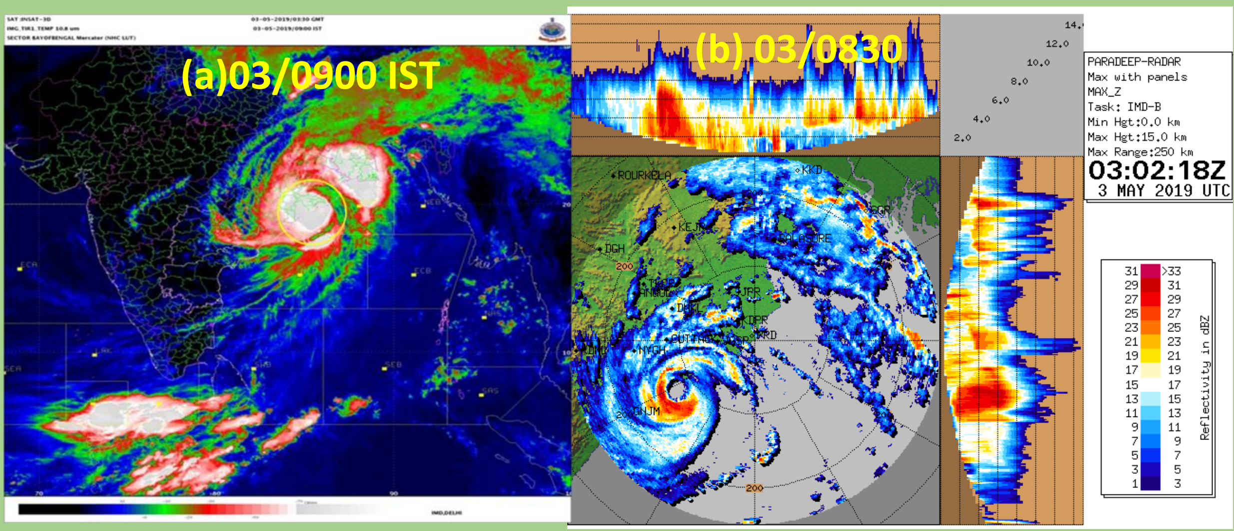
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Extremely Severe Cyclonic Storm, 'FANI' over the Bay of Bengal (26 April – 4 May 2019): A Report



(a) INSAT-3D Satellite imagery and (b) Radar imagery from DWR Paradeep for ESCS FANI over Bay of Bengal near landfall time.

Cyclone Warning Division

India Meteorological Department

New Delhi

May, 2019

Extremely Severe Cyclonic Storm "FANI" over the Bay of Bengal (26th April-4th May 2019)

1. Introduction

Extremely Severe Cyclonic Storm (ESCS) "FANI" originated from a low pressure area (LPA) which formed over east Equatorial Indian Ocean (EIO) and adjoining southeast Bay of Bengal (BoB) in the early morning (0000 UTC / 0530 IST) of 25th April. It lay as a well marked low pressure area (WML) over the same region in the same morning (0300 UTC / 0830 IST). Under favourable environmental conditions, it concentrated into a Depression (D) over the same region in the morning (0300 UTC) of 26th April. Moving nearly northwestwards, it intensified into a deep depression (DD) over the same region in the early morning (0000 UTC) and further into a cyclonic storm (CS) "FANI" around noon (0600 UTC) of 27th April over southeast BoB and adjoining east EIO. It then moved north-northwestwards and intensified, into a severe cyclonic storm (SCS) in the evening (1200 UTC) of 29th over central parts of south BoB. It then moved nearly northwards and further intensified into a very severe cyclonic storm (VSCS) in the early morning (0000 UTC) of 30th over southwest BoB. It then moved west-northwestwards and further intensified into an extremely severe cyclonic storm (ESCS) in the evening (1200 UTC) of 30th over westcentral and adjoining southwest BoB. It started recurving north-northeastwards from 1st early morning (0000 UTC). It temporarily intensified during afternoon (0900 UTC) of 2nd May to early hours (2100 UTC) of 2nd May reaching the peak intensity of 115 knots. Thereafter from 3rd early morning (0000 UTC) it weakened slightly. It continued to move north-northeastwards and crossed Odisha coast close to Puri as an ESCS with maximum sustained wind speed of 175-185 kmph (100 knots) gusting to 205 kmph between 0230 & 0430 UTC of 03rd May. Continuing to move north-northeastwards across coastal Odisha, it weakened into a VSCS over coastal Odisha around noon (0600 UTC) of 3rd May and lay close to east of Bhubaneswar. At 0900 UTC, it lay close to Cuttack (Odisha). Moving further north-northeastwards it weakened into an SCS over north coastal Odisha at night (1500 UTC) of 3rd May and lay centered about 20 km west of Balasore (Odisha). Thereafter, it weakened into a CS in the early morning (0000 UTC) of 4th May over western parts of Gangetic West Bengal and lay centered about 60 km northwest of Kolkata. It weakened into a deep depression in the morning (0300 UTC) over Bangladesh & adjoining Gangetic West Bengal about 40 km east-northeast of Krishnanagar and into a depression over Bangladesh about 120 km north-northwest of Dhaka around noon (0600 UTC) of 4th May. Moving further northeastwards, it became a well marked low pressure area over Meghalaya and neighbourhood during the night (1800 UTC) of 4th May. It further weakened into a low pressure area over north Myanmar and adjoining areas of northeastern states of India in the early morning (0000 UTC) and became insignificant in the morning (0300 UTC) of 5th May. The observed track of the system during 26th April-4th May is presented in **Fig.1(a)**. 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 developed near the equator (near 2.7^0N and 88.7^0E). Genesis of the cyclonic disturbance in such a lower latitude is very rare, last such activity was observed over the north Indian Ocean in January, 2005.

ii. It was the most intense cyclone to cross Odisha coast after Phailin in 2013 which crossed coast with a maximum sustained wind speed of 215 kmph.

iii. Climatologically, Fani was the most intense cyclonic storm crossing Odisha coast during pre-monsoon season during satellite era (1965 onwards). Last ESCS to cross Odisha coast in May was 1982 cyclone (31 May-05 June) which developed over southeast BoB near Andaman Islands on 31^{st} May. It crossed Odisha coast between Paradip and Chandbali during midnight of 3^{rd} June with MSW of 80 kts. Maximum intensity of this storm over the Sea was 120 kts. Tracks of severe cyclonic storms and above intensity storms crossing Odisha coast during May is presented in **Fig.1b**.

iv. It had one of the longest track. The track length of the cyclone was 3030 km.

v. It had a clockwise recurving track as it moved north-northwestwards initially and later moved north-northeastwards upto northeastern states across coastal Odisha and West Bengal. It was mainly steered by an anticyclonic circulation in middle & upper tropospheric levels to the northeast of the system centre.

vi. It had rapid intensification during 29^{th} afternoon to 30^{th} April evening over westcentral Bay of Bengal, mainly due to higher Ocean heat content, with increase in maximum sustained wind speed (MSW) from 45 knots at 0900 UTC of 29^{th} to 95 knots at 1500 UTC of 30^{th} April.

vii. The peak MSW of the cyclone was 200-210 kmph (115 knots) gusting to 230 kmph during 0900 UTC to 2100 UTC of 2^{nd} May over the westcentral BoB. The lowest estimated central pressure was 932 hPa from 0900 UTC to 1200 UTC of 2^{nd} May (**Fig.3a**).

viii. The system crossed Odisha coast close to Puri with maximum sustained wind speed of 175-185 kmph (100 knots) gusting to 205 kmph between 0230 & 0430 UTC of 03^{rd} May, 2019.

ix. The system maintained the cyclonic storm intensity for almost 21 hours even after landfall till 0000 UTC of 4^{th}.

x. The life period (D to D) of the system was 204 hours (8 days & 12 hours) against long period average (LPA) (1990-2013) of 134 hours (5 days & 14 hrs) for VSCS/ESCS categories over the BoB during pre monsoon season.

xi. It moved with 12 hour average translational speed of 14.6 kmph against LPA (1990-2013) of 14.7 kmph for VSCS category over north Indian Ocean (**Fig.3b**). However, after landfall it moved fast with an average speed of 24.0 kmph under the influence of upper tropospheric westerly trough lying to the west of the system.

The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 20.30 X10^2 knots, 16.72 X 10^4 knots^2 and 15.12 X10^6 knots^3 respectively against long period average during 1990-2013 of 5.28 X10^2 knots, 8.6 X 10^4 knots^2 and 2.8 X10^6 knots^3 respectively.

3. Monitoring of ESCS, ‘FANI’

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored one week prior to the formation of low pressure area over the Bay of Bengal and adjoining equatorial Indian Ocean on 25th April. First information about formation of low pressure during week ending 25th and beginning of week ending at 2nd May with probability of intensification into cyclonic storm was indicated in the extended range outlook issued by IMD on 18th April. Thus the cyclone was monitored & predicted continuously from 18th April onwards by IMD.

The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites and available ships & buoy observations in the region. From 1st May onwards till 4th May, the system was tracked gradually by IMD Doppler Weather Radars at Chennai, Machilipatnam, Visakhapatnam, Gopalpur, Paradeep and Kolkata as it moved from south to north. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the cyclone. A digitized forecasting system of IMD was utilized for analysis and comparison of various model guidance, decision making process and warning product generation.

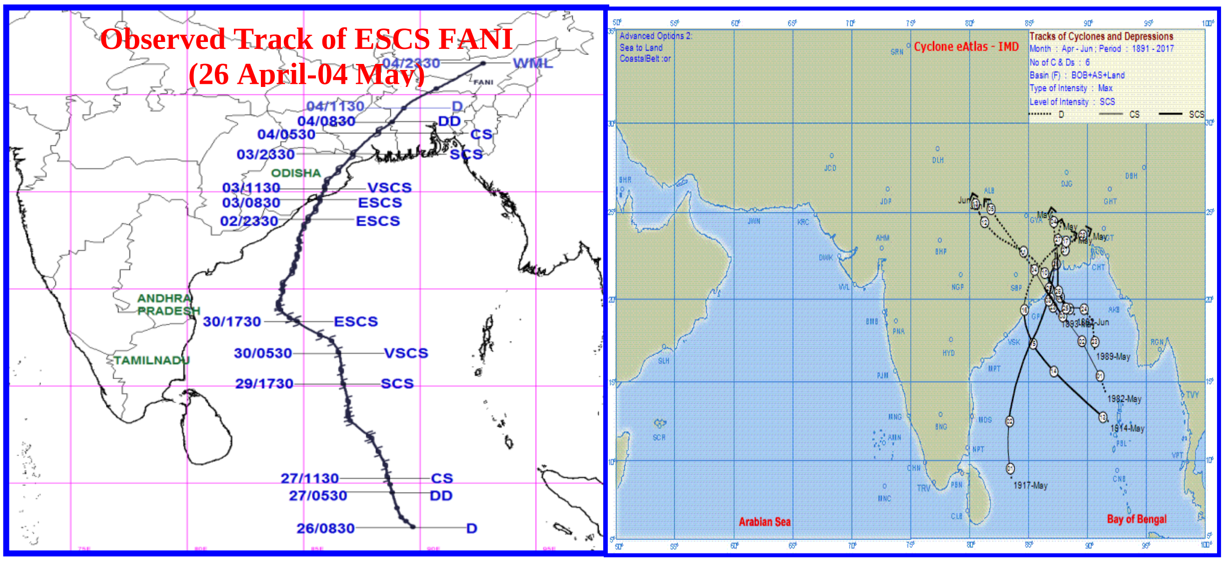


Fig.1 (a): Observed track of ESCS FANI over east EIO and adjoining southeast BoB (26 April-04 May, 2019) and (b) Tracks of severe cyclonic storms and above intensity storms crossing Odisha coast during pre monsoon season (1891-2018)

Table 1: Best track positions and other parameters of the Extremely Severe Cyclonic Storm “FANI” over the BoB during 26th April – 4th May, 2019

Date	Time (UTC)	Centre lat.⁰ N/ long. ⁰ E		C.I. NO.	Estimated Maximum Sustained Surface Wind (kt)	Estimated Central Pressure (hPa)	Estimated Pressure drop at the Centre (hPa)	Grade
26/04/2019	0300	2.7	89.7	1.5	25	998	4	**D**
	0600	3.0	89.4	1.5	25	998	4	D
	1200	3.2	89.2	1.5	25	998	4	D
	1800	3.7	88.8	1.5	25	998	4	D

27/04/2019	0000	4.5	88.8	2.0	30	997	5	**DD**
	0300	4.9	88.7	2.0	30	996	6	DD
	0600	5.2	88.6	2.5	35	995	7	**CS**
	0900	5.4	88.5	2.5	40	994	8	CS
	1200	5.9	88.5	3.0	45	992	10	CS
	1500	6.3	88.5	3.0	45	992	10	CS
	1800	6.6	88.2	3.0	45	992	10	CS
	2100	6.9	87.9	3.0	45	992	10	CS
28/04/2019	0000	7.3	87.9	3.0	45	992	10	CS
	0300	7.3	87.9	3.0	45	992	10	CS
	0600	7.4	87.8	3.0	45	992	10	CS
	0900	7.7	87.5	3.0	45	992	10	CS
	1200	8.2	87.0	3.0	45	992	10	CS
	1500	8.3	86.9	3.0	45	992	10	CS
	1800	8.4	86.9	3.0	45	992	10	CS
	2100	8.5	86.9	3.0	45	992	10	CS
29/04/2019	0000	8.6	86.9	3.0	45	992	10	CS
	0300	8.7	86.9	3.0	45	992	10	CS
	0600	9.2	86.9	3.0	45	992	10	CS
	0900	9.7	86.8	3.0	45	992	10	CS
	1200	10.1	86.7	3.5	55	986	16	**SCS**
	1500	10.4	86.7	3.5	55	986	16	SCS
	1800	10.8	86.6	3.5	55	986	16	SCS
	2100	11.1	86.5	3.5	60	986	16	SCS
30/04/2019	0000	11.7	86.5	4.0	65	980	22	**VSCS**
	0300	12.3	86.2	4.5	75	974	28	VSCS
	0600	12.6	85.7	4.5	80	970	32	VSCS
	0900	13.0	85.3	4.5	85	966	36	VSCS
	1200	13.3	84.7	5.0	90	962	40	**ESCS**
	1500	13.4	84.5	5.0	95	957	45	ESCS
	1800	13.5	84.4	5.0	95	957	45	ESCS
	2100	13.6	84.2	5.0	95	957	45	ESCS
01/05/2019	0000	13.9	84.0	5.0	95	957	45	ESCS
	0300	14.1	83.9	5.0	95	957	45	ESCS
	0600	14.2	83.9	5.0	95	957	45	ESCS
	0900	14.5	84.1	5.0	95	955	45	ESCS
	1200	14.9	84.1	5.5	100	950	50	ESCS
	1500	15.1	84.1	5.5	100	950	50	ESCS
	1800	15.2	84.1	5.5	100	950	50	ESCS
	2100	15.5	84.2	5.5	100	950	50	ESCS
02/05/2019	0000	15.9	84.5	5.5	105	945	55	ESCS
	0300	16.2	84.6	5.5	105	945	55	ESCS
	0600	16.7	84.8	5.5	110	940	60	ESCS
	0900	17.1	84.8	6.0	115	932	66	ESCS
	1200	17.5	84.8	6.0	115	932	66	ESCS
	1500	17.8	84.9	6.0	115	934	66	ESCS
	1800	18.2	85.0	6.0	115	934	66	ESCS
	2100	18.6	85.2	6.0	115	934	66	ESCS
03/05/2019	0000	19.1	85.5	6.0	105	945	55	ESCS
	0300	19.6	85.7	5.5	100	952	50	ESCS

