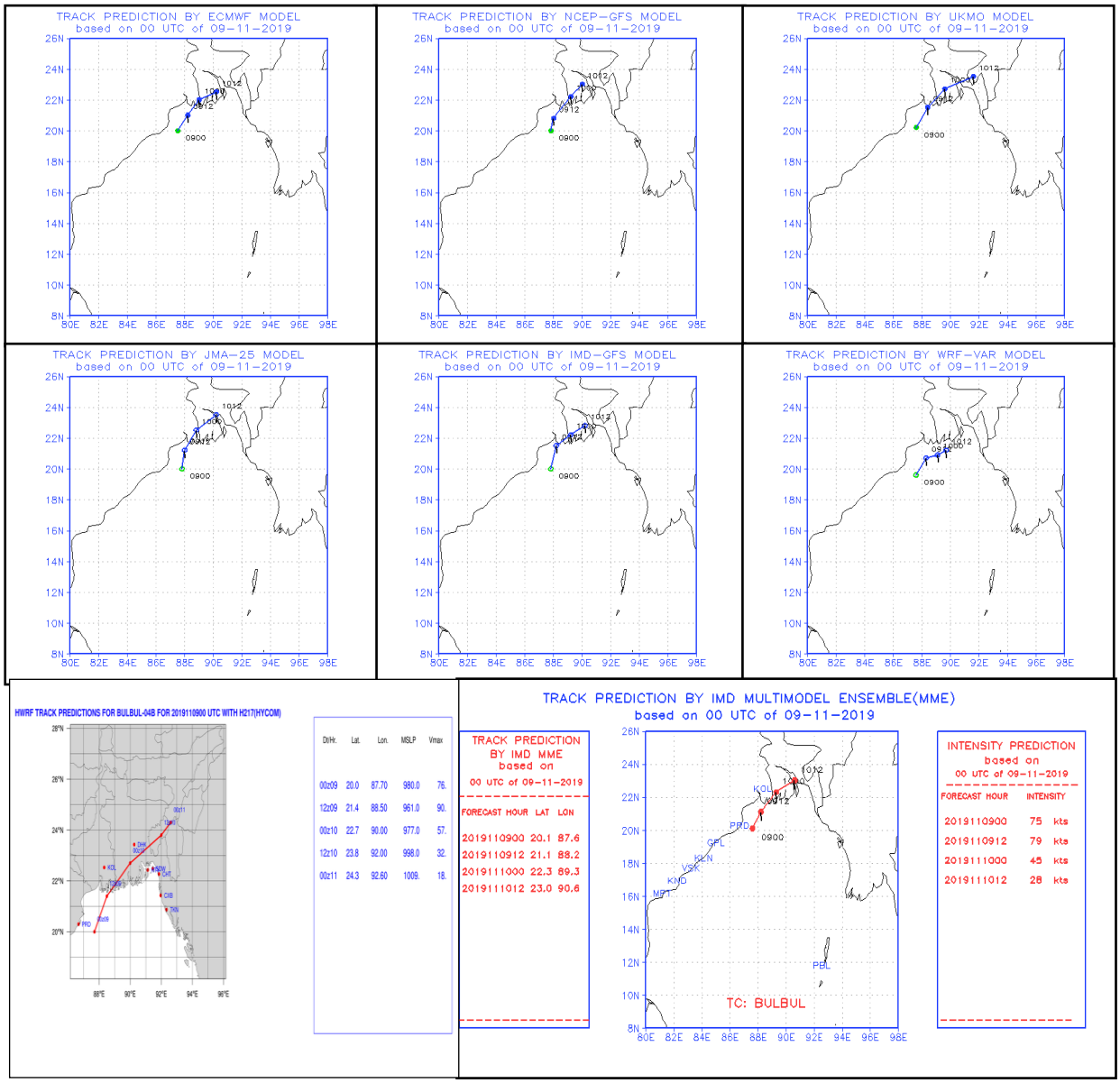


Fig. 12 (e): NWP model track forecast based on 0000 UTC of 09.11.2019

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 2**. From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors of MME was the least minimum for all lead periods followed by UKMO, NCEP GFS and HWRF.

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

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H	120H
IMD-MME	38(10)	47(10)	67(9)	92(8)	111(7)	125(6)	146(5)	204(5)	270(4)	324(3)
ECMWF	55	65	77	120	156	202	312	417	520	626
NCEP-GFS	47	50	66	88	106	139	141	210	306	408
UKMO	45	66	99	111	123	85	64	77	112	74
JMA	38	67	94	129	154	169	188	---	---	---
IMD-GFS	76	58	62	101	103	120	171	213	215	220
WRF-VAR	88	128	158	204	253	260	---	---	---	---
IMD-HWRF	56 (22)	66 (21)	81 (19)	71 (17)	99 (15)	130 (13)	180 (11)	247 (9)	317 (7)	309 (5)
NCUM	---	97(9)	---	131(9)	---	175(7)	---	192(5)	---	154(3)
NEPS	---	81(11)	---	127(9)	---	174(7)	---	173(5)	---	126(3)
UM REG	---	134 (11)	---	195 (9)	---	300 (7)	---	---	---	---

The landfall point and time forecast errors by various NWP models are presented in Table 3 (a-b).

