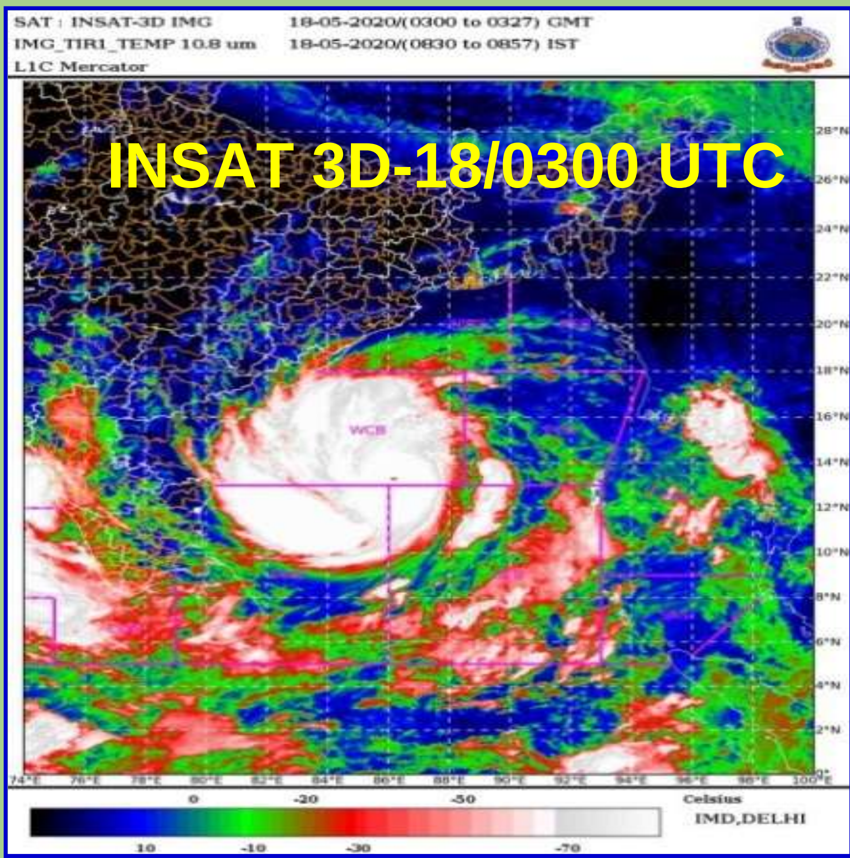
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Super Cyclonic Storm, ‘AMPHAN’ over Southeast Bay of Bengal (16 May – 21 May 2020): A Report



INSAT-3D enhanced colored IR imagery of 18th May, 2020

Cyclone Warning Division

India Meteorological Department

New Delhi

January, 2021

Super Cyclonic Storm, 'AMPHAN' over Southeast Bay of Bengal (16 May – 21 May 2020)

1. Introduction

- The Super Cyclonic Storm (SuCS) "AMPHAN" originated from the remnant of a Low Pressure Area which occurred in the near Equatorial Easterly wave over south Andaman Sea and adjoining southeast Bay of Bengal (BoB) during 1st – 5th May. Though the Low Pressure Area became less marked on 6th May, its remnant circulation meandered over south Andaman Sea and adjoining southeast BoB during 6th – 12th May. Under its influence, a fresh Low Pressure Area formed over southeast BoB and adjoining south Andaman Sea in the morning (0300 UTC) of 13th May.
- It lay as a well marked low pressure area (WML) over southeast BoB & neighbourhood in the morning (0300 UTC) of 14th May.
- Under favourable environmental conditions, it concentrated into a depression (D) over southeast BoB in the early morning (0000 UTC) of 16th May and further intensified into a deep depression (DD) in the same afternoon (0900 UTC).
- It moved north- northwestwards and intensified into Cyclonic Storm "AMPHAN" (pronounced as UM-PUN) over southeast BoB in the evening (1200 UTC) of 16th May, 2020. Moving nearly northwards, it further intensified into a Severe Cyclonic Storm (SCS) over southeast BoB in the morning (0300 UTC) of 17th May.
- It underwent rapid intensification during subsequent 24 hours and accordingly intensified into a Very Severe Cyclonic Storm (VSCS) by the afternoon (0900 UTC) of 17th, Extremely Severe Cyclonic Storm (ESCS) in the early hours of 18th (2100 UTC of 17th May) and into a Super Cyclonic Storm (SuCS) around noon (0600 UTC) of 18th May, 2020.
- It maintained the intensity of SuCS over westcentral BoB for nearly 24 hours, before weakening into an ESCS over westcentral BoB around noon (0600 UTC) of 19th May.
- Thereafter, it weakened slightly and crossed West Bengal – Bangladesh coasts as a VSCS, across Sundarbans, near latitude 21.65°N and longitude 88.3°E during 1530-1730 hrs IST (1000-1200 UTC) of 20th May, with maximum sustained wind speed of 155 – 165 kmph gusting to 185 kmph. It lay over West Bengal as a VSCS, gradually moving north-northeastwards during late evening to night (1200 – 1500 UTC) of 20th May. It moved very close to Kolkata during this period.
- Moving further north-northeastwards, it weakened into an SCS over Bangladesh & adjoining West Bengal around mid-night (1800 UTC) of 20th May, weakened further into a CS over Bangladesh in the early hours (2100 UTC of 20th) of 21st May, into DD over Bangladesh around noon of 21st May and into a D over north Bangladesh in the evening (1200 UTC) of the same day. It further weakened and lay as a well marked low pressure area over north Bangladesh and neighbourhood around mid-night (1800 UTC) of 21st May.
- The observed track of the system during 16th – 21st May is presented in **Fig.1**. 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 first SuCS over the BoB, after the Odisha SuCS of 1999.

ii. Climatologically, during satellite era a total of 7 severe cyclonic storms and above intensity storms developed within the grid ±2.5º of the genesis point (10.4ºN and 87.0ºE). Out of these, 5 crossed Bangladesh coast and 2 crossed north Andhra Pradesh coast (Fig. 2a). Considering the total number of severe cyclonic storms and above intensity storms crossing West Bengal-Bangladesh coasts in the month of May during satellite era, a total of 2 (1989, 2009) severe cyclonic storms and above intensity storms crossed West Bengal coast and 7 crossed Bangladesh coast (Fig.2b).

iii. It had a clockwise recurving track as it moved initially north-northwestwards till 1200 UTC of 17th and north-northeastwards thereafter. The total track length of the system was 1765 km. It was mainly steered by an anticyclonic circulation in middle & upper tropospheric levels to the northeast of the system centre.

iv. It under went intensification during 17th noon (0600 UTC) to 19th May early morning hours (2100 UTC of 18th) over westcentral BoB mainly due to low vertical wind shear (10-15 knots), very warm sea surface temperatures (SSTs – 30-31ºC), high tropical cyclone heat potential (100 - 120 KJ /cm^2) and increased cross equatorial wind surge. During this period, the system experienced an increase in maximum sustained wind speed (MSW) from 50 knots at 0600 UTC of 17th to 130 knots at 2100 UTC of 18th May.

v. The peak MSW of the cyclone was 240-250 kmph (130 knots) gusting to 275 kmph (145 knots) during 1800 UTC of 18th to 0000 UTC of 19th May over the westcentral BoB. The lowest estimated central pressure was 920 hPa during the same period (Fig.3a). Thereafter, the system started weakening over westcentral BoB under unfavourable environment (increase in vertical wind shear (20-25 knots)) and low Ocean thermal energy.

vi. The system crossed West Bengal-Bangladesh coasts as a very severe cyclonic storm across Sundarbans, near lat.21.65°N/long. 88.30°E during 1000-1200 UTC, with maximum sustained wind speed of 85 knots gusting to 100 knots.

vii. The system maintained the cyclonic storm intensity for almost 15 hours even after landfall from 1200 UTC of 20th May to 0300 UTC of 21st May.

viii. The life period (D to D) of the system was 138 hours (5 days & 18 hours) against Long Period Average (LPA) of 134 hours (5 days & 14 hrs) for VSCS/ESCS categories over BoB during pre monsoon season based on the data of 1990-2013.

ix. It moved with 12 hour average translational speed of 13.9 kmph against LPA (1990-2013) of 14.7 kmph for VSCS category over the north Indian Ocean (Fig.3b). During initial stages of it's development (0000 UTC of 16th to 1200 UTC of 18th May), AMPHAN moved slower than the average. Thereafter the speed increased and reached the maximum (29 kmph at 0600 UTC of 20th May) just prior to landfall.

x. The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 16.30 X10^2 knots, 15.45 X 10^4 knots^2 and 16.04 X10^6 knots^3 respectively against the LPA during 1990-2013 of

5.28 X10^2 knots, 8.6 X 10^4 $knots^2$ and 2.8 X10^6 $knots^3$ respectively for tropical cyclones over BoB during pre-monsoon season.

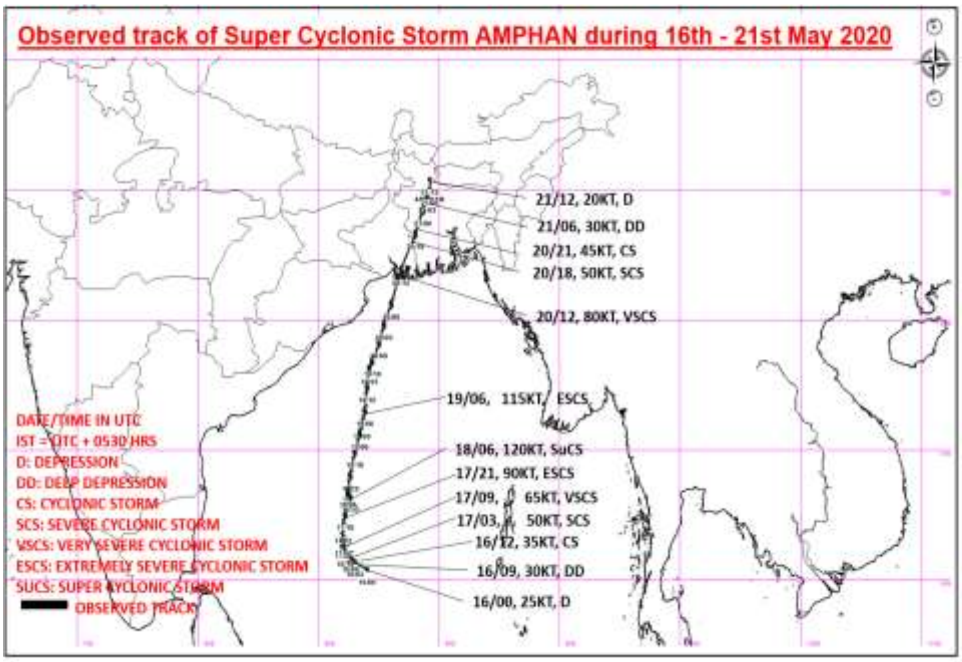


Fig.1: Observed track of SuCS 'AMPHAN' over the southeast Bay of Bengal (16-21 May, 2020)

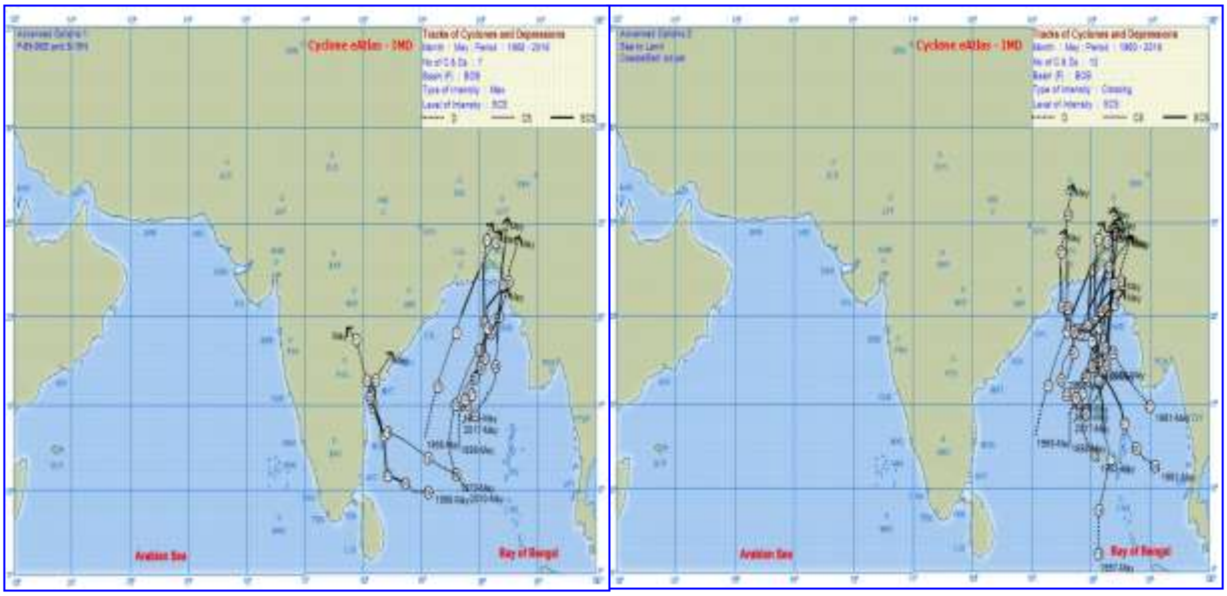


Fig.2: Tracks of severe cyclonic storms and above intensity storms (a) developing in the grid ±2.5^0 of genesis point and (b) crossing West Bengal-Bangladesh coasts in the month of May during satellite era 1960 onwards

Table 1: Best track positions and other parameters of the Super Cyclonic Storm, 'AMPHAN' over the Bay of Bengal during 16 May- 21 May, 2020

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
16/05/2020	0000	10.4	87.0	1.5	1000	25	03	**D**
	0300	10.7	86.5	1.5	1000	25	03	D
	0600	10.9	86.3	1.5	1000	25	03	D
	0900	10.9	86.3	2.0	998	30	05	**DD**
	1200	10.9	86.3	2.5	996	35	07	**CS**
	1500	11.0	86.2	2.5	995	40	08	CS
	1800	11.1	86.1	2.5	995	40	08	CS
	2100	11.3	86.1	3.0	994	45	10	CS
17/05/2020	0000	11.4	86.0	3.0	992	45	10	CS
	0300	11.4	86.0	3.0	990	50	12	**SCS**
	0600	11.5	86.0	3.5	988	55	15	SCS
	0900	11.7	86.0	4.0	980	65	22	**VSCS**
	1200	12.0	86.0	4.0	978	70	25	VSCS
	1500	12.8	86.2	4.0	978	70	25	VSCS
	1800	12.5	86.1	4.5	970	80	32	VSCS
	2100	12.9	86.4	5.0	962	90	40	**ESCS**
18/05/2020	0000	13.2	86.3	5.5	952	100	50	ESCS
	0300	13.3	86.2	6.0	936	115	66	ESCS
	0600	13.4	86.2	6.5	930	120	72	**SuCS**
	0900	13.7	86.2	6.5	930	120	72	SuCS
	1200	14.0	86.3	6.5	926	125	76	SuCS
	1500	14.5	86.4	6.5	926	125	76	SuCS
	1800	14.9	86.5	6.5	920	130	84	SuCS
	2100	15.2	86.6	6.5	920	130	84	SuCS
19/05/2020	0000	15.6	86.7	6.5	926	125	76	SuCS
	0300	16.0	86.8	6.0	930	120	72	SuCS
	0600	16.5	86.9	6.0	936	115	66	**ESCS**
	0900	17.0	86.9	6.0	942	110	60	ESCS
	1200	17.4	87.0	5.5	946	105	56	ESCS
	1500	18.1	87.1	5.5	950	100	50	ESCS
	1800	18.4	87.2	5.5	950	100	50	ESCS
	2100	18.7	87.2	5.5	950	100	50	ESCS
20/05/2020	0000	19.1	87.5	5.0	954	95	46	ESCS
	0300	19.8	87.7	5.0	958	90	40	ESCS
	0600	20.6	88.0	5.0	960	90	40	ESCS
	0900	21.4	88.1	5.0	960	90	40	ESCS

	Crossed West Bengal – Bangladesh coasts as a very severe cyclonic storm across Sundarbans, near lat.21.65°N/long. 88.3°E during1000-1200 UTC, with maximum sustained wind speed of 85 knots gusting to 100 knots.							
	1200	21.9	88.4	-	968	80	32	**VSCS**
	1500	22.7	88.6	-	978	65	32	VSCS
	1800	23.3	89.0	-	984	50	14	**SCS**
	2100	24.2	89.0	-	986	45	12	**CS**
21/05/2020	0000	24.2	89.3	-	988	40	10	CS
	0300	24.7	89.5	-	990	35	08	CS
	0600	25.0	89.6	-	992	30	06	**DD**
	1200	25.4	89.6	-	995	20	04	**D**
	1800	Weakened into a well marked low pressure area over north Bangladesh and neighbourhood						

3. Brief life history

3.1. Genesis

Under the influence of the remnant cyclonic circulation over south Andaman Sea and adjoining southeast BoB during 6th – 12th May, a fresh Low Pressure Area formed over southeast BoB and adjoining south Andaman Sea in the morning (0300 UTC) of 13th May. At 0000 UTC of 13th May, Madden Julian Oscillation (MJO) index lay in phase 2 with amplitude nearly 1. It was forecast to continue in same phase till 17th May with amplitude remaining more than 1. Thereafter during 18th-21st, it was forecast to move to phase 4 across phase 3 with amplitude remaining less than 1. Thus, MJO was supporting enhancement of convective activity over BOB for next 8 days. SST was 30-31˚C over entire BOB and over Andaman Sea. TCHP was more than 100 KJ/cm^2 over major parts of south & central BOB and eastern parts of Andaman Sea. It was about 60-80 KJ/cm^2 over remaining parts of Andaman Sea and BOB to the north of 17ºN and was decreasing towards extreme north BOB. The lower level positive vorticity was about 20-25 $x10^{-6}sec^{-1}$ over some parts of south and eastcentral BOB. Also a small zone of higher positive vorticity (40-50 $x10^{-6}sec^{-1}$) lay over southeast BOB with vertical extension upto 500 hPa level and was persisting over the same area during past 24 hours with magnitude remaining the same. The zone of positive lower level convergence zone became more organized and lay over southeast BOB and another over south Andaman Sea (each $10x10^{-5}sec^{-1}$). The zone of positive upper level divergence with same value during the period (10x10-5sec-1) lay over south Andaman Sea. Vertical wind shear (VWS) was low to moderate (5-20 kts) to the south of 10^0N over Andaman Sea and south BOB. It was becoming high to the north of 10^0N. The upper tropospheric ridge lay near 9^0N over BOB in association with anticyclonic circulation over north Andaman Sea.

At 0300 UTC of 14th May, it lay as a well marked low pressure area (WML) over southeast BOB & neighbourhood. At 0300UTC of 14th, similar MJO and sea conditions prevailed. Strength of higher positive vorticity zone increased during past 24 hours (60-80 $x10^{-6}sec^{-1}$) over southeast BOB with vertical extension upto 200 hPa level. The strength of convergence zone over southeast BOB also increased during past 24 hours ($15x10^{-5}sec^{-1}$). The upper level divergence increased significantly during the period ($15x10^{-5}sec^{-1}$) over southeast BOB. Vertical wind shear (VWS) was moderate (15-20 kts) to the south of 10^0N over Andaman Sea and south BOB. It was becoming high to the north of 10^0N. The upper tropospheric ridge lay near 10^0N over BOB. Total precipitable water imagery at 2241 UTC of 13th May indicated increased cross equatorial flow with significantly high warm moist air incursion into the system.

At 0300 UTC of 15th May, similar sea conditions prevailed. Considering the environmental conditions, the higher positive vorticity zone maintained it's strength (60-80 $x10^{-6}sec^{-1}$) over southeast BOB with vertical extension upto 500 hPa level. The convergence zone over southeast BOB was the same during past 24 hours ($15x10^{-5}sec^{-1}$) and was north-south oriented. Upper level divergence was the same during the period ($40x10^{-5}sec^{-1}$) over southeast BOB and was north-south oriented. Vertical wind shear (VWS) was moderate (15-20 kts) to the south of 10^0N over southwest and adjoining southeast BOB. It was becoming high to the north of 10^0N and Andaman Sea. The upper tropospheric ridge lay near 10^0N over BOB. The system maintained it's intensity of well marked low pressure area.

At 0000 UTC of 16th the system intensified into a depression. Similar sea conditions prevailed. Considering the environmental conditions, the strength of positive vorticity zone increased (50-100 $x10^{-6}sec^{-1}$) over the southeast BOB with vertical extension upto 500 hPa level. The convergence zone over southeast BOB increased during past 24 hours ($30x10^{-5}sec^{-1}$). Upper level divergence was the same during the period ($40x10^{-5}sec^{-1}$) over southeast BOB and was north-south oriented. Vertical wind shear (VWS) was moderate (10-15 kts) to the south of 10^0N over southwest and adjoining southeast BOB. It was becoming high to the north of 10^0N and Andaman Sea. The upper tropospheric ridge lay near 10^0N over BOB.

3.2. Intensification and movement

At 0900 UTC of 16th the system intensified into a deep depression. At that time, the Madden Julian Oscillation (MJO) index lay in phase 2 with amplitude more than 1. It was forecast to continue in same phase till 17th May with amplitude remaining more than 1 and becoming less than 1 thereafter in phase 3. Thus, MJO was supporting enhancement of convective activity over the Bay of Bengal (BOB) for next 5 days. Considering the sea conditions, the sea surface temperature (SST) was 30-31˚C over entire BOB and over Andaman Sea. The tropical cyclone heat potential was more than 100 KJ/cm^2 over major parts of south & central BOB and eastern parts of Andaman Sea. It was about 60-80 KJ/cm^2 over remaining parts of Andaman Sea and BOB to the north of 17ºN and was decreasing towards extreme north BOB. The enhanced positive vorticity zone maintained it's strength (more than $150x10^{-6}sec^{-1}$) around the system centre with vertical extension upto 200 hPa level. The lower level convergence zone over southeast BOB increased and was around $30x10^{-5}sec^{-1}$ around the system centre. Upper level divergence was the same during the period ($40x10^{-5}sec^{-1}$) over southeast BOB. Vertical wind shear (VWS) decreased and was low to moderate (15-20 kts) around the system centre. It was high remaining same to the north of 10^0N along the expected track. The upper tropospheric ridge lay near 11.5^0N over BOB. TPW imagery at 0741 UTC of 16th May indicated warm moist air incursion into the system centre.

At 1200 UTC of 16th, the system further intensified into the cyclonic storm **"Amphan"**. Similar sea conditions prevailed. The enhanced positive vorticity zone maintained it's strength (more than $200x10^{-6}sec^{-1}$) around the system centre with vertical extension upto 200 hPa level. The lower level convergence zone was around $20x10^{-5}sec^{-1}$ located over southwest of the system centre. Upper level divergence of $30x10^{-5}sec^{-1}$ located over southwest of the system centre. Vertical wind shear (VWS) further decreased and was low to moderate (10-15 kts) around the system centre. It was increasing to north of lat. 15^0N along the expected track. The upper tropospheric ridge lay near 12^0N over BOB. TPW imagery at 1041 UTC of 16th May indicated warm moist air incursion into the system area.

At 0300 UTC of 17th it intensified into a severe cyclonic storm. Similar sea conditions prevailed. The enhanced positive vorticity zone maintained it's strength (more than 200x10-6sec-1) around the system centre with vertical extension upto 200 hPa level. The low level convergence zone (around $30x10^{-5}sec^{-1}$) lay to the southeast of system centre. The upper level divergence was about $60x10^{-5}sec^{-1}$ around the system centre. Vertical wind shear (VWS) increased and was moderate to high (20-25 kts) around the system centre. It was increasing to north of latitude 15^0N along the expected track. The upper tropospheric ridge lay near 13^0N over BOB. The system moved nearly northwards along the axis of the ridge and was expected to continue same movement for next 24 hours. Thereafter, the system was likely to move to the north of the ridge axis and recurve north/northeastwards and move faster. Total precipitable water imagery at 0100 UTC of 17th May indicated continued warm moist air incursion into the system area.

At 0900 UTC of 17th, it further intensified into a very severe cyclonic storm. Similar sea conditions prevailed. The enhanced positive vorticity zone maintained it's strength (more than 200x10-6sec-1) around the system centre with vertical extension upto 200 hPa level. The lower level convergence zone was around $30x10^{-5}sec^{-1}$ located over southeast of the system centre. The upper level divergence decreased and was about $30x10^{-5}sec^{-1}$ located around the system centre. Vertical wind shear (VWS) continued to remain moderate to high (20-25 kts) around the system centre. It was increasing to the north of lat. 15^0N along the expected track. The upper tropospheric ridge lay near 13^0N over BOB. The system moved northwards along the axis of the ridge and was likely to continue the same movement for next 24 hours. Subsequently, the system was expected to move to the north of the ridge axis and would start recurving north/northeastwards and move faster. TPW water imagery of 17th May indicated continued warm moist air incursion into the system centre, mainly in its northwestern sector.

At 2100 UTC of 17th, it further intensified into an extremely severe cyclonic storm. Similar sea conditions prevailed. The positive vorticity increased and was around (250-300)$x10^{-6}$ sec^{-1} around the system centre with vertical extension upto 200 hPa level. The lower level convergence zone was 60-70 $x10^{-5}$ sec^{-1} around the system centre. The upper level divergence was about $x10^{-5}$ sec^{-1} to the north of system centre. Vertical wind shear (VWS) was low to moderate (10-15 kts) around the system centre. It was increasing to 20-25 kts to the north between 15-20°N along the expected track. The upper tropospheric ridge lay near 17.0°N over BoB. The system moved near northwards along the periphery of the anticyclone and it was likely to continue in the same direction for some more times. Thereafter, the system was likely to recurve north-northeastwards.

At 0600 UTC of 18th, it further intensified into a super cyclonic storm, MJO index lay in phase 2 with amplitude more than 1 during 18th-20th May. Thus, MJO phase and amplitude were supporting enhancement of convective activity over BoB. SST was 30-31˚C over entire BOB. TCHP was more than 100 KJ/cm^2 over major parts of south & central BOB. It was about 60-80 KJ/cm^2 over BOB to the north of 17ºN and was decreasing towards extreme north BOB. The positive vorticity was around (250-300) x 10^{-6} sec^{-1} around the system centre with vertical extension upto 200 hPa level. The lower level convergence zone was around (50-60) $x10^{-5}sec^{-1}$ to the southwest of the system centre. The upper level divergence was about 30x $x10^{-5}sec^{-1}$ to the west of the system centre. Vertical wind shear (VWS) was low to moderate (10-15 kts) around the system centre. It was increasing to 20-30 kts to the north between 15-20^{0}N along the expected track. The upper tropospheric ridge lay near 17.0^{0}N over BOB. The system moved northwards along the periphery of the ridge and it was likely to continue in the same direction for some more time. Thereafter, the system was likely to recurve in the north-northeastward direction. TPW imagery of 18th May indicated continued warm moist air incursion over the system area, mainly in its northwestern sector.

At 0600 UTC of 19th, the system weakened into an extremely severe cyclonic storm. MJO index lay in phase 2 with amplitude more than 1 for next two days. It was forecast to remain in phase 3 with amplitude more than 1 during subsequent three days (20th-22nd). Thus, MJO phase and amplitude were supporting enhancement of convective activity over BoB. SST was 30-31˚C over entire Bay of Bengal, but system was entering into the area with lower TCHP of 70-90 KJ/cm^2 which was further decreasing towards north BoB along the system track. The positive vorticity was around (250-300) $x10^{-6}$ sec^{-1} around the system centre with vertical extension upto 200 hPa level. The lower level convergence zone was $50x10^{-5}sec^{-1}$ located around the system centre. The upper level divergence decreased and was about $20x10^{-5}$ sec^{-1} to northeast of the system centre. Vertical wind shear (VWS) was moderate to high (20-25 kts) around the system centre. It was increasing to 30-40 kts to the north between 15-20°N along the expected track. The upper tropospheric ridge lay near 16.0°N over BoB. The system moved north-northeastwards along the periphery of the ridge to it's south.

The system crossed the coast during 0900-1200 UTC of 20th. The positive vorticity was around $250\text{-}300x10^{-6}$ sec^{-1} around the system centre with vertical extension upto 200 hPa level. The lower level convergence was (30-40) $x10^{-5}$ sec^{-1} around the system centre. The upper level divergence also reduced to $10x10^{-5}$ sec^{-1} around the system centre. Vertical wind shear (VWS) was moderate to high (25-30 kts) around the system centre. It was increasing to 30-40 kts to the north of 23°N along the expected track. The upper tropospheric ridge lay near 21.5°N over Bay of Bengal. The system moved north-northeastwards along the periphery of the anticyclone over Myanmar.

At 1800 UTC of 20th, the system further weakened into a severe cyclonic storm. Considering the environmental conditions, the positive vorticity was $250\text{-}300x10^{-6}$ sec^{-1} around the system centre with vertical extension upto 200 hPa level. The lower level convergence was (30-40) $x10^{-5}$ sec^{-1} around the system centre. The upper level divergence reduced to $10x10^{-5}$ sec^{-1} around the system centre. Vertical wind shear (VWS) was moderate to high (25-30 kts) around the system centre. It was increasing to 30-40 kts at north of 23°N along the expected track. The upper tropospheric ridge was at north and now lay near 22.0°N over Bay of Bengal. At this period the system was moving north-northeastward along the periphery of the anticyclone which lay over Myanmar.

Similar trend continued and the system weakened into a cyclonic storm at 2100 UTC of 20th, into a deep depression at 0600 UTC of 21st, into a depression at 1200 UTC of 20th and into a well marked low pressure area at 1800 UTC of 21st.

The total precipitable water (TPW) imageries (Source: TC Forecaster Website: https://rammb-data.cira.colostate.edu/tc_realtime/index.asp) during life cycle of SUCS Amphan are presented in Fig. 3. These imageries indicate excessive increase in warm moist air around the system centre on 1330 UTC of 16th May. The warm moist air supply continued till 1800 UTC of 18th May. Thereafter, it gradually decreased. The system also exhibited decrease in intensity on 19th & 20th prior to landfall.