	Crossed Odisha coast close to Puri (near lat. 19.75^0N and Long. 85.7^0E) between 0230 & 0430 UTC of 3rd May							
	0600	20.2	85.9	-	85	966	36	**VSCS**
	0900	20.5	86.0	-	75	970	28	VSCS
	1200	21.1	86.5	-	70	976	22	VSCS
	1500	21.5	86.7	-	60	980	18	**SCS**
	1800	21.9	87.1	-	55	986	16	SCS
	2100	22.5	87.9	-	50	990	12	SCS
04/05/2019	0000	23.1	88.2	-	40	994	8	**CS**
	0300	23.6	88.8	-	30	996	6	**DD**
	0600	24.3	89.3	**-**	25	998	5	**D**
	1200	25.2	90.7	**-**	20	1000	4	D
	1800	**Weakened into well marked low pressure area over central Assam & neighbourhood**						

3. Brief life history

3.1. Genesis

At 0000 UTC of 25th April, the Madden Julian Oscillation (MJO) index lay in phase 3 with amplitude more than 1. MJO phase and amplitude were favourable for enhancement of convective activity over NIO. The sea surface temperature (SST) was 30-31˚C over south BoB and EIO. The tropical cyclone heat potential (TCHP) was around 60-80 KJ/cm^2 over the region. A positive zone of lower level positive vorticity (100 x10^{-6} sec^{-1}) lay over east EIO and adjoining southeast BoB. Two pockets of positive low level convergence (20x10^{-5}sec^{-1}) were seen over the same region. The upper level divergence was 40 x10^{-5}sec^{-1} over the same region. Vertical wind shear was around 15-20 kts over the same region with decreased wind shear over south Odisha and adjoining Andhra Pradesh coasts (10-20 kts). Under these favourable conditions, an LPA formed over east EIO and adjoining southeast BoB in the early morning (0000 UTC) of 25th April. It further lay as a WML over the same region at 0300 UTC of 25th.

3.2. Intensification and movement

At 0300 UTC of 26th, similar MJO and sea conditions prevailed. The lower level positive vorticity was about 100 x10^{-6} sec^{-1} over east EIO and adjoining southeast BoB. The low level convergence increased and was around 50 x10^{-5}sec^{-1} over the region. The upper level divergence also increased and was about 50 x10^{-5}sec^{-1}. Vertical wind shear was moderate (15-20 knots) around the system. The total precipitable water vapour (TPW) imagery indicated warm moist air incursion into the core of the system (**Fig. 2**). Under these conditions, the system intensified into a D over east EIO & adjoining southeast BoB near 2.7°N/89.7°E. An anticyclonic circulation lay over south Thailand and adjoining south Andaman Sea in the middle and upper tropospheric levels steering the system in northwest direction.

At 0000 UTC of 27th, similar MJO and sea conditions prevailed. The lower level positive vorticity increased and was about 130 x10^{-6}sec^{-1} around the system centre. The low level convergence increased was about 60 x10^{-5}sec^{-1} around the system centre. The upper level divergence was 50 $x10^{-5}sec^{-1}$ around the system centre. Vertical wind shear was moderate to high (15-25 knots) around the system. The anticyclonic circulation lay over south Thailand and adjoining south Andaman Sea in the middle and upper tropospheric levels. Under these conditions, the system into a DD and moving northwestwards lay centered over east EIO & adjoining southeast BoB near latitude 4.5°N/ 88.0°E.

At 0600 UTC of 27th, similar MJO and sea conditions prevailed. The TCHP was around 70-90 KJ/cm^2 over the system area and indicated an increasing trend along the forecast track. The TCHP imagery based on 27th conditions indicated that the system would enter into an area of significantly high values of TCHP during 29th April to 2nd May, causing rapid intensification of the system during the period. The TPW imagery indicated warm air advection into the core of the system. The lower level positive vorticity increased and was about 150 $x10^{-6}sec^{-1}$ to the southwest of the system centre. The low level convergence was about 50 $x10^{-5}sec^{-1}$ to the southwest of the system centre and upper level divergence was 30 $x10^{-5}sec^{-1}$ to the west of the system centre. Vertical wind shear was moderate to high (15-25 knots) around the system. The anticyclonic circulation continued over south Thailand and adjoining south Andaman Sea in the middle and upper tropospheric levels. Under these conditions, the system further moved north-northwestwards, intensified into a CS and lay centered over southeast BoB & adjoining east equatorial Indian Ocean near 5.2°N/88.5°E.

At 0300 UTC of 28th, MJO lay in phase 4 with amplitude more than 1. It was expected to continue in the same phase for next 3-4 days. Similar sea conditions prevailed. TPW imagery indicated warm air advection into the core of the system. The lower level positive vorticity was about 150 $x10^{-6}$ sec^{-1} to the west of the system centre. The low level convergence was about 20 $x10^{-5}$ sec^{-1} to the west of system centre and upper level divergence was $30x10^{-5}$ sec^{-1} to the west of the system centre. Vertical wind shear was moderate to high (15-25 knots) around the system. The anticyclonic circulation continued over south Thailand and adjoining south Andaman Sea in the middle and upper tropospheric levels. Under these conditions, the system further moved north-northwestwards, maintained the intensity of CS and lay centered over southeast BoB near 7.3°N/87.9°E.

At 0300 UTC of 29th, the MJO lay in phase 4 with amplitude more than 1. It was forecast to continue in same phase with amplitude greater than 1 for next 2 days and thereafter to move into phase 5 with amplitude greater than 1. Hence, MJO was favourable for enhancement of convection & intensification of the system over BoB. The SST was 30-32˚C over westcentral and south BoB. The TCHP was around 80-90 KJ/cm^2 over the system area and was increasing along the forecast track. TPW imageries indicated warm air advection into the core of system. The lower level positive vorticity remained the same and was about 150 x $10^{-6}sec^{-1}$ to the southwest of system center. The low level convergence increased and was around 30 x $10^{-5}sec^{-1}$ to the northwest of the system centre. Upper level divergence increased and was around 50 $x10^{-5}sec^{-1}$ to the northwest of the system centre. Vertical wind shear was low (05-10 knots) around the system and along the forecast track. The system was lying in the periphery of the anticyclonic circulation over south Thailand and adjoining south Andaman sea in the middle and upper tropospheric levels. The system was thus expected to be steered by this anticyclonic circulation leading to northwestward movement till evening of 01st May and to recurve northeastwards from morning of 02nd May. Low vertical shear and significantly high values of TCHP were conducive for the system to intensify rapidly during 29th - 30th April. Thereafter, with the expected re-curvature of the system, it was likely to move northeastwards and weaken slightly as it would move to regions of colder sea and high wind shear. Under these conditions, the system further moved north-northwestwards, maintained the intensity of CS and lay over southeast BoB near 8.7°N/86.9°E.

At 1200 UTC of 29th, MJO lay in phase 4 with amplitude more than 1. Similar sea conditions prevailed. TPW imagery indicated enhanced warm air advection into the core of the system. Low level positive vorticity increased considerably and was around 200 x $10^{-6}sec^{-1}$ around the system center. Other dynamical conditions were also favourable. Under these conditions, the system intensified into a severe cyclonic storm and lay centered over southeast and adjoining southwest BoB near 10.1°N/86.7°E.

At 0000 UTC of 30th, similar MJO and SST conditions prevailed. The system entered a zone with higher TCHP. It was around 80-90 KJ/cm^2 over southwest BoB near the system centre. TPW imageries indicated warm air advection to the system centre. The low level convergence increased and was around $50x10^{-5}sec^{-1}$ to the southwest of the system centre. Upper level divergence was around 40 $x10^{-5}sec^{-1}$ to the southwest of the system centre. Under these favourable conditions, the system intensified into a VSCS. Under the influence of anticyclone over southeast BoB in the middle and upper tropospheric levels, it moved nearly northwards and lay centered over southeast and adjoining southwest BoB near 11.7°N/86.5°E.

At 1200 UTC of 30th, similar MJO and sea conditions prevailed. TPW imagery indicated warm moist air incursion into the core of the system. The low level convergence further increased and was around $60x10^{-5}sec^{-1}$ to the southwest of the system centre with other dynamical features remaining the same. The anticyclonic circulation over southeast BoB in the middle and upper tropospheric levels continued to steer the system. Under these conditions, the system intensified into an ESCS, moved northwestwards and lay centered over southwest BoB and adjoining areas near 13.3°N/84.7°E.

Similar favourable environment continued and the system continued to intensify gradually reaching it's peak intensity of 115 kts at 0900 UTC of 2nd. The system was lying in the periphery of anticyclone over southeast BoB. It thus gradually recurved north-northeastwards along it's periphery from 0900 UTC of 1st May. Thereafter, due to land interactions, incursion of dry air from southern Peninsular India in the western sector of the system and decreased upper level divergence, the system started weakening from 0000 UTC of 3rd May and crossed Odisha coast close to Puri as an ESCS with maximum sustained wind speed of 175- 185 kmph gusting to 205 kmph between 0230 & 0430 UTC of 3rd May. Similar conditions prevailed and the system further weakened into a VSCS at 0600 UTC of 3rd May. However, the eastward component in the movement increased as after landfall the system was steered by the westerly trough in the deep layer mean wind lying to the west of the system centre and the anticyclonic circulation over Myanmar and neighbourhood in the middle and upper tropospheric levels. It further weakened into an SCS at 1500 UTC 3rd, a CS at 0000 UTC of 4th, a DD at 0300 UTC, a D at 0600 UTC and a WML over central Assam and neighbourhood at 1800 UTC of 4th May.

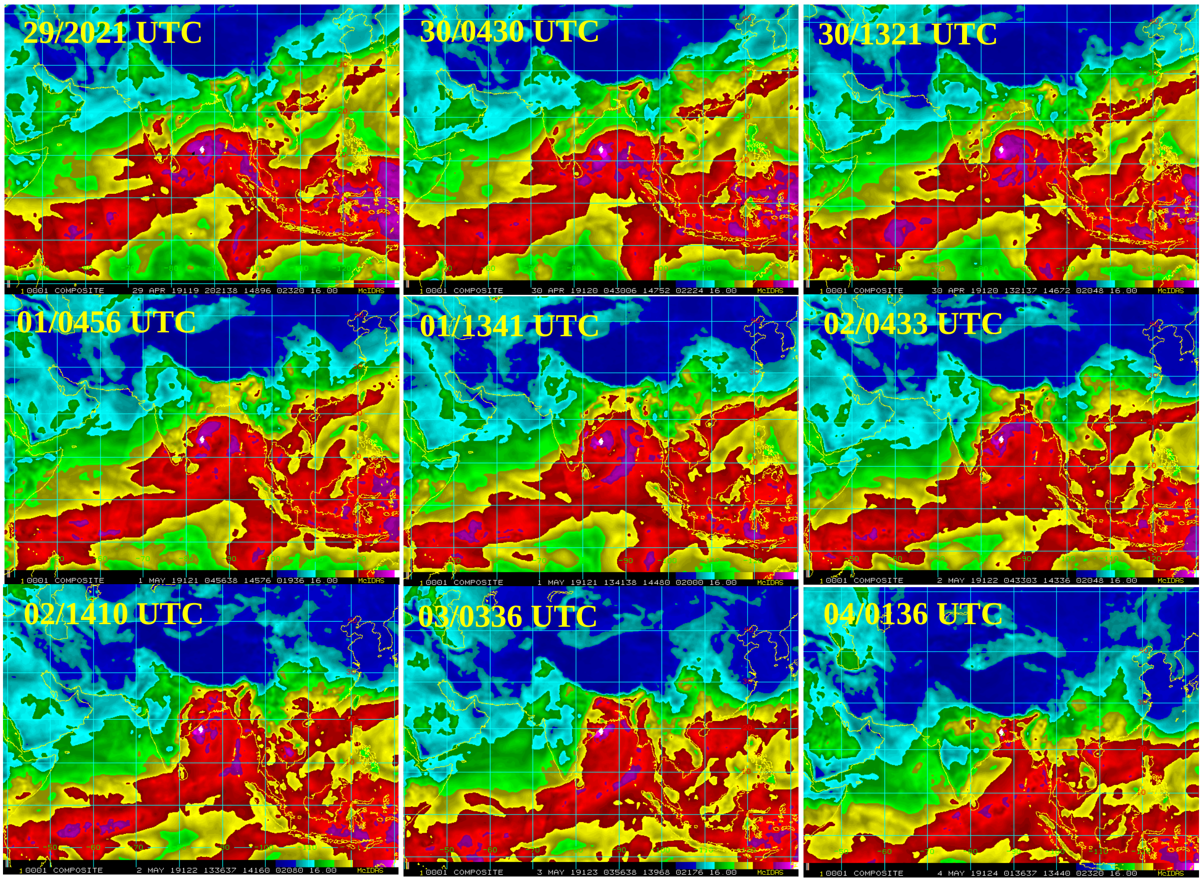


Fig. 2: Total Precipitable Water (TPW) vaour imageries during ESCS FANI (26 April - 04 May), 2019

The mean wind speed & wind shear in middle (500 & 850 hPa levels) and deep layer (200 & 850 hPa levels) around the system centre is presented in **Fig.3**. The mean wind shear speed around the system between 200 & 850 hPa levels remained moderate (10-20 kts) till 1200 UTC of 2nd May. Thereafter, it further decreased becoming low (around 5 kts) during 1800 UTC of 2nd to 0600 UTC of 3rd. It increased thereafter becoming moderate from 1800 UTC of 3rd and high from 0000 UTC of 4th. The direction of wind shear was west-southwest till 0600 UTC of 2nd causing the shearing of cloud mass to the east-northeast of system centre. Thereafter, it became northerly from 1200 UTC of 2nd onwards indicating shearing of cloud mass to the south of system centre. The wind shear between 500 & 850 hPa levels was low to moderate throughout the life span of FANI.