Table-3a. Landfall point forecast errors (km) of NWP Models at different lead time (hour) ('NLF' indicates No Landfall Forecast)

Forecast Lead Time (hour) →	63 h (07 Nov/00z)	51 h (07Nov/12z)	39 h (08Nov/00z)	27 h (08Nov/12z)	15 h (9Nov/00z)	3 h (9Nov/12z)
ECMWF	NLF	59	59	50	35	59
NCEP GFS	77	110	50	82	50	57
UKMO	17	59	50	65	40	57
JMA	NLF	28	28	35	40	39
IMD-GFS	42	42	28	30	35	28
WRF-VAR	301	266	NLF	NLF	NLF	NLF
IMD-MME	97	83	52	12	12	12

Table-3b. Landfall time forecast errors (hour) at different lead time (hr)
('+' indicates delay landfall, '-' indicates early landfall)

Forecast Lead Time (hour) →	**63 h (07 Nov/00z)**	**51 h (07Nov/12z)**	**39 h (08Nov/00z)**	**27 h (08Nov/12z)**	**15 h (9Nov/00z)**	**3 h (9Nov/12z)**
ECMWF	NLF	+1	-4	-3	+2	+5
NCEP GFS	+7	+5	+1	+1	+2	+6
UKMO	-1	-4	-6	-4	-2	+2
JMA	NLF	+8	0	-4	-1	-1
IMD-GFS	+7	-5	+4	-3	-3	+1
WRF-VAR	-6	-5	NLF	NLF	NLF	NLF
IMD-MME	+27	+2	0	-1	0	+4

The landfall point and time forecast errors by IMD HWRF are presented in Table 4.

Table 4: Landfall point and time forecast errors by IMD HWRF

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr
HWRF Landfall Time Error (Hrs)	0	-3	-6	-3	-3	-9	24	--	3
HWRF Landfall Point Error (Kms)	11	32	42	59	74	94	351	--	25

9.4 Intensity forecast errors by various NWP Models

The intensity forecasts of IMD-SCIP model and HWRF model are shown in Table **5 (a-b).** The intensity predicted by IMD SCIP for various lead periods as compared to observed intensity and the SCIP based forecast errors based on absolute errors and root mean square errors is presented in **Fig.13(a-b)**. IMD SCIP most of the times underestimated the intensity of the system.

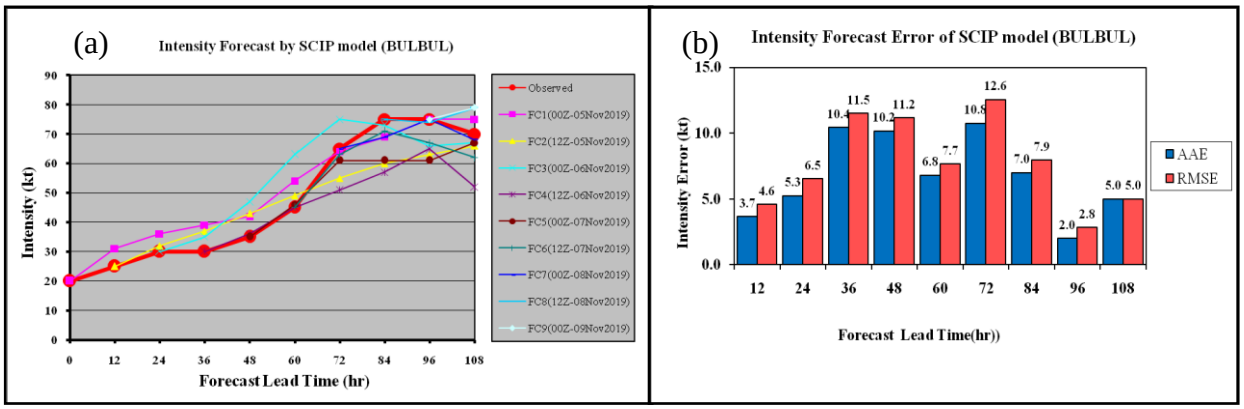


Fig. 13: (a) SCIP based Intensity Forecast and (b) Intensity forecast errors based on AAE and RMSE

Table 5 (a). 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	108 H
IMD-SCIP (AAE)	3.7(9)	5.3(8)	10.4(7)	10.2(6)	6.8(5)	10.8(4)	7.0(3)	2.0(2)	5.0(1)
IMD-SCIP (RMSE)	4.6	6.5	11.5	11.2	7.7	12.6	7.9	2.8	5.0

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

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108H	120H
HWRF (AAE)	7.5(22)	12.8(21)	15.1(19)	11.2(17)	10.4(15)	12.2(13)	9.9(11)	11.1(9)	19.1(7)	23.4(5)
HWRF (RMSE)	9.8(22)	15.8(21)	19.2(19)	16.0(17)	13.3(15)	14.4(13)	13.3(11)	16.1(9)	23.7(7)	34.2(5)

10. Operational Forecast Performance

10.1. Genesis Forecast

- First information about possible cyclogenesis over eastcentral BoB during later half of week (01-06 November) with low probability (01-33%) was indicated in the extended range outlook issued by IMD on 24th October 2019. (about 12 days prior to formation of depression over eastcentral & adjoining southeast BoB on 05th November, early morning (0000 UTC).
- First information about formation of LPA over north Andaman Sea & neighbourhood around 04th November was given in Tropical Weather Outlook issued on 31st October (about 120 hours prior to formation of LPA in the early morning [(0000 UTC) of 05th]. It was also predicted that it would move west-

northwestwards and concentrate into a depression around 05th (about 72 hours prior to formation of depression over eastcentral BoB on 05th early morning (0000 UTC).