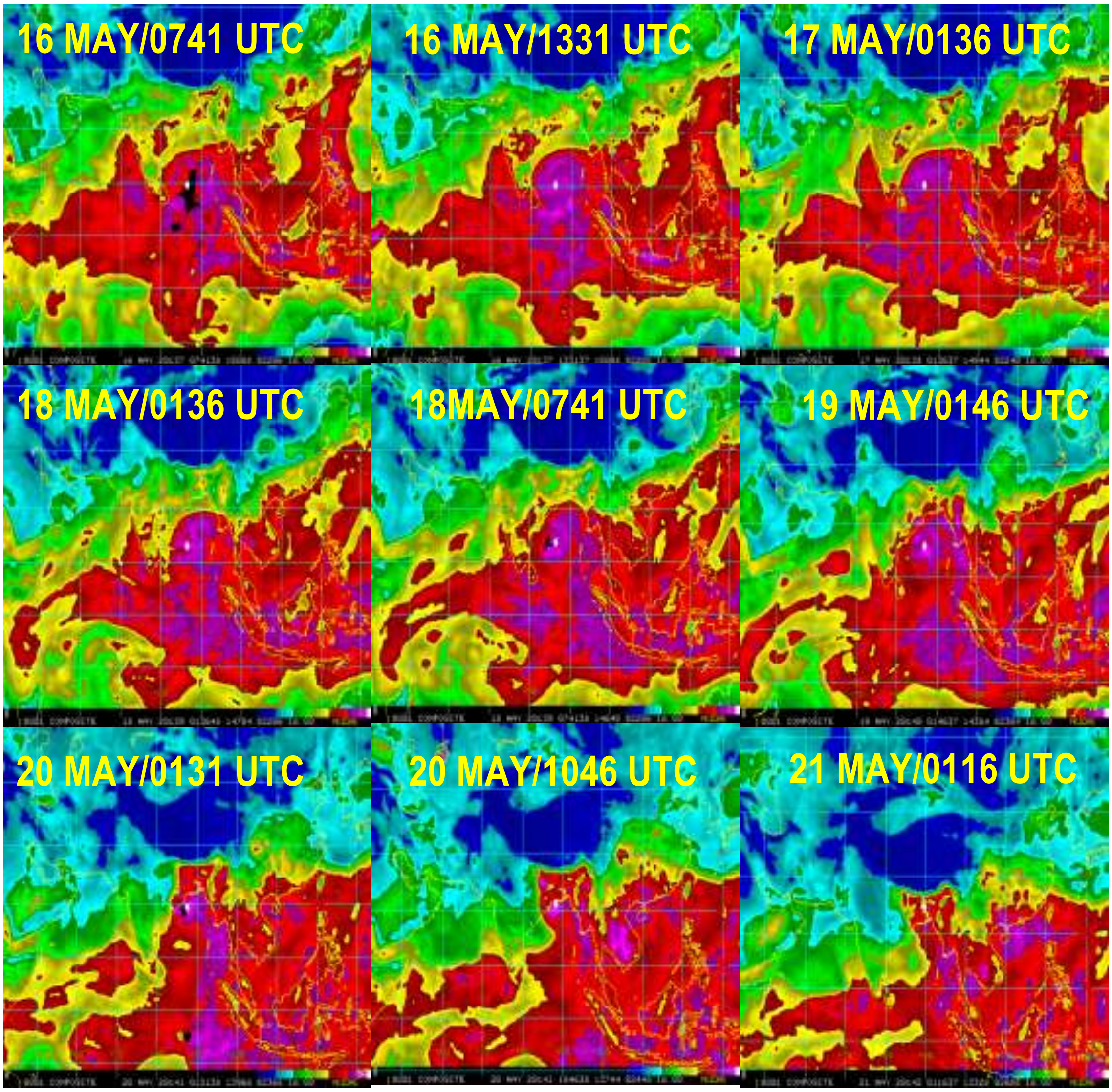


Fig. 3: Typical total precipitable water imageries during life cycle of SuCS Amphan (16th-21st May, 2020).

The mean wind speed and wind shear in middle and deep layer is presented in Fig. 4. The mean wind shear speed in the deep layer was low to moderate (10-20 knot) during the entire life period of the system. The mean wind shear was low in the middle layer. The mean wind speed in the deep and middle layer was low (05-10 knot) till 1200 UTC of 19th May. The mean wind direction in the deep layer represented the near northward movement of the system.

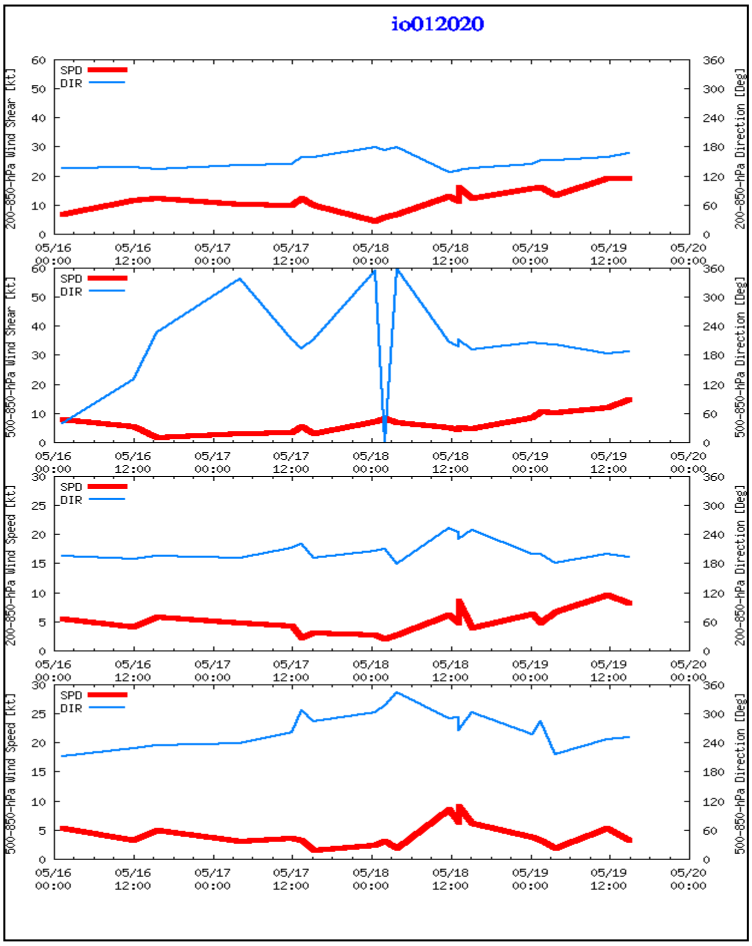


Fig.4: Wind shear and wind speed in the middle and deep layer around the system during ESCS FANI (26 April -05 May), 2020

It moved with 12 hour average translational speed of 13.9 kmph against LPA (1990-2013) of 14.7 kmph for VSCS category over the north Indian Ocean (Fig.5). During initial stages of it's development (0000 UTC of 16^{th} to 1200 UTC of 18^{th} May), AMPHAN moved slower than the average. Thereafter the speed increased and reached the maximum (29 kmph at 0600 UTC of 20^{th} May) just prior to landfall.

Fig. 5: Six hourly mean translational speed & direction of movement

4.3 Maximum Sustained Surface Wind speed and estimated central pressure

The six hourly average translational speed during the life cycle of SuCS Amphan is presented in Fig. 6. The six hourly maximum sustained wind speed and estimated central pressure is presented in Fig. 3b. After landfall, the system exhibited rapid weakening during 1500 UTC of 20th to 0600 UTC of 21st May.

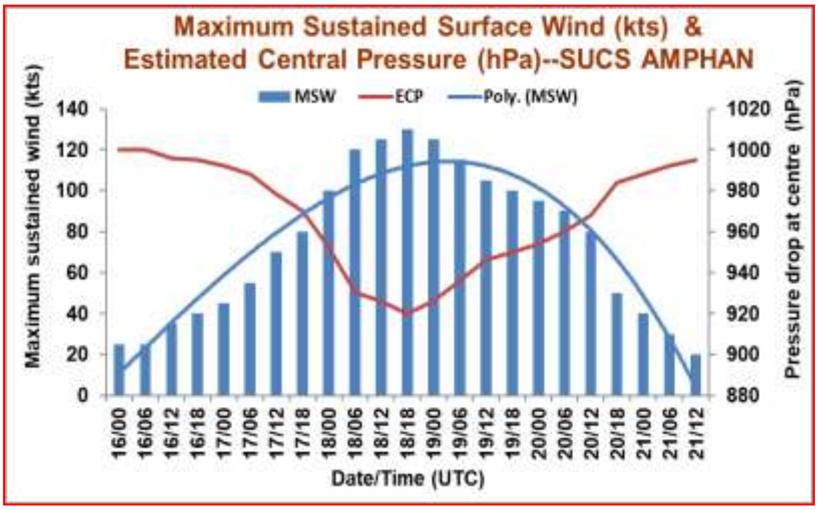


Fig. 6: Maximum sustained surface winds (kts) & Estimated Central Pressure

5. Monitoring of SuCS, 'AMPHAN'

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the system was monitored since 23rd April about three weeks prior to the formation of the Low Pressure Area over the southeast BoB on 13th May. A Low Pressure Area formed over south Andaman Sea and adjoining southeast Bay of Bengal on 1st May. It meandered over the region for next 5 days and became less marked on 6th. However, associated cyclonic circulation persisted over the region till 12th. In the extended range outlook issued on 7th May, IMD indicated possible Cyclogenesis during the second week over south Andaman Sea and adjoining southeast Bay of Bengal. Accordingly, continuous watch of this circulation was maintained. On 9th May, it was indicated that a Low Pressure Area would form over the region on 13th May (96 hours prior to formation of the system) under the influence of the remnant cyclonic circulation persisting over the region during 6th-12th. On 11th, it was indicated that cyclogenesis (formation of depression) would occur around 16th May (48 hours prior to formation of the Low Pressure Area and 120 hours prior to formation of depression) over the BoB.

The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites including SCATSAT, ASCAT etc. and available ships & buoy observations in the region. From 18th May midnight (1800 UTC) onwards till 20th May, the system was tracked gradually by IMD Doppler Weather Radars (DWRs) at Visakhapatnam, Gopalpur, Paradip, Kolkata and Agartala as it moved from south to north. IMD also utilised DWR products from 'DRDO Integrated Test Range', Chandipur, Balasore for tracking the system. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions, various global models and IMD's dynamical-statistical models developed in-house 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 guidance from various models, decision making process and warning product generation. Typical satellite and radar imageries are presented in **Fig. 7**

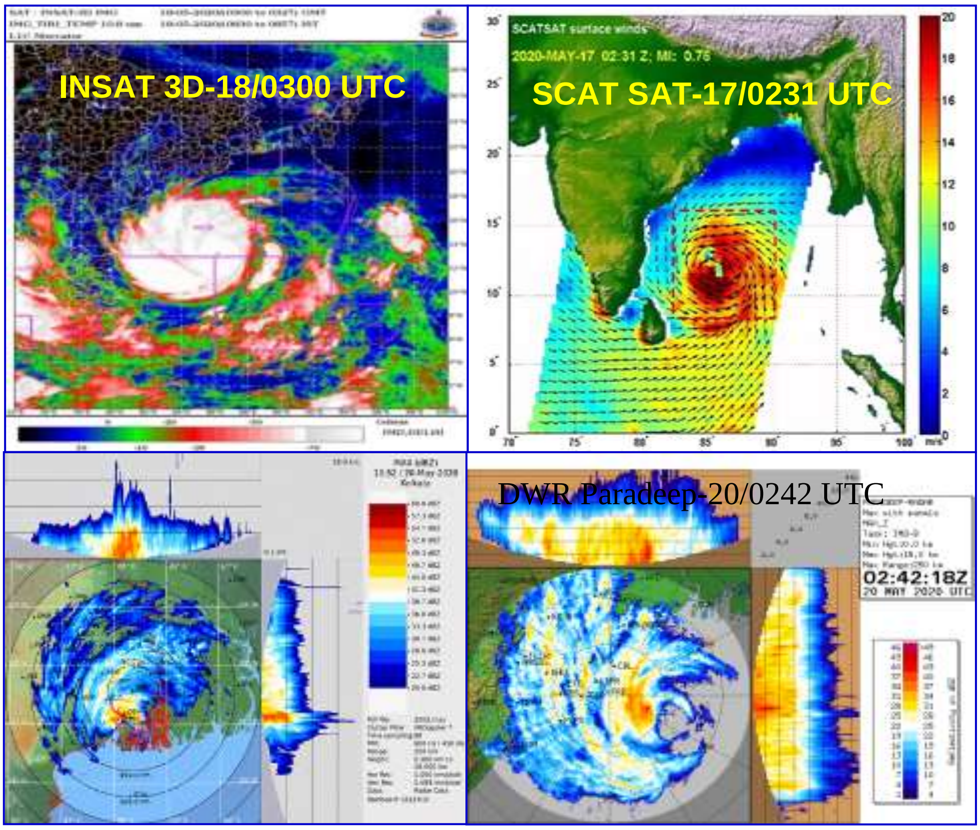


Fig. 7: Typical satellite and radar imageries of SuCS Amphan

5.1. Features observed through satellite

At 0000 UTC of 16th, the intensity of the system was T1.5. Associated broken low to medium clouds with embedded intense to very intense convection lay over Bay of Bengal between 6.0°N to 13.0°N longitude 83.0°E to 90.0°E. Minimum CTT was minus 93^{0}C . Convection and organization had increased further.

At 0900 UTC of 16th, the intensity of the system was T 2.0. Broken low to medium clouds with embedded intense to very intense convection lay over Bay of Bengal between Latitudes 5.0°N & 13.5°N and Longitudes 82.0°E & 90.0°E. Minimum CTT minus 93°C

At 1200 UTC of 16th, vortex over south east Bay & neighborhood had further intensified rapidly. The intensity of the system was T 2.5 associated with CDO pattern. Minimum CTT minus 93^{0}C. Associated broken low to medium clouds with embedded intense to very intense convection over Bay between latitude 6.0°N to 16.0°N long 81.0°E to 91.0°E.

At 0300 UTC of 17th, the intensity of the system was T3.0 associated with curved band pattern. Minimum CTT was minus 93^{0}C. Associated broken low to medium clouds with embedded intense to very intense convection lay over Bay between latitude 7.5°N to

14.0°N long 81.0°E to 89.0°E. The SCAT SAT imagery at 1411 UTC of 16th May was indicating winds around 40 kts to the south of system centre with matching index of 0.79.

At 0900 UTC of 17th, it further intensified and the current intensity of the system was T4.0 associated with a banding eye pattern in the visible imagery. Minimum CTT was minus 93^{0}C. Associated broken low to medium clouds with embedded intense to very intense convection over Bay between latitude 7.5°N to 14.0°N long 81.0°E to 89.0°E.

At 2100 UTC of 17th, the system continued to maintain the intensity T6.5. Wall cloud temperature was minus 93°C. Associated broken low to medium clouds with embedded intense to very intense convection prevails between latitude 10.1°N to 21.5°N long 81.5°E to 92.5°E.

At 0600 UTC of 18th, the system further intensified and the current intensity of the system was T6.5. Eye clearly visible with circular pattern and it was continuing with a diameter of 15 km. Eye had become colder with temperature minus 21.0^{0}C. Wall cloud temperature was minus 93^{0}C. Minimum cloud top temperature was minus 93^{0}C. Associated broken low to medium clouds with embedded intense to very intense convection prevails between latitude 10.0°N to 18.0°N long 81.0°E to 90.0°E.

At 0600 UTC of 19th, the system intensity wasT5.5/6.0 with ragged eye of diameter around 25 km visible. Wall cloud top temperature was minus 93.1^{0}C. Associated broken low to medium clouds with embedded intense to very intense convection prevailed between latitude 13.0°N to 19.5°N long 83.5°E to 90.0°E.

At 1200 UTC of 20th, the vortex lay over the land close to West Bengal coast. Associated broken low to medium clouds with embedded intense to very intense convection lay over Bay between latitude 19.0°N & 27.0°N longitude 85.0°E & 92.5°E. Wall clouds' minimum cloud top temperature was minus 93^{0}C.

At 1800 UTC of 20th, the vortex lay over the land close to West Bengal coast. Associated broken low to medium clouds with embedded intense to very intense convection lay over the Bay between latitude 19.0°N to 27.0°N longitude 85.0°E to 92.5°E. Wall clouds' minimum cloud top temperature was minus 93^{0}C.

At 0000 UTC of 21st , the vortex lay over the land close to West Bengal coast associated broken low to medium clouds with embedded intense to very intense convection lay over Bay between latitude 20.0°N to 28.0°N longitude 85.0°E to 92.5°E. Wall clouds minimum cloud top temperature minus 83^{0}C.

At 0600 UTC of 21st, the vortex lay over the land in areas of central parts of Bangladesh. Centre was not clearly visible in satellite imagery. Higher clouds had sheared away towards north-east from the system centre. Associated broken low to medium clouds with embedded intense to very intense convection lay over Bangladesh and west Assam Meghalaya. Minimum cloud top temperature was minus 68^{0}C.

At 1200 UTC of 21st, the remnant vortex lay over central parts of Bangladesh & neighbourhood. The vortex center was not clearly defined. Associated scattered low to medium clouds with embedded isolated weak to moderate convection lay over Bangladesh, Assam, Meghalaya, Tripura and Mizoram.

Typical INSAT-3D imageries during entire life cycle of SuCS APHAN (16th-21st May) are presented in Fig. 8(a)-Fig 8(e).

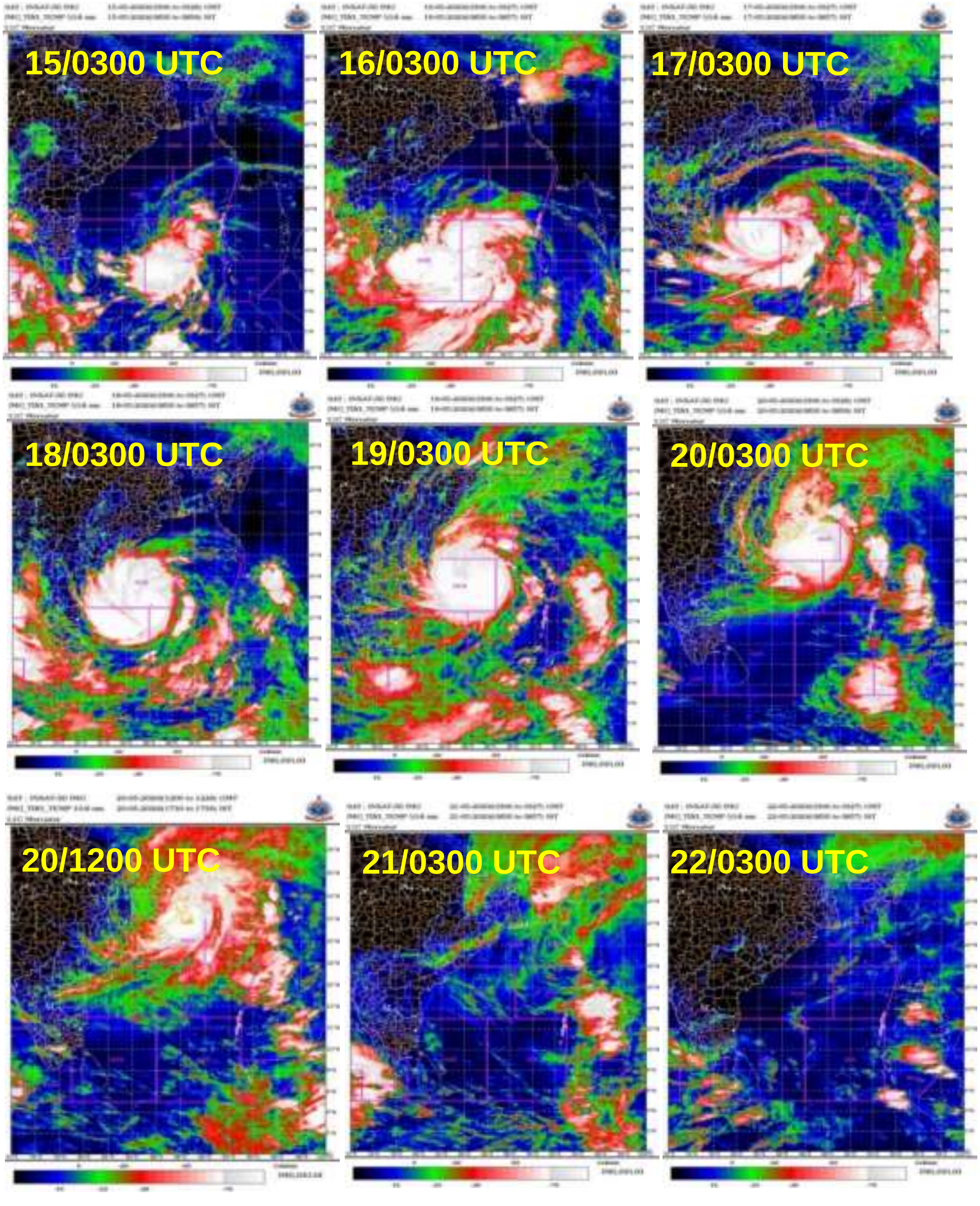


Fig. 8(a): INSAT-3D enhanced colour imageries during life cycle of SuCS AMPHAN (15-21 May, 2020)

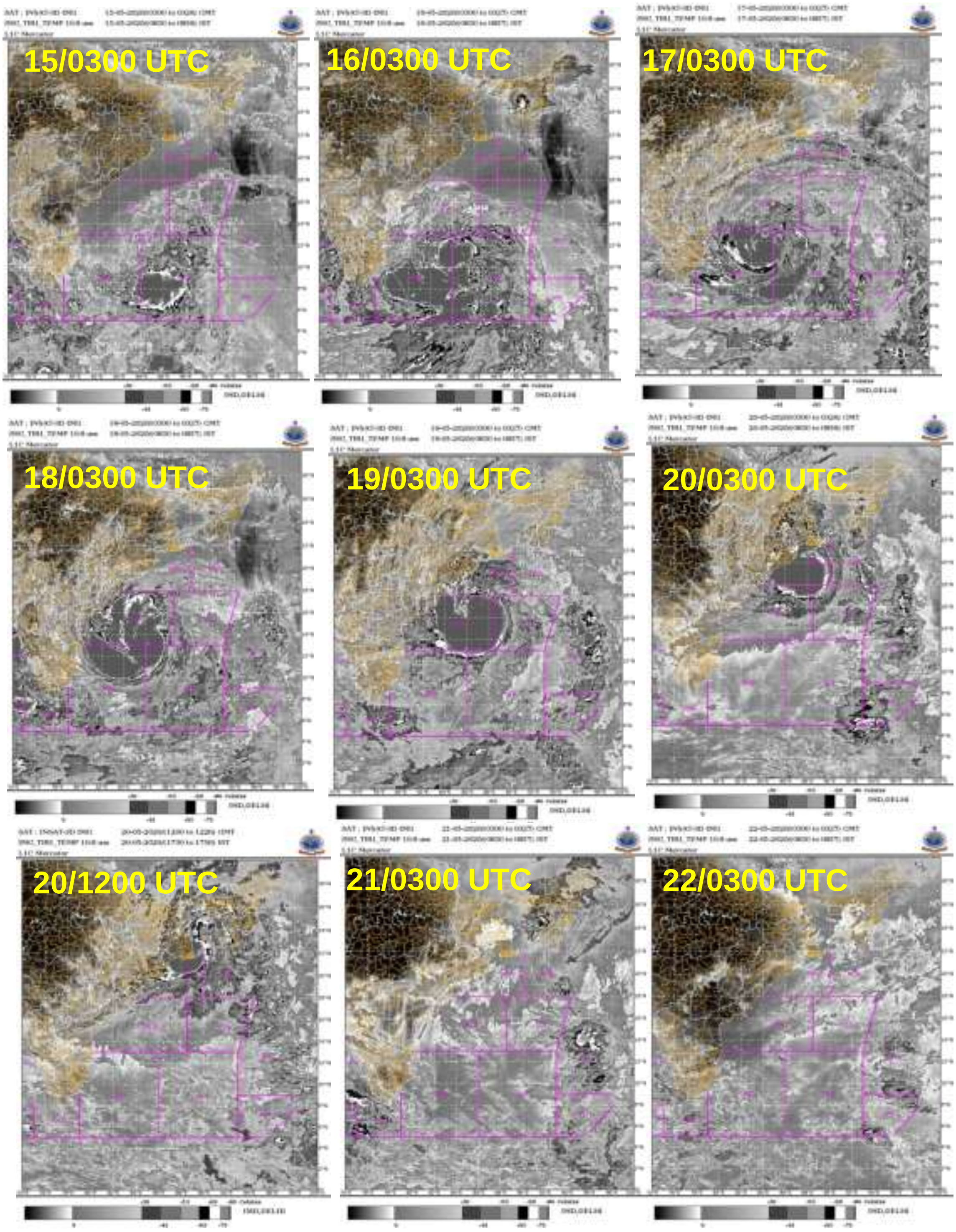


Fig. 8(b): INSAT-3D BD imageries during life cycle of SuCS AMPHAN (15-22 May, 2020)

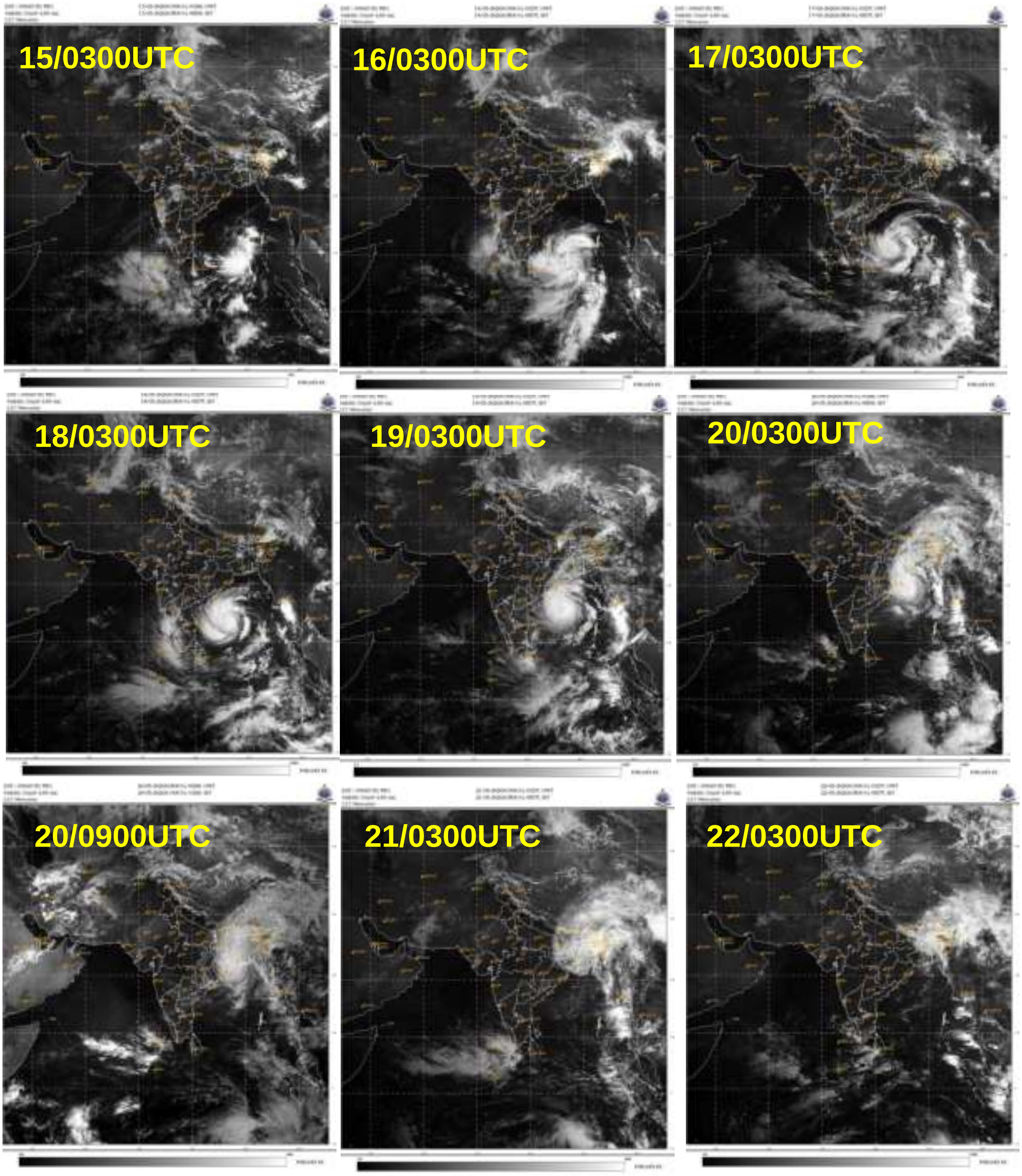


Fig. 8(c): INSAT-3D Visible imageries during life cycle of SuCS AMPHAN (15-22 May, 2020)