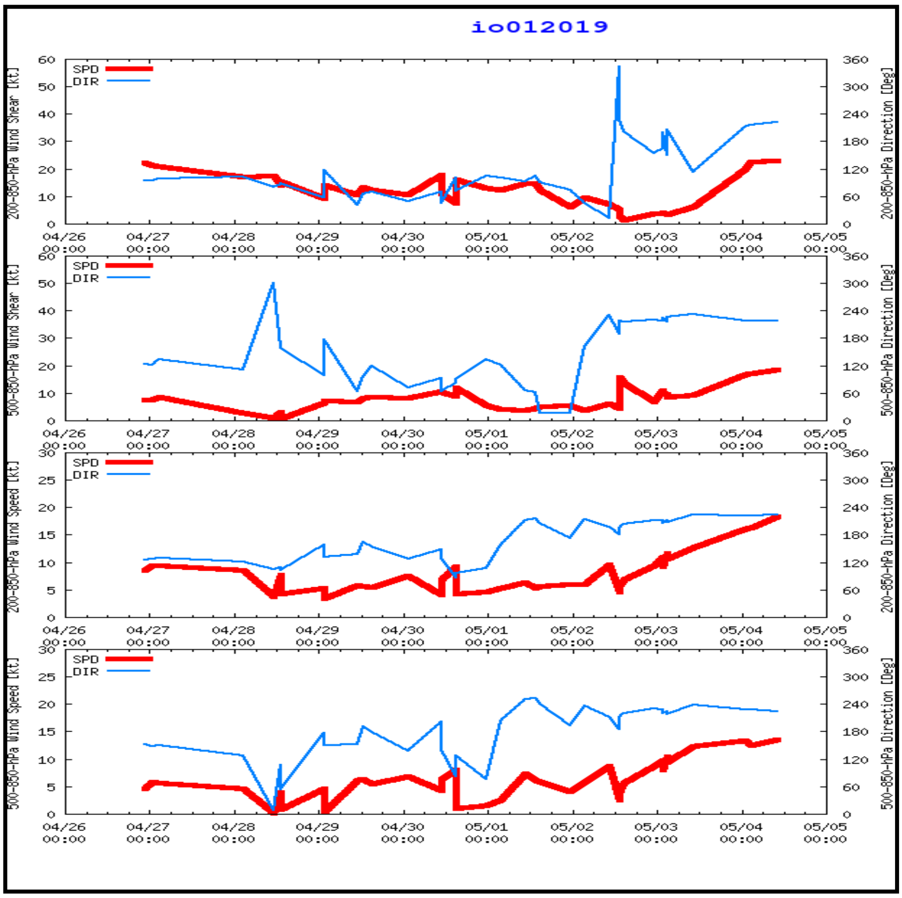


Fig.3 Mean wind shear and wind speed in the middle (500 & 850 hPa levels) and deep layer (200 & 850 hPa levels) around the system during ESCS FANI (26 April -04 May), 2019

From **Fig.3**, it is seen that from the genesis stage, the mean deep layer winds between 200-850 hPa levels steered the system nearly north-northwestwards till 0000 UTC of 30th April, followed by northwestward movement till 1200 UTC of 30th and north-northeastwards recurvature thereafter. The twelve hourly movement of ESCS FANI is presented in **Fig.4**. The 6 hourly average translational speed of the cyclone was about 14.8 kmph against long period average (during 1990-2013) of 14.7 kmph for VSCS category over north Indian Ocean. However, after landfall it moved fast with an average speed of 24.0 kmph under the influence of upper tropospheric westerly trough lying to the west of system.

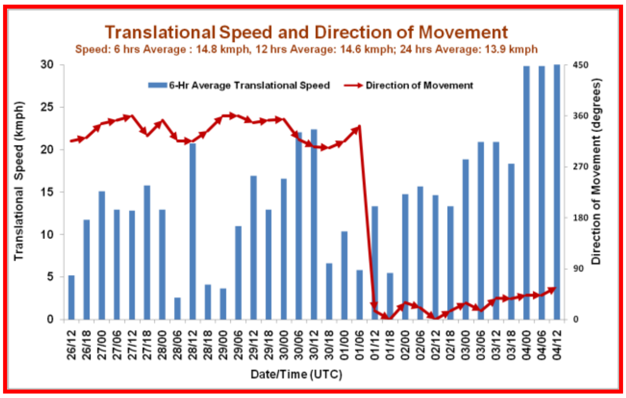


Fig. 4: Six hourly average translational speed (kmph) and direction of movement in association with ESCS FANI (26 April -04 May), 2019

4.3 Maximum Sustained Surface Wind speed and estimated central pressure

The lowest estimated central pressure and the maximum sustained wind speed (MSW) are presented in **Fig.5**. The lowest estimated central pressure had been 932 hPa at 0900 UTC to 1200 UTC of 2nd May. The peak MSW of the cyclone was 115 knots (200-210 kmph gusting to 230 kmph) during 0900 UTC to 2100 UTC of 2nd May over the westcentral BoB. It had rapid intensification during 30th April (0600 UTC) to 01st May (0000 UTC) with increase in wind speed by more than 30 kts in past 24 hrs over westcentral Bay of Bengal, mainly due to higher Ocean heat content and low to moderate vertical wind shear.

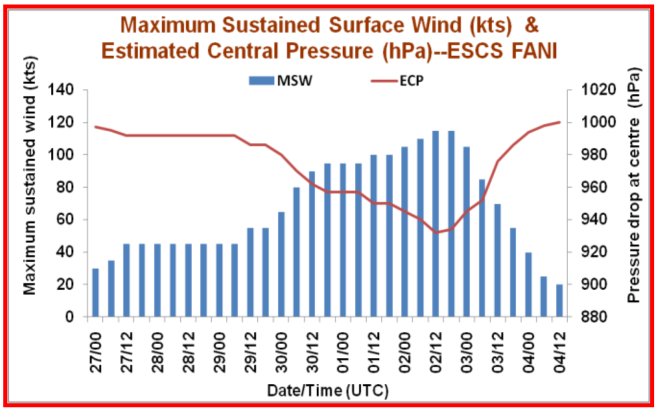


Fig.5. Lowest estimated central pressure and the maximum sustained wind speed

5. Monitoring

5. 1. Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D and 3DR imageries. Satellite imageries of international geostationary satellites Meteosat-8 & MTSAT, high resolution polar orbiting satellites and scatterometer imageries from ASCAT/SCATSAT were also considered for monitoring the system. Typical INSAT-3D visible/ IR imageries, enhanced colored imageries and cloud top brightness temperature imageries are presented in **Fig.6**. It is seen that the system showed shear pattern during genesis and growth stage upto the intensity of CS. The clouds were organized in central dense overcast (CDO) pattern during 1200 UTC of 27th to 0600 UTC of 29th in the CS stage. From 1200 UTC of 29th to 0600 UTC of 30th, the clouds were organized in curved band pattern in the SCS and VSCS stage. The cloud mass further organized into CDO pattern during 1200 UTC of 30th April to 0600 UTC of 1st May in the ESCS stage. Eye was first seen at 0900 UTC of 1st May. Clear circular eye was seen till 0000 UTC of 3rd May. Thereafter, due to increased vertical wind shear, the cloud mass got sheared in northeastward direction after landfall.

At 0300 UTC of 26th, the intensity of the system was T1.5. Broken low to medium clouds with embedded intense to very intense convection lay over EIO and adjoining southeast BoB between latitude 1.5°N to 8.4°N and long 78.0°E to 92.0°E. Minimum cloud top temperature (CTT) was minus 93°C. Satellite imagery indicated increase in convection and increased organisation of clouds around the system centre. The clouds were organized in curved band pattern

At 0000 UTC of 27th, the intensity of the system was T 2.0. Broken low to medium clouds with embedded intense to very intense convection lay over EIO and adjoining south BoB between latitude 2.5°N to 7.5°N and long 85.5°E to 92.5°E. Minimum CTT was minus 93°C. satellite images indicate increase in convection and further organisation of clouds around the system centre. The clouds were organized in curved band pattern.

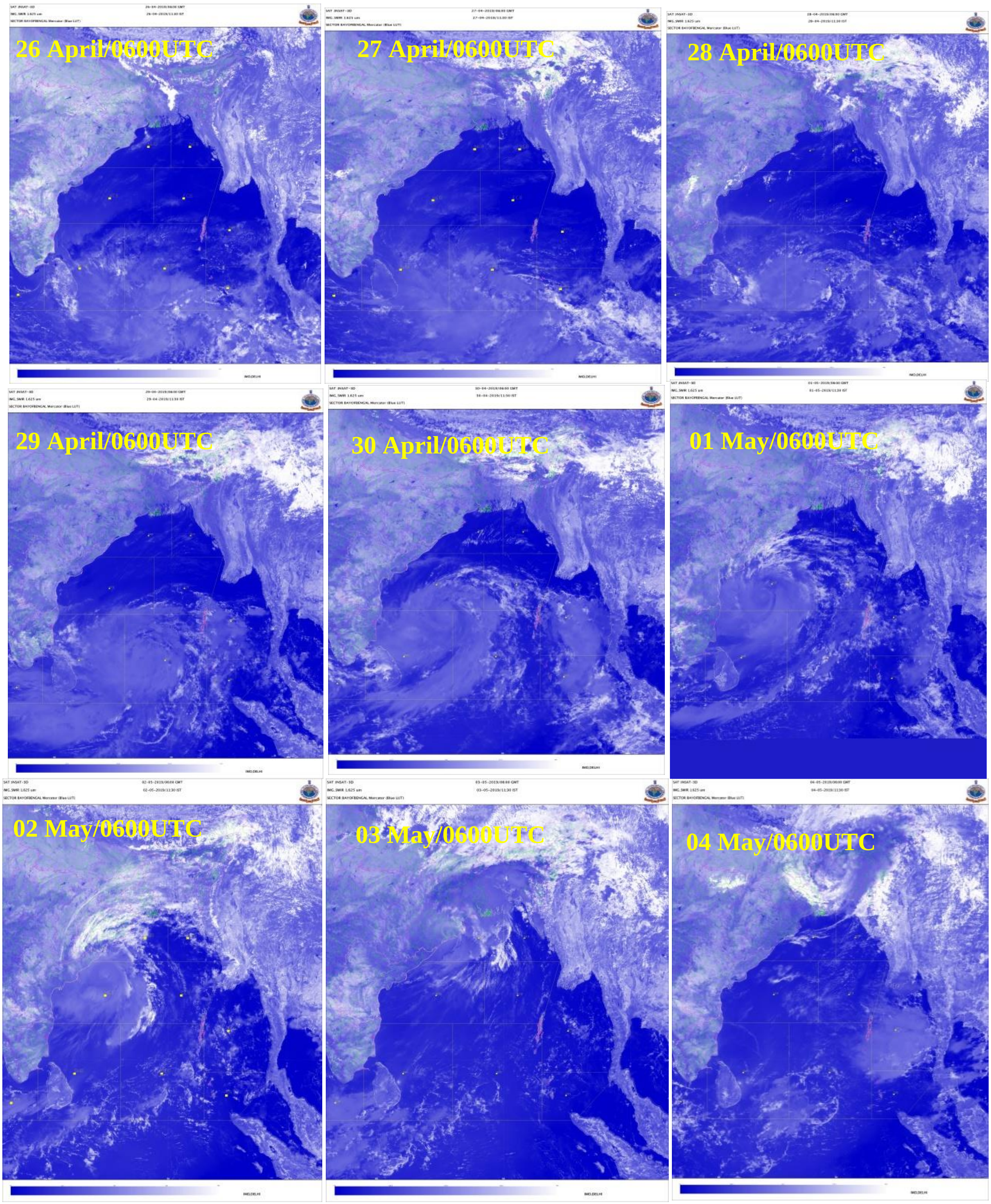


Fig. 6a: INSAT-3D SWIR imageries during life cycle of ESCS FANI (26 April -04 May), 2019

At 0600 UTC on 27th April, the intensity of the system was T 2.5. Broken low to medium clouds with embedded intense to very intense convection lay over EIO and adjoining south BoB between latitude 2.0°N to 9.0°N and long 83.0°E to 93.0°E. Minimum CTT was minus 93°C. Imagery indicated further organisation of clouds. At 1200 UTC of 27th April, there was further organisation of cloud mass. The intensity of the system was T3.0. Broken low to medium clouds with embedded intense to very intense convection lay over EIO and adjoining south BoB between latitude 3.0°N to 8.0°N and longitude 85.0°E to 90.0°E. Minimum CTT was minus 93°C. There was further consolidation of convection around the system centre leading to central dense overcast (CDO) pattern. At 1200 UTC on 29th, the current intensity of the system was C.I.3.5. The clouds were organised in curved band pattern. The convection wrapped 0.8 on 10 degree log spiral yielding T 3.5. Broken low to medium clouds with embedded intense to very intense convection lay over south BoB between latitude 8.0°N to 14.0°N and long 82.5°E to 92.0°E. Minimum CTT was minus 93°C.

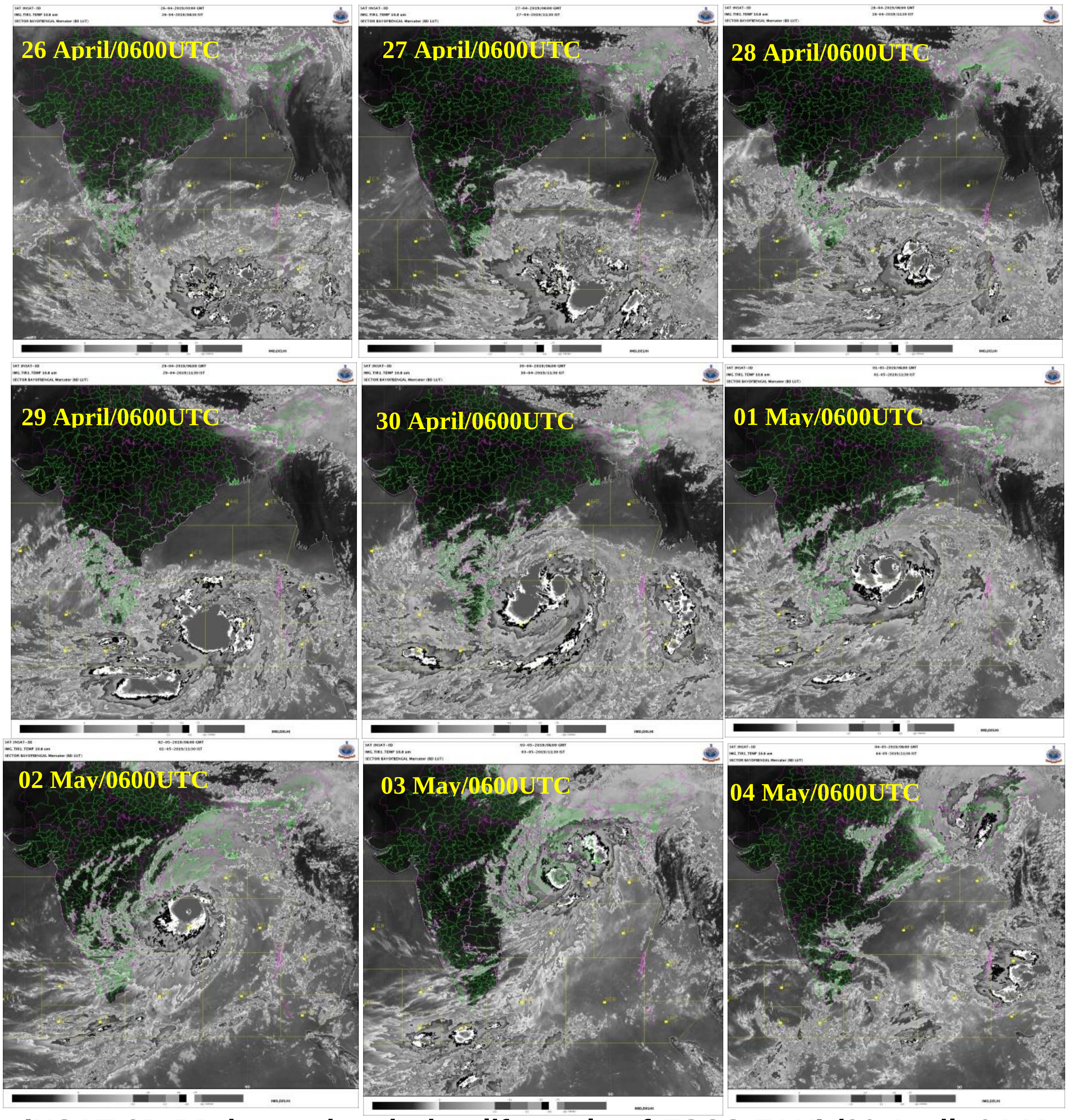


Fig. 6b: INSAT-3D BD imageries during life cycle of ESCS FANI (26 April -04 May), 2019

At 0000 UTC on 30th, the intensity of the system was T 4.0. Broken low to medium clouds with embedded intense to very intense convection lay over south BoB between latitude 7.0°N to 14.9°N and long 81.0°E to 99.0°E. Minimum CTT was minus 93°C. At 1200 UTC on 30th, there was further organisation of cloud mass and the current intensity of the system was C.I. 5.0. The clouds were organised in CDO pattern. Broken low to medium clouds with embedded intense to very intense convection lay over south BoB between latitude 10°N to 16.0°N and long 80.0°E to 90.0 °E. Minimum CTT was minus 93°C.