10.2. Landfall Forecast

- In the Cyclone alert issued for West Bengal coast at 0000 UTC of 8th November, indication was given that the system is very likely to cross West Bengal – Bangladesh coasts between Sagar Islands (West Bengal) & Khepupara (Bangladesh) during the early hours of 10th November. Bulbul actually crossed West Bengal coast, close to Sunderban Dhanchi Forest near 21.55°N/88.0°E during the night (1500 to 1800 UTC) of 09th November.
- The warning was further refined and in the bulletin issued at 0900 UTC of 8th November, it was indicated that the system would cross west Bengal – Bangladesh coasts, between Sagar Islands & Khepupara across Sunderban Delta, around the mid-night of 9th November as a Severe Cyclonic Storm with sustained wind speed of 110-120 kmph gusting to 135 kmph. The system crossed West Bengal coast, close to Sunderban Dhanchi Forest, during 1500 – 1800 UTC, as a SCS with maximum sustained surface wind speed of 110-120 kmph gusting to 135 kmph. Typical observed and forecast track along with cone of uncertainty and wind distribution is presented in **Fig. 14**.

  Thus the landfall region, timing and intensity could be precisely predicted about 30 hours in advance. Adverse weather like heavy rainfall, strong wind and storm surge associated with the system were also well predicted by IMD. Since first bulletin, state of sea and warnings for fishermen in deep seas of central and northern parts of the BoB and along & off Odisha – West Bengal - Bangladesh coasts were issued both in textual and graphical form. Storm surge guidance was also issued for Bangladesh – West Bengal coasts.

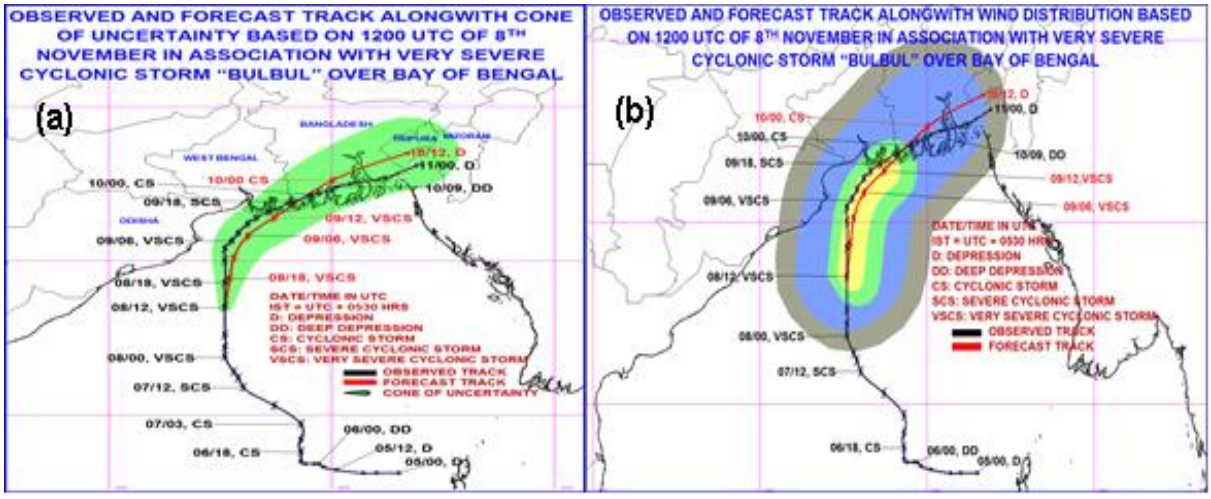


Fig.14: Observed and forecast track of VSCS 'BUL BUL' along with (a) cone of uncertainty and (b) wind distribution indicating accuracy in landfall, track and intensity predictions near West Bengal coast.

10.3. Landfall Forecast Errors:

- The landfall point forecast errors for 12, 24 and 48 hrs lead period were 11.2, 49.9, and 50.5 km respectively against long period average errors of 26.5, 46.6 and 69.7 km during 2014-18 respectively **(Fig. 15a).**
- The landfall time forecast errors for 12, 24 and 48 hrs lead period were 1, 3 and 5 hours respectively against long period average errors of 2.0, 2.9 and 5.1 hours during 2014-18 respectively **(Fig. 15b).**

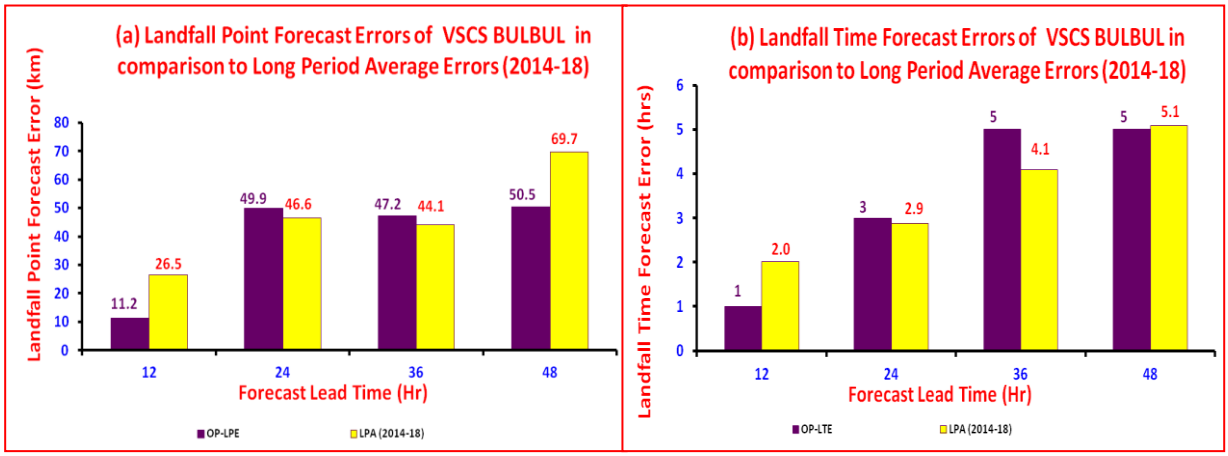


Fig. 15: (a) Landfall point and (b) Landfall time forecast Errors of VSCS 'BULBUL' as compared to long period average (2014-18)

10.4. Track Forecast Errors:

- The track forecast errors for 24, 48 and 72 hrs lead period were 67, 77, and 131 km respectively against the average track forecast errors of 86, 132, and 178 km during last five years (2014-18) respectively (**Fig.16a)**.
- The track forecast skill was about 55%, 73%, and 71% against the long period average (LPA) of 58%, 70%, and 74% during 2014-18 for 12, 24 and 48 hrs lead period respectively (**Fig.16b)**.