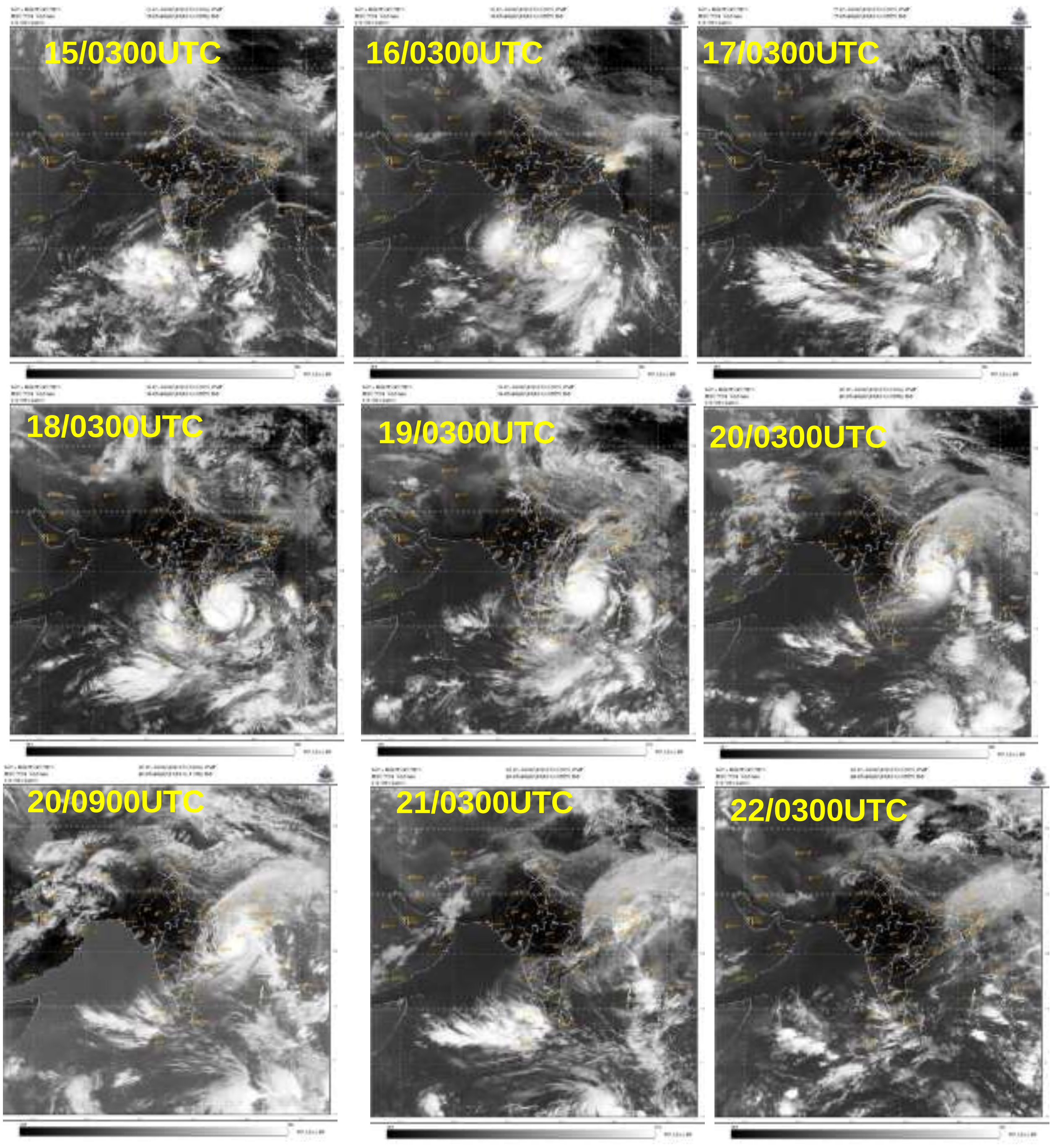


Fig. 8(d): INSAT-3D IR imageries during life cycle of SuCS AMPHAN (15-22 May, 2020)

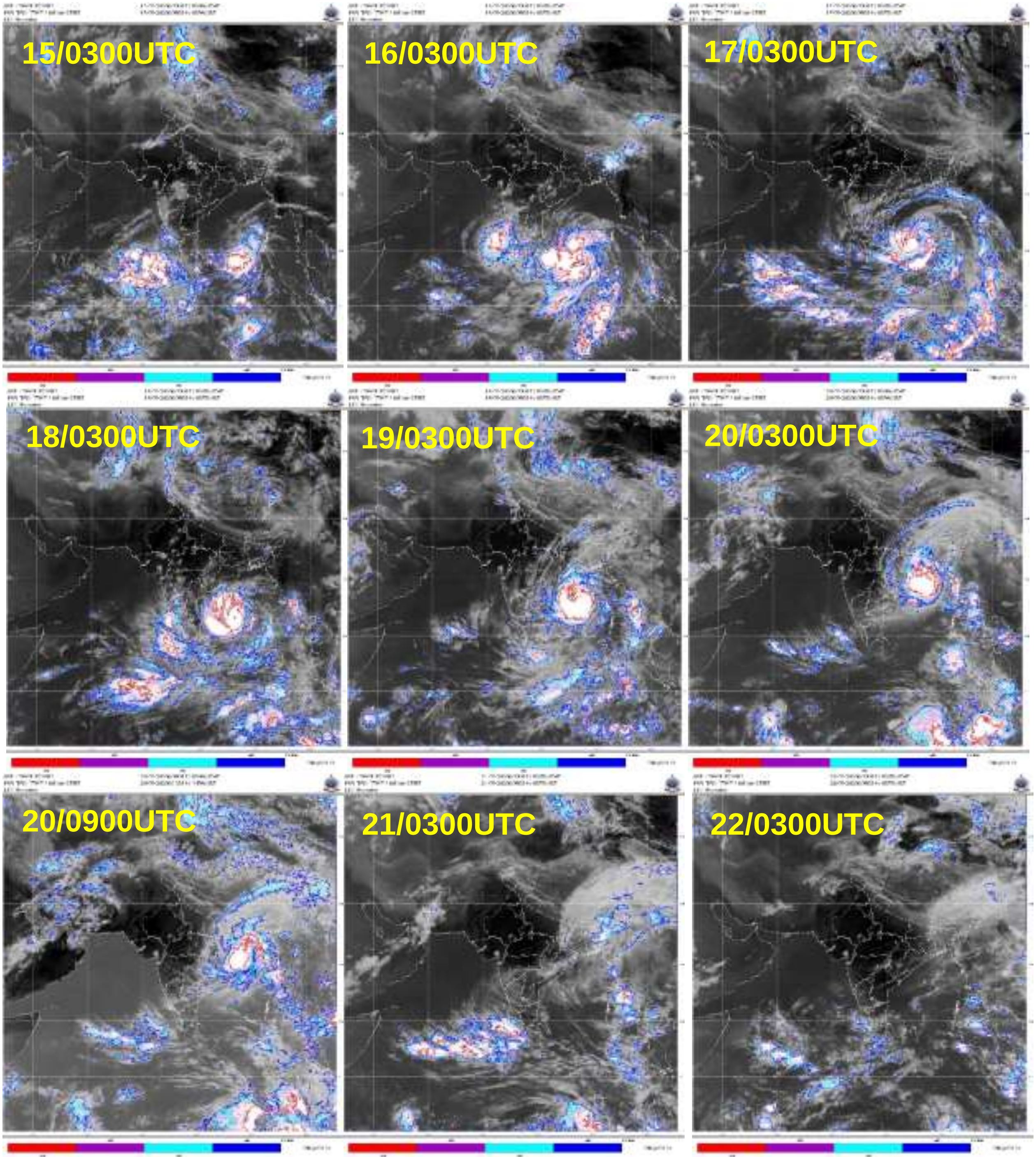


Fig. 8(e): INSAT-3D Cloud Top Brightness Temperature (CTBT) imageries during life cycle of SuCS AMPHAN (15-22 May, 2020)

Typical SCAT SAT imageries during life cycle of SUCS Amphan (13th May-20th May) since inception as low pressure area are presented in Fig. 9.

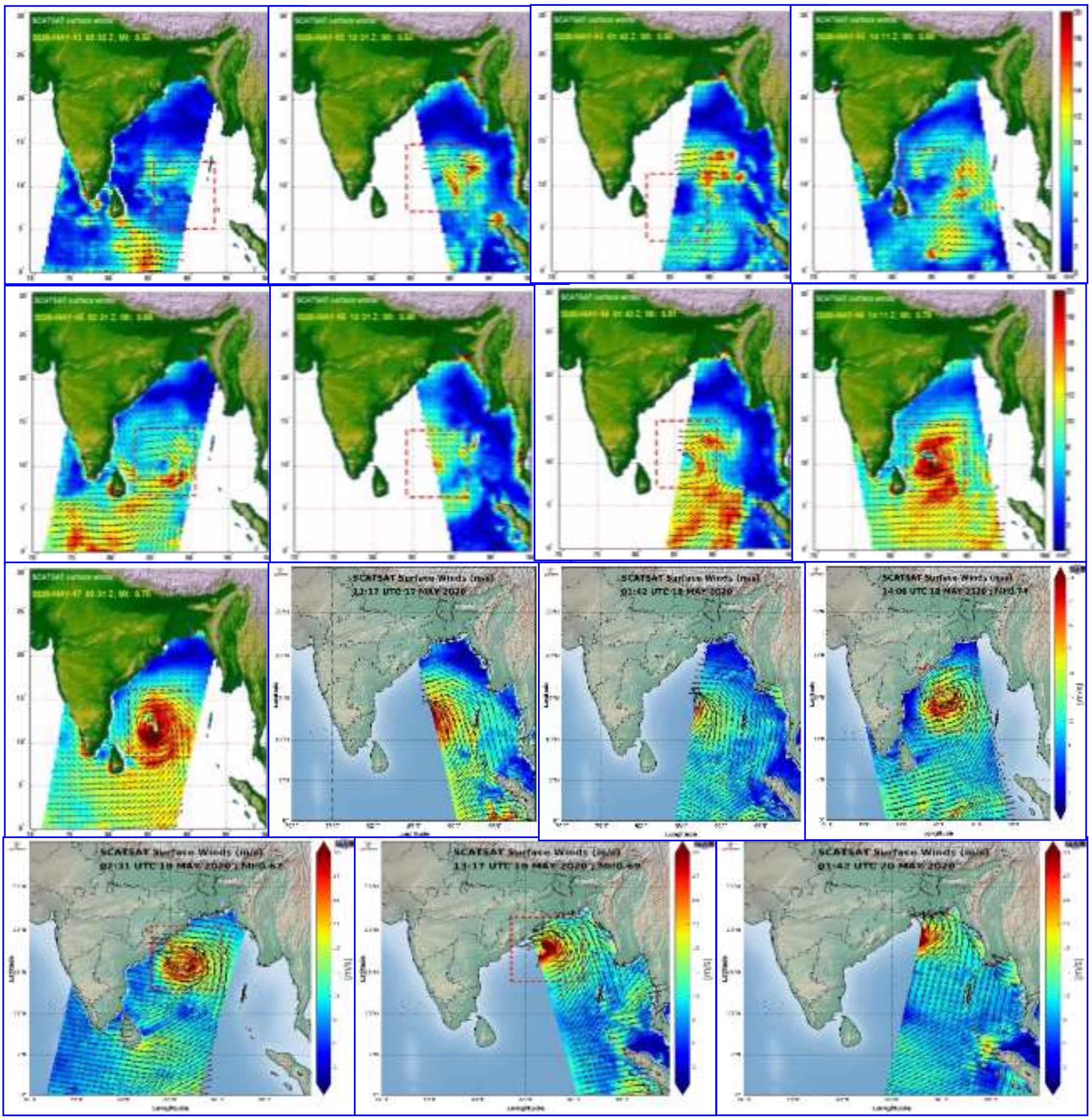


Fig. 9: SCAT SAT imageries during life cycle of SuCS AMPHAN (13-20 May, 2020)

Typical ASCAT imageries during life cycle of SuCS Amphan (13th -20th May), since inception as low pressure area are presented in Fig.10.

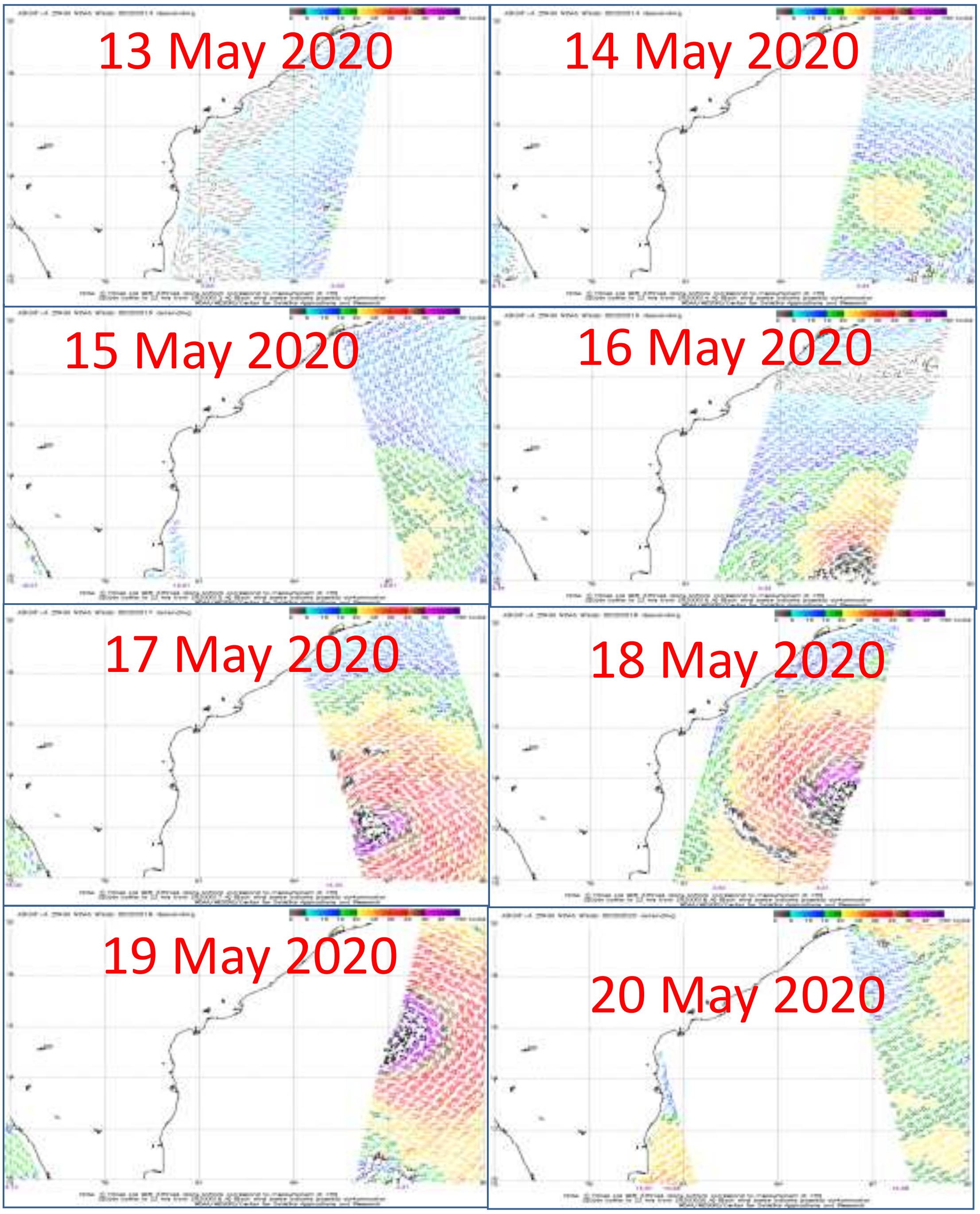


Fig.10: ASCAT imageries during life cycle of SuCS AMPHAN (13-20 May, 2020)

SuCS Amphan was continuously monitored by IMD's Doppler Weather Radars at Visakhapatnam, Gopalpur, Paradip, Chandipur, Kolkata and Agartala while moving from westcentral BoB to northeast India. Typical radar imageries from Visakhapatnam, Gopalpur, Paradip, Chandipur and Kolkata radar centres are presented in Fig. 11(a)-Fig 11(f).

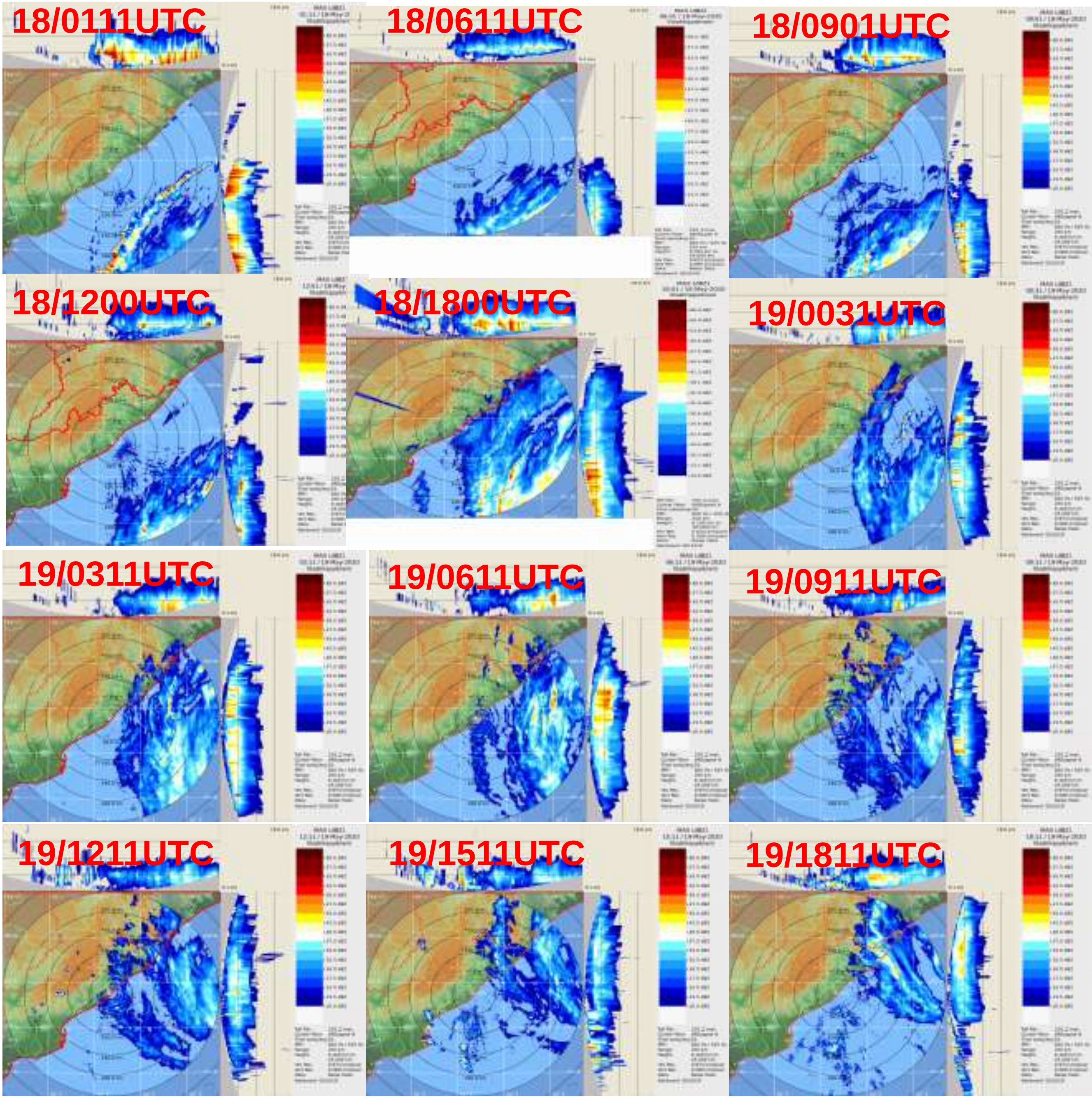


Fig. 11(a): Typical Radar Max dBZ imageries from DWR Visakhapatnam during **18-19 May, 2020**

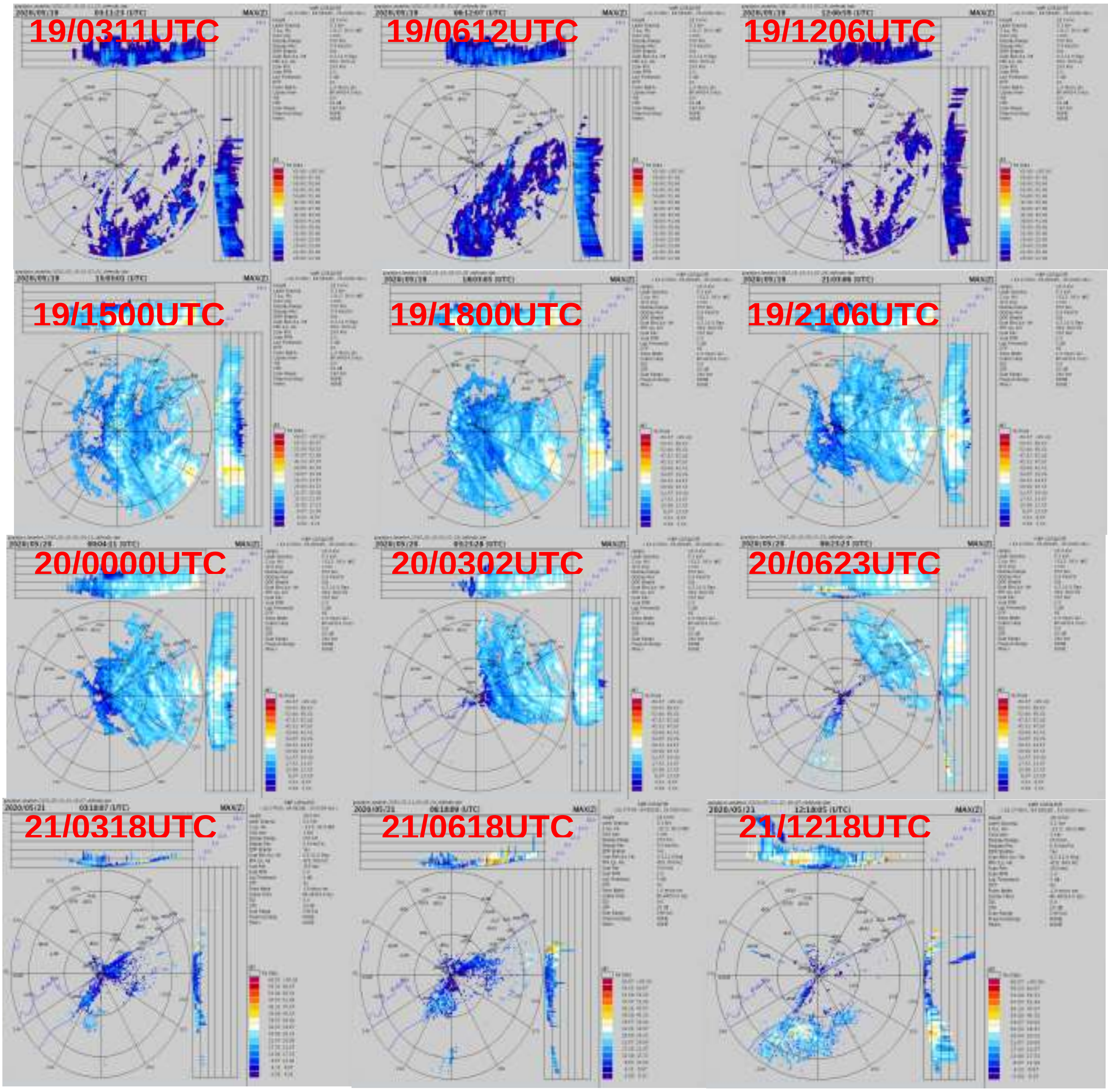


Fig. 11(b): Typical Radar Max Z imageries from DWR Gopalpur during **during 19-21 May, 2020**

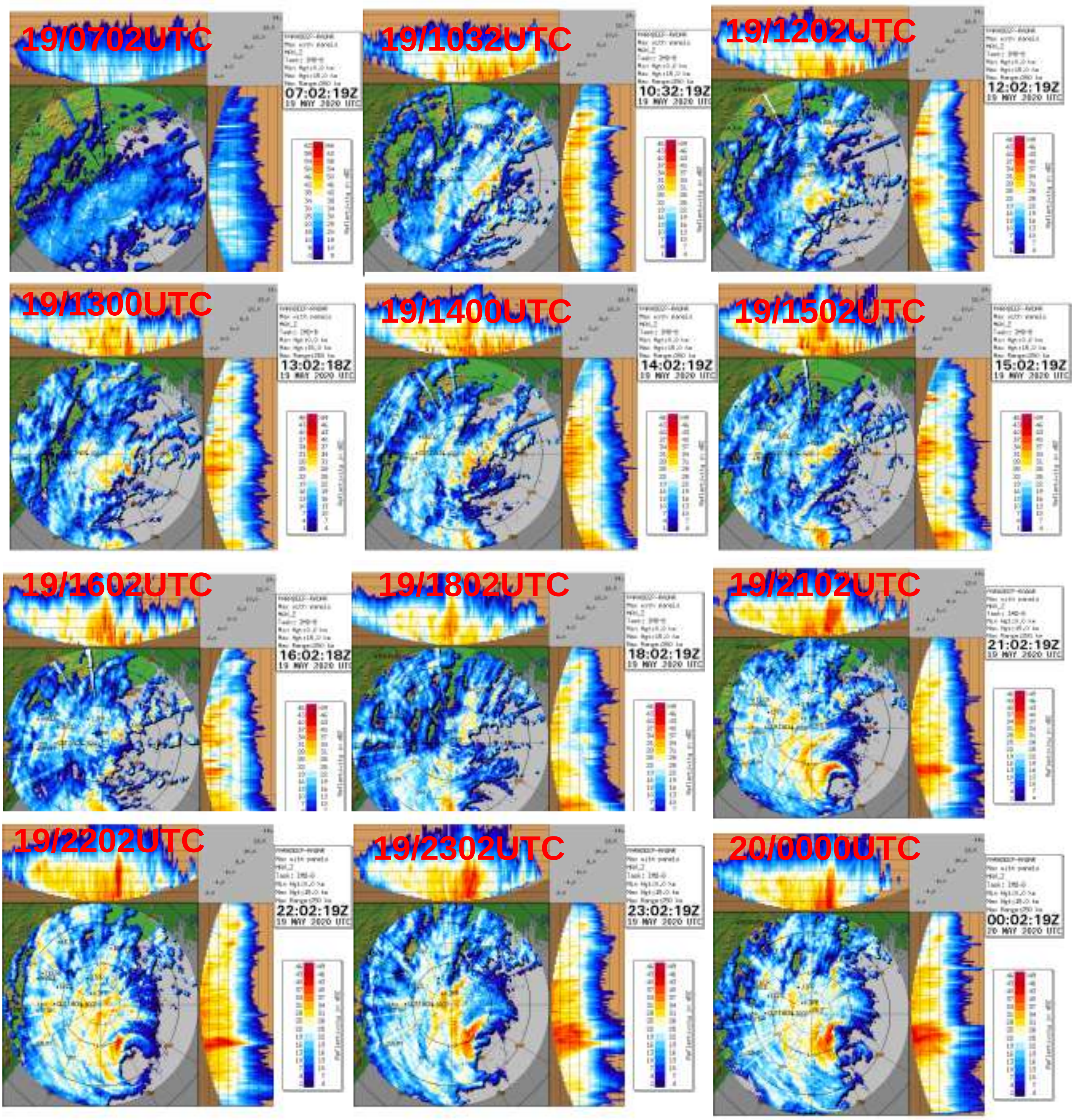


Fig. 11 (c): Typical Radar Max Z imageries of DWR Paradip during **during 19-20 May, 2020**

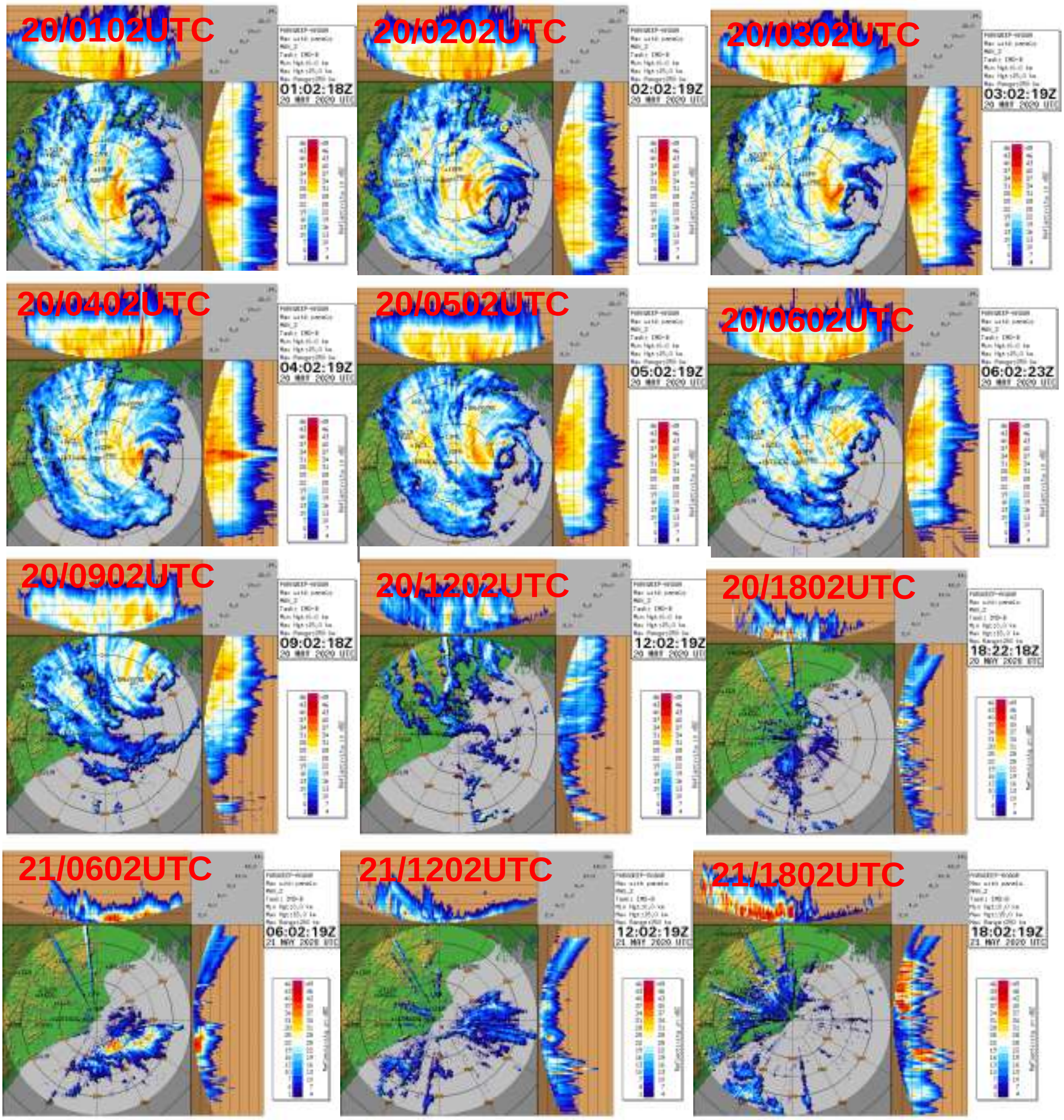


Fig. 11(d): Typical Radar Max Z imageries of DWR Paradip during **during 20-21 May, 2020**