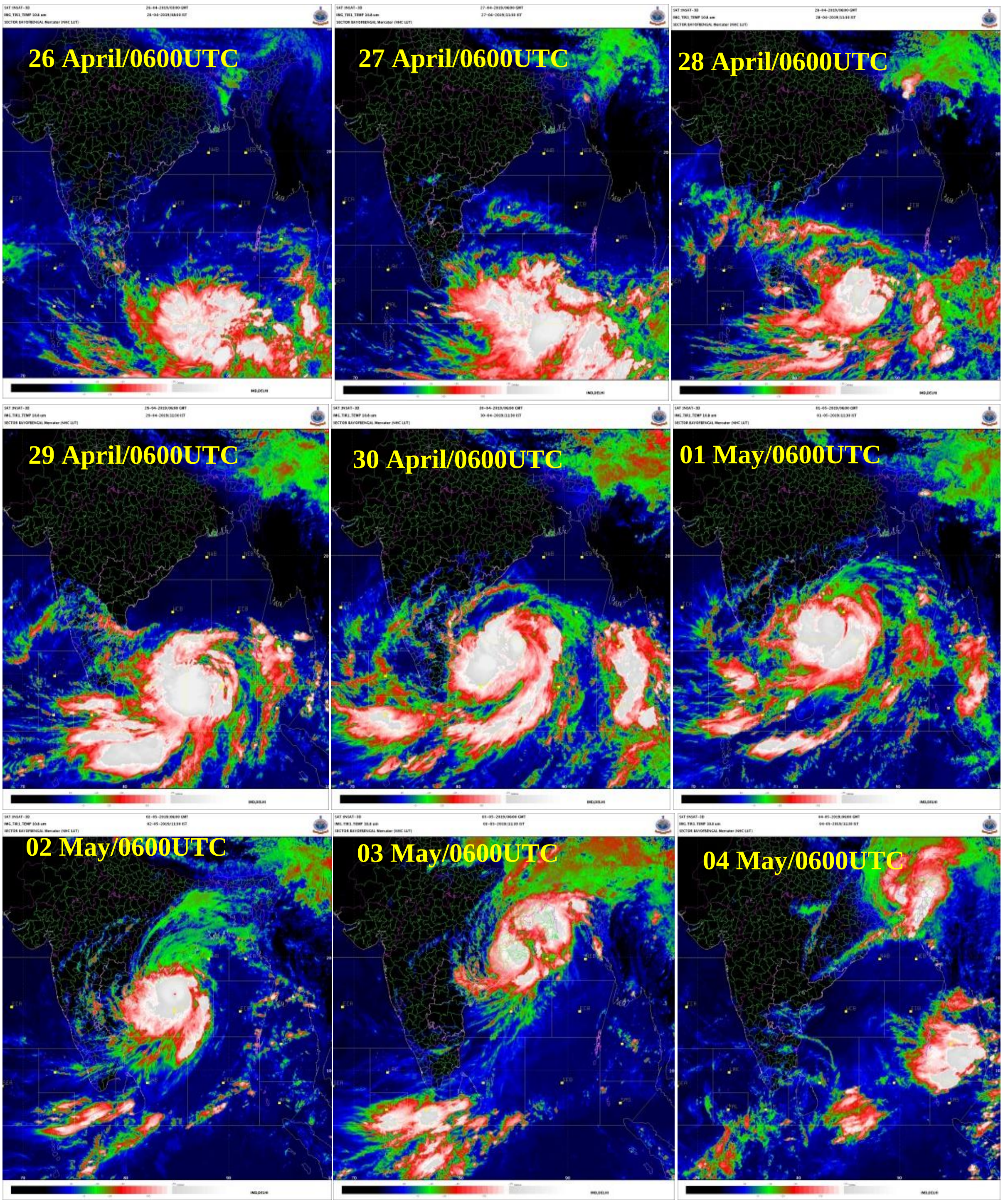


Fig. 6c: INSAT-3D enhanced colored imageries during life cycle of ESCS FANI (26 April -04 May), 2019

At 0000 UTC of 01st May, the current intensity of the system was C.I.5.0. The cloud mass was organised in CDO pattern. Broken low to medium clouds with embedded intense to very intense convection lay over south BoB between latitude 10.5°N to 15.0°N and long 81.0°E to 85.0°E. Minimum CTT was minus 93°C. At 0000 UTC of 02nd, the current intensity of the system was C.I. 5.5. Broken low to medium clouds with embedded intense to very intense convection lay over south BoB between latitude 14.0°N to 17.0°N and west of longitude 85.5 °E. Minimum CTT was minus 93°C.

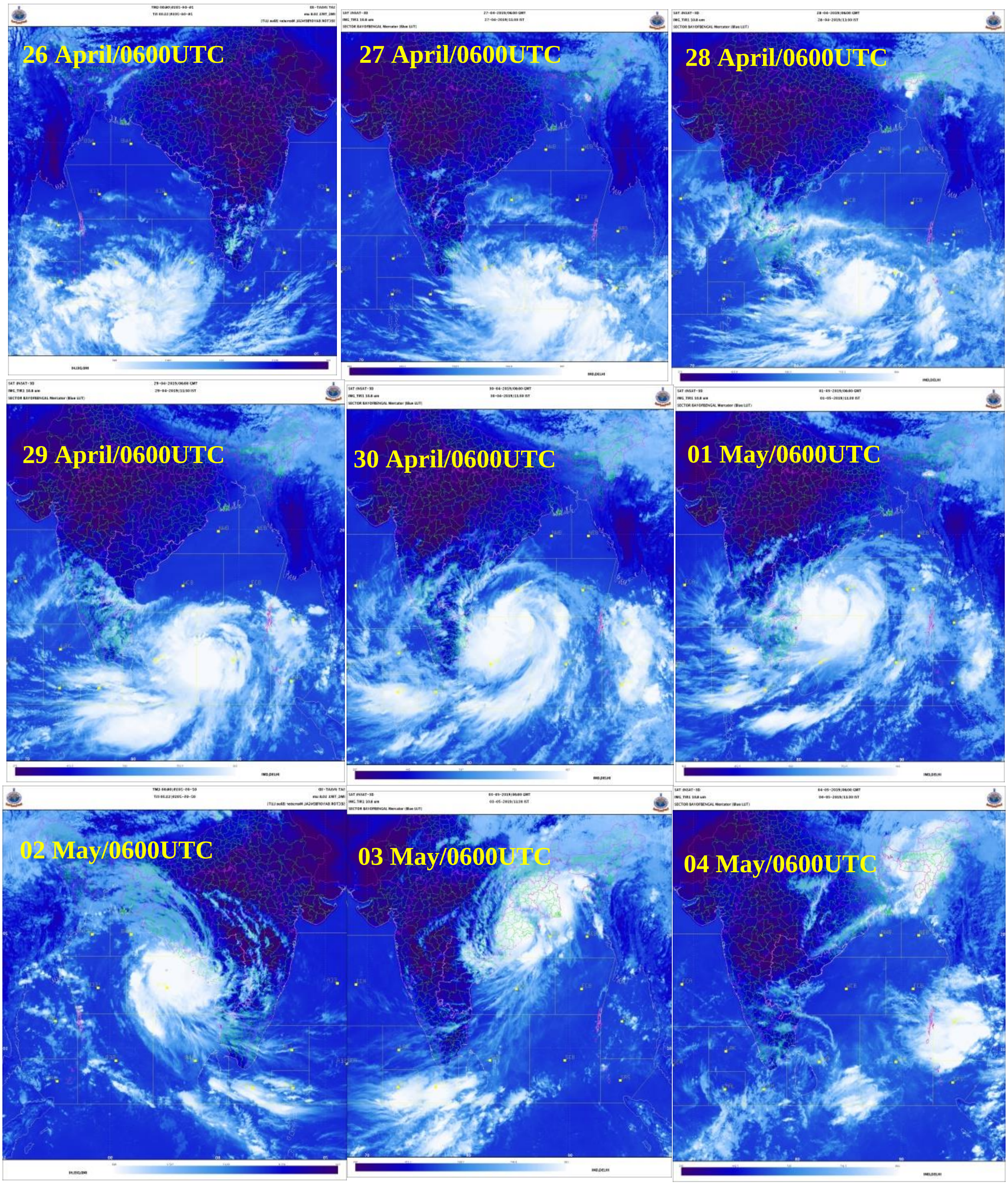


Fig. 6d: INSAT-3D IR1 imageries during life cycle of ESCS FANI (26 April -04 May), 2019

At 0900 UTC of 2nd May, the current intensity of the system was C.I. 6.0. Eye was visible in satellite imagery. Broken low to medium clouds with embedded intense to very intense convection lay over south BoB between latitude 15.5°N to 19.0°N to the west of long.86.5 °E. Minimum cloud top temperature was minus 93°C. At 0300 UTC of 03rd May, the system was crossing Odisha coast with an intensity of C.I. 6.0. Eye was not visible in satellite imagery. At 0600 UTC of 03rd, the system was over coastal Odisha. Broken low to medium clouds with embedded intense to very intense convection lay over south coastal Odisha and Gangetic West Bengal, north BoB between latitude 18.0˚N to 22.0˚N and west of longitude 85.8˚E. Minimum cloud top temperature was minus 84˚C.

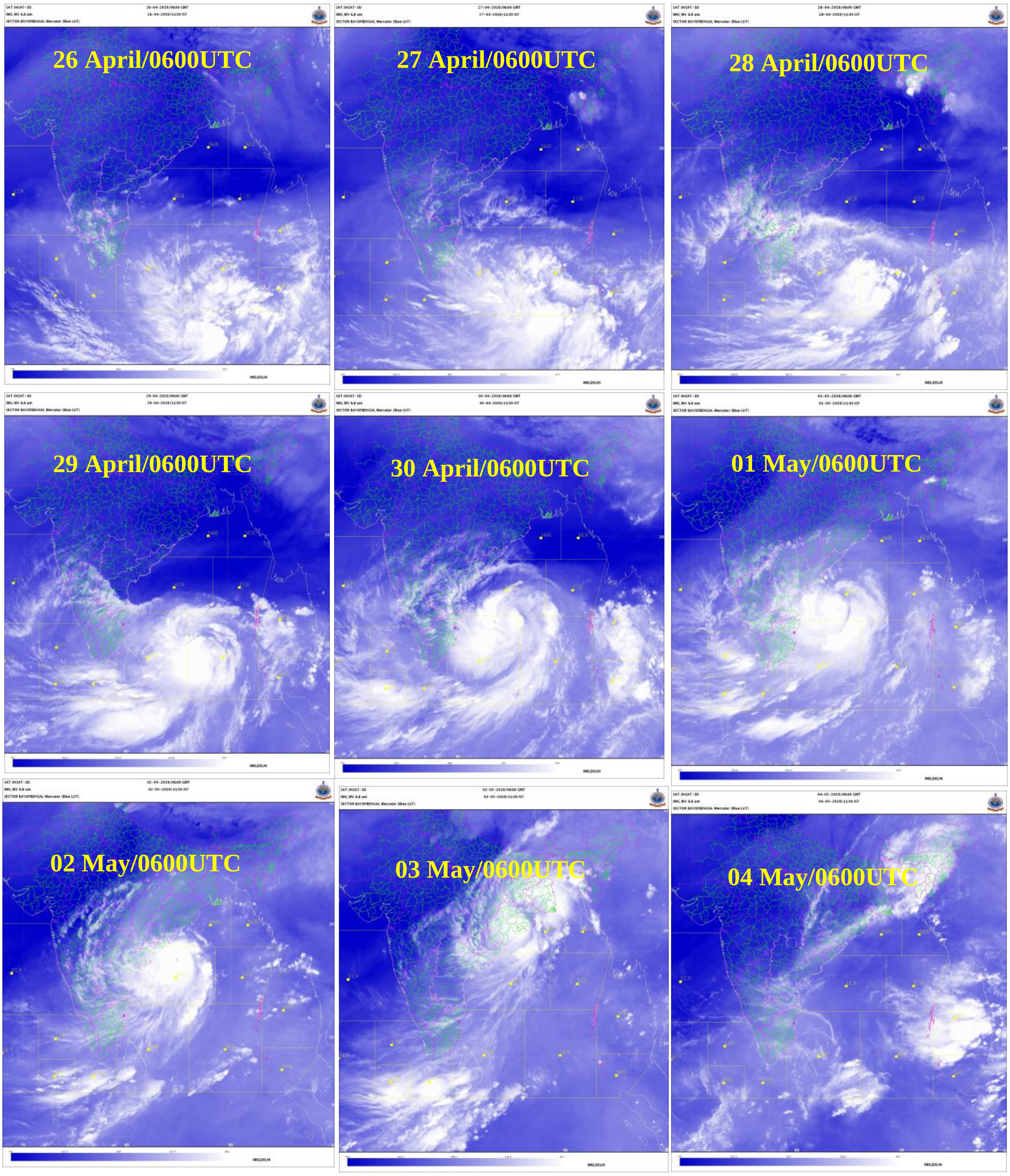


Fig. 6e: INSAT-3D Water Vapor imageries during life cycle of ESCS FANI (26 April - 04 May), 2019

At 1500 UTC of 03rd May, the system was over coastal Odisha. Broken low to medium clouds with embedded intense to very intense convection lay over Odisha, Jharkhand, south Gangetic West Bengal and north BoB between latitude 20.0˚N to 24.0˚N to the west of longitude 87.5˚E. Minimum CTT was minus 92˚C. On 04th May, the clouds were sheared northeastwards. At 0000 UTC, broken low to medium clouds with embedded intense to very intense convection lay over northeast Jharkhand, south Gangetic West Bengal and north BoB between latitude 22.0˚N to 25.5˚N and west of longitude 91.8˚E to 93.0˚E. Minimum CTT was minus 92˚C. At 0600 UTC, broken low to medium clouds with embedded intense to very intense convection lay over Bangladesh, sub Himalayan West Bengal, Assam, Meghalaya, Tripura, and adjoining north Mizoram. Minimum CTT was minus 81˚C and moderate to intense convection lay over east Bihar, northeast Jharkhand and north Gangetic West Bengal. At 1800 UTC, the system weakened into a WML over central Assam and neighbourhood. Broken low to medium clouds with embedded intense to very intense convection lay over east Assam and neighbourhood. Minimum cloud top temperature was minus 74°C.