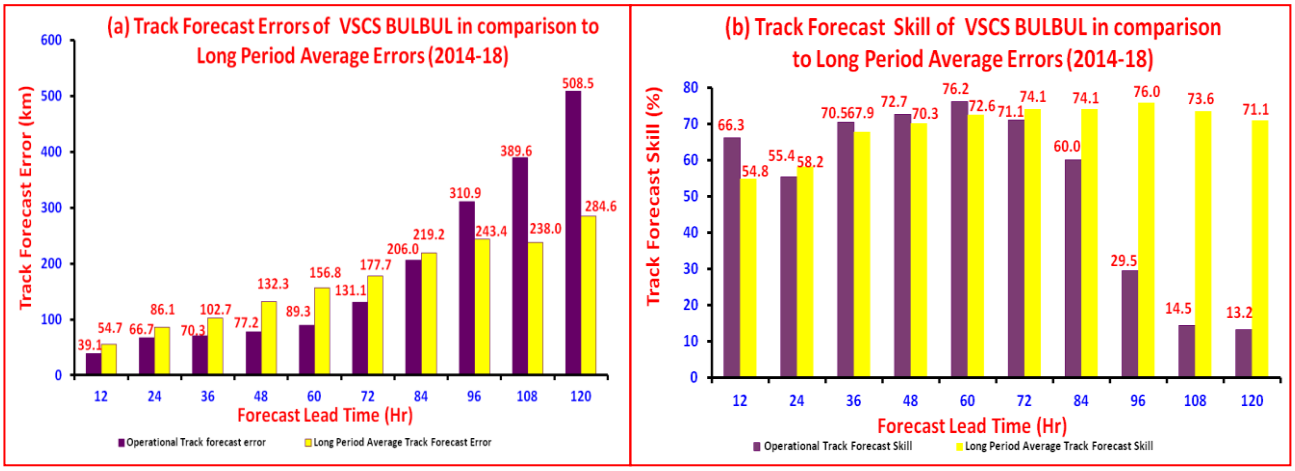


Fig. 16: Track forecast (a) Errors and (b) skill of VSCS 'BUL BUL' as compared to long period average (2014-18)

10.5. Intensity Forecast Errors:

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 8.6, 8.1 and 8.9 knots against the LPA of 9.6, 14.1 and 14.3 knots respectively **(Fig. 17a).**
- The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 9.2, 9.2 and 11.3 knots against the LPA of 12.5, 19.0 and 19.0 knots respectively **(Fig. 17b).**

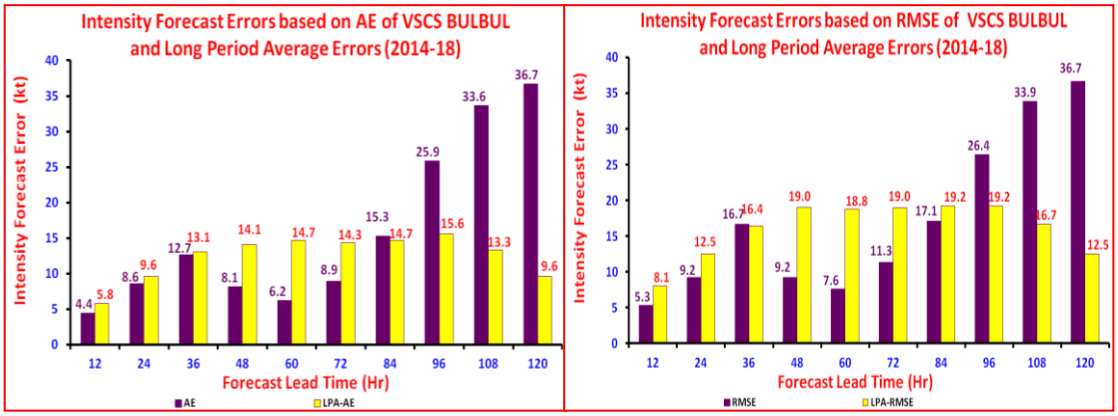


Fig. 17: (a) Absolute errors (AE) and (b) Root Mean Square errors (RMSE) in intensity forecast (winds in knots) in association with VSCS 'BUL BUL' as compared to long period average (2014-18)

- The skill in intensity forecast based on AE for 24, 48 and 72 hrs lead period was 54, 81 and 83 % against the LPA of 43, 68 and 72 % respectively **(Fig. 18).**
- The skill in intensity forecast based on RMSE for 24, 48 and 72 hrs lead period was 56, 83 and 85 % against the LPA of 49, 59 and 85 % respectively **(Fig. 18).**