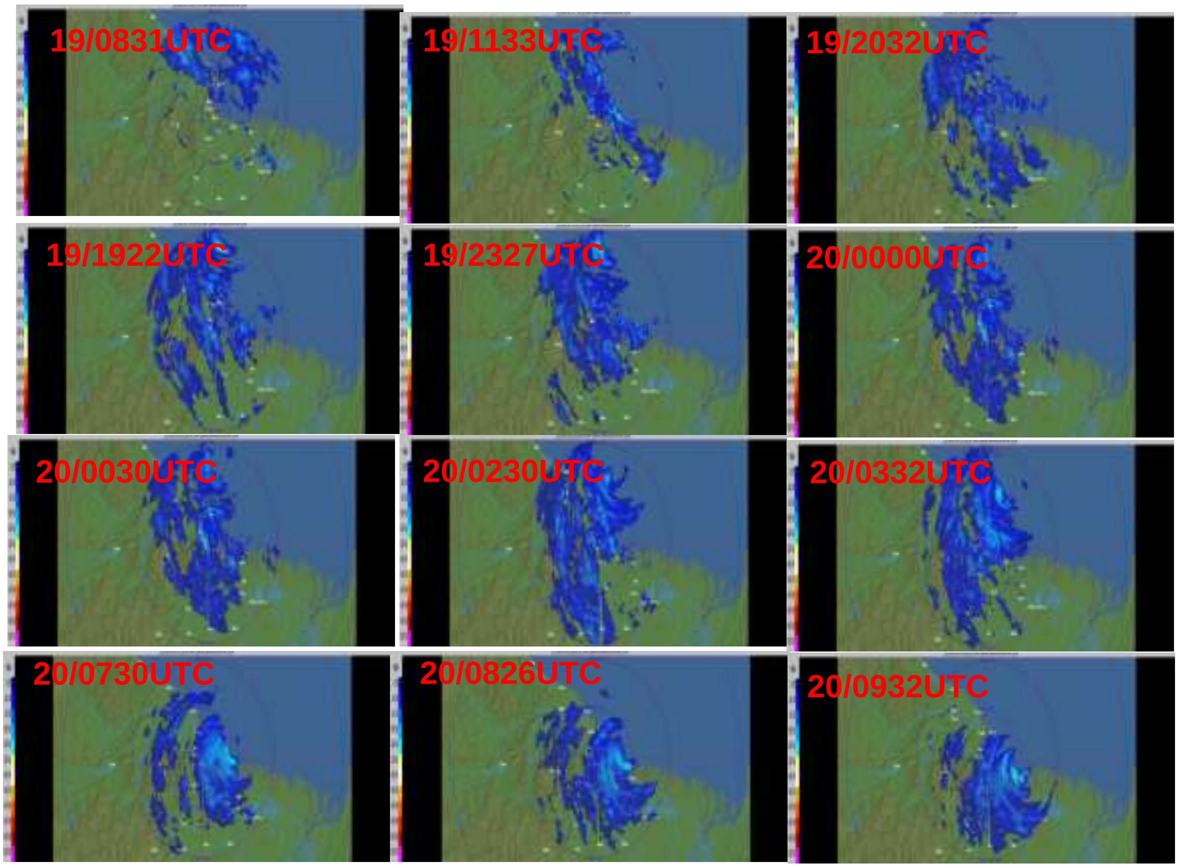


Fig. 11 (e): Typical Radar MaxZ imageries of 'DRDO Integrated Test Range', Chandipur during **19-20 May, 2020**

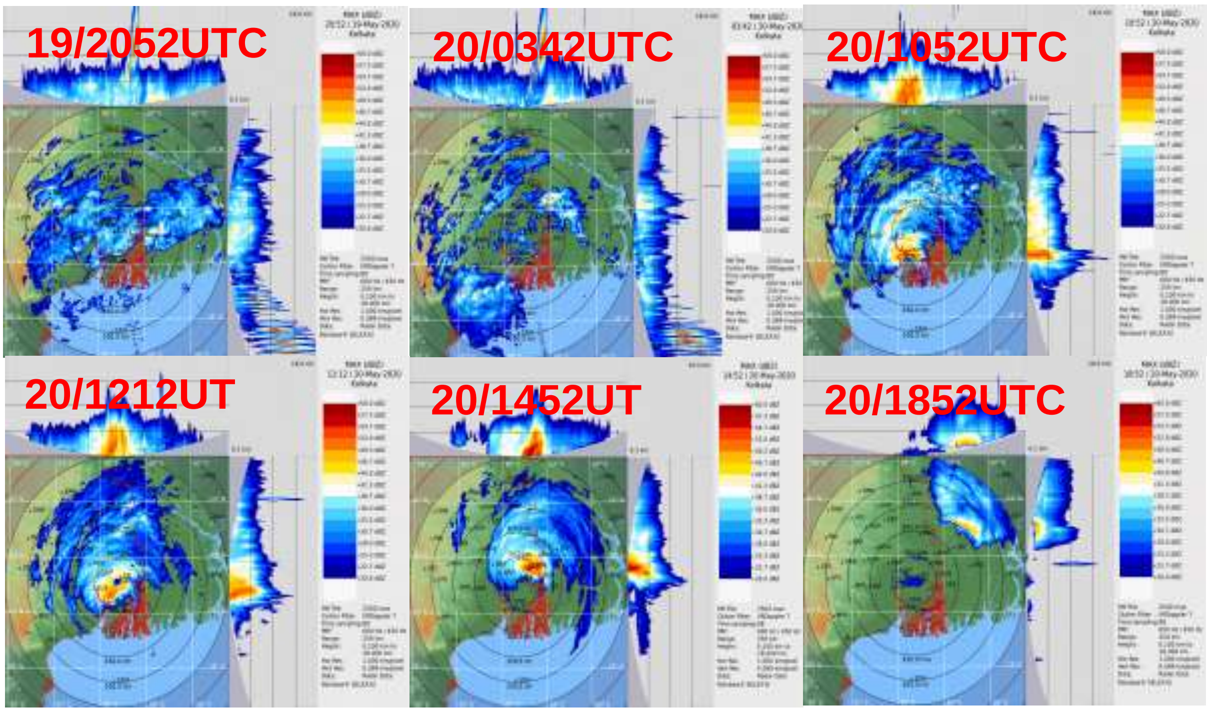


Fig. 11(f) : Typical Radar Max dBZ imageries from DWR Kolkata during during 19-20 May, 2020

6. **Dynamical features**

IMD GFS analysis of mean sea level pressure, winds at 10m, 850 hPa, 500 hPa and 200 hPa levels based on 0000 UTC during 13th -21st May, 2020 are presented in Fig.12. On 13th May, IMD GFS indicated a low pressure area over southeast BOB with vertical extension of the cyclonic circulation upto 500 hPa level.

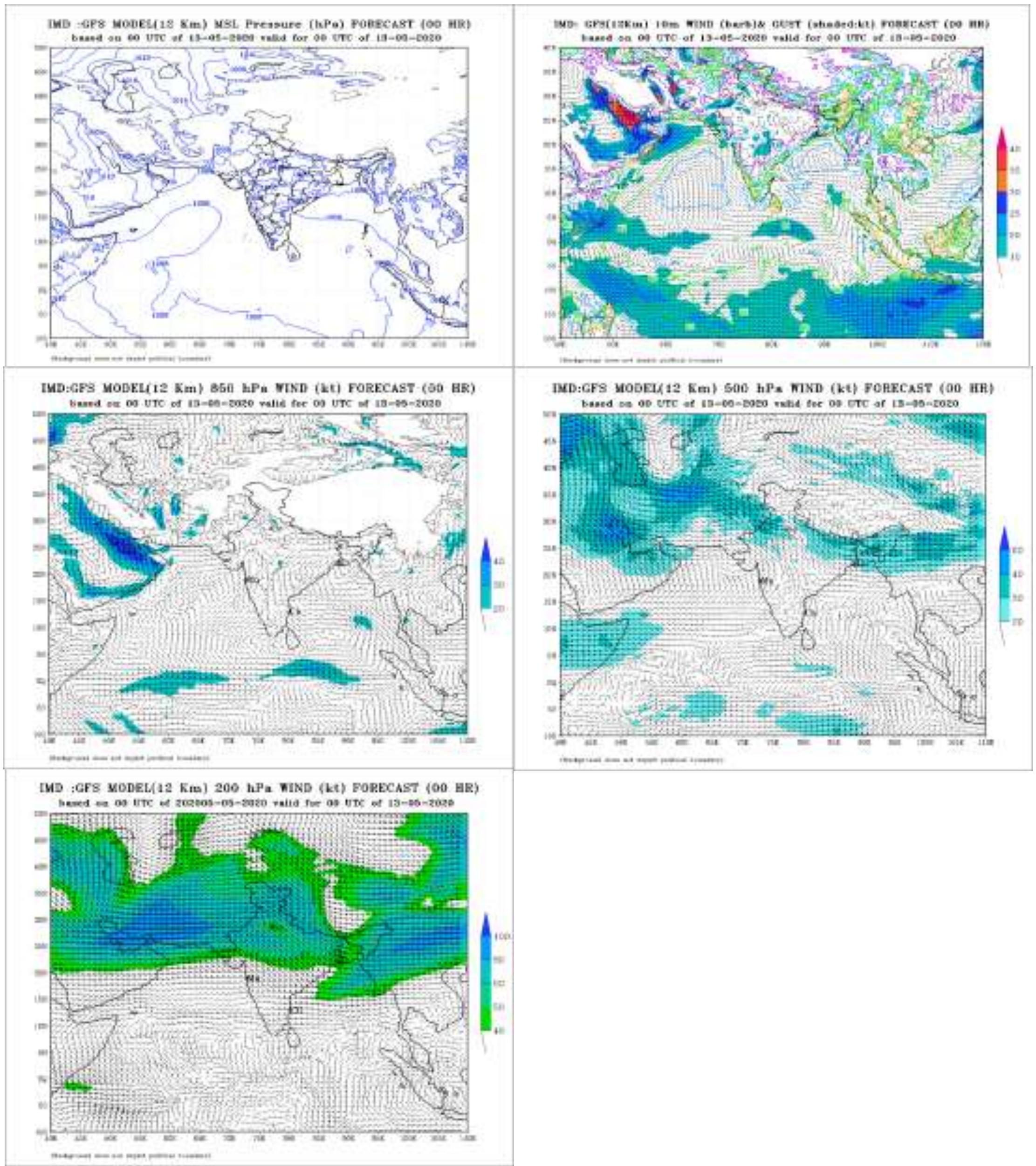


Fig. 12 (a): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 13th May,2020

On 14th May, IMD GFS indicated a low pressure area over southwest & adjoining southeast BOB with vertical extension of the cyclonic circulation upto 500 hPa level.

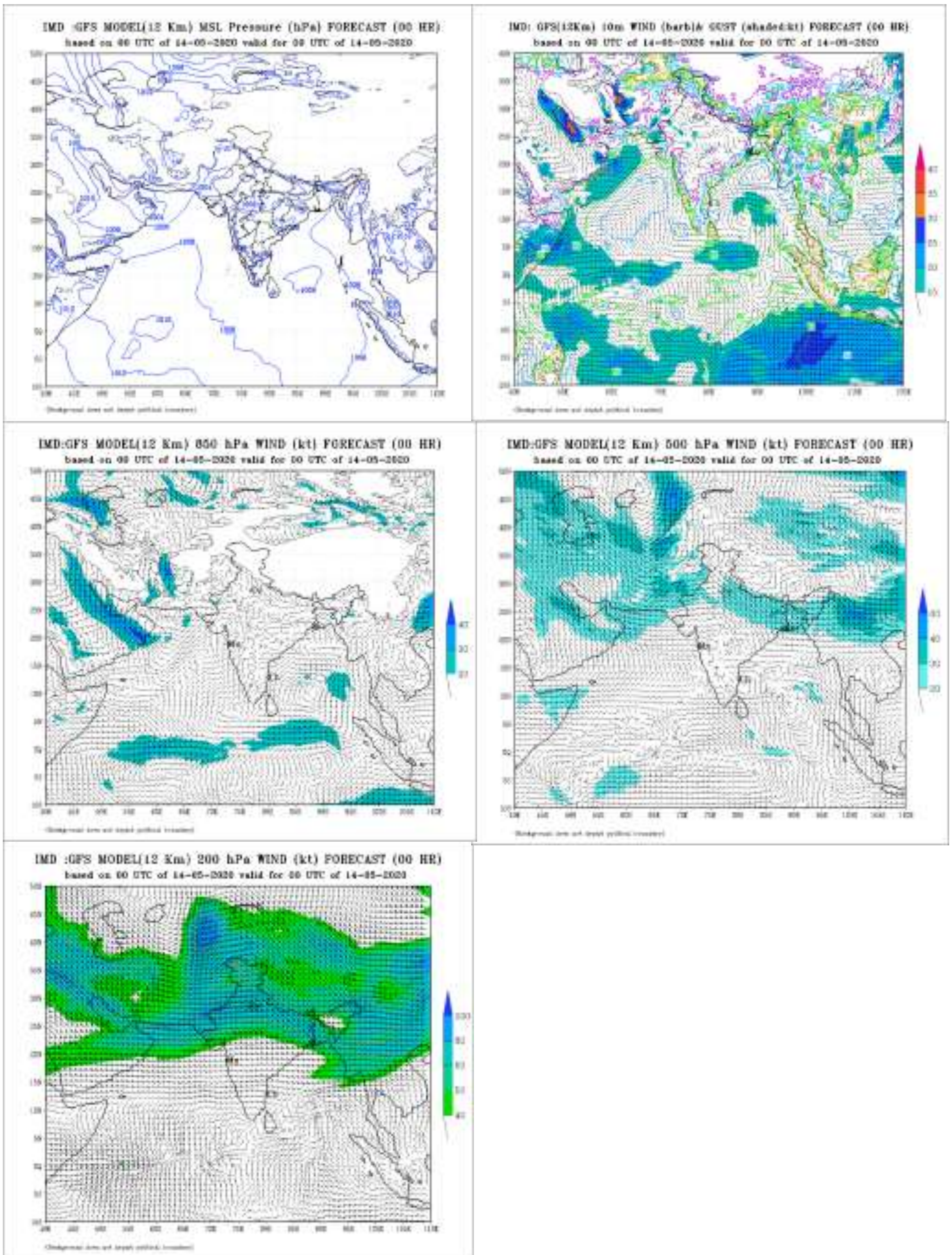


Fig. 12 (b): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 14th May,2020

On 15th May, IMD GFS indicated a well marked low pressure area over southwest BOB with vertical extension of the cyclonic circulation upto 200 hPa level.

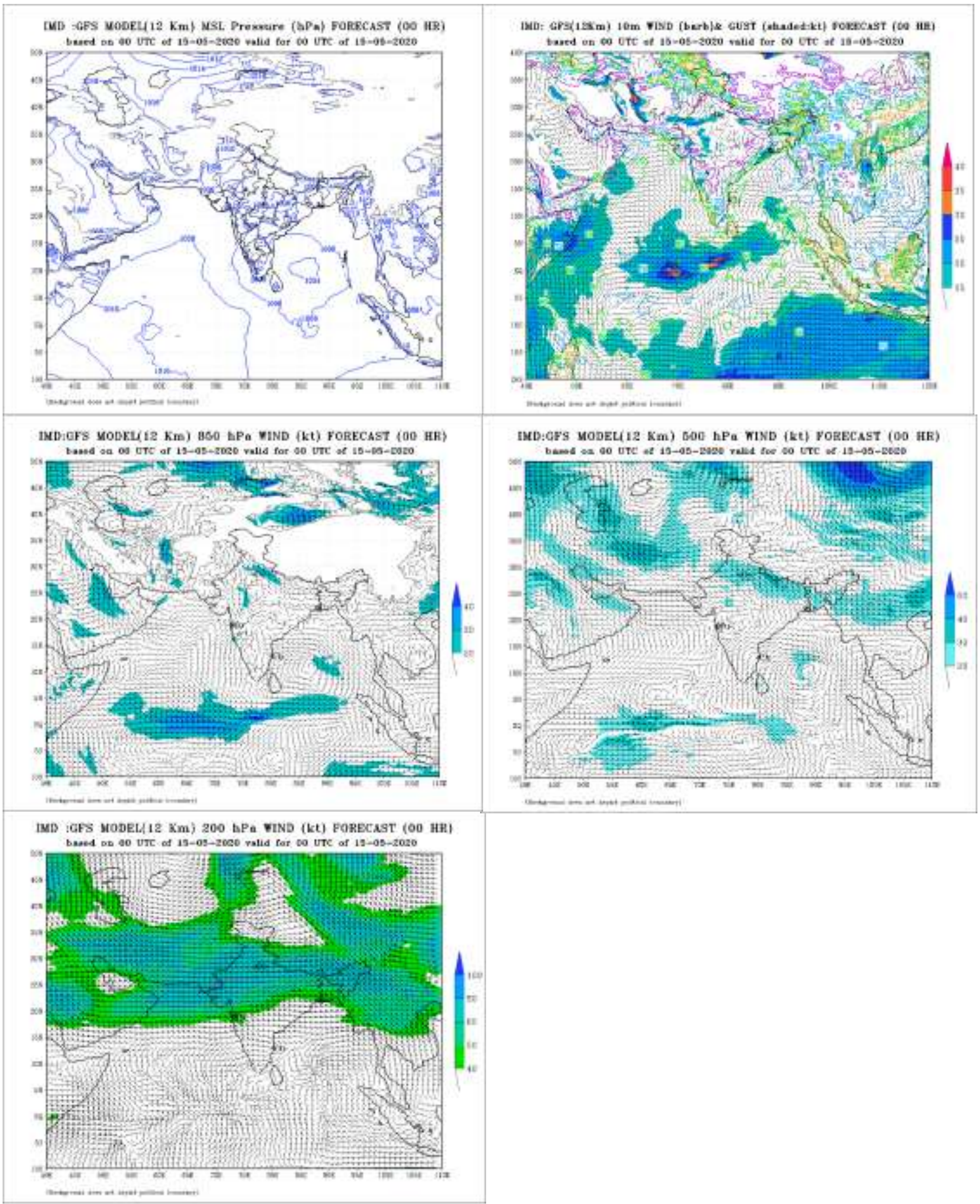


Fig. 12 (c): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 15th May, 2020

On 16th May, IMD GFS indicated a deep depression over southwest BOB with vertical extension of the cyclonic circulation upto 500 hPa level. Actually, it was a depression on 16th May over southeast BoB. IMD GFS slightly over estimated the intensity of the system.

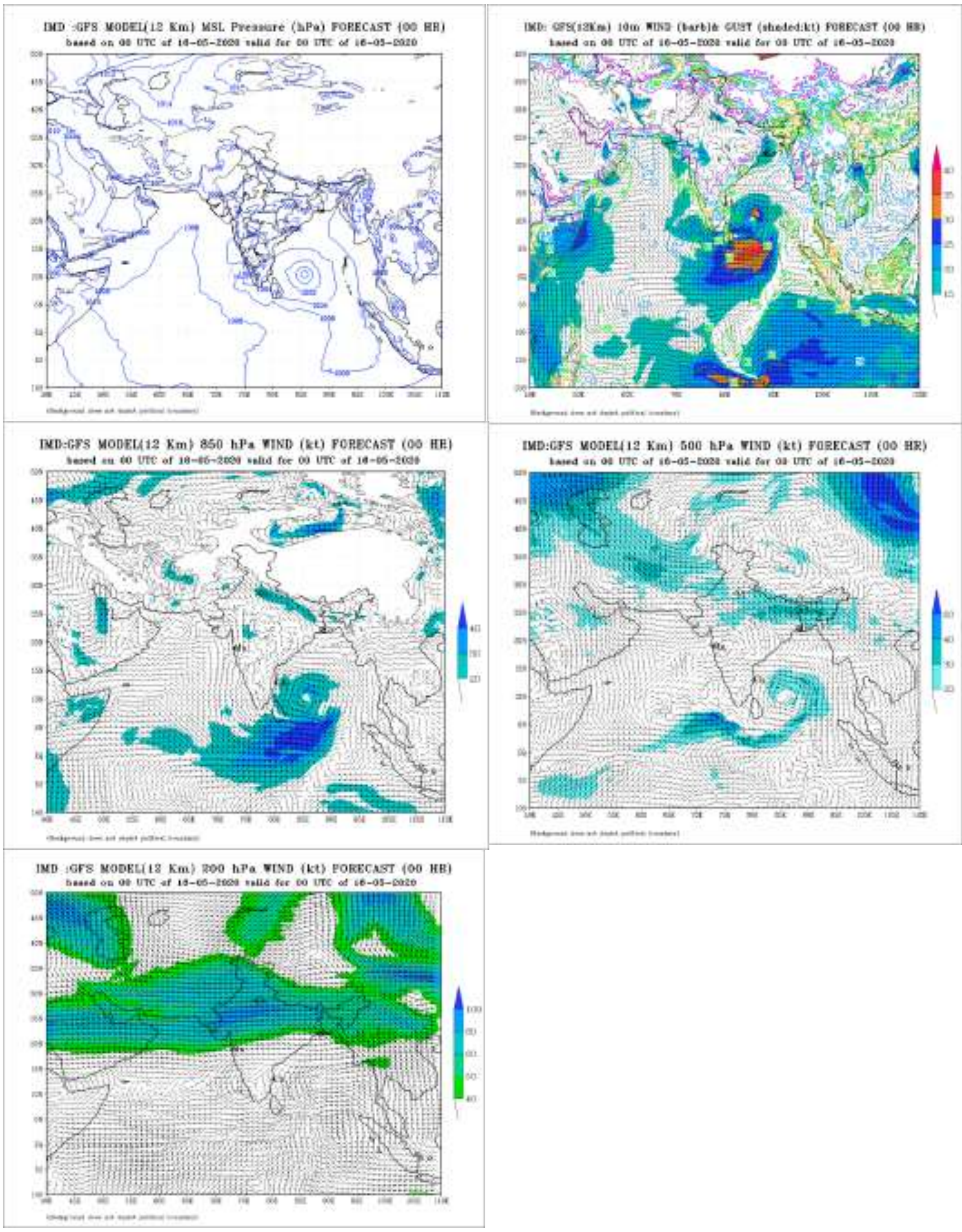


Fig. 21 (d): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 16th May,2020

On 17th May, IMD GFS indicated rapid intensification of the system It lay as a severe cyclonic storm over southwest BoB with vertical extension of the cyclonic circulation upto 200 hPa level. GFS also indicated near northwards movement of the system. Actually, it was a cyclonic storm at 0000 UTC of 17th May over southeast BoB. IMD GFS over estimated the intensity of the system.

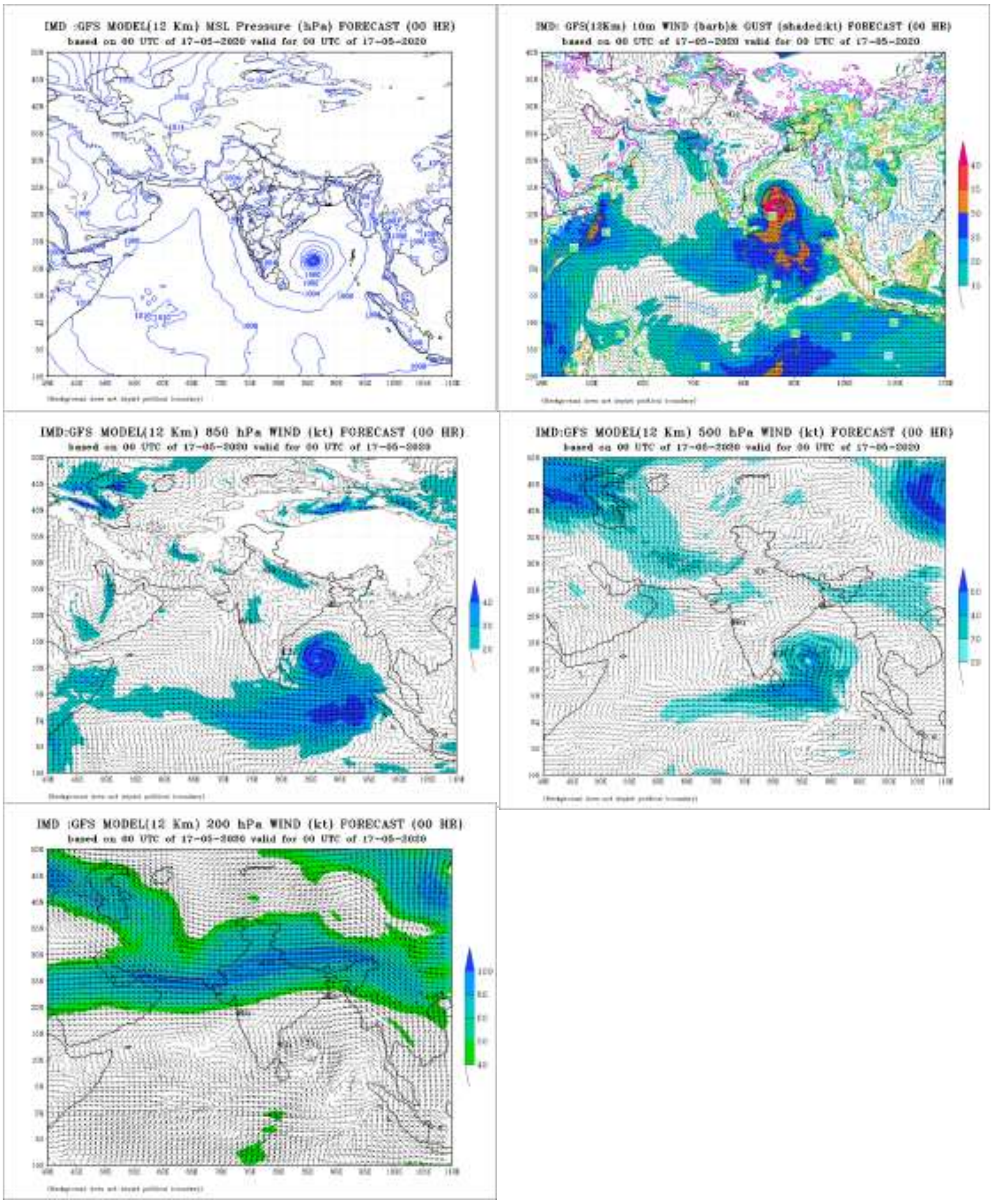


Fig. 12 (e): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 17 May,2020

On 18th May, IMD GFS indicated further intensification of the system. It lay as a very severe cyclonic storm over westcentral BOB with vertical extension of the cyclonic circulation upto 200 hPa level. GFS also indicated near northwards movement of the system. Actually, it was an extremely severe cyclonic storm at 0000 UTC of 18th May over westcentral BoB. IMD GFS correctly picked up intensity and movement f the system.

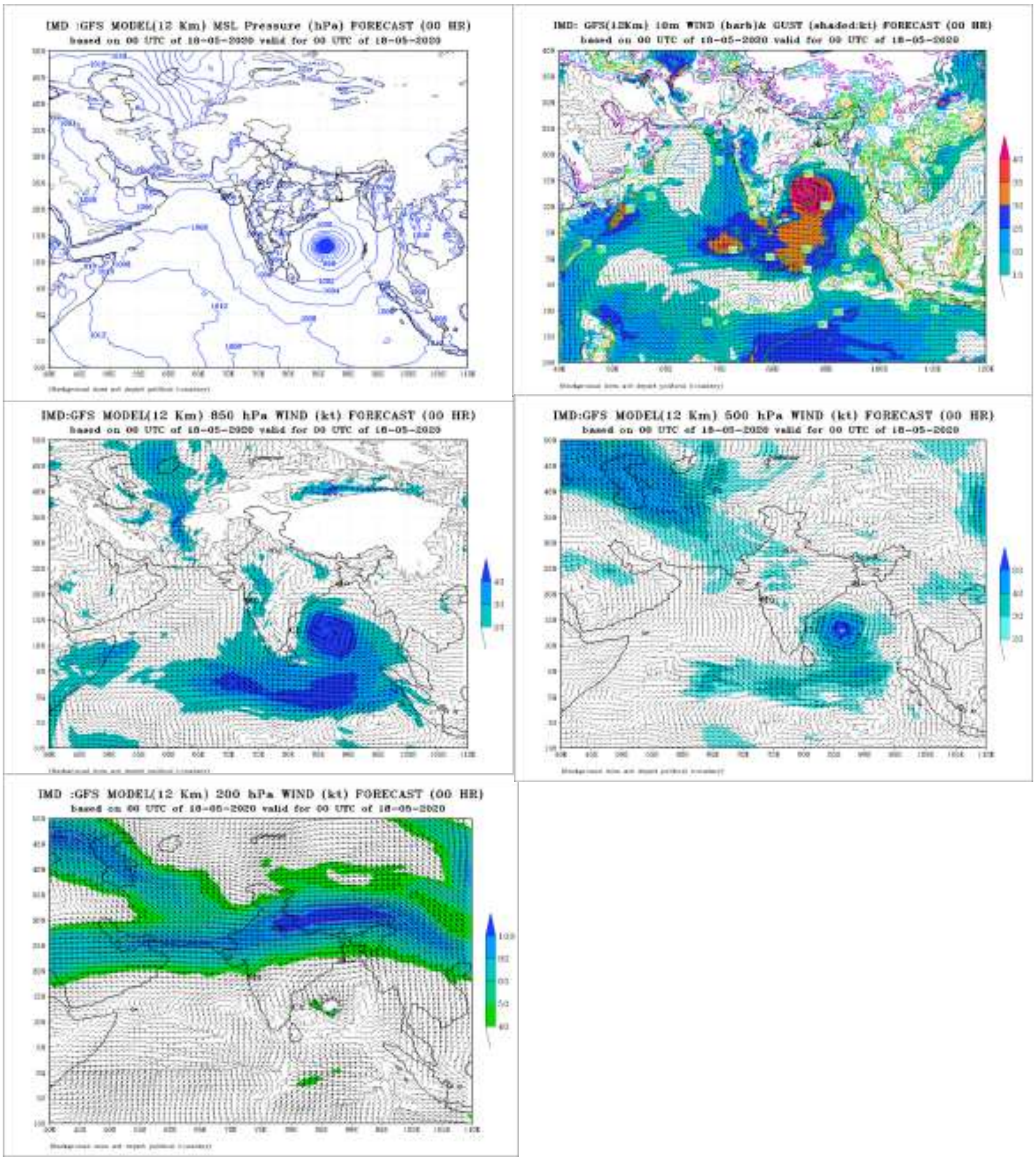


Fig. 12 (f): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 18th May,2020

On 19th May, IMD GFS indicated a very intense system over westcentral BoB with vertical extension of the cyclonic circulation upto 200 hPa level. GFS also indicated northeastwards movement of the system. Actually, it was a super cyclonic at 0000 UTC of 19th May over westcentral BoB. IMD GFS correctly picked up intensity and movement of the system.