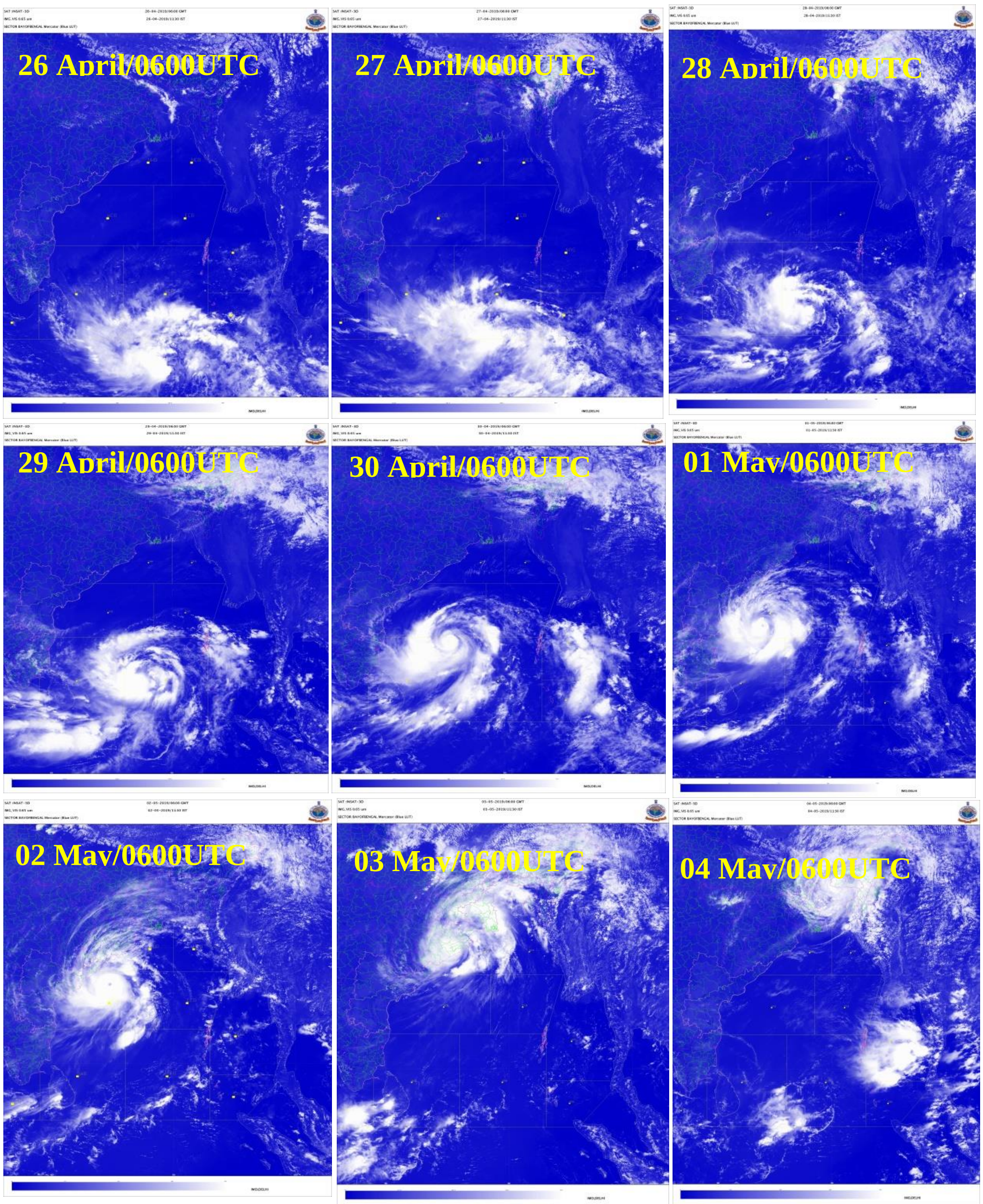


Fig. 6e: INSAT-3D Visible imageries during life cycle of ESCS FANI (26 April -04 May), 2019

Typical scatterometry imageries from ASCAT during the life cycle of FANI are presented in Fig. 6f. On 1st and 2nd, the entire circulation was captured well by ASCAT imageries. However, due to rain contamination, the intensity could not be correctly fixed.

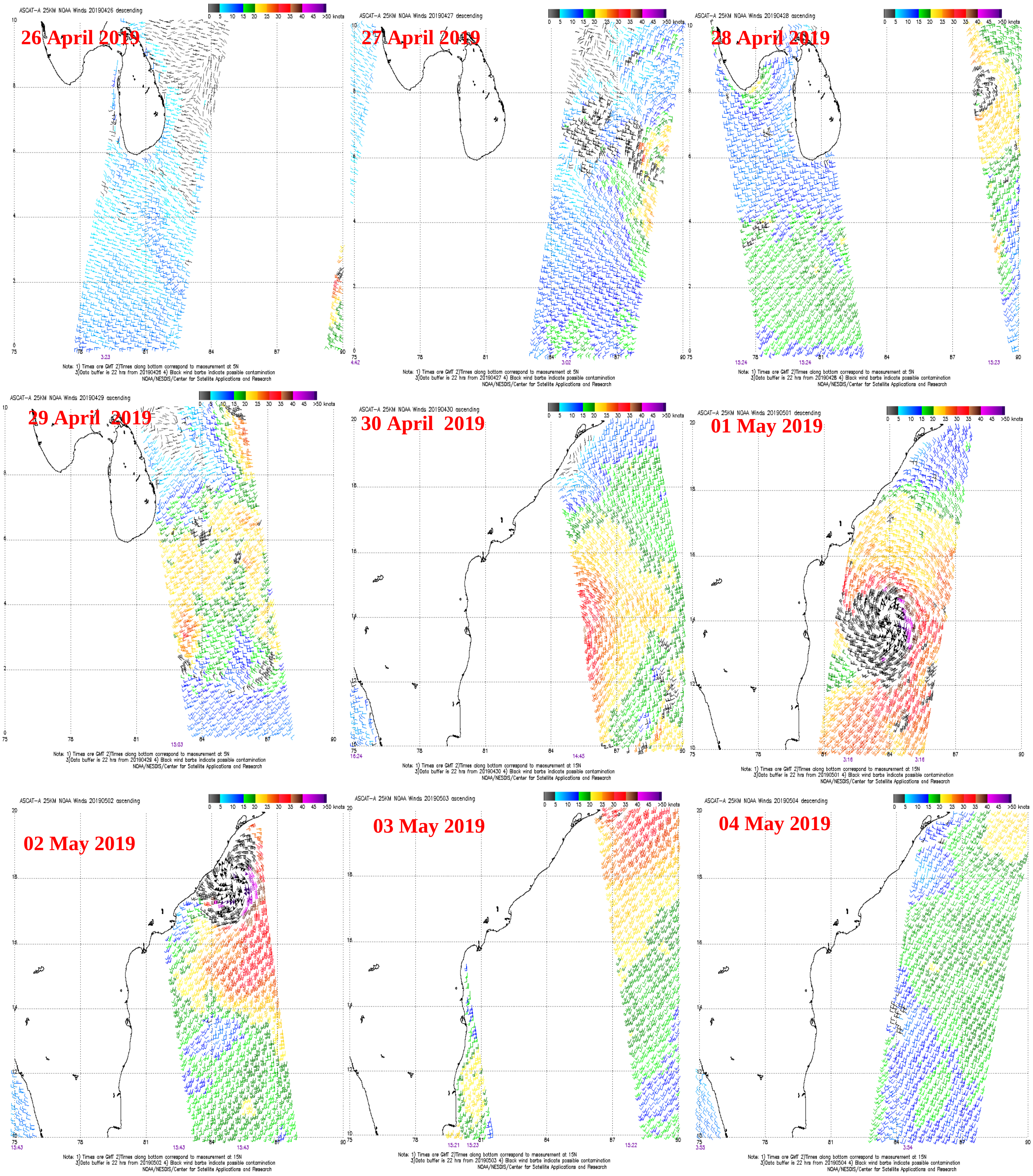


Fig. 6f: ASCAT imageries during life cycle of ESCS FANI (26 April -04 May), 2019

Typical imageries from SCAT SAT are presented in Fig. 6g. The centre was well captured on 28th April and 1st May. The SCATSAT based analysis indicated Matching Index (M.I.) more than 0.6 (threshold value for development of tropical cyclones) on 28th April. On 28th April, it was a cyclonic storm.

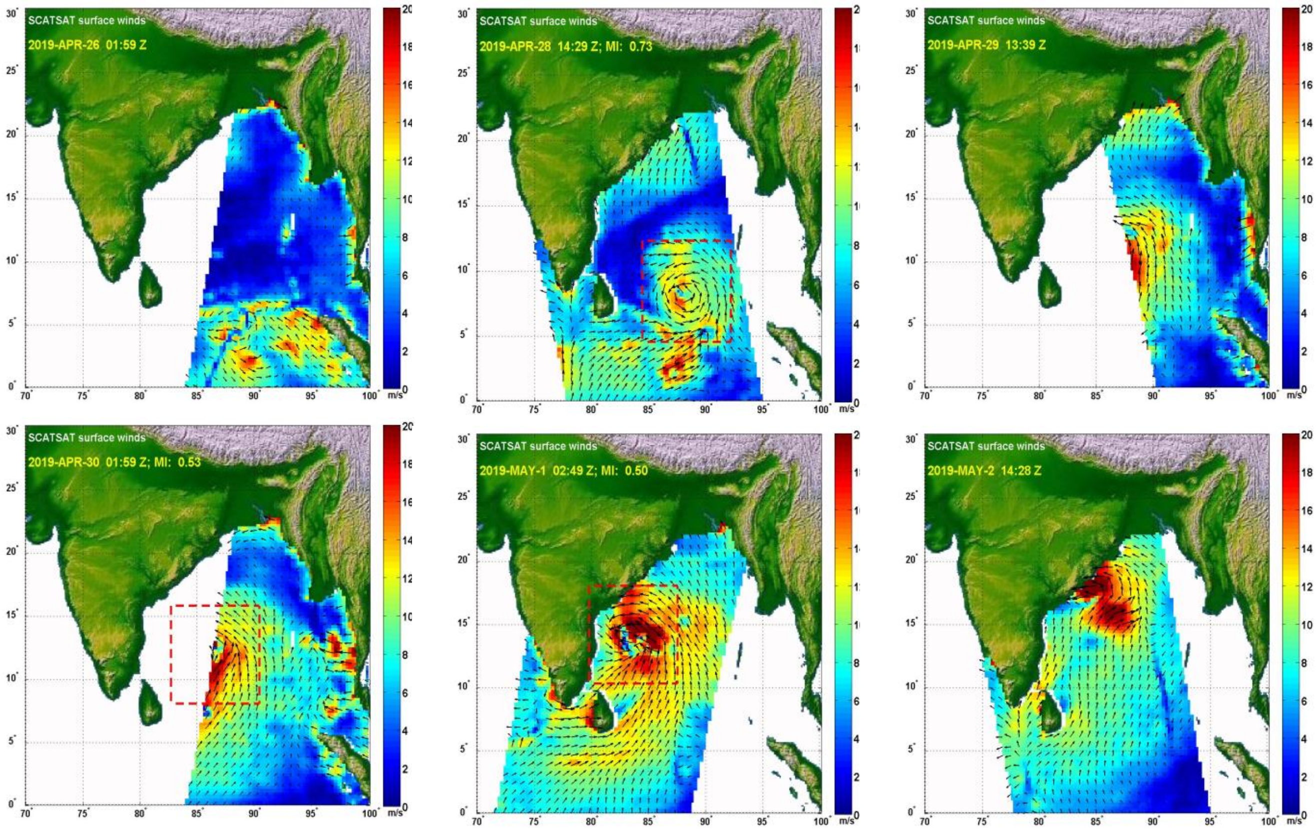


Fig. 6g: SCATSAT imageries during life cycle of ESCS FANI (26 April -04 May), 2019

Typical micro wave imageries from polar orbiting satellites F-16, F-17, F-18, Windsat and GCOM-W1 are presented in Fig. 6h. Eye could be clearly seen during 30th April to 3rd May.

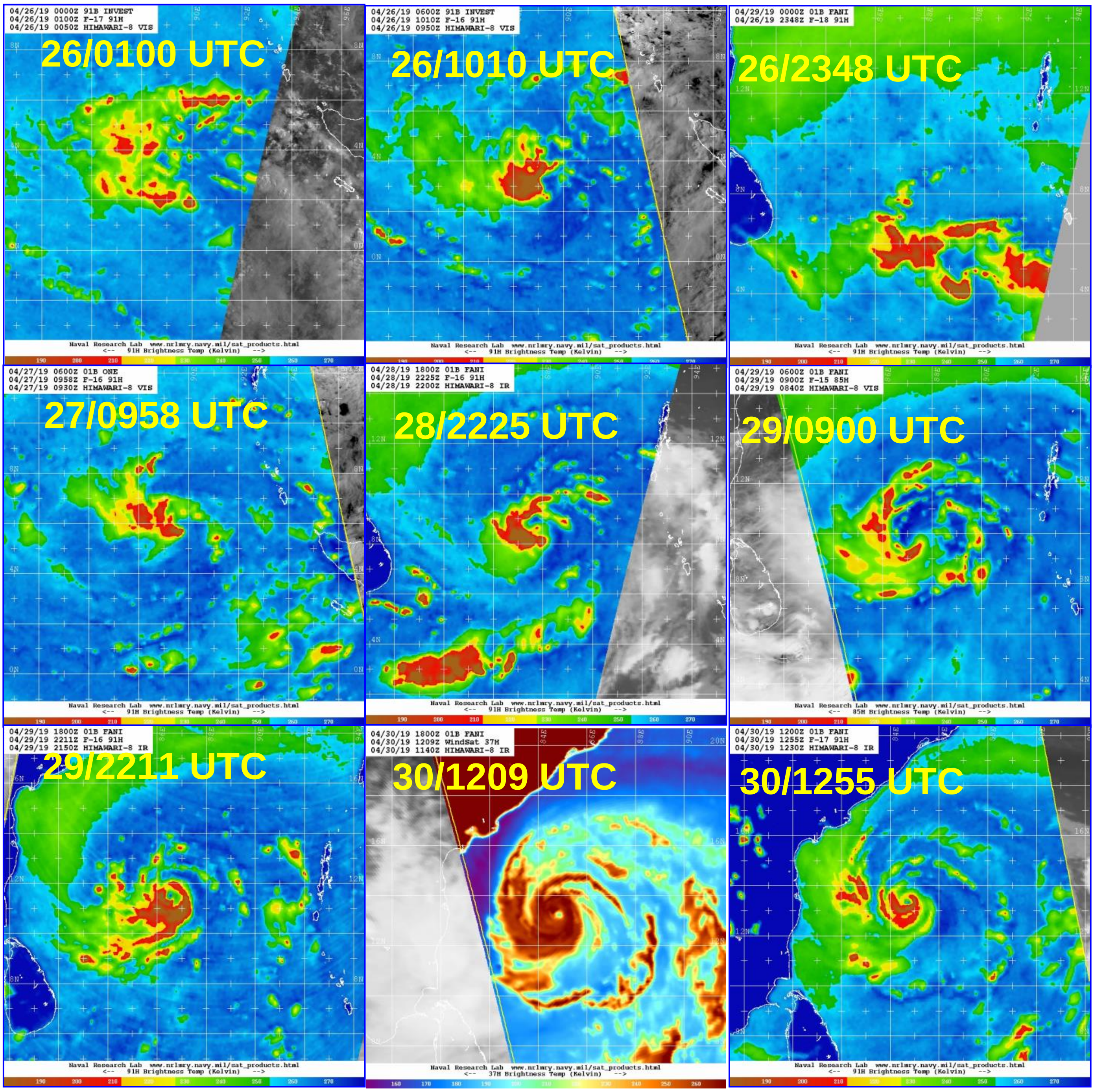


Fig. 6h: Microwave imageries during life cycle of ESCS FANI (26 April -04 May), 2019