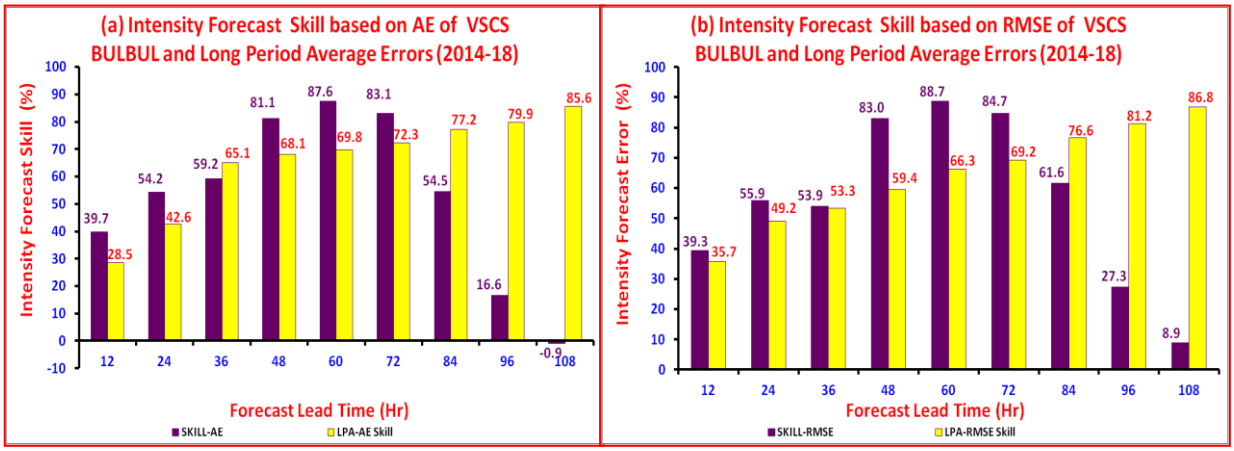


Fig. 18: Skill in intensity forecast (%) based on (a) Absolute errors (AE) and (b) Root Mean Square errors (RMSE) in association with VSCS 'BUL BUL' as compared to long period average (2014-18)

11. Warning Services

Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track, intensity and landfall forecast for +06, +12, +18, +24, +36 and +48… +120 hrs lead period till the system weakened into a Low pressure area. The above forecasts were issued from the stage of depression onwards along with the cone of uncertainty in the track forecast five times a day and every three hours during the cyclone period. The hourly updates were also provided to Bangladesh on the day of landfall till the system crossed West Bengal coast. Typical graphical product is presented in **Fig. 14a**.
- **Cyclone structure forecast for shipping and coastal hazard management:** The radius of maximum wind and radii of MSW ≥28 knots, ≥34 knots, ≥50 knots and ≥64 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36 …..and +120 hrs lead period. Typical graphical product is presented in **Fig. 14b**.
- **Four stage Warning:**
  - Cyclone Watch: Cyclone watch for West Bengal - north Odisha coasts was issued at 1440 hours IST (0910 UTC) of 7th November when the system was a CS over eastentral BoB (56 hrs prior to the system crossing West Bengal coast).
  - Cyclone Alert: 32 hrs prior to actual crossing, issued for coastal districts of West Bengal (east & west Medinipur, North & south 24 Parganas) in the Bulletin issued at 0500 hrs IST (0000 UTC) of 08th November.
  - Cyclone Warning: Was issued on 08th November, 1110 hrs IST [0610 UTC] (about 24 hrs prior to the commencement of Gale winds and heavy rains) for West Bengal coast
  - Post landfall Outlook for northern districts of Gangetic West Bengal, south Assam, Meghalaya and Tripura, indicating expected winds, damage and action suggested after landfall of the system was issued at 0830 hrs IST (0300 UTC) of 09th November (about 12 hrs prior to actual landfall).

- **Adverse weather warning bulletins:** The tropical cyclone forecasts along with expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update to central, state and district level disaster management agencies including MHA NDRF, NDMA for all concerned states along the east coast of India including Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and Andaman & Nicobar Islands. The storm surge warnings were also issued to Oman. Typical storm surge guidance product is presented in **Fig.19**. The bulletins also contained the suggested action for disaster managers and general public in particular for fishermen. These bulletins were also issued to Defense including Indian Navy & Indian Air Force.
- **Warning graphics:** The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The adverse weather warnings related

to gale/squally wind & storm surge were also presented in graphics in the website.

- **Warning and advisory through social media:** Daily updates (every six hourly or whenever there was any significant change in intensity/track/landfall) were uploaded on face book and twitter regularly during the life period of the system. Bulletins were also issued to state level disaster managers through whatsapp. The tropical cyclone advisories were also sent to Bangladesh Meteorological Department through whatsapp.
- **Press release and press briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services division at New Delhi and bulletins for maritime interest were issued by Area Cyclone Warning Centres of IMD at Kolkata & Chennai, and Cyclone Warning Centres at Bhubaneswar and Visakhapatnam to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen were issued for deep Sea of central and North Bay of Bengal and the coasts of Odisha and West Bengal.
- **Advisory for international Civil Aviation:** The Tropical Cyclone Advisory Centre (TCAC) bulletin for International Civil Aviation were issued every six hourly to all meteorological watch offices in Asia Pacific region for issue of significant meteorological information (SIGMET). It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong.
- **Diagnostic and prognostic features of cyclone:** The prognosis and diagnosis of the systems were described in the RSMC bulletins.
- **Hourly Bulletin:** Hourly updates on the location, distance from recognised station, intensity and landfall commenced from 0300 UTC of 09th November till 0000 UTC of 10th November, on the day of system crossing coast.
- **Bulletins issued by RSMC New Delhi, IMD are presented in Table 6(a) and those issued by ACWC Kolkata, CWC Bhubaneswar and CWC Visakhapatnam in Table 6(b).**