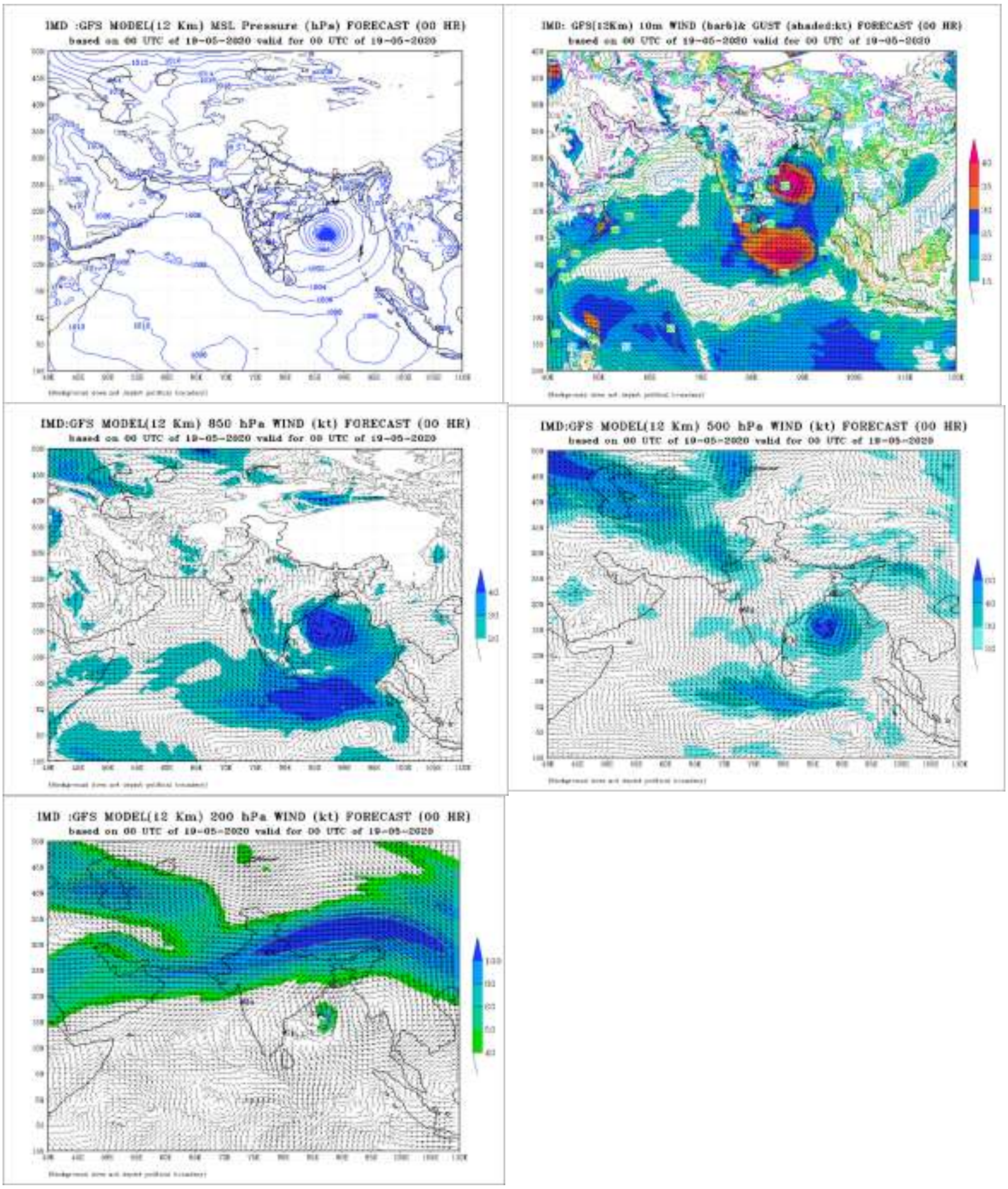


Fig.12 (g): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 19th May,2020

On 20th May, IMD GFS indicated slight weakening of the system. It lay as a very severe cyclonic storm over northwest BoB off Odisha coast. The system extended vertically upto 200 hPa level. GFS also indicated northeastwards movement of the system. Actually, it was an extremely severe cyclonic storm cyclonic storm at 0000 UTC of 20th May over northwest BoB. GFS also picked up an anticyclone over Myanmar to the west of system and strong westerlies in the upper level indicating steering of the system in northeastwards direction. IMD GFS correctly picked up intensity and movement of the system.

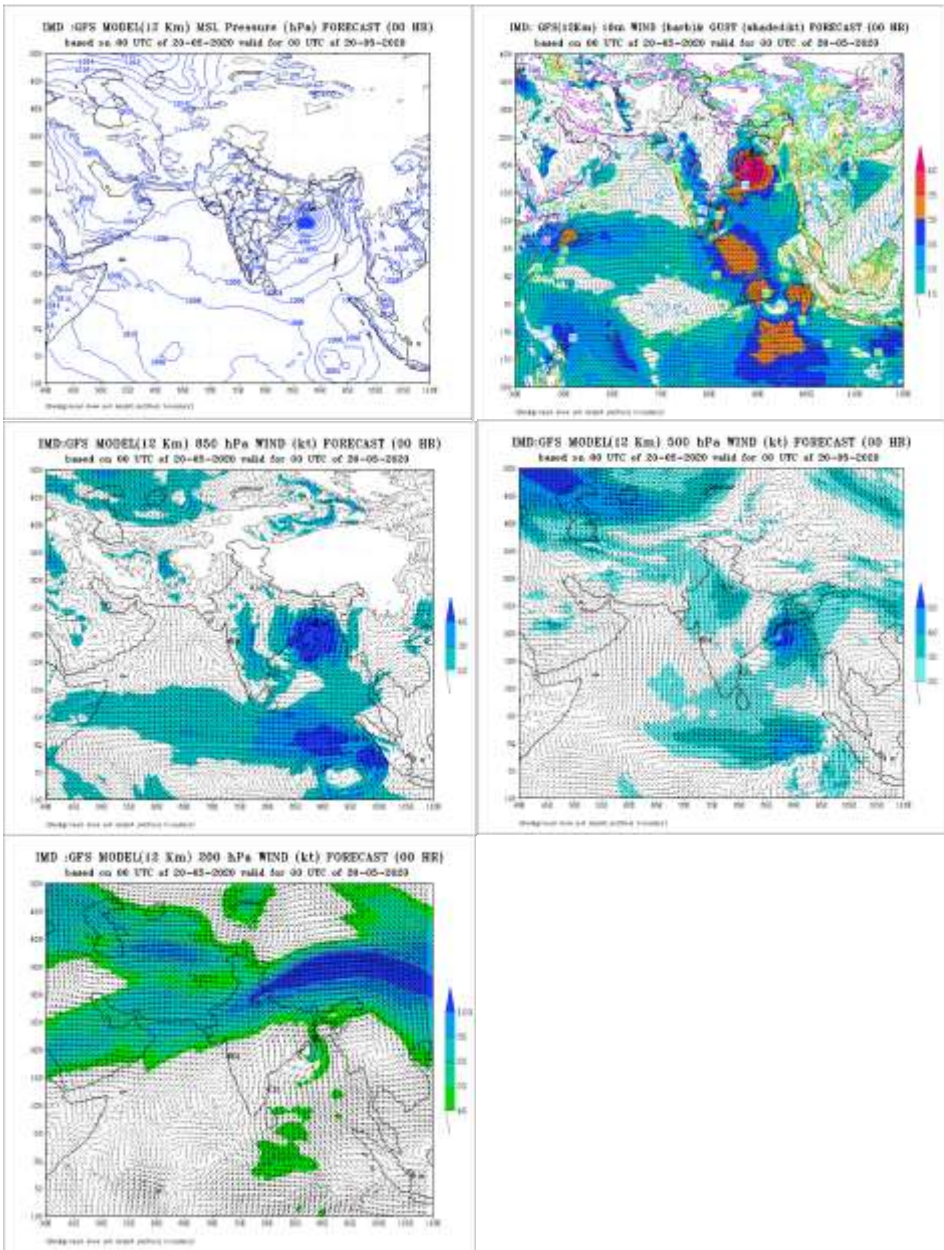


Fig. 12 (h): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 20th May, 2020

On 21st May, IMD GFS indicated a cyclonic storm over Bangladesh and adjoining Gangetic West Bengal.

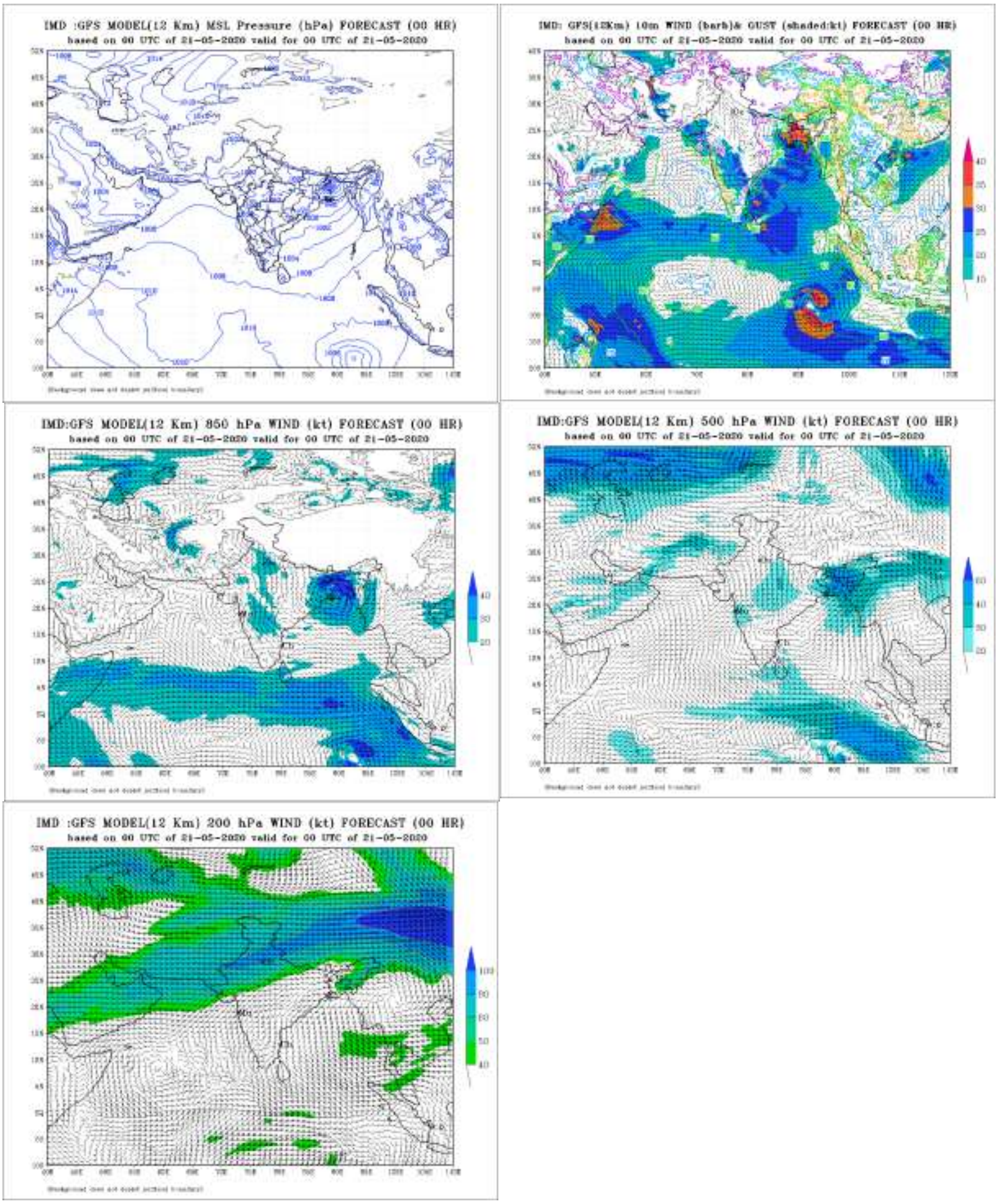


Fig. 12 (i): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 21st May,2020

IMD GFS thus correctly picked up intensification, movement and weakening of the system.

7. Realized Weather:

7.1. Realised rainfall

Rainfall associated with SuCS AMPHAN based on IMD-NCMRWF GPM merged gauge 24 hours cumulative rainfall ending at 0830 IST of date is depicted in **Fig 13**.

It indicates occurrence of heavy to very heavy rainfall at a few places over coastal Odisha & Gangetic West Bengal on 20th May, heavy rainfall at isolated places over Gangetic West Bengal & adjoining Bangladesh and Assam, Meghalaya & Arunachal Pradesh on 21st May and heavy rainfall at isolated places over Assam, Meghalaya, Arunachal Pradesh, Sikkim, Nagaland, Manipur & Mizoram on 22nd May.

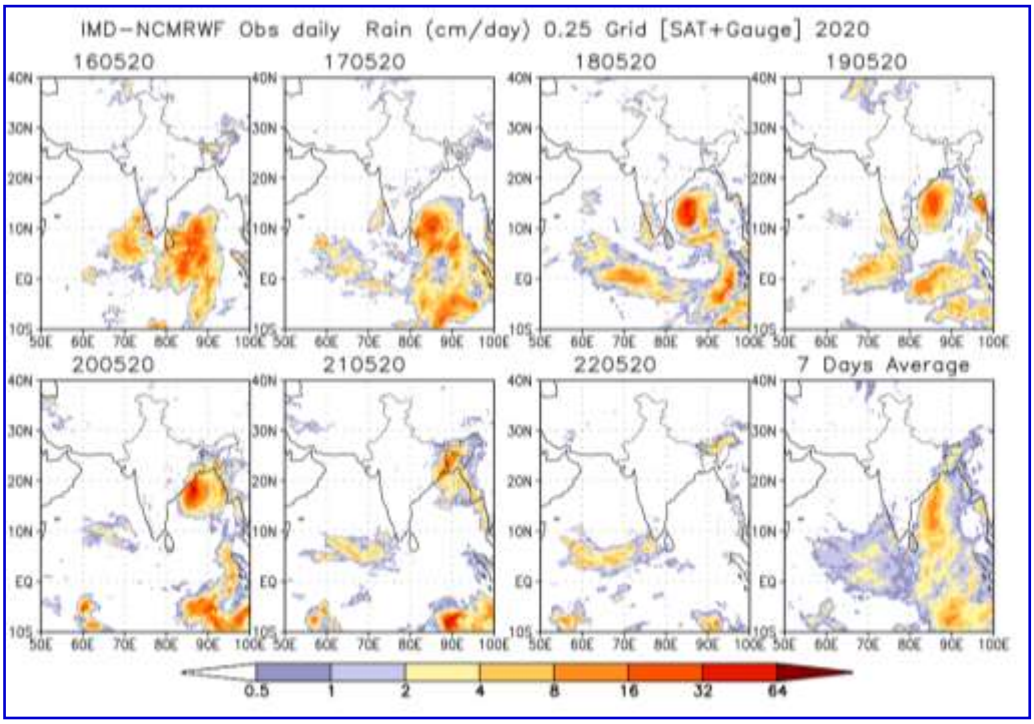


Fig.13: IMD-NCMRWF GPM merged gauge 24 hr cumulative rainfall (cm) ending at 0830 IST of date during 16th May – 22nd May and 7 days average rainfall (cm/day)

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

20 May 2020

Gangetic West Bengal: Contai-11, Digha-9,

Odisha: Paradip-21, Balikuda-18, Kakatpur & Kujanga-16 each, Astaranga & Alipingal-14 each, Niali-12, Raghunathpur, Puri, Marsaghai, Nilgiri, Kantapada & Garadapur-9 each, Gop, Chandanpur, Betanati, Rajkanika, Jagatsinghpur, Tirtol & Baripada-8 each and Binjharpur, Satyabadi, Nischintakoili, Chandbali, Bhograi, Jajpur, Dhamnagar, Soro, Tihidi, Bari & Basudevpur-7 each,

21 May 2020

Assam & Meghalaya: Williamnagar-23, Mawsynram-15, Sohra (RKM)-13, Bhaghmara-11 and Sohra & Shillong-9 each

SHWB & Sikkim: Sevoke-7,

Gangetic West Bengal: Alipore-24, Dum Dum-20, Harinkhola & Debagram-13 each, Burdwan-10, Manteswar & Digha-9 each and Mohanpur, Kharagpur, Suri, Mangalkote, Bankura, Lalgarh & Midnapore-7 each,
Odisha: Bhograi-13, Rajghat & Jaleswar-12 each and Chandanpur & Bangiriposi-11 each, Paradip, Samakhunta, Betanati & Baripada-9 each and Chandikhol, Joshipur & Danagadi-7 each

22 May 2020
Arunachal Pradesh: Bhalukpong-12, Bomdila-10, Itanagar & Ziro-9 each, Roing-8, Pasighat Aero-7,
Assam & Meghalaya: Cherrapunji (RKM)-25, Mawsynram-22, Sohra -21, Khliehriat-15, Goalpara-12, Nongstein, Dhubri & Mela bazar -10 each, Goibargaon, N.Lakhimpur/Lilabari & Shillong-8 each and Tamulpur, Barapani, Williamnagar, DRF & Tezpur-7 each,
Nagaland, Manipur, Mizoram & Tripura: Sabroom-13,
SHWB & Sikkim: Buxaduar-8,

7.2. Realised wind:

Kolkata (Dum Dum) reported 130 kmph at 1855 hrs IST (1325 UTC) and Kolkata (Alipore) 112 kmph at 1752 hrs IST (1222 UTC) of 20th May.

Also Paradip reported 106 kmph at 0630 hrs IST (0100 UTC) , Chandbali, 80 kmph at 0830 hrs.IST (0300 UTC) and Balasore 91 kmph during 1330 – 1430 hrs. IST (0800 & 0900 UTC) of 20th May.

Maximum sustained wind speed recordings from Automated Weather Stations (AWS) at Canning, Nimpith and Sagar Islands on 20th May are shown in **Fig.14**.

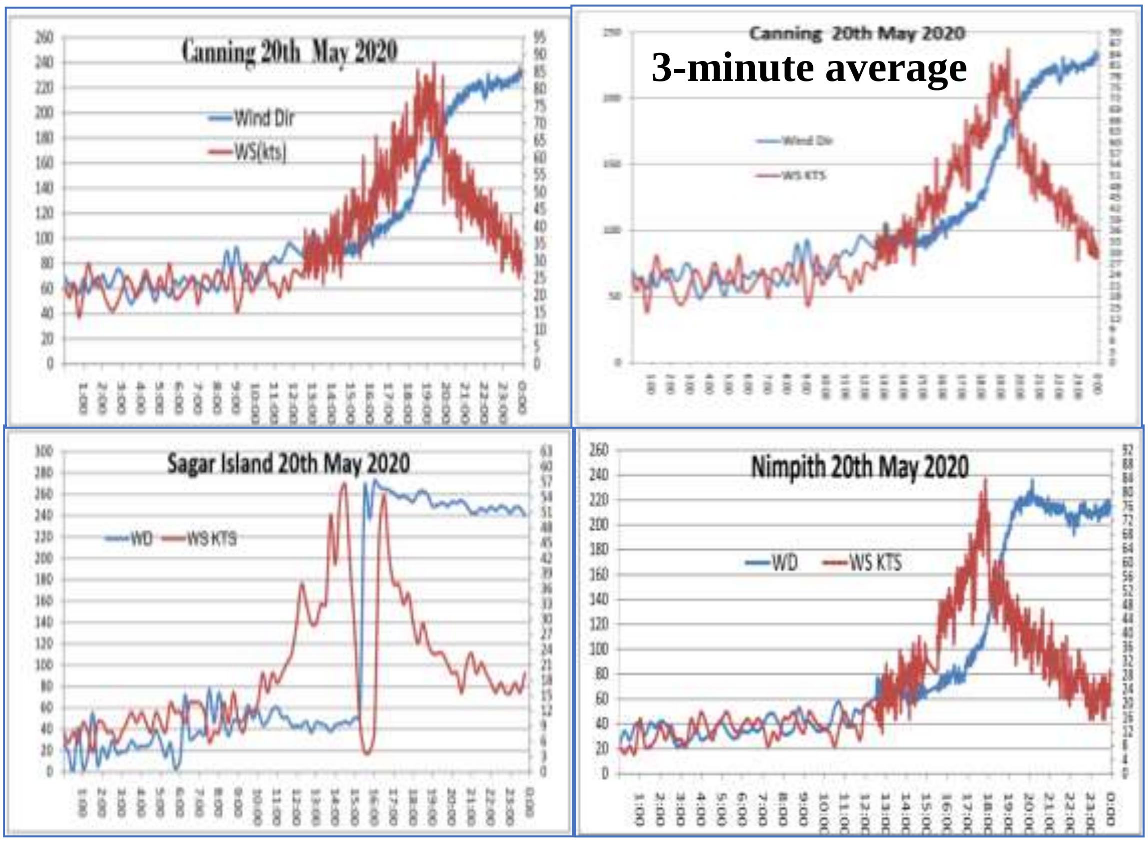


Fig.14: AWS data from Canning, Sagar Island & Nimpith on 20th May 2020

Five hours period during 1600-2100 hrs IST witnessed wind speed 60-80 kmph with many gusts of 100 kmph (with maximum of 114 kmph) over Kolkata. **Fig.15** indicates the wind recorded at Alipore (Kolkata) on 20th May 2020.

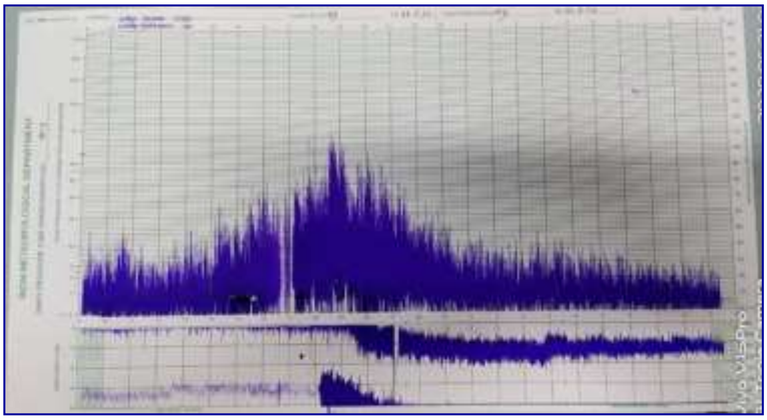


Fig.15: Wind anemograph recordings at Kolkata (Alipore) on 20th May 2020

7.3. Realised storm surge:

As per the Post Cyclone landfall survey conducted by Area Cyclone Warning Centre (ACWC) Kolkata, Tidal waves of 15 Feet height inundated low lying areas of South & North 24 Parganas and adjoining areas of east Medinipur Districts of West Bengal.

8. Damage due to SuCS, AMPHAN

98 persons lost their lives in West Bengal due to Amphan. No death was reported from Odisha.

Fig. 16: (a)Hanging electric pole(The Hindu,23rd May) (b)Flooded Kolkata Airport (NDTV,4TH June) (c) Damaged homes (outlookindia.com,22nd May) (d) Flooded area of West Bengal (cnn.com,22nd May)

Fig. 16(e): A bus crashed after a tree fell on it in Kolkata (The Hindu, 22nd May) (f) Uprooted trees (dnaindia.com,21st,May)

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. The performance of the individual models, MME forecasts, SCIP, GPP, RII for SuCS AMPHAN are presented and discussed in following sections.

9.1 Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for AMPHAN

Fig. 17 (a-f) indicates that the GPP could predict the potential zone for cyclogenesis on 11th over southeast BoB about 120 hours 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. Average GPP ≥ 8.0 is the threshold value for system likely to develop into a cyclonic storm and average GPP < 8.0 indicates a non-developing system: The area average analysis of GPP based on 0000 & 1200 UTC during 13th – 16th May is presented in Fig. 18. The area average analysis was predicting the system to develop into a cyclonic storm since 13th May onwards.

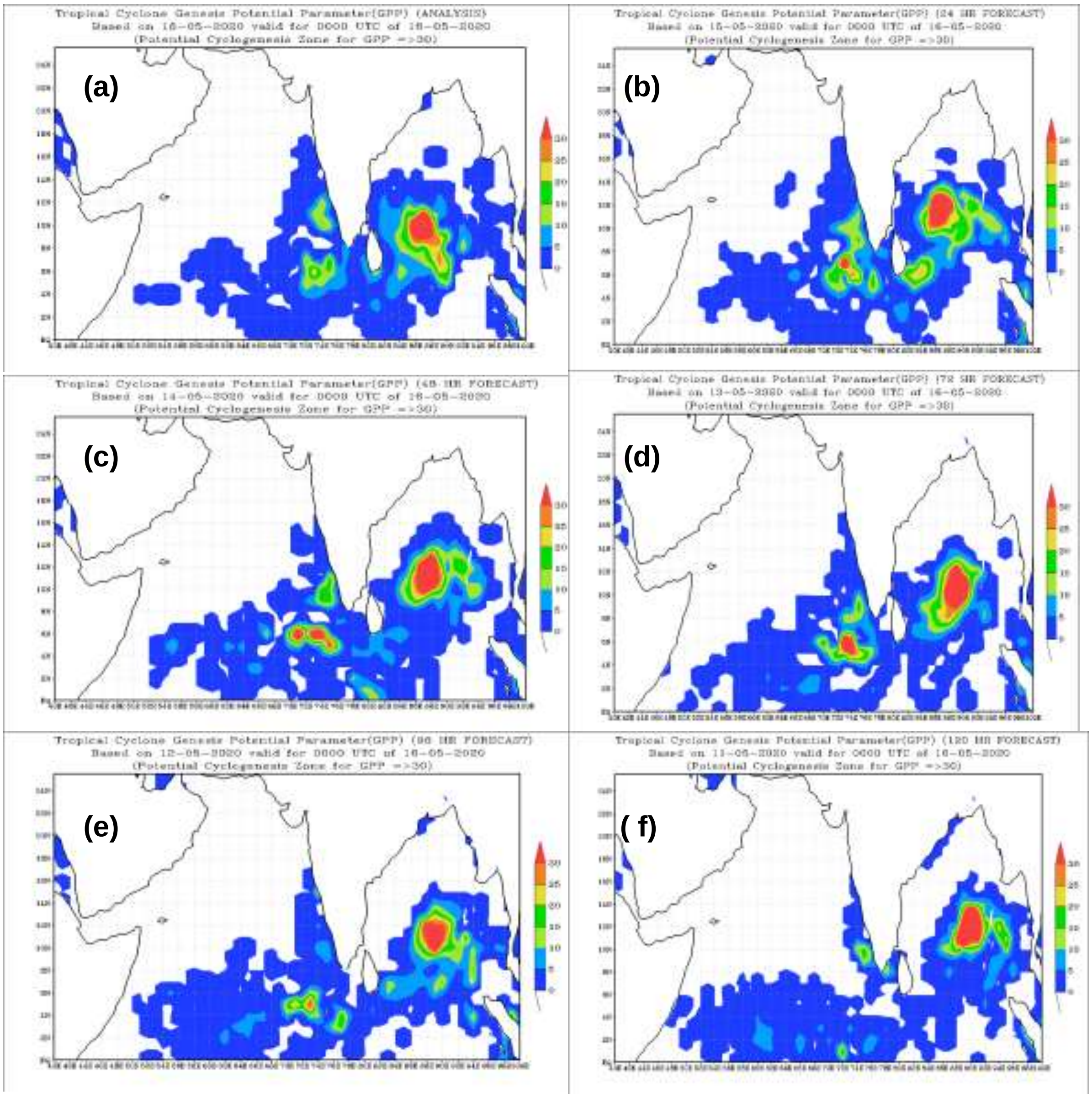


Fig.17 (a-f): Predicted zone of cyclogenesis for 0000 UTC of 16th May based on 0000 UTC of 11th-16th May 2020

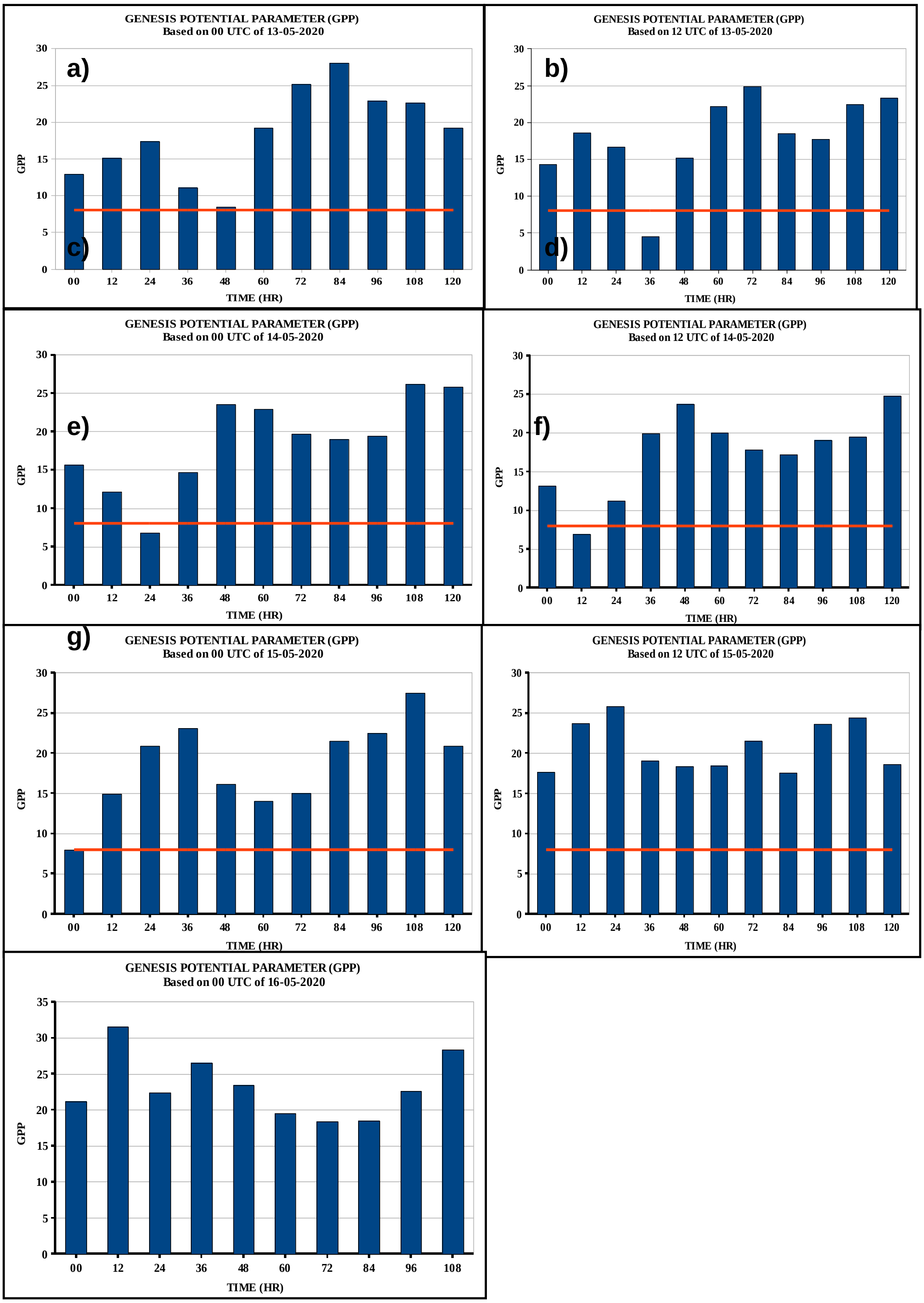
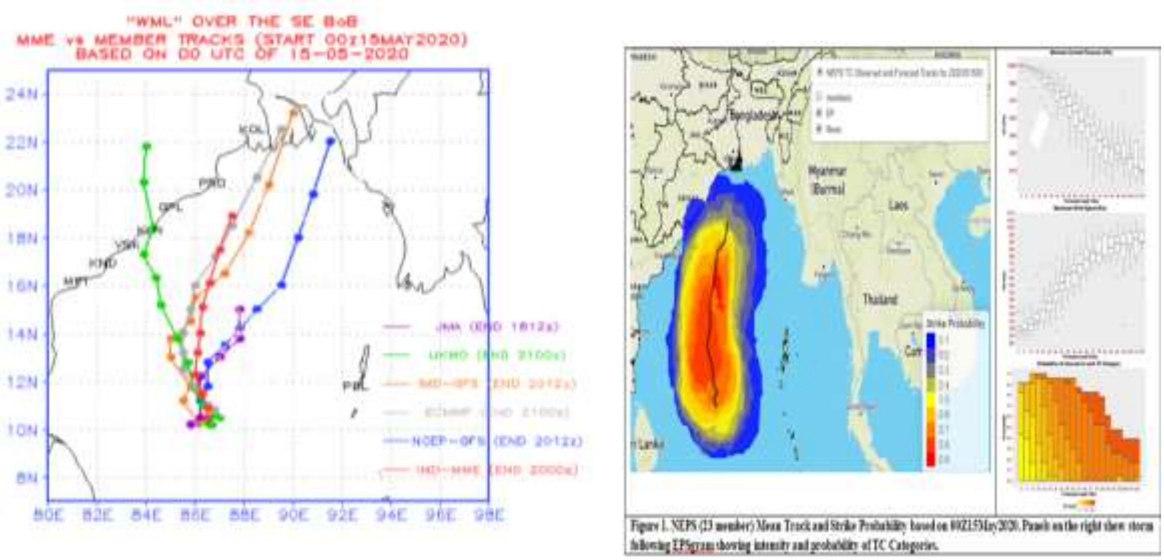
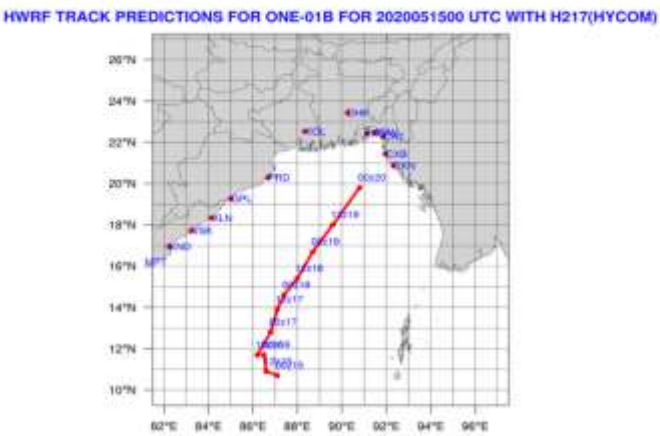


Fig. 18: Area average analysis and forecasts of GPP based on (a) 0000 of 13th, (b) 1200 UTC of 13th, (c) 0000 UTC of 14th and (d) 1200 UTC of 14th (e) 0000 UTC of 15th(f) 1200 UTC of 15th(g) 0000 UTC of 16th ,May 2020

9.2 Track prediction by NWP models

Tracks predicted by various NWP models including IMD GFS, IMD MME, IMD HWRF, NCMRWF Unified Model (NCUM), NCEP GFS, ECMWF, UKMO and JMA during 15th May to 21st May are presented in **Fig.19**. Based on initial conditions of 0000 UTC of 15th May, there was large divergence among various models w.r.t. track. IMD GFS and ECMWF were predicting landfall over Bangladesh. MME, JMA & NCEP GFS, HWRF and NEPS were indicating weakening over sea. UKMO was predicting weakeneing over south Andhra Pradesh. HWRF was indicating the system to intensify upto Super cyclonic storm stage.