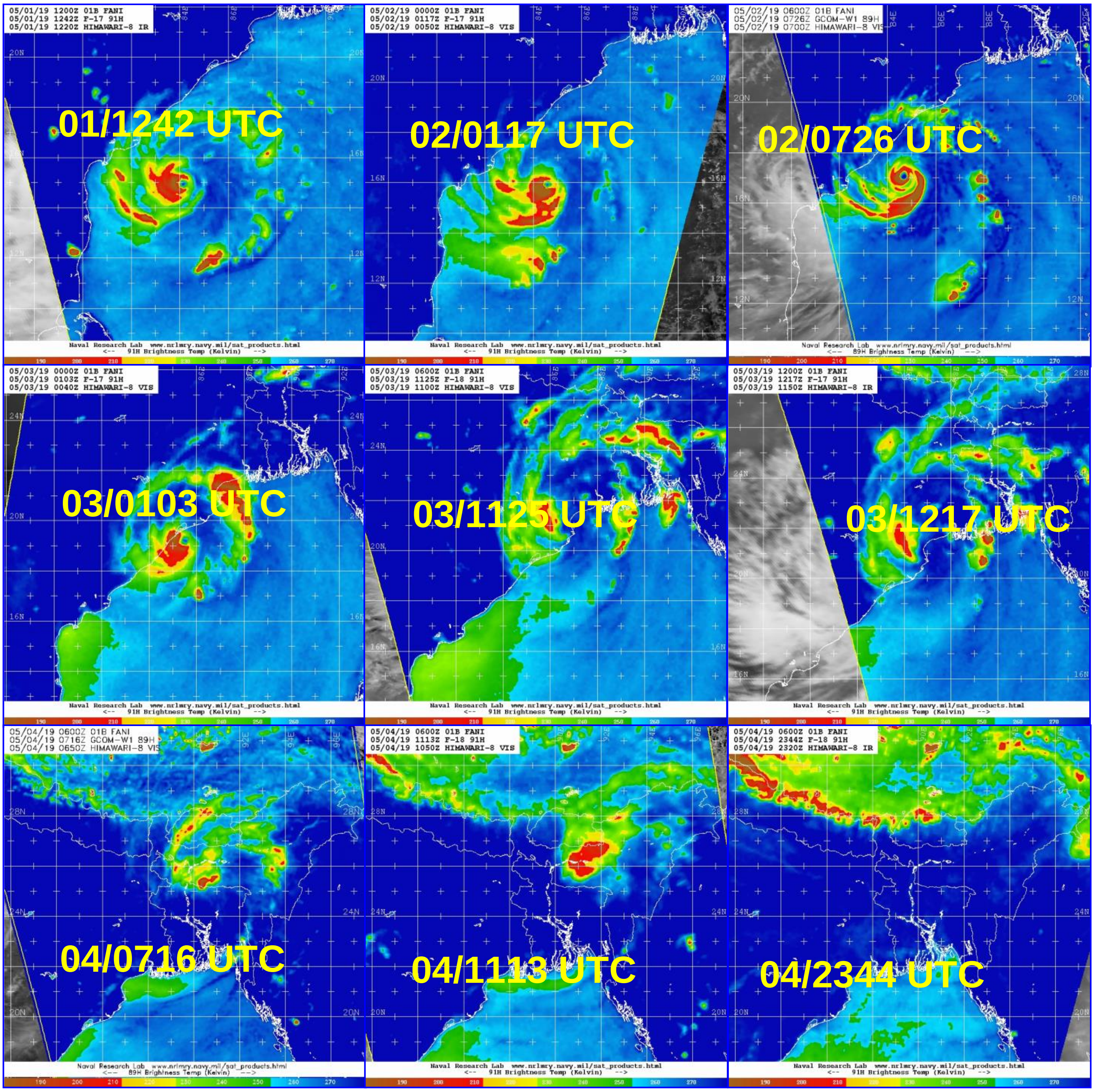


Fig. 6h: Microwave imageries during life cycle of ESCS FANI (26 April -04 May), 2019

5.1. Features observed through Radar

The ESCS FANI was tracked by DWRs Chennai, Machillipatnam, Visakhapatnam, Paradeep, Gopalpur and Kolkata during it's movement from southwest to north BoB. Typical DWR imageries from these radars are presented in Fig. 7. DWR Chennai tracked the system during 30th April to 1st May. It could capture eye till 0009 UTC of 1st May. Thereafter, the system moved away from it's range.

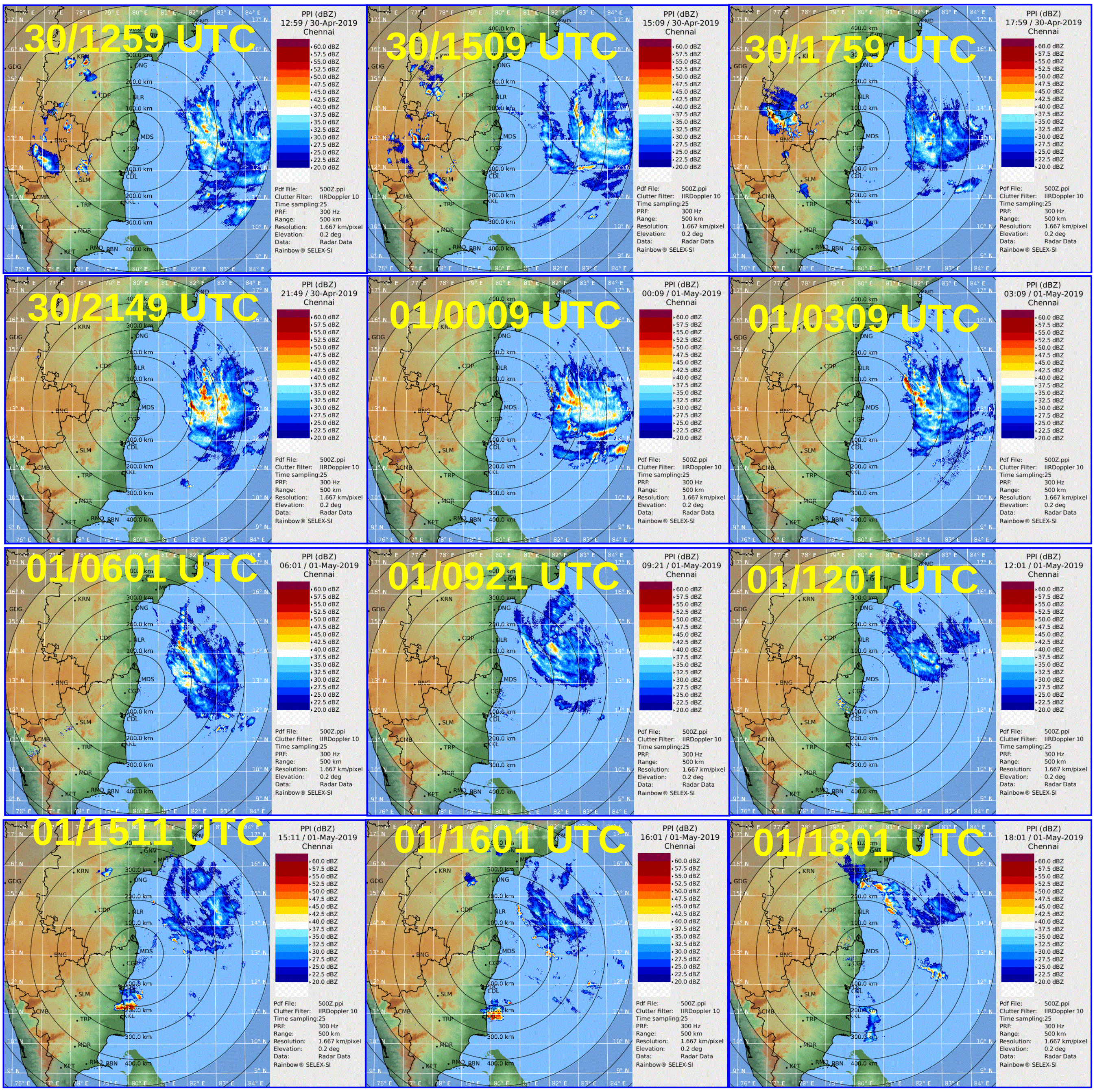


Fig.7(i): Typical Radar imagery MAX-Z from DWR Chennai during 30 April -01 May

DWR Gopalpur captured the system during 2nd to 3rd May. Eye and the structure of cyclone was well captured by DWR Gopalpur during the period.

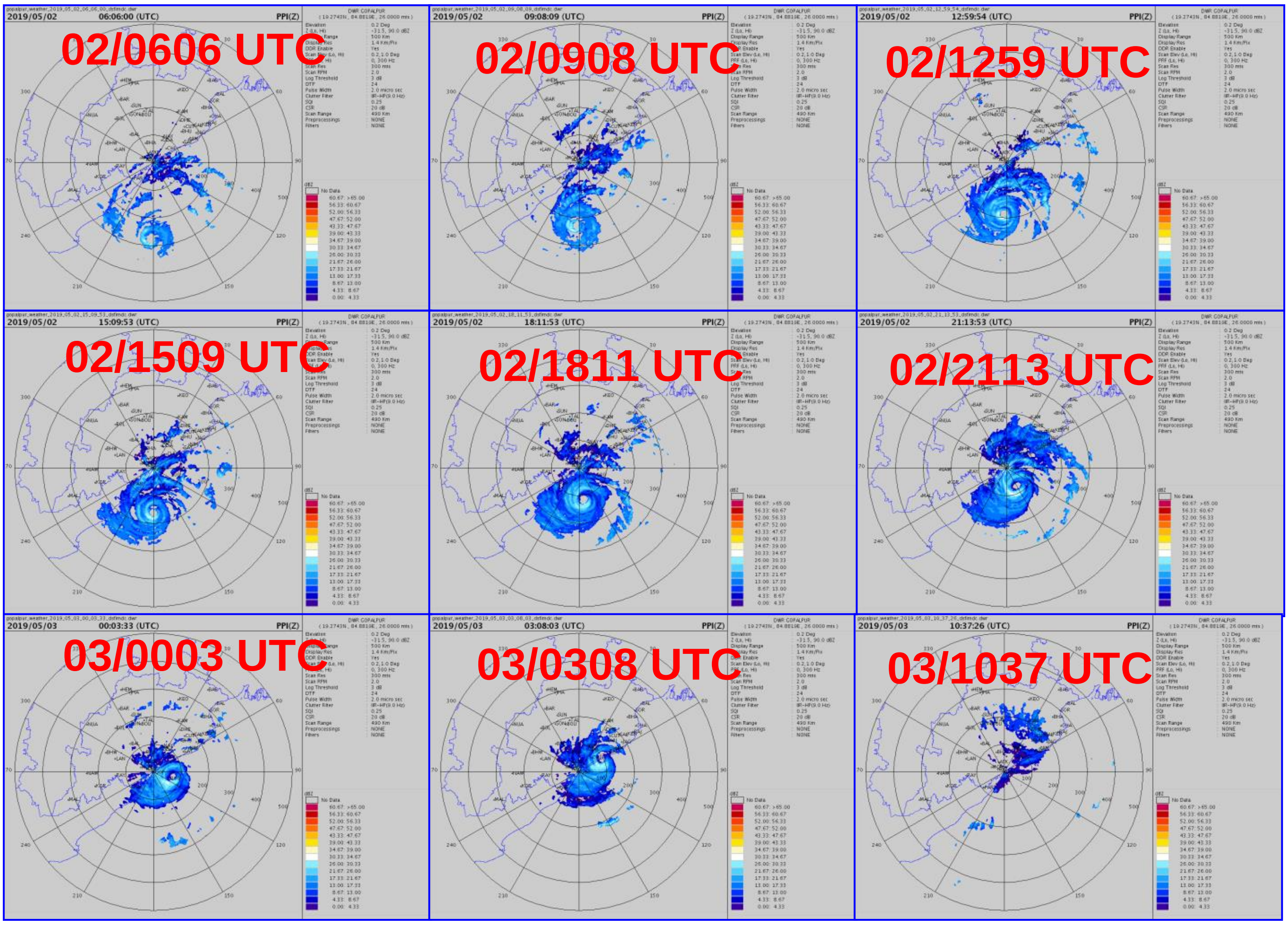


Fig.7(ii): Typical Radar imagery MAX-Z from DWR Gopalpur during 02-03 May

Typical imageries from DWR Machilipatnam are presented in Fig. 7 (iii).