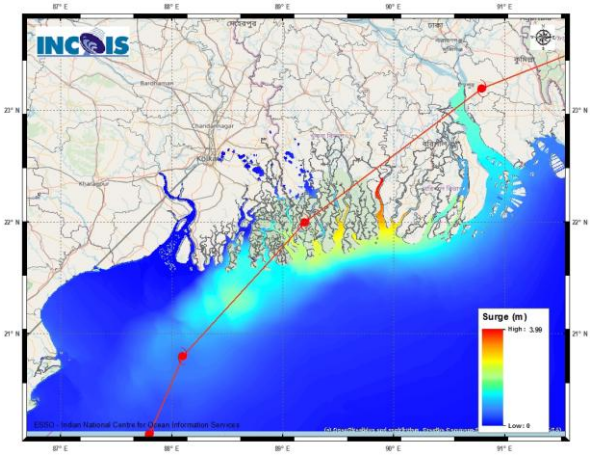


Fig. 19: Typical storm surge guidance in association with VSCS BUL BUL

Table 6 (a): Bulletins issued by RSMC New Delhi

S.N	Bulletin	No. of Bulletins	Issued to
1	National Bulletin	41	1. IMD's website, RSMC New Delhi website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defense Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Chief Secretary- Tami Nadu, Andhra Pradesh, Odisha, West Bengal Administrator- Andaman & Nicobar Islands, Union Territory of Karaikal, Yanam & Puducheri.
2	Bulletin from DGM, IMD	8	Cabinet Secretary, Principal Secretary to PM, Secretary, Ministry of Home Affairs, Ministry of Agriculture, Ministry of I & B, MoES, Secretary, DST, Control Room, NDM, Ministry of Home Affairs, Director of Punctuality, Indian Railways, Director General, Doordarshan, Director General, AIR, Secretary, NDMA, Director General, NDRF, Chief Secretary Tamil Nadu, Andhra Pradesh, Odisha, West Bengal Administrator- Andaman & Nicobar Islands, Union Territory of Karaikal, Yanam & Puducherri.
3	RSMC Bulletin	41	1. IMD's website 2. WMO/ESCAP member countries and WMO through GTS and E-mail.
4	GMDSS Bulletins	20	1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)
5	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	19	1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation. 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website
6	Tropical Cyclone Vital Statistics	18	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
1	Warnings through SMS	Daily four times	(i) SMS to disaster managers at national level and concerned states (every time when there was change in intensity) (ii) To general public- to users registered with RSMC website from the states of Tamil Nadu, Andhra Pradesh, Odisha, West Bengal. (iii) To fishermen by INCOIS (iv) To farmers through Kisaan Portal (v) To farmers of Bangladesh by Department of Agriculture, Bangladesh Meteorological Department

2	Warnings through Social Media	Daily four times a day	Cyclone Warnings were uploaded on Social networking sites (Face Book, Twitter and Whatsapp) since inception to weakening of system (every time when there was change in track, intensity and landfall characteristics).
3	Press Release	8	Disaster Managers, Media persons by email and uploaded on website
4	Press Briefings	Frequently	Regular briefing daily
5	Hourly Updates	36	Hourly bulletins by email, website, social media

Table 6 (b): Bulletins issued by ACWC Kolkata, CWC Bhubaneswar & CWC Visakhapatnam

Sl. No.	Type of bulletin	No. of bulletins issued		
		ACWC Kolkata	CWC Bhubaneswar	CWC Visakhapatnam
1.	Sea area Bulletin	26	-	-
2.	Coastal weather Bulletin	West Bengal coast – 19 A & N coast - 12	33	19
3.	Fishermen warning	West Bengal coast – 18 A & N coast - 12	41	18
4.	Port warnings	West Bengal – 24 A & N - 19	54	11
5.	Heavy rainfall warning	West Bengal – 25 (For 2 days) A & N – 08 (For 3 days)	03	NIL
6.	Gale wind warning	West Bengal coast – 27 (For 2 days) A & N coast - 04	28	NIL
7.	Storm surge warning	West Bengal coast - 17	NIL	NIL
8.	Information & warnings issued to State & other agencies	West Bengal – Special weather Bulletin – 32, Hourly – 22, Press releases – 3 A&N - 10	36 (First special Bulletin was issued on 5th November 2019, at 1030 hrs IST), 04 press releases	2 press releases
9.	SMS / Social media messages	20.000 (approximately)	27,548	200

12. **Adverse weather forecast verification**

The verification of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Tables 7-10. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table 7: Verification of Heavy Rainfall Warning Forecast (5-11 November)

Date/Base Time of observation	24 hr Heavy rainfall warning ending at 0300 UTC of next day	Realised 24-hour heavy rainfall ending at 0300 UTC of date
05.11.2019/0300	**Andaman and Nicobar Islands:** Heavy falls at isolated places over Andaman and Nicobar Islands during 5 th and 6 th Nov, 2019.	**9th November** Odisha Paradip-16, Chandbali-15, Rajkanika-14, Tirtol & Balipatna-10 each and Bhadrak-7. West Bengal Digha-7. **10th November** Odisha Bhograi-9 West Bengal Dhapa -21, Canning-19, Joka -16, Cantai & Jora Bridge -13, Kakdwip- 12, Ultadanga & Positional Astronomy Centre, IMD -11 each, Newmarket, Ballygunge, Patuli, Behala, Dumdum, Digha & Haldia-10 each, Alipore & Barrackpur -9 each, Mominpur & Palmer Bridge -8 each, Shibpur -7 (Other than Canning & Kakdwip, all other places are in Kolkata). After crossing the coast & weakening, it
06.11.2019/0300	No heavy rainfall warning	
07.11.2019/0300	**Odisha:** (i) Isolated heavy to very heavy falls over Puri, Kendrapara and Jagatsinghpur districts and heavy falls at isolated places over in the remaining districts on 8th November **(ii)** Isolated heavy to very heavy falls over Balasore, Bhadrak, Kendrapara and Jagatsinghpur districts and heavy falls at isolated places over Mayurbhanj, Cuttack and Jajpur districts on 9th November. **West Bengal**: (i) Extremely heavy falls at isolated places North and South 24 Parganas, isolated heavy to very heavy falls over East and West Medinipur, Howrah, Hooghly on 9th November **(ii)** Isolated heavy to very heavy falls at isolated places North and South 24 Parganas, isolated heavy falls over East Medinipur, Howrah, Hooghly and Nadiya districts on 9th November.	
08.11.2019/0300	**Odisha:** (i) Isolated heavy falls over Puri, Kendrapara, Bhadrak and Jagatsinghpur districts on 8th November. (ii) Isolated heavy to very heavy falls over Balasore, Bhadrak, Kendrapara and Jagatsinghpur districts and heavy falls at isolated places over Mayurbhanj and Jajpur districts on 9th November. **West Bengal**: (i) Isolated heavy falls over North and South 24 Parganas and east Medinipur districts on 8th November. (ii) **Coastal districts of West Bengal**: Heavy to very heavy falls at few places and extremely heavy falls (≥ 20 cm in 24 hours) at isolated places over North & South 24 Parganas, East and West Medinipur, and isolated heavy to very heavy rainfall over Howrah and Hooghly on 9th November 2019. (iii) Heavy to very heavy falls at a few places over North and South 24 Parganas, Nadiya and	