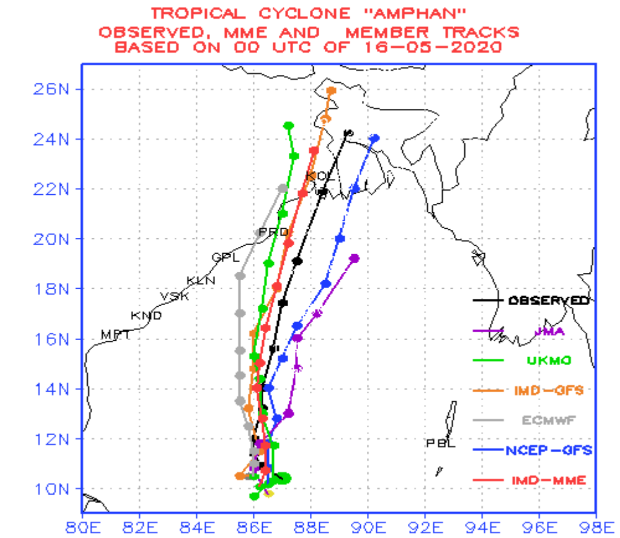


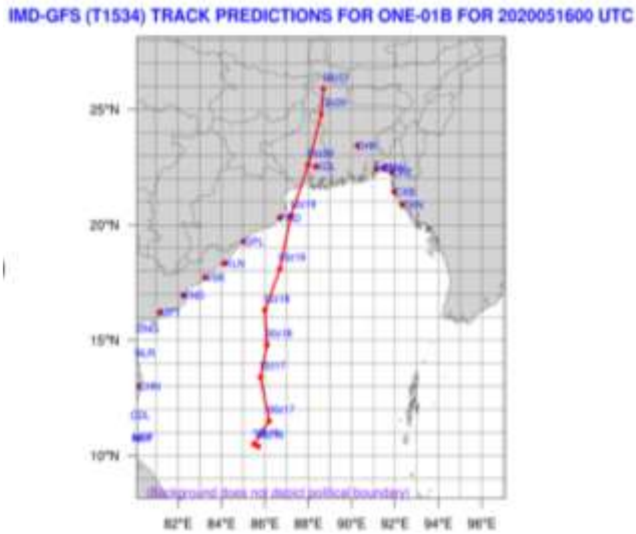


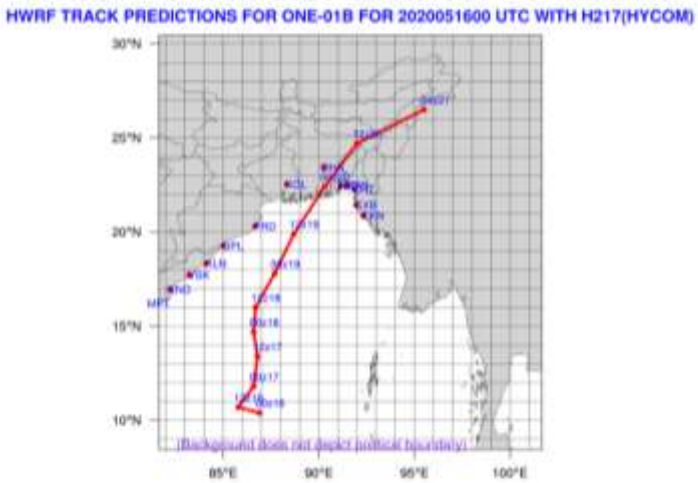
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z15	10.7	87.10	1003.	23.
12z15	10.9	86.60	1003.	28.
00z16	11.7	86.50	995.0	35.
12z16	11.7	86.20	988.0	44.
00z17	12.8	86.80	978.0	57.
12z17	13.9	87.10	969.0	54.
00z18	14.6	87.40	959.0	75.
12z18	15.4	88.00	941.0	92.
00z19	16.7	88.70	921.0	121
12z19	18.0	89.60	910.0	128
00z20	19.8	90.80	910.0	126

Fig. 19 (a): NWP model track forecast based on 0000 UTC of 15th May,2020

Based on initial conditions of 0000 UTC of 16th May, there was still large divergence among various models w.r.t. track. All models except JMA were now indicating landfall over Odisha and Wet Bengal. JMA was predicting weakening over sea. HWRF was indicating the system to intensify upto Super cyclonic storm stage on 0000 UTC of 19th with system reaching peak intensity of 130 kts at 1200 UTC of 19th.



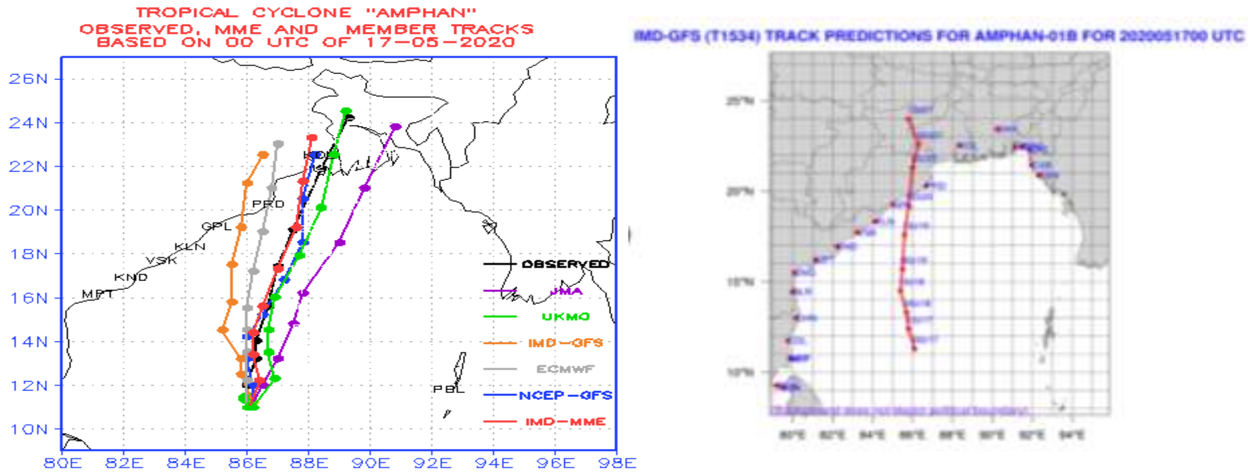


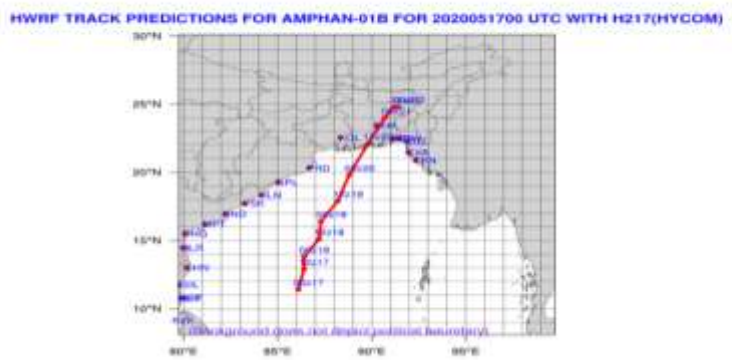


Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z16	10.4	86.90	999.0	27.
12z16	10.7	85.80	992.0	51.
00z17	11.8	86.60	981.0	64.
12z17	13.4	86.80	961.0	79.
00z18	14.7	86.60	944.0	87.
12z18	16.0	86.70	928.0	122
00z19	17.8	87.70	923.0	118
12z19	19.9	88.70	909.0	129
00z20	22.4	90.30	925.0	104
12z20	24.7	92.00	969.0	59.
00z21	26.5	95.50	997.0	29.

Fig. 19 (b): NWP model track forecast based on 0000 UTC of 16th May, 2020

Based on initial conditions of 0000 UTC of 17th May, there was still large divergence among various models w.r.t. track. All models were now indicating landfall over varying from south Odisha to Bangladesh. JMA and HWRF were predicting landfall over Bangladesh. MME, UKMO, NCEP GFS were predicting landfall over West Bengal. HWRF was indicating the system to intensify upto very severe cyclonic storm stage on 0000 UTC of 20th with system reaching peak intensity of 82 kts at 0000 UTC of 20th. On 17th HWRF underestimated the intensity of the system.

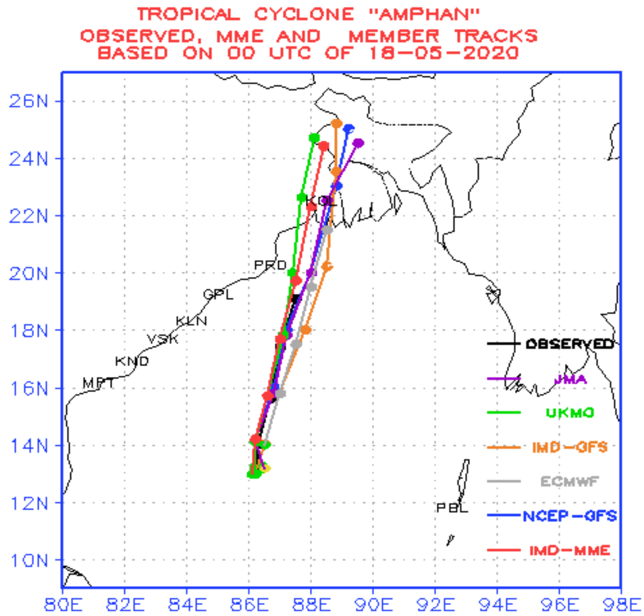


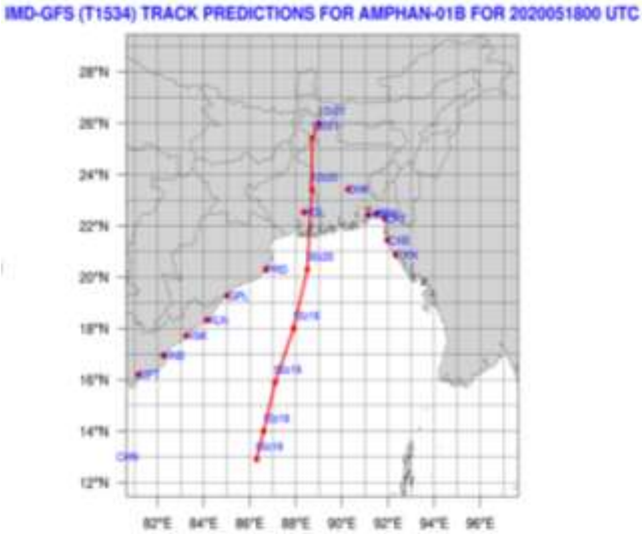


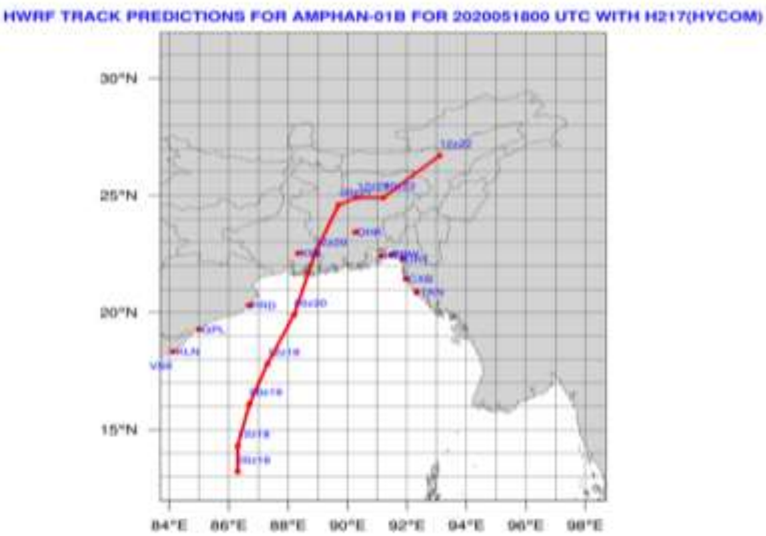
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z17	11.4	86.10	994.0	45.
12z17	12.9	86.40	982.0	54.
00z18	13.8	86.40	975.0	71.
12z18	15.1	87.20	974.0	63.
00z19	16.4	87.30	972.0	62.
12z19	17.9	88.20	963.0	62.
00z20	19.8	88.80	942.0	82.
12z20	22.1	89.80	946.0	76.
00z21	24.0	90.70	976.0	48.
12z21	24.8	91.20	994.0	35.
00z22	24.8	91.40	1002.	22.

Fig. 19 (c): NWP model track forecast based on 0000 UTC of 17th May, 2020

Based on initial conditions of 0000 UTC of 18th May, all models converged and indicated landfall over West Bengal. HWRF predicted peak intensity of 120 kts at 1200 UTC of 19th. Thus, HWRF could pick up peak intensity but with a delay of about 24 hours. The system reached it's peak intensity at 0600 UTC of 18th.



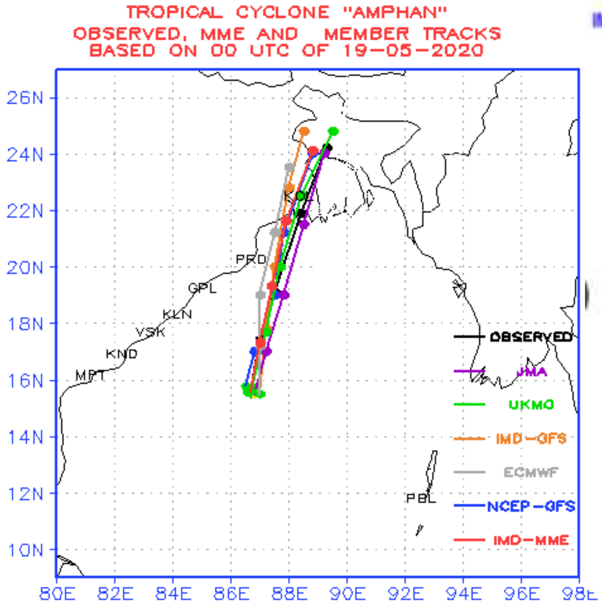


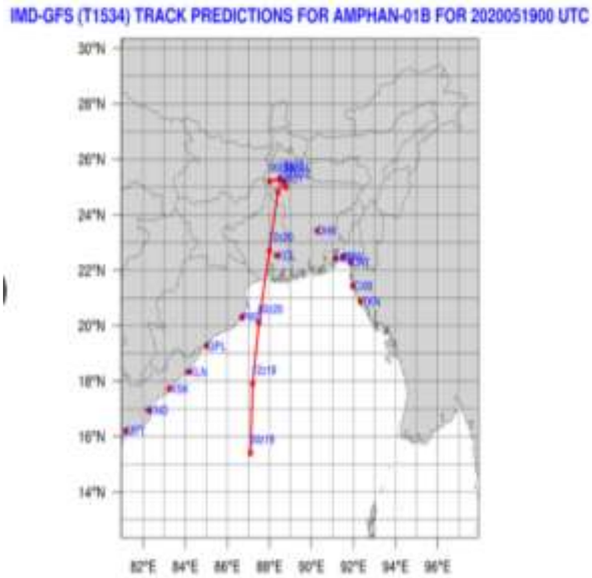


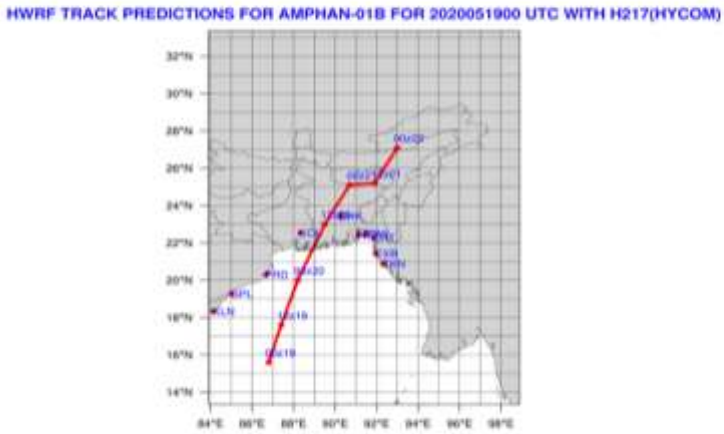
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z18	13.2	86.30	950.0	88.
12z18	14.3	86.30	938.0	112
00z19	16.1	86.70	932.0	112
12z19	17.8	87.30	930.0	118
00z20	19.9	88.20	929.0	113
12z20	22.5	88.90	942.0	72.
00z21	24.6	89.70	977.0	50.
12z21	24.9	90.30	994.0	34.
00z22	24.9	91.20	1003.	21.
12z22	26.7	93.10	1007.	24.

Fig. 19(d): NWP model track forecast based on 0000 UTC of 18th May, 2020

Based on initial conditions of 0000 UTC of 19th May, all models converged and indicated landfall over West Bengal. HWRF predicted landfall over Sunderbans around 1200 UTC of 20th. Thus, track and landfall point & time were correctly picked up by HWRF. However, intensity was underestimated by the system.



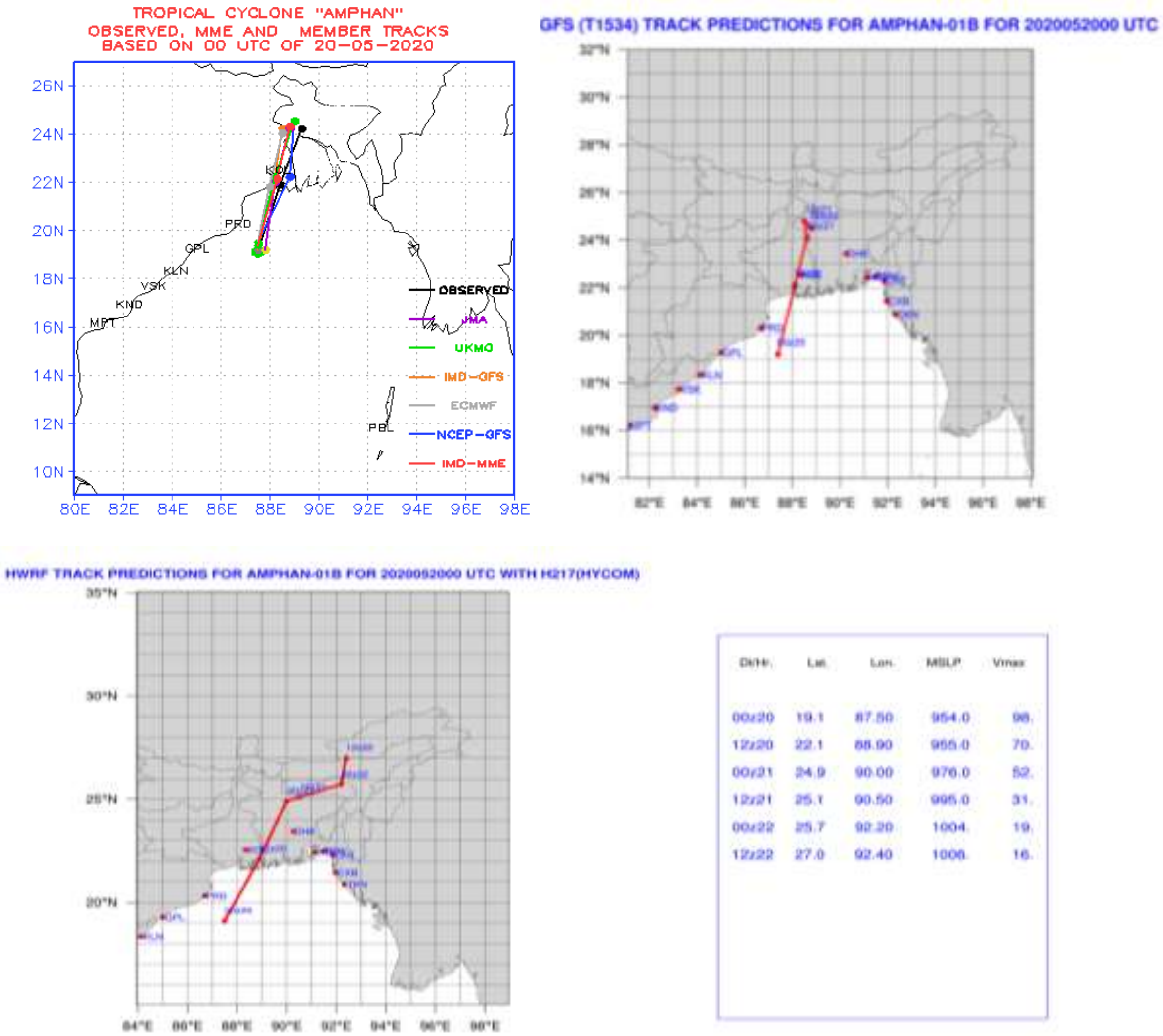




Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z19	15.6	86.80	940.0	115
12z19	17.6	87.40	937.0	111
00z20	20.0	88.20	929.0	115
12z20	23.0	89.50	945.0	71.
00z21	25.1	90.70	985.0	42.
12z21	25.2	91.90	1002.	22.
00z22	27.1	93.00	1006.	25.

Fig. 19 (e): NWP model track forecast based on 0000 UTC of 19th May, 2020

Based on initial conditions of 0000 UTC of 20th May, all models converged and indicated landfall over West Bengal. HWRF predicted landfall over Sunderbans around 1000 UTC of 20th as a VSCS (around 80 kts). Thus, track and landfall point & time were correctly picked up by HWRF.



Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z20	19.1	87.50	954.0	98.
12z20	22.1	88.90	955.0	70.
00z21	24.9	90.00	976.0	52.
12z21	25.1	90.50	995.0	31.
00z22	25.7	92.20	1004.	19.
12z22	27.0	92.40	1006.	16.

Fig. 19 (f): NWP model track forecast based on 0000 UTC of 20th May, 2020

9.3 Track forecast errors

Average track forecast errors by various NWP models are presented in Table 2a. For 24 hrs lead period track forecast error was the least i.r.o. MME followed by NCEP GFS, JMA, HWRF and IMD GFS. For 48 hrs lead period, the track forecast error was the least i.r.o. MME, NCEP GFS and IMD HWRF. For 72 hours lead period, the error was the least i.r.o. MME, ECMWF, NCEP GFS and HWRF. The along track and cross track errors by different models are presented in Table 2 (b & c). Along track errors were less as compared to cross track errors.

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Table-2a: 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	108h	120h
IMD-MME*	26(9)	36(9)	55(8)	58(7)	57(6)	67(5)	71(4)	99(3)	76(2)	145(1)
ECMWF	51	73	101	118	74	101	139	209	261	339
NCEP-GFS	31	42	61	74	96	123	148	209	171	94
UKMO	50	61	79	112	140	184	216	170	198	215
JMA	40	59	93	123	170	205	280	---	---	---
HWRF	53 (18)	80 (18)	96 (17)	107 (15)	120 (13)	152 (11)	198 (9)	262 (7)	286 (5)	407 (3)
IMD-GFS	52	62	95	132	157	173	239	312	221	198
NCUM	58	62	98	124	187	237	294	326	429	--
NEPS	58	77	117	157	219	272	321	335	310	282

** The numbers within the parentheses against DP Errors for IMD-MME indicate the number of forecasts issued corresponding to the lead-time. The number of forecasts, corresponding to a particular lead-time, is the same for all the models (No forecast for JMA beyond 84h).*

Table-2b. Average along-track forecast errors (ATE) in km
(Number of forecasts verified is given in the parentheses)

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr	120 Hr
HWRF	24 (18)	28 (18)	35 (17)	38 (15)	57 (13)	81 (11)	119 (9)	148 (7)	216 (5)	336 (3)

Table-2c Average cross-track forecast errors (CTE) in km
(Number of forecasts verified is given in the parentheses)

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr	120 Hr
HWRF	116 (18)	154 (18)	173 (17)	178 (15)	170 (13)	168 (11)	191 (9)	268 (7)	260 (5)	299 (3)
IMD-GFS	77	66	123	150	167	203	232	381	--	--
IMD-GEFS	53	71	105	114	125	140	173	220	--	--

9.4. Landfall forecast errors

Average model errors in landfall point and time are presented in Table 3 (a & b). The tables indicate that landfall point errors upto 72 hrs lead period were the least by MME followed by HWRF. Landfall time errors by MME were the least for all lead period.

Table-3a. Landfall point forecast errors (km) of NWP Models at different lead time (hour) (Number of forecasts verified is given in the parentheses)

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr
HWRF	33	18	56	33	25	40	165	211	211
MME	11	11	22	--	44	33	44	55	66

Table-3b. Landfall time forecast errors (hour) at different lead time (hr)

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr
HWRF	0	0	-3	0	+3	0	+3	0	-9
MME	0	1	2	-1	-1	0	2	1	1

9.5. Intensity forecast errors by various NWP Models

The intensity forecasts errors of various models are presented in Table 4. It is seen that errors were the least by MME followed by IMD GFS, HWRF & GEFS.

Table-4. Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots of various models (Number of forecasts verified is given in the parentheses)

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr	72 Hr	84 Hr	96 Hr	108 Hr	120 Hr
HWRF (AAE)	12.9 (18)	17.7 (18)	19.6 (17)	21.0 (15)	16.0 (13)	19.5 (11)	23.0 (9)	13.4 (7)	14.8 (5)	9.7 (3)
IMD-GFS (AAE)	12.2	15	12.2	7.5	14.3	8.7	15.3	24.5	--	--
IMD-GEFS (AAE)	23.7	23.3	21.8	20.6	21	20.8	19	23.5	--	--
IMD-SCIP (AAE)	6.1	13	19.3	21.3	20.2	9	9.3	23	19	--
HWRF (RMSE)	15.6 (18)	20.2 (18)	24.5 (17)	28.1 (15)	22.4 (13)	22.7 (11)	24.6 (9)	14.8 (7)	14.5 (5)	10.8 (3)
IMD-GFS (RMSE)	14.5	19.4	15.5	8	17.6	10.2	22.7	27.5	--	--
IMD-GEFS (RMSE)	26.6	26.4	26.3	23	23.9	23.2	22.6	30.2	--	--
IMD-SCIP (RMSE)	8.1	15.5	21.3	23.4	23.3	9.7	9.7	23	19	--

Intensity forecast by IMD Statistical Cyclone Intensity Prediction (SCIP) model is presented in Fig. 20 (a). It is seen that upto 72 hrs lead period, IMD SCIP under estimated the intensity of the system and beyond that it over estimated the intensity of the system. However, HWRF underestimated the intensity upto 60 hours lead period. But for longer lead period, intensity was correctly captured.