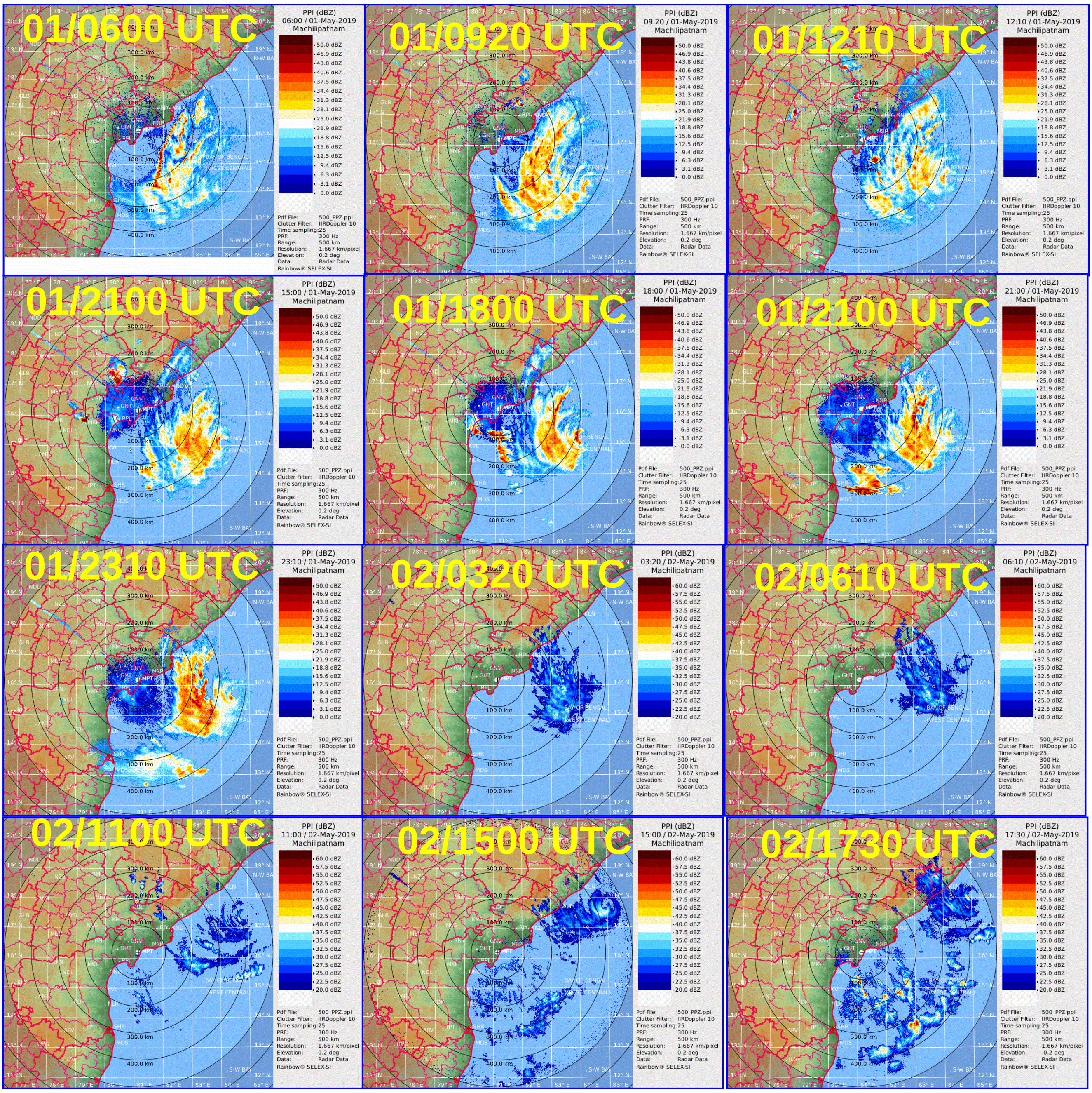


Fig.7(iii): Typical Radar imagery MAX-Z from DWR Machilipatnam during 01-02 May

Typical DWR imageries from DWR Paradeep are presented in Fig. 7 (iv). From 2nd evening onwards, it could capture the rain bands entering the Odisha coast. The front part of eye could be seen entering the coast from 0300 UTC of 3rd.

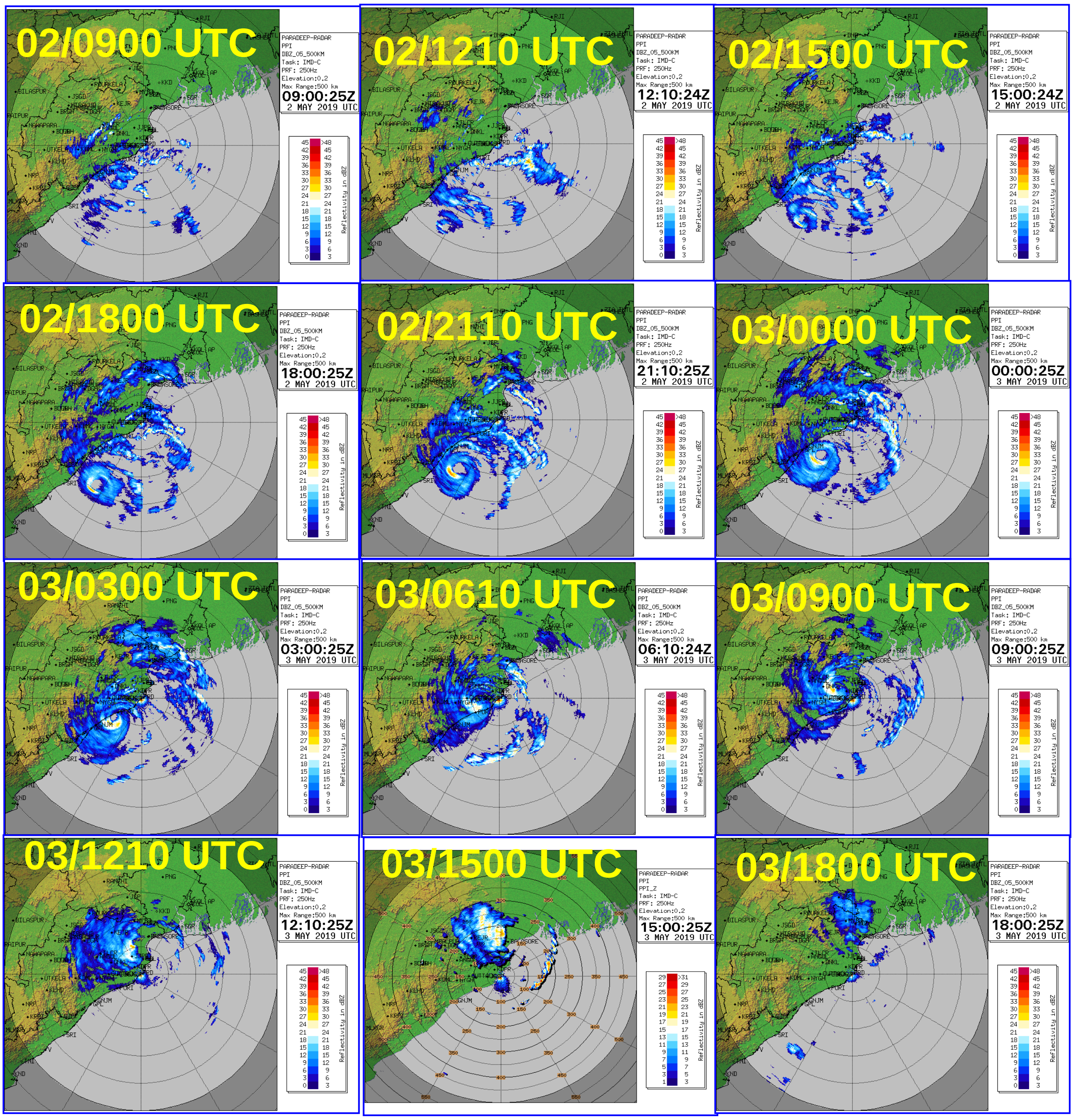


Fig.7(iv): Typical Radar imagery MAX-Z from DWR Paradeep during 02-03 May

Typical imageries from DWR Visakhapatnam are presented in Fig. 7 (v).

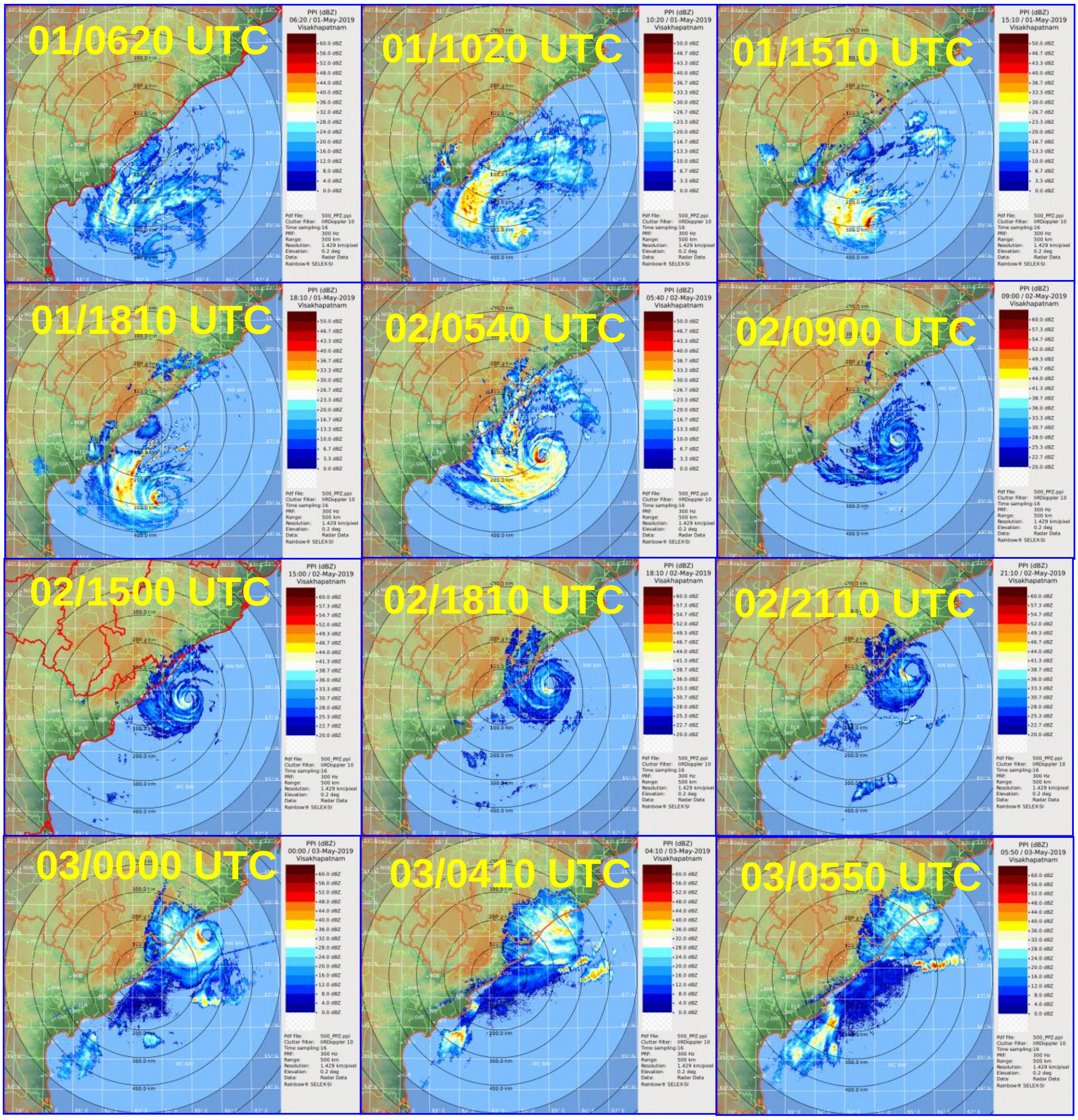


Fig.7(v): Typical Radar imagery MAX-Z from DWR Visakhapatnam during 01-03 May

Typical imageries from DWR Kolkata are presented in Fig. 7 (vi).

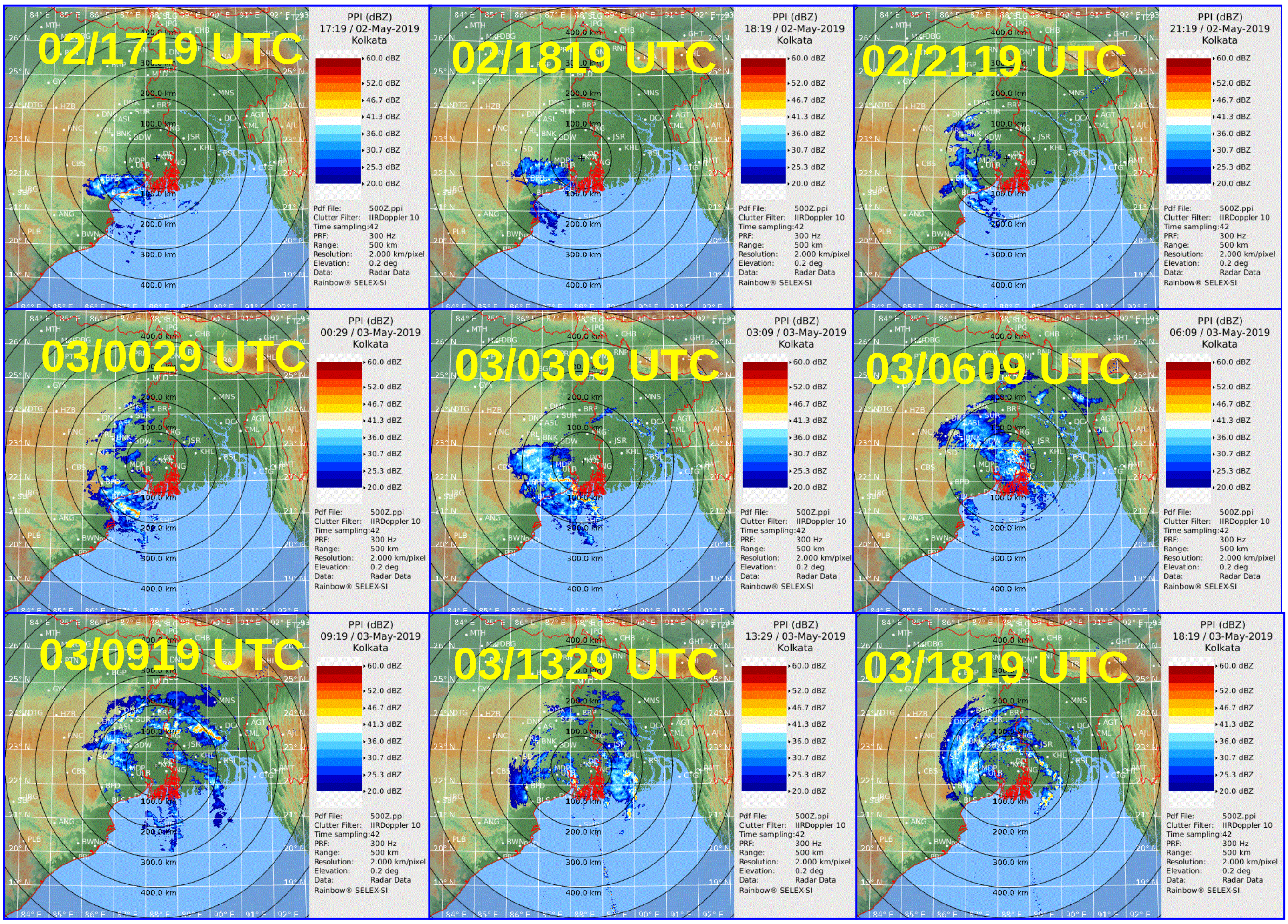


Fig.7(vi): Typical Radar imagery MAX-Z from DWR Kolkata during 02-03 May

6. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 26th April-04th May are presented in Fig.8. At 0000 UTC of 26th April, the analysis field indicated a low pressure area over EIO and adjoining southeast BoB.