	heavy falls at isolated places over East Medinipur district on 10th November 2019.	caused isolated heavy rains over Tripura for a day. **11th November** Tripura Sabroom – 8
09.11.2019/0300	**Odisha:** (i) Isolated heavy to very heavy falls over north coastal districts of Odisha including Balasore, Bhadrak, Kendrapara and Jagatsinghpur districts and with heavy falls at isolated places over Jajpur district on 9th November. **West Bengal**: (i) Heavy to very heavy falls at a few places and extremely heavy falls (≥ 20 cm in 24 hours) at isolated places over North & South 24 Parganas, East Medinipur, and isolated heavy to very heavy rainfall over West Medinipur, Howrah and Hooghly on 9th Novdember. (ii) Heavy falls at isolated places over North and South 24 Parganas and Nadiya till 10th November morning **North-eastern States:** Isolated heavy falls over Mizoram and Tripura on 9th and over South Assam & Meghalaya, Tripura, and Mizoram on 10th.	

Table 8: Verification of Squally/Gale wind forecast (5-11 November)

Date/Base Time of observation	Gale/ Squally wind Forecast at 0300 UTC of date	Realised wind
05.11.2019/0300	**Andaman and Nicobar Islands:** Squally wind speed reaching 40-50 kmph gusting to 60 kmph is prevailing over Andaman Islands, north Andaman Sea and Adjoining areas southeast & eastcentral Bay of Bengal. It is likely to increase becoming 60–70 kmph gusting to 80 kmph by 6th November morning and decrease gradually thereafter. Bay of Bengal: Squally wind speed reaching 50-60 kmph gusting to 70 kmph very likely to over eastcentral Bay of Bengal around the system centre for next 12 hours and will become gale wind speed reaching 80-90 kmph gusting to 100 kmph by 7th November morning. It will gradually increase further over central parts of Bay of Bengal, becoming 120-130 kmph gusting to 145 kmph by 8th November evening. **Odisha & West Bengal coasts**: Squally wind speed reaching 40 – 50 kmph gusting to 60 kmph likely to commence over northwest Bay of Bengal.	Realised Max sustained wind speed (MSW) recorded on 09.11.19: Kolkata (Alipore) reported MSW of 60 kmph at 2230 IST on 09.11.19 and at 0015 IST on 10.11.19; Digha reported 45-50 kmph during 1940-1945 IST on 9th November

06.11.2019/0300	**Andaman and Nicobar Islands**: Strong wind speed reaching 35-45 kmph gusting to 55 kmph is likely to prevail over Andaman Islands, north Andaman Sea during next 24 hours. **Bay of Bengal**: Squally wind speed reaching 50-60 kmph gusting to 70 kmph is prevailing over eastcentral and adjoining southeast Bay of Bengal around the system centre. It will become gale wind speed reaching 70-80 kmph gusting to 90 kmph by 7th November morning. It will gradually increase further becoming 120-130 kmph gusting to 145 kmph over northwest and adjoining central Bay of Bengal by 9th November evening.	
07.11.2019/0300	**Bay of Bengal:** Gale wind speed reaching 65-75 kmph gusting to 85 kmph is prevailing over east central Bay of Bengal around the system centre. It is very likely to increase gradually and become 85-95 kmph gusting to 105 kmph by 8th November morning. It will increase further becoming 120-130 kmph gusting to 145 kmph over north Bay of Bengal by 9th November morning for subsequent 12 hours. **Odisha coast**: Strong wind speed reaching 35 – 45 kmph gusting to 55 kmph becoming squally 45-55 gusting to 65 by afternoon of 8th over Kendrapara, Jagatsinghpur, Balasore and Bhadrak districts. Gale wind speed reaching 70-80 kmph gusting to 90 kmph likely towards evening of 9th November over Jagatsinghpur, Balasore and Bhadrak districts. It is likely to decrease from 10th onwards. Puri, Ganjam and Jajpur districts are likely to experience squally wind speed reaching 40-50kmph gusting to 60 kmph on 8th and 9th November. **West Bengal coast**: Squally wind speed reaching 40 – 50 kmph gusting to 60 kmph likely to commence over West Bengal coasts from 8th November night and gradually increase.	
08.11.2019/0300	**Bay of Bengal**: Gale wind speed reaching 120-130 kmph gusting to 140 kmph is prevailing over	