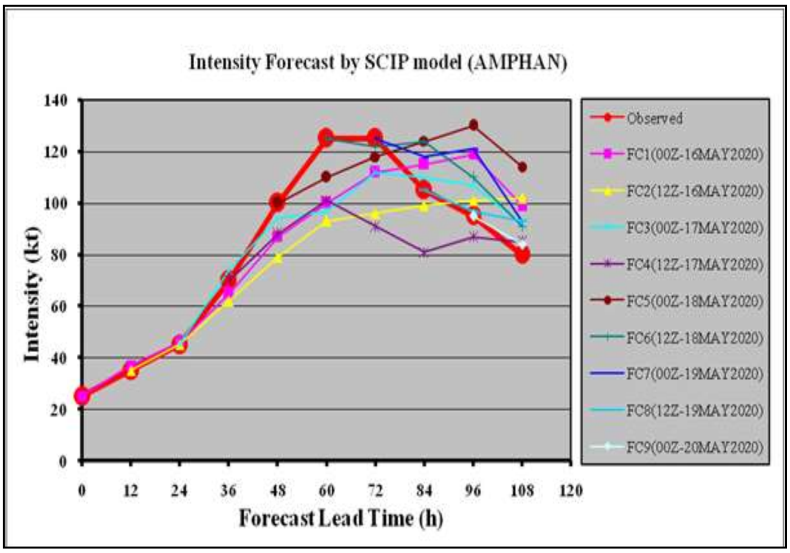

Fig.20 (a): Intensity forecast based on 0000 and 1200 UTC during 16th May to 20st May and (b) Landfall intensity prediction by SCIP Model

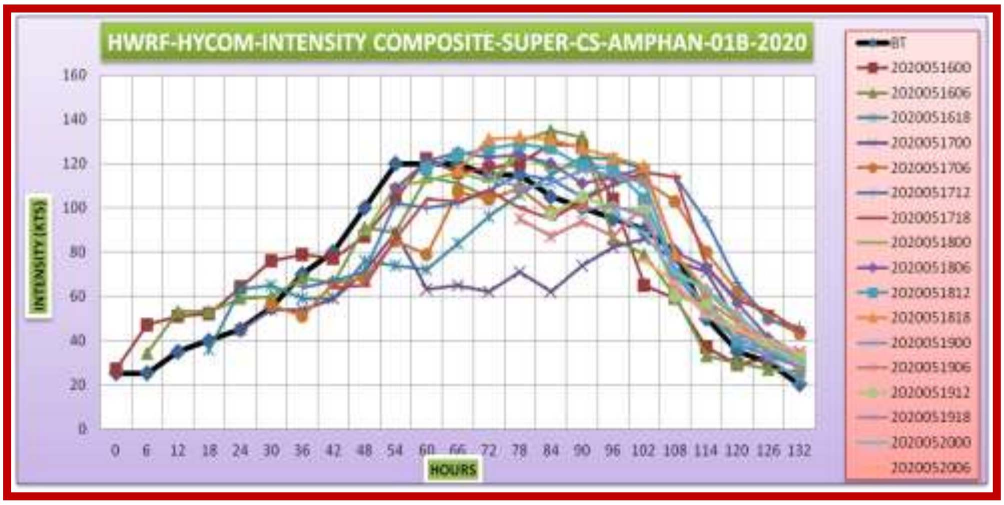

Fig. 20 (b): HWRF intensity forecast for various lead periods i.r.o. "SUPER-CS-AMPHAN-01B-2020"

10. Operational Forecast Performance

10.1. Genesis Forecast

- The system was monitored since 23rd April about three weeks prior to the formation of Low Pressure Area over the southeast BoB on 13th May.
- In the extended range outlook issued on 7th May, cyclogenesis (formation of Depression) was predicted with low probability in the later part of week during 8th-14th May 2020. It was also predicted that the system would intensify further and move initially north-northwestwards and recurve north-northeastwards thereafter towards north BoB.
- In the Tropical Weather Outlook issued on 9th May, it was indicated that a Low Pressure Area would form over the region on 13th May (96 hours prior to formation of the system) under the influence of the remnant cyclonic circulation persisting over the region during 6th-12th.
- In the Tropical Weather Outlook issued on 11th May, it was indicated that cyclogenesis (formation of depression) would occur around 16th May (48 hours prior to formation of the Low Pressure Area and 120 hours prior to formation of depression) over the BoB. The Low pressure area formed on 13th May and concentrated into a Depression on 16th May morning.

10.2 Track, Intensity and Landfall Forecast

- First information was provided in the **extended range outlook issued on 7th May** **(about 6 days prior to formation of LPA, 9 days prior to formation of depression and 13 days prior to Landfall)** indicated that the system would intensify into a cyclonic storm and move initially northwestwards and recurve north-northeastwards towards north BoB
- In the **Tropical Weather Outlook, Press release and informatory message to the Government of India issued on 13th April** **(on the day of development of LPA, 3 days prior to formation of depression and 7 days prior to Landfall)**, it was indicated that the system would intensify into a cyclonic storm by 16th evening and would move initially northwestwards till 17th and then recurve north-northeastwards towards north BoB.
- Actually, the depression formed in the morning (0000 UTC) of 16th, cyclonic storm in the evening (1200 UTC) of 16th and the system moved north-northwestwards till 17th evening (1200 UTC) followed by north-northeastward recurvature thereafter and crossed West Bengal coast on 20th Afternoon.
- **In the first bulletin issued at 0845 IST of 16th May** **(104 hrs prior to landfall)** with the formation of Depression, it was indicated that the system would intensify into a cyclonic storm and will move north-northwestwards till 17th May followed by north-northeastward re-curvature towards West Bengal coast during 18th-20th May and cross West Bengal coast with maximum sustained wind speed of 155-165 kmph gusting to 180 kmph.

- **In the bulletin issued at 1645 hrs IST of 16th May** **(24 hrs prior to rapid intensification),** rapid intensification of the system was predicted and the system rapidly intensified from 17th afternoon onwards.
- **In the bulletin issued at 0845 hrs IST of 17th May** **(80 hrs prior to landfall)**, it was precisely mentioned that the system would cross West Bengal-Bangladesh coasts between Sagar Island (West Bengal) and Hatiya Islands (Bangladesh coast) during afternoon to evening of 20th May with maximum sustained wind speed of 155-165 kmph gusting to 185 kmph. The predicted track indicated Landfall across Sunderbans on 20th Afternoon.
- IMD continuously predicted since 16th May that Amphan will cross West Bengal coast as a very severe cyclonic storm (VSCS) with wind speed of 155-165 kmph gusting to 180 kmph on 20th May.
- The observed and forecast track alongwith cone of uncertainty and wind distributions around the centre for various lead periods are presented in Fig. 21 (a-c). About 84 hours prior to landfall, IMD could correctly forecast track, landfall point, time and intensity correctly.

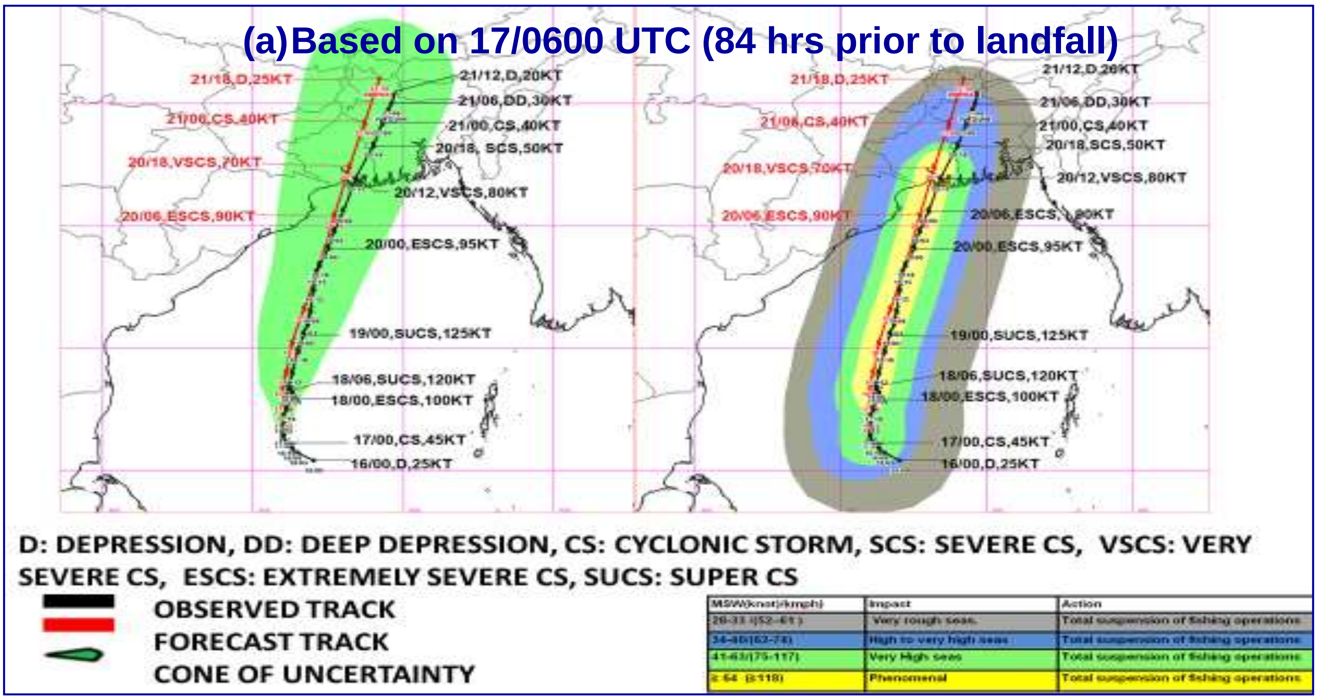

Fig.21(a): Observed and forecast track along with cone of uncertainty and quadrant wind distribution based on 0600 UTC of 17th May **(84 hrs prior to landfall)** **of SuCS AMPHAN indicating accuracy in landfall, track & intensity predictions**

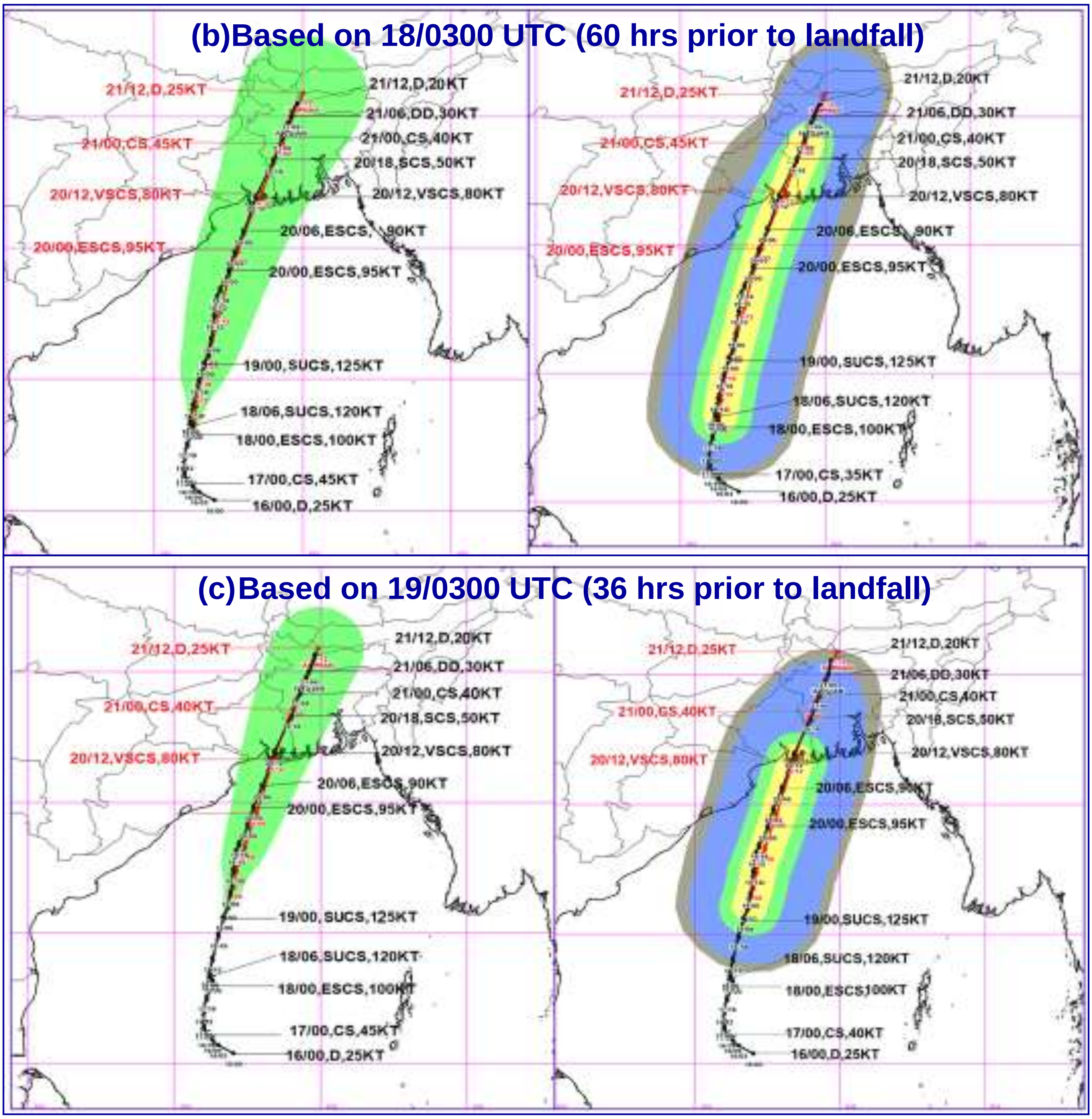

Fig.21(b) &(c): Observed and forecast track alongwith cone of uncertainty and quadrant wind distribution based on (b) 0300 UTC of 18th May (60 hours prior to landfall) and (c) 0300 UTC of 19th May (36 hours prior to landfall) of SuCS AMPHAN indicating accuracy in landfall, track & intensity predictions

10.3. Landfall Forecast Errors:

The landfall point and time Forecast errors compared to long period average (LPA) errors during 2015-19 are presented in Table 5 and Fig. 22 (a-b).

- The landfall point forecast errors for 24, 48 and 72 hrs lead period were 5.5, 11.0, and 35.2 km respectively against the LPA errors of 44.7, 69.4 and 109.3 km during 2015-19 respectively **(Fig. 22 a).**
- The landfall time forecast errors for 24, 48 and 72 hrs lead period were 0.5, 0, and 2.0 hours respectively against the LPA errors of 3.0, 5.4 and 8.6 hours during 2015-19 respectively **(Fig. 22b).**
- **For all lead periods, the landfall errors were exceptionally less than the LPA errors during 2015-19. Considering the Eye (Centre) Diameter of Cyclone 'Amphan' as 15 km at the time of landfall, there was almost zero error in landfall time and point forecast upto 48 hrs lead period.**

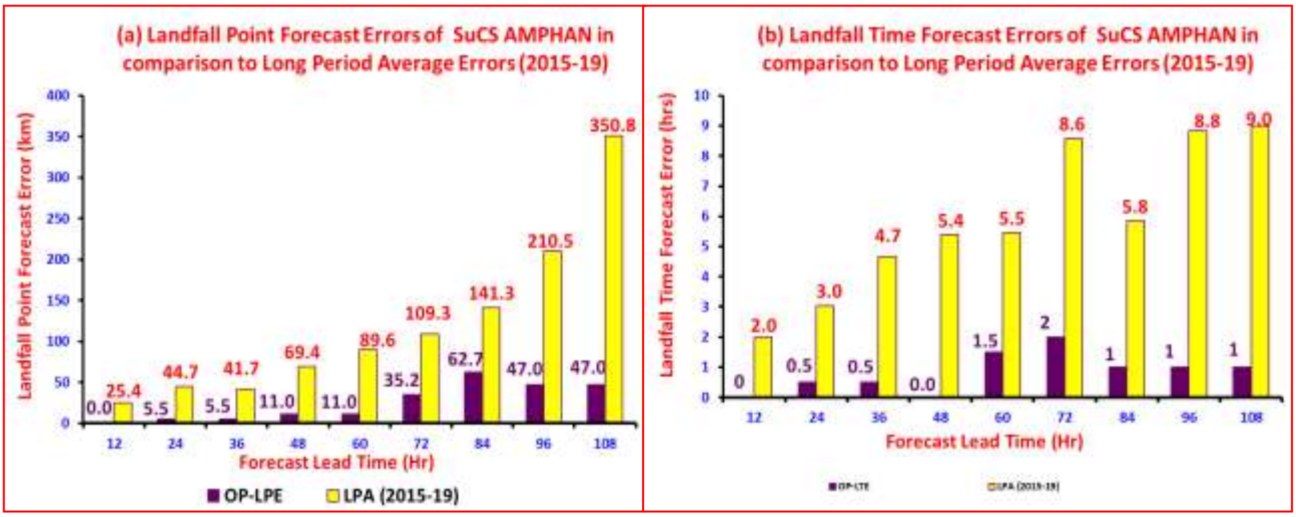

Fig. 22: Landfall (a) point and (b) time forecast errors of SUCS AMPHAN as compared to long period average (2015-19)

Table 5: Landfall point and time forecast errors of SuCS Amphan as compared to long period average (LPA) errors during 2015-19

Lead Period (hrs)	Base Time	Landfall Point (^{0}N/^{0}E)		Landfall Time (hours)		Operational Error		LPA error (2015-19)	
		Forecast	Actual	Forecast	Actual	LPE (km)	LTE (hours)	LPE (km)	LTE (hours)
12	20/00	21.65/88.30	21.65/88.30	20/1100	20/1100	0.0	0.0	25.4	2.0
24	19/12	21.70/88.30	21.65/88.30	20/1130	20/1100	5.5	+0.5	44.7	3.0
36	19/00	21.65/88.35	21.65/88.30	20/1130	20/1100	5.5	+0.5	41.7	4.7
48	18/12	21.65/88.40	21.65/88.30	20/1100	20/1100	11.0	0.0	69.4	5.4
60	18/00	21.65/88.40	21.65/88.30	20/0930	20/1100	11.0	-1.5	89.6	5.5
72	17/12	21.90/88.10	21.65/88.30	20/1300	20/1100	35.2	+2.0	109.3	8.6
84	17/00	21.63/88.87	21.65/88.30	20/1200	20/1100	62.7	+1.0	141.3	5.8
96	16/12	21.80/87.90	21.65/88.30	20/1000	20/1100	47.0	-1.0	210.5	8.8
108	16/00	21.80/87.90	21.65/88.30	20/1200	20/1100	47.0	+1.0	350.8	9.0

"+" indicates delayed prediction and "-" indicates early prediction

10.4. Track Forecast Errors:

The track forecast errors (Forecast position – Actual position of Cyclone centre) and skill as compared to Climatological and Persistence forecast are presented in Table 6 and Fig. 22 (a-b).

- The track forecast errors for 24, 48 and 72 hrs lead period were 59.4, 59.9, and 61.0 km respectively against the LPA errors of 80.6, 125.5, and 171.2 km respectively (**Fig.22a)**.
- The track forecast skill was about 60%, 78%, and 88% against the LPA skill of 61%, 73%, and 74% for 24, 48 and 72 hrs lead period respectively (**Fig.22 b)**.
- **Track forecast errors were exceptionally less than the past five years average errors for all lead periods. Similarly, track forecast skill was higher than the past five years average skill for all lead periods beyond 24 hours**.

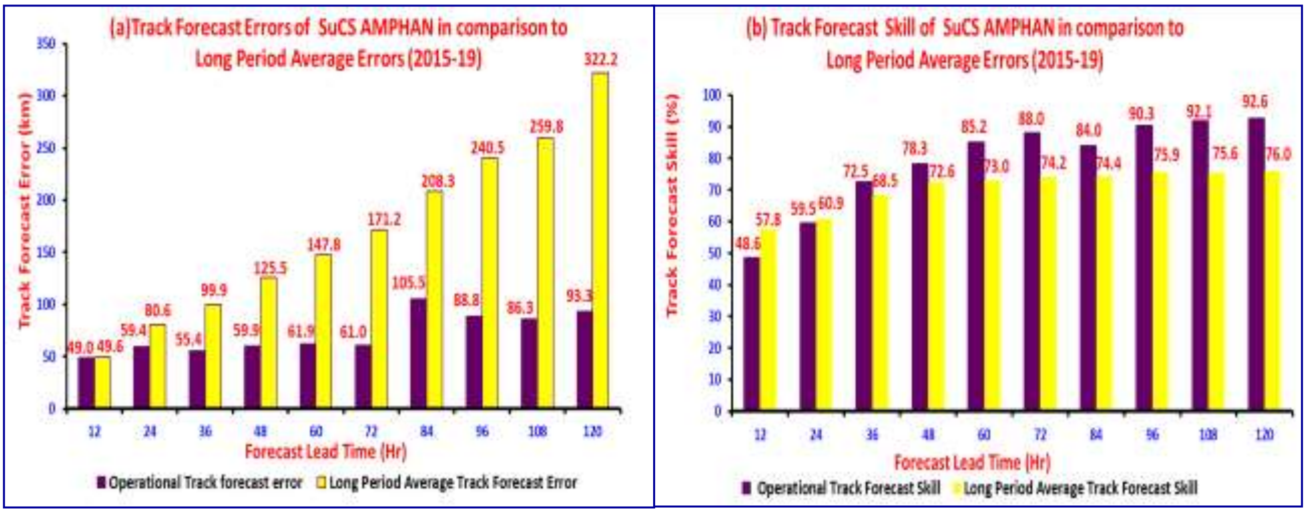

Fig. 22 (a) & (b): Track forecast errors and skill of SUCS AMPHAN as compared to long period average (2015-19)

Table 5: Operational track forecast errors (km) & Skill (%) compared to long period average during 2015-19

Lead Period (hrs)	No. of obs. Verified	Operational Track Forecast		Long Period Average (2015-19) Track Forecast	
		Error (km)	Skill (%)*	Error (km)	Skill (%)*
12	18	49.0	48.6	49.6	57.8
24	16	59.4	59.5	80.6	60.9
36	15	55.4	72.5	99.9	68.5
48	13	59.9	78.3	125.5	72.6
60	11	61.9	85.2	147.8	73.0
72	9	61.0	88.0	171.2	74.2
84	7	105.5	84.0	208.3	74.4
96	5	88.8	90.3	240.5	75.9
108	3	86.3	92.1	259.8	75.6
120	1	93.3	92.6	322.2	76.0

10.5. Intensity Forecast Errors:

The intensity forecast errors (Forecast wind – Actual wind) and skill based on absolute errors and root mean square errors are presented in Table 6 and Fig. 23 & 24 respectively.

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 13.4, 15.0 and 9.0 knots against the LPA errors of 8.9, 13.0, and 15.4 knots during 2015-19 respectively **(Fig. 23).**
- The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 18.8, 22.1 and 12.2 knots against the LPA errors of 11.5, 16.7, and 19.2 knots respectively **(Fig. 23).**

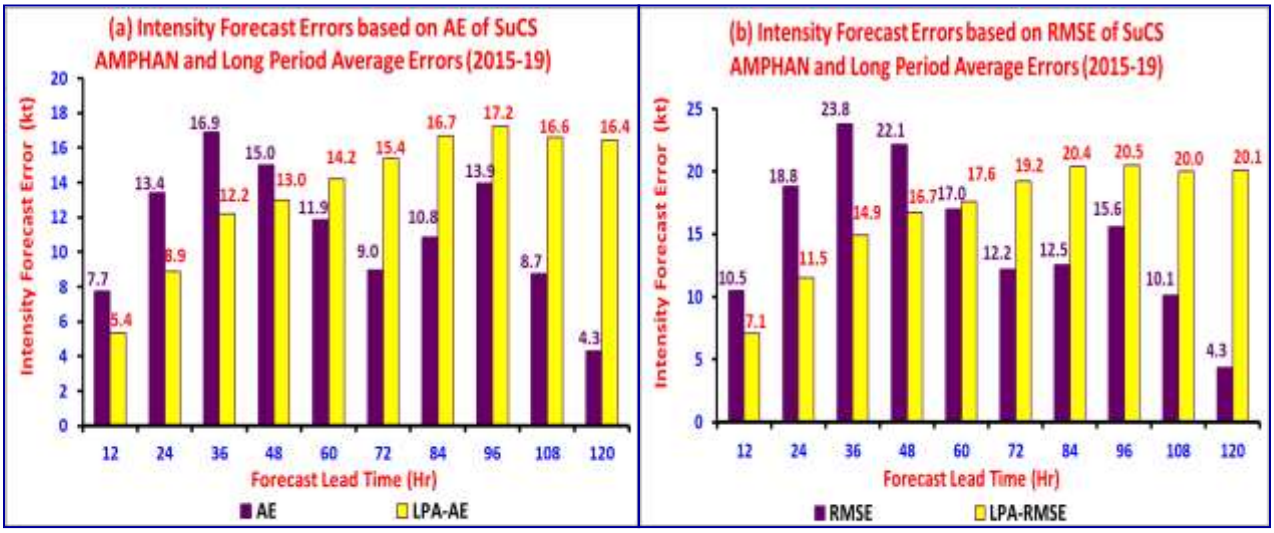

Fig. 23: Absolute errors (AE) and Root Mean Square errors (RMSE) in intensity forecast (winds in knots) of SUCS AMPHAN as compared to long period average (2015-19)

- The skill (%) in intensity forecast as compared to persistence forecast based on AE for 24, 48 and 72 hrs lead period was 56%, 80% and 94% against the LPA of 45%, 69% and 72% respectively **(Fig. 24 a).**
- The skill (%) in intensity forecast based on RMSE for 24, 48 and 72 hrs lead period was 50%, 76% and 93% against the LPA of 49%, 63% and 72% respectively **(Fig. 24 b).**
- Thus even being a Super cyclone, the intensity forecast was skill full and better than the Long Period Average.

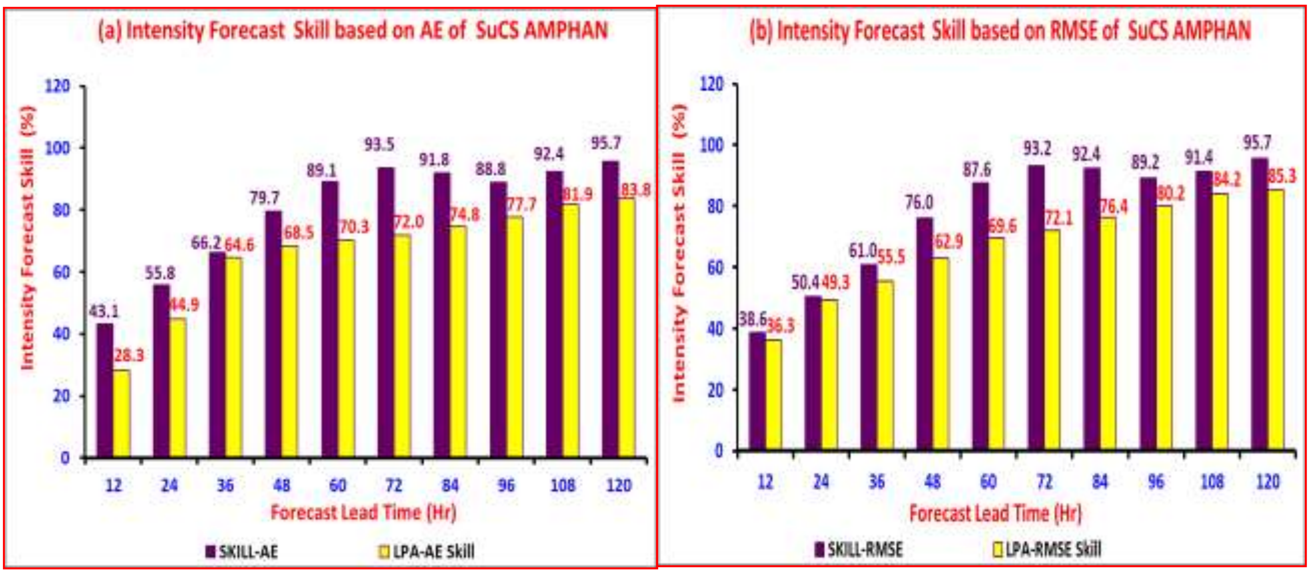

Fig. 24: Skill (%) in intensity forecast based on (a) Absolute errors (AE) and (b) Root Mean Square errors (RMSE) of SUCS AMPHAN as compared to long period average (2015-19)

Table 5: Mean Intensity forecast errors (kt) and Skill (%) in association with SUCS AMPHAN compared to long period average errors and skill during 2015-19

Lead Period (hrs)	N	Average error in Intensity forecast (kts)		LPA (2015-19) Intensity forecast error (kts)		Operational Skill* (%) in intensity forecast		LPA (2015-19) Skill* (%) in intensity forecast	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	18	7.7	10.5	5.4	7.1	43.1	38.6	28.3	36.3
24	16	13.4	18.8	8.9	11.5	55.8	50.4	44.9	49.3
36	15	16.9	23.8	12.2	14.9	66.2	61.0	64.6	55.5
48	13	15.0	22.1	13.0	16.7	79.7	76.0	68.5	62.9
60	11	11.9	17.0	14.2	17.6	89.1	87.6	70.3	69.6
72	9	9.0	12.2	15.4	19.2	93.5	93.2	72.0	72.1
84	7	10.8	12.5	16.7	20.4	91.8	92.4	74.8	76.4
96	5	13.9	15.6	17.2	20.5	88.8	89.2	77.7	80.2
108	3	8.7	10.1	16.6	20.0	92.4	91.4	81.9	84.2
120	1	4.3	4.3	16.4	20.1	95.7	95.7	83.8	85.3

N: No. of observations verified; AE: Absolute Error; RMSE: Root Mean Square Error, LPA: Long Period Average (2014-18).