	westcentral & adjoining eastcentral Bay of Bengal around the system centre. It is very likely to increase gradually and become 145-155 kmph gusting to 170 kmph by early hours of 9th November over northwest & adjoining westcentral Bay of Bengal for subsequent 12 hours and decrease gradually thereafter. **Odisha coast**: Strong wind speed reaching 35– 45 kmph gusting to 55 kmph prevails along & off Odisha coast. It is very likely to increase becoming squally wind speed reaching 45-55 kmph gusting to 65 kmph by afternoon of 8th along & off Kendrapara, Jagatsinghpur, Balasore and Bhadrak districts. Gale wind speed reaching 70-80 kmph gusting to 90 kmph very likely from around noon of 9th November along & off Jagatsinghpur, Kendrapara, Balasore and Bhadrak districts for subsequent 12 hours and decrease thereafter. Puri and Ganjam districts are likely to experience squally wind speed reaching 40-50 kmph gusting to 60 kmph from afternoon of 8th November for the subsequent 24 hours. **West Bengal coast:** Squally wind speed reaching 40 – 50 kmph gusting to 60 kmph likely to commence over West Bengal coast from 8th November night. It will gradually increase becoming gale wind speed reaching 110-120 kmph gusting to 135 kmph from 09th midnight to 10th forenoon along & off East Medinipur, North & South 24 Parganas. Squally wind speed reaching 40-60 Kmph gusting to 70 Kmph also likely over adjoining districts of West Medinipur, Howrah and Hooghly.	
09.11.2019/0300	**Bay of Bengal**: Gale wind speed reaching 130-140 kmph gusting to 155 kmph is prevailing over northwest Bay of Bengal around the system centre. It is very likely to decrease gradually and become 115-125 kmph gusting to 140 kmph by today, the 9th evening and decrease gradually thereafter. **Odisha coast:** Gale wind speed reaching 70-80 kmph gusting to 90 kmph is likely to continue along & off Kendrapara, Jagatsinghpur districts during next 3 hours, and along & off	

	Balasore and Bhadrak districts for next 6 hours. Puri and Ganjam districts are likely to experience squally wind speed reaching 40-50 kmph gusting to 60 kmph during next 06 hours. **West Bengal coast**: Squally wind speed reaching 70-80 kmph gusting to 90 kmph is prevailing along and off West Bengal coast. It will gradually increase becoming gale wind speed reaching 115-125 kmph gusting to 140 kmph from the evening of today, the 9th November for next 12 hours along & off East Medinipur, North & South 24 Parganas. Squally wind speed reaching 50- 60 Kmph gusting to 70 kmph also likely over adjoining districts of West Medinipur, Howrah and Hooghly during the same period.	
10.11.2019/0300	Gale wind, speed reaching 75-85 kmph gusting to 95 kmph, prevailing around the system centre over coastal Bangladesh and neighbourhood. It will decrease becoming 60- 70 kmph gusting to 80 kmph over coastal Bangladesh and adjoining North Bay of Bengal, by afternoon of today, the 10th November. Squally wind speed reaching 40-50 kmph gusting to 60 kmph likely along & off south & north 24 Parganas during next 06 hours and decrease thereafter. Strong wind speed reaching 30-40 Kmph gusting to 50 Kmph likely to prevail over Mizoram and Tripura during next 12 hours	

Table 9: Verification of Storm Surge Forecast

Date/Base Time of observation	Storm Surge Forecast	Realised surge
08.11.2019/0300	Storm surge of about 1.0 to 1.5 meter height above astronomical tide to inundate low lying areas of South and North 24 Parganas and east Medinipur during the time of landfall.	
09.11.2019/0300	Storm surge of about 1.0 to 2.0 meter height above Astronomical tide is very likely to inundate low lying areas of South and North 24 Parganas and 0.5-1.0 meter height above Astronomical tide is very likely to inundate low lying areas of east Medinipur during the time of landfall. The maximum extent of inundation is likely to be around 2 km over South and North 24 Parganas	

13. Appreciation earned for monitoring and forecasting of VSCS 'BULBUL' from the concerned State governments & from Bangladesh Meteorological Department:

The state Governments and respective Disaster management Agencies appreciated the timeliness and accuracy of the Cyclone Warning bulletins issued by IMD. Bangladesh Meteorological Department also appreciated the Cyclone advisories as well as Hourly Bulletins issued by RSMC New Delhi.

14. Summary

The Very Severe Cyclonic Storm (VSCS) "BUL BUL" originated from the remnant of Severe Tropical Storm 'MATMO' (28th October - 2nd November) over west Pacific Ocean that emerged into north Andaman Sea. It formed as a low pressure area over north Andaman Sea in the early morning (0000 UTC) of 04th November. It concentrated into a Depression (D) over east central and adjoining southeast Bay of Bengal (BoB) in the early morning (0000 UTC) of 05th November. It intensified into cyclonic storm "BUL BUL" in the late night (1800 UTC) of 06th November over eastcentral and adjoining southeast BoB. It further intensified into a VSCS in the early morning (0000 UTC) of 08th November over westcentral and adjoining eastcentral BoB. It weakened into an SCS and crossed West Bengal coast, close to Sunderban Dhanchi Forest near 21.55°N/88.0°E during the night (1500 to 1800 UTC) of 09th November as SCS with maximum sustained surface wind speed of 110-120 kmph gusting to 135 kmph. Continuing to move northeastwards, it weakened into a WML over southern parts of Tripura & neighbourhood in the morning hours (0300 UTC) of 11th November.

15. Acknowledgement:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge contribution from WMO and Bangladesh Meteorological Department in dissemination of bulletins and warnings associated with VSCS 'BUL BUL'. IMD and RSMC New Delhi also acknowledge the contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of VSCS 'BUL BUL'. We acknowledge the contribution of all sister organisations of Ministry of Earth Sciences including National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), Indian Institute of Tropical Meteorology (IITM) Pune, research institutes including IIT Bhubaneswar, IIT Delhi.