10.6. Adverse weather forecast verification

The verifications of adverse weather like heavy rainfall, gale wind and storm surge forecast issued by IMD are presented in Tables 6-8. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table 6: Verification of Heavy Rainfall Forecast

Date/Base Time of forecast (UTC)	24 hr Heavy rainfall warning ending at 0300 UTC of next day	Realised 24-hour heavy rainfall ending at 0300 UTC of date
16.05.2020/0300	Andaman & Nicobar Islands Heavy falls at isolated places is very likely over Andaman & Nicobar Islands on 16th May. Odisha & Gangetic West Bengal Heavy falls at isolated places from 18th May evening, heavy to very heavy rainfalls at a few places on 19th May and isolated heavy rainfall over northeast Odisha on 20th May 2020. Coastal districts of Gangetic West Bengal are likely to experience heavy falls at a few places on 19th May, heavy to very heavy falls at a few places with extremely heavy falls at isolated places over Gangetic West Bengal on 20th May.	17 May 2020 A & N Island: Nancowary-2 and IAF Carnicobar & Car Nicobar-1 each 18 May 2020 A & N Island: Car Nicobar-5, IAF Carnicobar-4 and Nancowary-1, Odisha: Jhumpura-10 and Gurundia -8 19 May 2020 SHWB & Sikkim: Mangan-7 20 May 2020 Gangetic West Bengal: Contai-11, Digha-9, Odisha: Paradeep-21, Balikuda-18, Kakatpur & Kujanga-16 each, Astaranga & Alipingal-14 each, Niali-12, Raghunathpur, Puri, Marsaghai, Nilgiri, Kantapada & Garadapur-9 each, Gop, Chandanpur, Betanati, Rajkanika, Jagatsinghpur, Tirtol & Baripada-8 each and Binjharpur, Satyabadi, Nischintakoili, Chandbali, Bhograi, Jajpur, Dhamnagar, Soro, Tihidi, Bari & Basudevpur-7 each, 21 May 2020 Assam & Meghalaya: Williamnagar-23, Mawsynram-15, Sohra (RKM)-13, Bhaghmara-11 and Sohra & Shillong-9
17.05.2020/0300	(i) Rainfall (over Andaman & Nicobar Islands): •Light to moderate rainfall at most places is very likely over Andaman & Nicobar Islands during next 24 hours. •Rainfall (over Odisha & Gangetic West Bengal) eavy falls at isolated places from 18th May evening. Rainfall at most places with heavy to very heavy rainfall at a few places on 19th May and isolated heavy rainfall over north coastal Odisha on 20th May 2020. Coastal districts of Gangetic West Bengal are likely to experience heavy falls at isolated places on 19th May. Heavy to very heavy falls at a few places & extremely heavy falls at isolated places likely over coastal districts of West Bengal on 20th May.	
18.05.2020/0300	**Odisha** Coastal Odisha is likely to experience heavy falls at isolated places over coastal Odisha (Gajapati, Ganjam, Puri, Jagatsinghpur & Kendrapara Districts) on 18th May, 2020. Heavy to very heavy rainfall at a few places over north coastal Odisha (Jagatsinghpur, Kendrapara, Jajpur, Balasore, Bhadrak & Mayurbhanj Districts) and isolated heavy falls over Khordha & Puri districts on 19th May	

	and isolated heavy rainfall over north Odisha (Bhadrak, Balasore, Mayurbhanj, Jajpur, Kendrapara and Keonjhar Districts) on 20th May 2020. **West Bengal** Coastal districts of Gangetic West Bengal (East Medinipur, South & North 24 Parganas) are likely to experience heavy falls at isolated places on 19th May. Rainfall at most places with heavy to very heavy falls at a few places & extremely heavy falls at isolated places likely over Gangetic West Bengal (east & west Medinipur, south & north 24 Parganas, Howrah, Hoogli, Kolkata and adjoining districts) on 20th May and isolated heavy rain over interior districts on 21st May, 2020. **Sub-Himalayan West Bengal and Sikkim** Heavy to very heavy falls at a few places over Malda & Dinajpur districts on 20th May and over most of the districts of Sub-Himalayan West Bengal & Sikkim on 21st May, 2020. **Assam & Meghalaya** Heavy to very heavy falls at a few places over the western districts of Assam & Meghalaya on 21st May.	each SHWB & Sikkim: Sevoke-7, Gangetic West Bengal: Alipore-24, Dum Dum-20, Harinkhola & Debagram-13 each, Burdwan-10, Manteswar & Digha-9 each and Mohanpur, Kharagpur, Suri, Mangalkote, Bankura, Lalgarh & Midnapore-7 each, Odisha: Bhograi-13, Rajghat & Jaleswar-12 each and Chandanpur & Bangiriposi-11 each, Paradeep, Samakhunta, Betanati & Baripada-9 each and Chandikhol, Joshipur & Danagadi-7 each, 22 May 2020 Arunachal Pradesh: Bhalukpong-12, Bomdila-10, Itanagar & Ziro-9 each, Roing-8, Pasighat Aero-7, Assam & Meghalaya: Sohra (RKM)-25, Mawsynram-22, Sohra-21, Khliehriat-15, Goalpara-12, Goalpara-11, Nongstein, Dhubri & Mela bazar -10 each, Goibargaon, N.Lakhimpur/Lilabari & Shillong-8 each and Tamulpur, Barapani, Williamnagar, DRF & Tezpur-7 each, Nagaland, Manipur, Mizoram & Tripura: Sabroom-13, SHWB & Sikkim:
19.05.2020/0300	**Odisha** Coastal Odisha to experience heavy to very heavy rainfall at isolated places Jagatsinghpur, Kendrapara and Bhadrak Districts and isolated heavy falls over Jajpur, Balasore, Cuttack, Mayurbhanj, Khordha & Puri districts on 19th May and isolated heavy to very heavy rainfall at isolated places over north coastal Odisha (Jagatsinghpur, Bhadrak and Keonjhargarh Districts) on 20th May 2020. **West Bengal** Coastal districts of Gangetic West Bengal (East Medinipur, South & North 24 Parganas) are likely to experience light to moderate rainfall at many places commencing from today, the 19th May afternoon. Rainfall intensity is likely to increase gradually and become maximum on 20th May. Heavy to very heavy falls at a few places & extremely heavy falls at isolated places likely over Gangetic West Bengal (east & west Medinipur, south & north 24 Parganas, Howrah, Hoogli, Kolkata and adjoining districts) on 20th May and isolated	

	heavy rain over interior districts on 21st May, 2020. **Sub-Himalayan West Bengal and Sikkim** Heavy to very heavy falls at a few places over Malda & Dinajpur districts on 20th May and over most of the districts of Sub-Himalayan West Bengal & Sikkim on 21st May, 2020. **Assam & Meghalaya** Heavy to very heavy falls at a few places over the western districts of Assam & Meghalaya on 21st May.	Buxaduar-8,
20.05.2020/0300	**Odisha** Heavy to very heavy rainfall very likely at isolated places over north coastal Odisha (Balasore, Bhadrak, Mayurbhanj, Jajpur, Kendrapara and Keonjhargarh Districts) and isolated heavy falls over Jagatsinghpur district on 20th May 2020. **West Bengal** Heavy to very heavy falls at a few places & extremely heavy falls at isolated places likely over Gangetic West Bengal (east & west Medinipur, south & north 24 Parganas, Howrah, Hoogli, Kolkata and adjoining districts) on 20th May and isolated heavy rain over interior districts on 21st May, 2020. **Sub-Himalayan West Bengal and Sikkim** Heavy to very heavy falls at a few places over Malda & Dinajpur districts on 20th May and over most of the districts of Sub-Himalayan West Bengal & Sikkim on 21st May, 2020. **Assam & Meghalaya** Heavy to very heavy falls at a few places over the western districts of Assam & Meghalaya on 21st May.	
21.05.2020/0300	**Assam & Meghalaya** Heavy to very heavy & extremely heavy falls (≥20 cm) at isolated places very likely on 21st May, 2020. **Arunachal Pradesh** Heavy to very heavy falls at isolated places very likely on 21st May, 2020.	

Table 7: Verification of Squally/Gale wind forecast (16-21 May)

Date/Base Time of Forecast (UTC)	Gale/ Squally wind Forecast at 0300 UTC of date	Realised wind
16.05.2020/0300	• Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is likely along and off Odisha coast from 19th morning and along and off West Bengal coast from 19th afternoon. The wind speed will gradually increase becoming gale wind speed reaching 75 to 85 kmph gusting to 95 kmph from 20th morning along and off north Odisha and West Bengal coast. It will gradually increase thereafter. • Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is likely over Andaman Sea during next 48 hours. • Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is prevailing over southeast and adjoining southwest Bay of Bengal. It is likely to increase becoming 90-100 gusting to 110 kmph over eastcentral and adjoining west central Bay of Bengal by 17th morning, 120-130 gusting to 145 kmph over southern parts of central Bay of Bengal by 18th morning, 155-165 gusting to 180 kmph over northern parts of central Bay of Bengal and adjoining north Bay of Bengal on 19th , and 160-170 gusting to 190 kmph over north Bay of Bengal by 20th morning.	155-165kmph gusting to 185 kmph along & off coastal Districts of West Bengal and 100-110 kmph gusting to 120 kmph along & off north coastal Districts of Odisha. Kolkata (Dum Dum) reported 130 kmph at 1855 hrs IST and Kolkata (Alipore) 112 kmph at 1752 hrs IST of 20th May. Also Canning reported 85 knots 9157 kmph), Nimpith 84 knots (155 kmph) and Sagar islands 60 knots (111 kmph) Paradip reported 106 kmph at 0630 hrs IST (0100 UTC) , Chandbali, 80 kmph at 0830 hrs. IST (0300 UTC) and Balasore 91 kmph during 1330 – 1430 hrs. IST (0800 & 0900 UTC) of 20th May.
17.05.2020/0300	• Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is likely to commence along and off south Odisha coast from 18th evening, extend to along & off north Odisha coast from 19th morning and along and off West Bengal coast from 19th afternoon. The wind speed will gradually increase becoming gale wind speed reaching 75 to 85 kmph gusting to 95 kmph from 20th morning along and off north Odisha and West Bengal coasts. It will gradually increase thereafter along & off West Bengal coast. • Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is likely over Andaman Sea during next 24 hours. • Squally wind speed reaching 80 to 90	

	kmph gusting to 100 kmph is prevailing over southeast and adjoining southwest Bay of Bengal. It is likely to increase becoming 125-135 gusting to 150 kmph over southern parts of central Bay of Bengal by 18th morning, 160-170 gusting to 190 kmph over northern parts of central Bay of Bengal and adjoining North Bay of Bengal on 19th, and 155-165 gusting to 180 kmph over north Bay of Bengal during 20th May.	
18.05.2020/0300	West Bengal & Odisha • Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is likely to commence along and off south Odisha coast from 18th evening, increase becoming 55 to 65 kmph gusting to 75 kmph extend to along & off north Odisha coast from 19th morning and along and off West Bengal coast from 19th afternoon. • The wind speed will gradually increase becoming gale wind speed reaching 75 to 85 kmph gusting to 95 kmph from 20th morning along and off north Odisha (Jagatsinghpur, Kendrapara, Bhadrak, Balasore and Mayurbhanj districts) and West Bengal (east & west Medinipur, south & north 24 Parganas, Howrah, Hoogli, Kolkata Districts). It will gradually increase thereafter becoming 110 to 120 kmph gusting to 135 kmph along & off the above-mentioned districts of North Odisha. • Gale wind speed reaching 155 to 165 kmph gusting to 185 kmph very likely along & off east Medinipur and north & south 24 Parganas districts and 100-110 kmph gusting to 120 kmph over Kolkata, Hoogli, Howrah and West Mednipur Districts of West Bengal during the time of landfall (20th afternoon to night). • Squally wind speed reaching 55-65 kmph gusting to 75 kmph likely to prevail over Puri, Khordha, Cuttack, Jajpur districts of Odisha during 20th May 2020. Deep Sea area • Gale wind speed reaching 210-220 gusting to 240 kmph is prevailing over	

	west-central and adjoining central parts of south Bay of Bengal. It is likely to increase becoming 220-230 gusting to 250 kmph over northern parts of central Bay of Bengal and adjoining North Bay of Bengal from tonight to 19th May morning, likely to increase further becoming 230-240 gusting to 255 kmph by tonight. • Gale wind speed reaching 220-230 gusting to 255 kmph over north Bay of Bengal from 19th morning and gradually decrease becoming 155- 165 kmph gusting to 180 kmph by 20th evening.	
19.05.2020/0300	West Bengal & Odisha • Squally wind speed reaching 45 to 55 kmph gusting to 65 kmph is prevailing along & off south Odisha coast. It is very likely to increase and extend northwards becoming 55 to 65 kmph gusting to 75 kmph northwards to north Odisha coast by today afternoon and along & off West Bengal coast by tonight. • The wind speed will gradually increase becoming gale wind speed reaching 75 to 85 kmph gusting to 95 kmph from 20th morning along and off north Odisha (Jagatsinghpur, Kendrapara, Bhadrak, Balasore and Mayurbhanj districts) coast and West Bengal (east & west Medinipur, south & north 24 Parganas, Howrah, Hoogli, Kolkata Districts) coast. It will gradually increase thereafter becoming 100 to 110 kmph gusting to 125 kmph along & off the above mentioned districts of North Odisha. • Gale wind speed reaching 155 to 165 kmph gusting to 185 kmph very likely along & off east Medinipur and north & south 24 Parganas districts and 110-120 kmph gusting to 130 kmph over Kolkata, Hoogli, Howrah and West Medinipur Districts of West Bengal during the time of landfall (20th afternoon to night). • Squally wind speed reaching 55-65 kmph gusting to 75 kmph likely to prevail over Puri, Khordha, Cuttack, Jajpur districts of Odisha during 20th	

	May 2020. Deep Sea area • Gale wind speed reaching 225-235 gusting to 255 kmph is prevailing over westcentral Bay of Bengal. It is likely to prevail over northern parts of central Bay of Bengal and adjoining North Bay of Bengal during 19th May. • Gale wind speed reaching 180-190 gusting 210 kmph over north Bay of Bengal from 19th afternoon. It will gradually decrease becoming 165-175 kmph gusting to 195 kmph by 20th afternoon.	
20.05.2020/0300	West Bengal & Odisha • Gale wind, speed reaching 90 to 100 kmph gusting to 110 kmph is prevailing along and off Jagatsinghpur, Kendrapara, Bhadrak, Balasore and Mayurbhanj districts of Odisha and squally wind speed reaching 55 to 65 kmph gusting to 75 kmph is prevailing along & off remaining coastal districts of Odisha (Puri, Khordha, Cuttack, Jajpur) during 20th May 2020. • It will gradually increase becoming 100 to 110 kmph gusting to 125 kmph along & off the above mentioned districts of North Odisha during forenoon to afternoon of 20th May 2020. • Gale wind speed reaching 80 to 90 kmph gusting to 100 kmph is prevailing along and off West Bengal coast (east & west Medinipur, south & north 24 Parganas, Howrah, Hoogli, Kolkata Districts). • Gale wind speed reaching 155 to 165 kmph gusting to 185 kmph very likely along & off east Medinipur and north & south 24 Parganas districts and 110-120 kmph gusting to 130 kmph over Kolkata, Hoogli, Howrah and West Medinipur Districts of West Bengal during the time of landfall (20th afternoon to night). Deep Sea area • Gale wind speed reaching 165-175 gusting to 195 kmph is prevailing over	

	northwest and adjoining westcentral Bay of Bengal. Gale wind, speed reaching 150-160 gusting to 175 kmph is prevailing over northern parts of central Bay of Bengal. It will gradually decrease becoming 155-165 kmph gusting to 185 kmph over North Bay of Bengal during the evening hours of today, the 20th May.	
21.05.2020/0300	Squally wind speed reaching 50 to 60 kmph gusting to 70 kmph very likely over Western Assam & Western Meghalaya till evening and reduce gradually thereafter.	

Table 8: Verification of Storm Surge Forecast

Date/Base Time of observation	Storm Surge Forecast at 0300 UTC of date	Realised surge
18.05.2020/0300	Storm Surge of about 4-5 meters above Astronomical Tide is likely to inundate low lying areas of south & north 24 Parganas and about 3-4 meters over the low lying areas of East Medinipur District of West Bengal during the time of Landfall.	Maximum tidal wave of 4.6 meters height inundated the low lying areas of South & North 24 Parganas districts and adjoining areas of east Medinipur district of West Bengal as estimated by the post Cyclone landfall survey Team of ACWC Kolkata. No significant Storm Surge has been reported along Odisha coast.
19.05.2020/0300	Storm Surge of about 4-5 meters above Astronomical Tide is likely to inundate low lying areas of south & north 24 Parganas and about 3-4 meters over the low lying areas of East Medinipur District of West Bengal during the time of Landfall.	
20.05.2020/0300	Storm Surge of about 4-5 meters above Astronomical Tide is likely to inundate low lying areas of south & north 24 Parganas and about 3-4 meters over the low lying areas of East Medinipur District of West Bengal during the time of Landfall.	

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 commencing from 16th May morning 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 24 hours prior to landfall till the system maintained the intensity of cyclonic storm over West Bengal.
- **Cyclone structure forecast for shipping and coastal hazard management:** The radius of maximum wind and radii of MSW ≥28, ≥34, ≥50 and ≥64 knots wind in four quadrants of cyclone was issued every six hourly, commencing from 16th May morning giving forecast for +06, +12, +18, +24, +36 and +120 hrs lead period.
- **Four stage Warning:**

➢ In the first bulletin released at 0845 hrs IST of 16th May **(104 hrs prior to landfall)**, **Pre-cyclone Watch** for West Bengal-north Odisha coasts was issued.

➢ The warnings were further upgraded and **Cyclone Watch** for West Bengal and north Odisha coasts was issued at 2030 hrs IST of 16th May **(92 hrs prior to landfall).**

➢ **Cyclone Alert (Yellow Message)** for West Bengal and north Odisha coasts was issued at 0840 hrs IST of 17th May **(80 hrs prior to landfall).**

➢ **Cyclone Warning (Orange Message)** for West Bengal and north Odisha coasts was issued at 0845 hrs IST of 18th May **(56 hrs prior to landfall).**

➢ **Post landfall outlook (Red Message)** for interior districts of Gangetic West Bengal, Assam and Meghalaya was issued at 2330 hrs IST of 19th May **(17 hrs prior to landfall).**

- **Adverse weather warning bulletins:** Adverse weather warning bulletins: The tropical cyclone forecasts alongwith expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update to central, state and district level disaster management agencies including MHA NDRF, NDMA for all concerned states along the east coast of India including Andaman & Nicobar Islands, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Assam & Meghalaya, Manipur, Mizoram & Tripura. 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 heavy rain, gale/squally wind & storm surge were also presented in graphics alongwith colour codes in the website.

- **Warning and advisory through social media:** Daily updates (every three hourly or whenever there was any significant change in intensity/track/landfall) were uploaded on Facebook and Twitter during the life period of the system since the development of low pressure area over BoB. However, from 20th morning (0000 UTC) onwards, hourly updates were issued and sent to disaster managers by email, uploaded on websites, posted on Facebook and Twitter till the system maintained the intensity of cyclonic storm.
- **Press Conference, Press release and Media briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website and SMS. Joint Press conference was held by Director General of Meteorology (IMD), Director General (NDRF) on 19th, 20th & 21st May at National Media Centre. First press release was issued on 13th May, when the system was a low pressure area.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services division at New Delhi and bulletins for maritime interest were issued by Area cyclone warning centres of IMD at Chennai, Kolkata and Cyclone warning centres at Bhubaneswar and Visakhapatnam to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen for deep Sea BoB and the states of West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Andaman & Nicobar Islands were issued since 13th May on the development of low pressure area over southeast BoB and adjoining south Andaman Islands.
- **Advisory for international Civil Aviation:** The Tropical Cyclone Advisory Centre (TCAC) bulletin for International Civil Aviation were issued every six hourly to all meteorological watch offices in Asia Pacific region for issue of significant meteorological information (SIGMET). It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong.
- **Diagnostic and prognostic features of cyclone:** The prognostics and diagnostics of the systems were described in the RSMC bulletins.
- **Hourly Bulletin:** Hourly updates on the location, distance from recognised station, intensity and landfall commenced from 20th morning (0000 UTC) onwards till the system maintained the intensity of cyclonic storm.

Statistics of bulletins issued by RSMC New Delhi, Area Cyclone Warning Centre Kolkata, Cyclone Warning Centre Bhubaneswar & Visakhapatnam in association with the SuCS AMPHAN are given in **Table 9 (a & b).**

Table 9 (a): Bulletins issued by RSMC New Delhi

S.N	Bulletin type	No. of Bulletins	Issued to
1	Informatory Message	3	1. IMD website, RSMC New Delhi website and Mausam 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, Press Information Bureau, Chief Secretary to Government of Kerala, Tamil Nadu, Andaman & Nicobar Islands, Andhra Pradesh, Odisha, West Bengal, Assam, Meghalaya, Arunachal Pradesh. 3. First informatory message was issued on 13th May.
2	National Bulletin	45	1. IMD website, RSMC New Delhi website and Mausam 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, Press Information Bureau, Chief Secretary to Government of Kerala, Tamil Nadu, Andaman & Nicobar Islands, Andhra Pradesh, Odisha, West Bengal, Assam, Meghalaya, Arunachal Pradesh. 3. First Bulletin was issued on 16th May morning.
3	RSMC Bulletin	45	1. IMD's website, RSMC website and Mausam website 2. WMO/ESCAP member countries including Bangladesh and Myanmar through GTS and E-mail. 3. First message was issued on 16th May morning.
4	GMDSS Bulletins	33	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) 3. First Bulletin was issued on 16th May morning.
5	Tropical Cyclone Advisory Centre Bulletin	22	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 4. First message was issued on 16th May morning.
6	Tropical Cyclone Vital Statistics	22	Modelling group of IMD, National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc.

7	Warnings through SMS	Frequently	SMS to disaster managers at national level and concerned states (every time when there was change in track, intensity and landfall characteristics) (i) 3,14,016 SMS to General Public by IMD Headquarters to users registered at RSMC website www.rsmcnewdelhi.imd.gov.in (ii) 2,420 SMS to senior level disaster managers at centre and affected states along the east coast by IMD Headquarters (iii) 75,06,968 SMS to registered users including fishermen by INCOIS (iv) INCOIS also issued 39 INCOIS-IMD joint bulletins (in short template) issued through NAVIC (for communication to fishermen in open sea) (v) 28,78,069 SMS to farmers in the affected regions of Andhra Pradesh, Odisha, West Bengal, Meghalaya and Assam by Kisan Portal (vi) 1,43,41,131 Notifications sent through Mobile App UMANG on 19th and 20th May (vii) Google also issued Cyclone Alert notifications to the people in affected areas of West Bengal and Odisha (viii) Concerned State Governments of Odisha and West Bengal also disseminated warnings using various Mobile communicating systems
8	Warnings through Social Media	Daily	Cyclone Warnings were uploaded on Social networking sites (Face book, Tweeter and WhatsApp) since inception to weakening of system (every time when there was change in track, intensity and landfall characteristics) and hourly on the day of landfall on 20th May.
9	Press conference	Daily	3 – Joint press conferences were held by DG IMD & DG NDRF from National Media Centre on 19th, 20th & 21st May.
10	Press Release	11	Disaster Managers, Media persons by email and uploaded on website
11	Press Briefings	Daily	Regular briefing daily and frequently as and when media persons visited the National Weather Forecasting Centre
12	Hourly Updates	19	Hourly bulletins by email, website, social media

Table 9 (b): Statistics of bulletins issued by ACWC Kolkata and CWC Bhubaneswar & Visakhapatnam

S.No.	Type of Bulletin	No. of Bulletins issued		
		ACWC Kolkata	CWC Bhubaneswar	CWC Visakhapatnam
1.	Sea Area Bulletin	38	-	-
2.	Coastal Weather Bulletins	38 each for West Bengal and Andaman & Nicobar Islands	29	25
3.	Fishermen Warnings issued	31 each for West Bengal and 32 Andaman & Nicobar Islands	37	35
4.	Port Warnings	31 Hooghly Port & Sagar Islands and 29 Port Blair	36	15
5.	Heavy Rainfall warning	33	09	NIL
6.	Gale Wind Warning	31	36	5
7.	Storm Surge Warning	16	NIL	NIL
8.	Information & Warning issued to State Government and other Agencies	35 Bulletins 500 Phone calls	39 bulletins	10
9.	SMS	SMS NIL Whatsapp-70,000	SMS NIL Whatsapp-41327	SMS 1591 Whatsapp-38 to 55 media members
10.	Press Conference/Briefing/All India Radio	4/50/10	05	07

12. Major challenges during monitoring and prediction of SuCS AMPHAN:

There were 4 main challenges while monitoring Amphan.

i. Amphan moved very slowly during initial 2 days with a speed of 4-5 kmph and very fast during last 2 days prior to landfall with windspeed of about 20-30 kmph. Thus, the movement of the system was not uniform. It was very challenging to determine the speed of movement in different phases accurately and thus determining the landfall time correctly.

ii. The challenge was more severe while considering the numerical model guidance about the possible track of the cyclone. We usually examine about 12 global and regional models including six models run by Ministry of Earth Sciences and six international models. The model guidance wrt track was highly inconsistent with variation from day to day and also from morning to evening. There was a large spread in the tracks suggested by different models even two days before the landfall. So developing a consensus based on these models was very challenging.

iii. Amphan underwent rapid intensification (increase in intensity by 30 knots [55 kmph) in 24 hours] from 17th noon (1130 hrs IST) to 19th early morning (2100 UTC of 18th) which is one of the rare record of intensification in this ocean basin, an increase in wind speed by almost 2.3 times).

iv. Amphan originated from a low pressure area (LPA) which developed over south Andaman Sea on 1st May. It persisted over the same region for about 5 days and became less marked. However, the remnant cyclonic circulation moved gradually west-northwestwards and remained over southeast BoB and adjoining south Andaman Sea for a long time upto 12th May. It again reappeared as an LPA on 13th May over southeast BoB. Considering the model guidance about genesis (formation of depression- a cyclonic circulation system with wind speed of 32-50 kmph), there was false alarm from 25th April onwards about the genesis of the cyclone over the BoB and it's landfall over different coasts like Bangladesh, Myanmar and Andaman & Nicobar Islands. It was a challenge to predict the place and occurrence of LPA and it's possible intensification into a depression, it's intensification and movement towards a particular coast. However, IMD utilized all the objective tools to compare, comprehend and analyse the NWP model guidance and the observations from various satellites, buoys, ships and coastal observations to correctly predict the genesis of LPA on 13th May. Also with the formation of LPA on 13th May, IMD issued the first Press Release and Special Informatory Message to the concerned states and central government agencies about it's possible intensification into a cyclone and it's movement towards north BoB following a recurving track.

13. Major initiatives during SuCS AMPHAN:

(i) For the first time, during Amphan track was uploaded on GIS based platform
(ii) Notifications on Amphan were also sent through Govt. of India Mobile App, Umang
(iii) Notifications were also sent through Google Network.

14. Appreciations earned for accurate forecast of SuCS AMPHAN:

(i) Chief Minister of Odisha appreciated the cyclone warning services of IMD during cyclone Amphan
(ii) DG NDRF appreciated the accurate predictions of landfall time, point, track and intensity of Amphan that helped them plan evacuation measures effectively
(iii) Chief Disaster Risk Reduction Centre, UNDP appreciated the accurate warnings including adverse weather warnings during Amphan
(iv) WMO appreciated the services of RSMC New Delhi during Amphan
(v) Indian Air Force appreciated the accurate prediction of Amphan by IMD, stating that it gave them ample advance notice to initiate steps to mitigate the damages and causalities.
(vi) Leading national & international print and electronic media published the story of monitoring of Amphan and life profile of DGM IMD

15. Summary

The Super Cyclonic Storm (SuCS) “AMPHAN” originated from the remnant of a Low Pressure Area which occurred in the near Equatorial Easterly wave over south Andaman Sea and adjoining southeast Bay of Bengal (BoB) during 1st – 5th May. Though the Low Pressure Area became less marked on 6th May, its remnant circulation meandered over south Andaman Sea and adjoining southeast BoB during 6th – 12th May. Under its influence, a fresh Low Pressure Area formed over southeast BoB and adjoining south Andaman Sea in the morning (0300 UTC) of 13th May.It lay as a well marked low pressure area (WML) over southeast BoB & neighbourhood in the morning (0300 UTC) of 14th May. Under favourable environmental conditions, it concentrated into a depression (D) over southeast BoB in the early morning (0000 UTC) of 16th May and further intensified into a deep depression (DD) in the same afternoon (0900 UTC). It moved north- northwestwards and intensified into Cyclonic Storm “AMPHAN” (pronounced as UM-PUN) over southeast BoB in the evening (1200 UTC) of 16th May, 2020. Moving nearly northwards, it further intensified into a Severe Cyclonic Storm (SCS) over southeast BoB in the morning (0300 UTC) of 17th May. It underwent rapid intensification during subsequent 24 hours and accordingly intensified into a Very Severe Cyclonic Storm (VSCS) by the afternoon (0900 UTC) of 17th, Extremely Severe Cyclonic Storm (ESCS) in the early hours of 18th (2100 UTC of 17th May) and into a Super Cyclonic Storm (SuCS) around noon (0600 UTC) of 18th May, 2020. It maintained the intensity of SuCS over westcentral BoB for nearly 24 hours, before weakening into an ESCS over westcentral BoB around noon (0600 UTC) of 19th May. Thereafter, it weakened slightly and crossed West Bengal – Bangladesh coasts as a VSCS, across Sundarbans, near latitude 21.65°N and longitude 88.3°E during 1530-1730 hrs IST (1000-1200 UTC) of 20th May, with maximum sustained wind speed of 155 – 165 kmph gusting to 185 kmph. It lay over West Bengal as a VSCS, gradually moving north-northeastwards during late evening to night (1200 – 1500 UTC) of 20th May. It moved very close to Kolkata during this period. Moving further north-northeastwards, it weakened into an SCS over Bangladesh & adjoining West Bengal around mid-night (1800 UTC) of 20th May, weakened further into a CS over Bangladesh in the early hours (2100 UTC of 20th) of 21st May, into DD over Bangladesh around noon of 21st May and into a D over north Bangladesh in the evening (1200 UTC) of the same day. It further weakened and lay as a well marked low pressure area over north Bangladesh and neighbourhood around mid night (1800 UTC) of 21st May.

16. Acknowledgement:

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Organisation (SAC-ISRO) for their valuable support. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai, Kolkata, Cyclone Warning Centre (CWC) Bhubaneswar, Visakhapatnam, Meteorological Centre (MC) Agartala, Doppler Weather Radar Stations at Visakhapatnam, Chandipur, Gopalpur, Paradip, Kolkata & Agartala and coastal observatories of Odisha & north Andhra Pradesh. The contribution from Numerical Weather Prediction Division, Satellite and Radar Divisions, Surface & Upper air instruments Divisions, New Delhi and Information System and Services Division at IMD is also duly acknowledged.

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