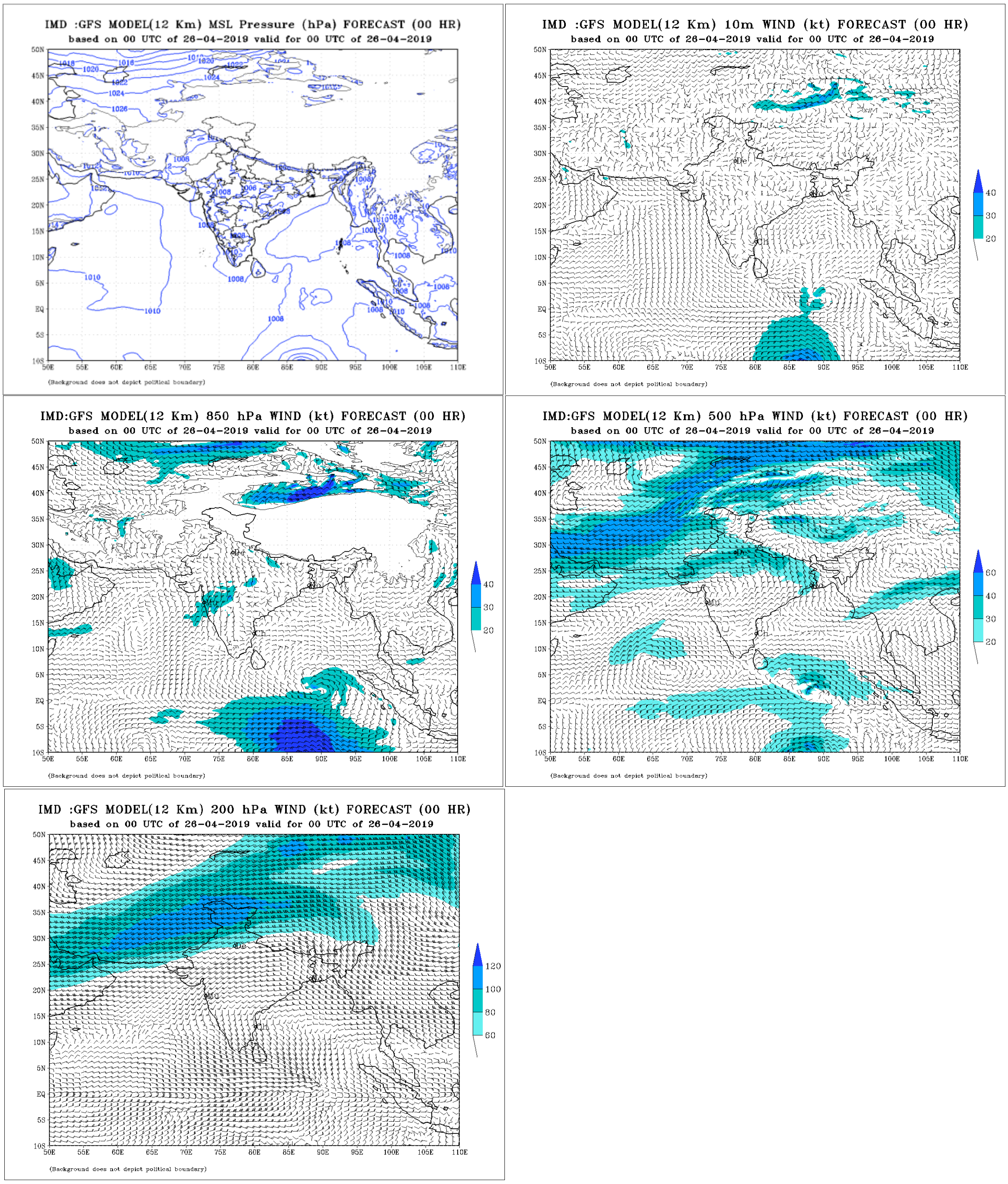


Fig. 8(a): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 26th April 2019

At 0000 UTC of 27th, the analysis field indicated a deep depression over southeast BoB near 5.0^{0}N/90.0^{0}E with vertical extension upto 500 hPa level. Actually, the system lay over southeast BoB near 4.5^{0}N/88.0^{0}E as a deep depression.

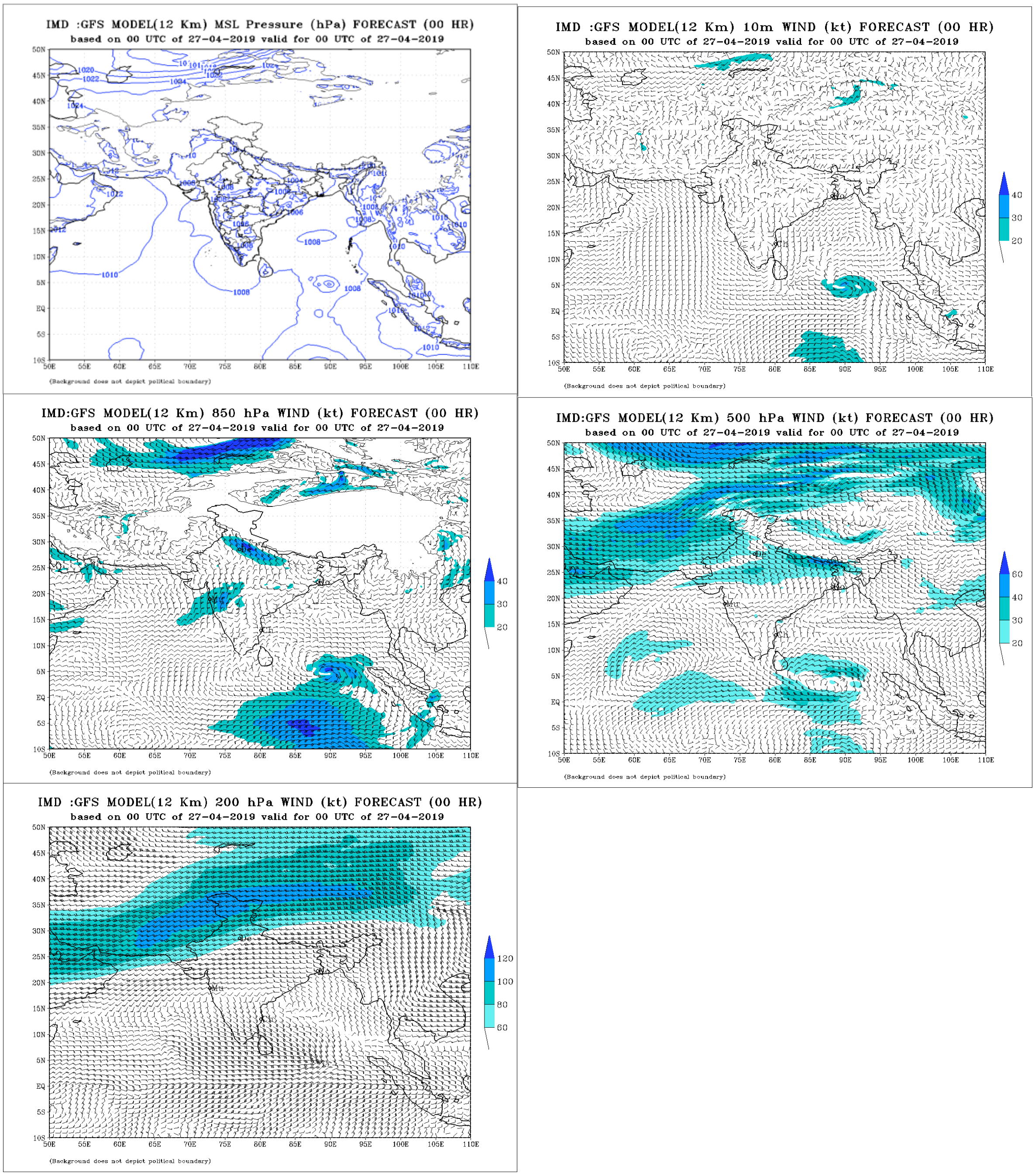


Fig. 8(b): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 27th April 2019

The analysis field based on 0000 UTC of 28th April, indicated further intensification of system into a cyclonic storm over southwest BoB with vertical extension upto 500 hPa level. Actually, it lay as a cyclonic storm over southwest and adjoining southeast BoB.

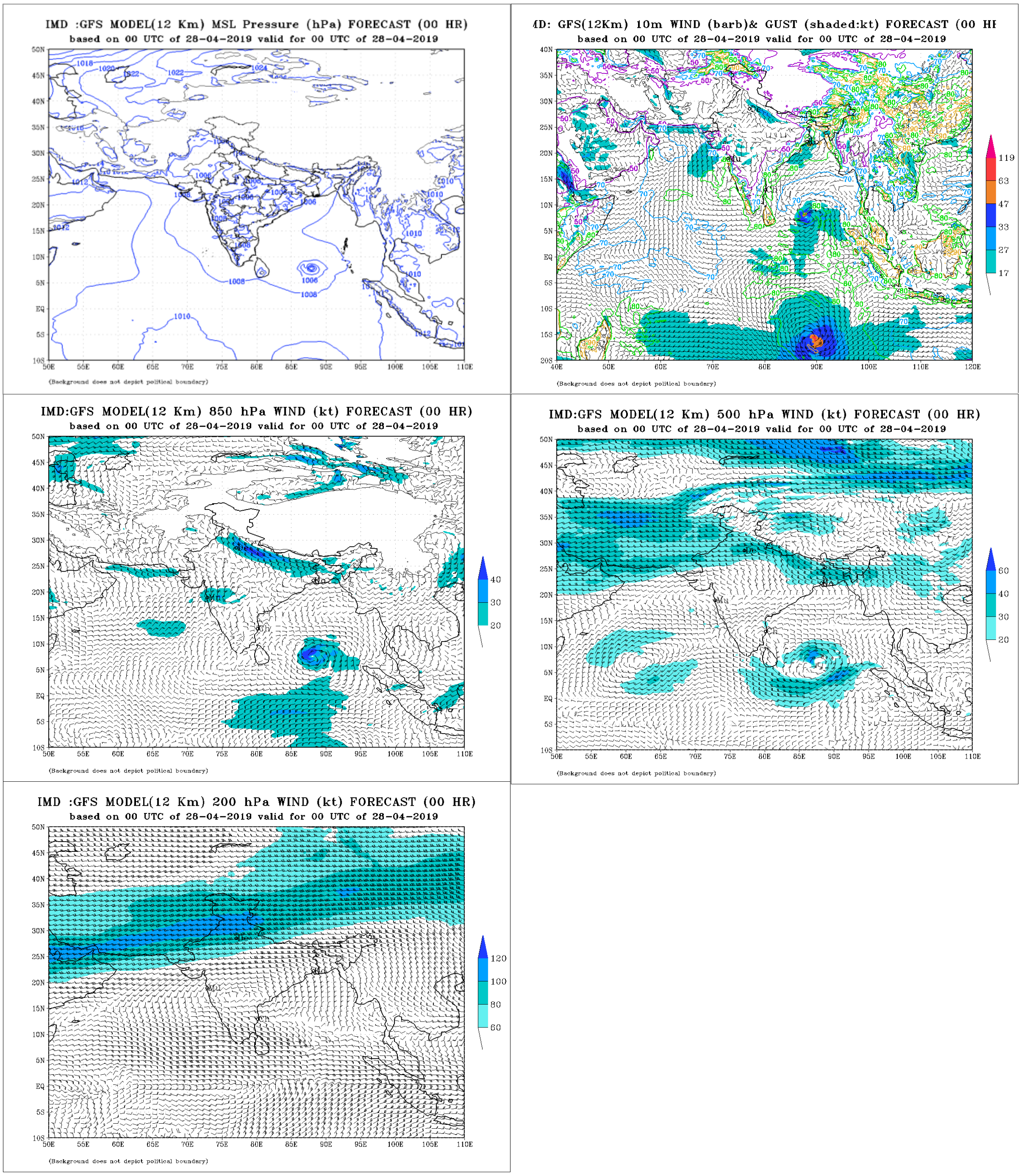


Fig. 8(c): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 28th April 2019

The analysis field based on 0000 UTC of 29th April indicated further intensification of the system into severe cyclonic storm over southwest BoB near 9.0^0N/85.0^0E. Actually, it lay as a CS over southwest BoB near 8.6^0N/86.9^0E.

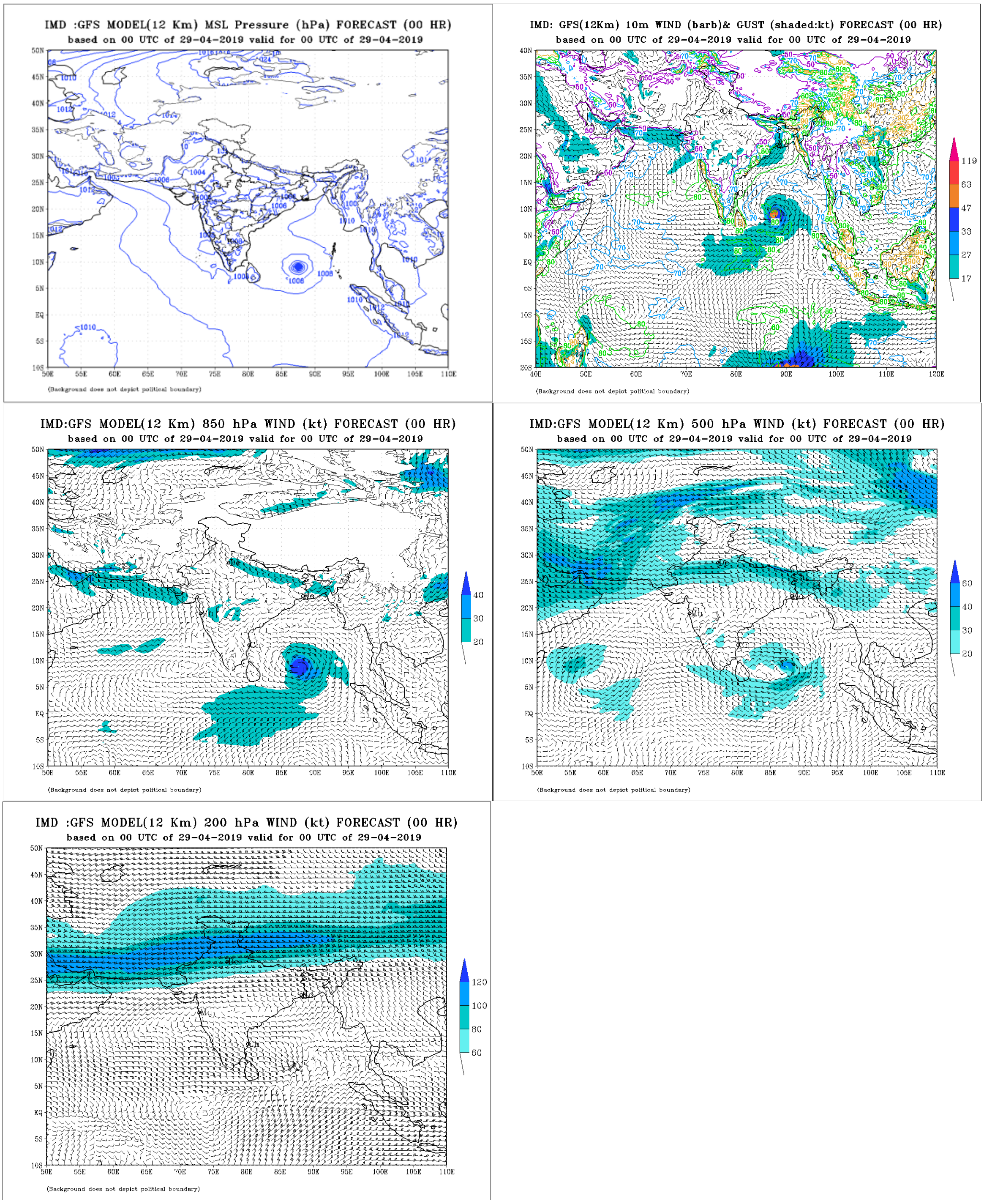


Fig. 8(d): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 29th April 2019

The analysis field based on 0000 UTC of 30th April indicated further intensification of the system into VSCS over southwest BoB near 12.5.0^{0}N/86.0^{0}E. Actually, it lay as a VSCS over southwest BoB near 11.7^{0}N/86.5^{0}E.

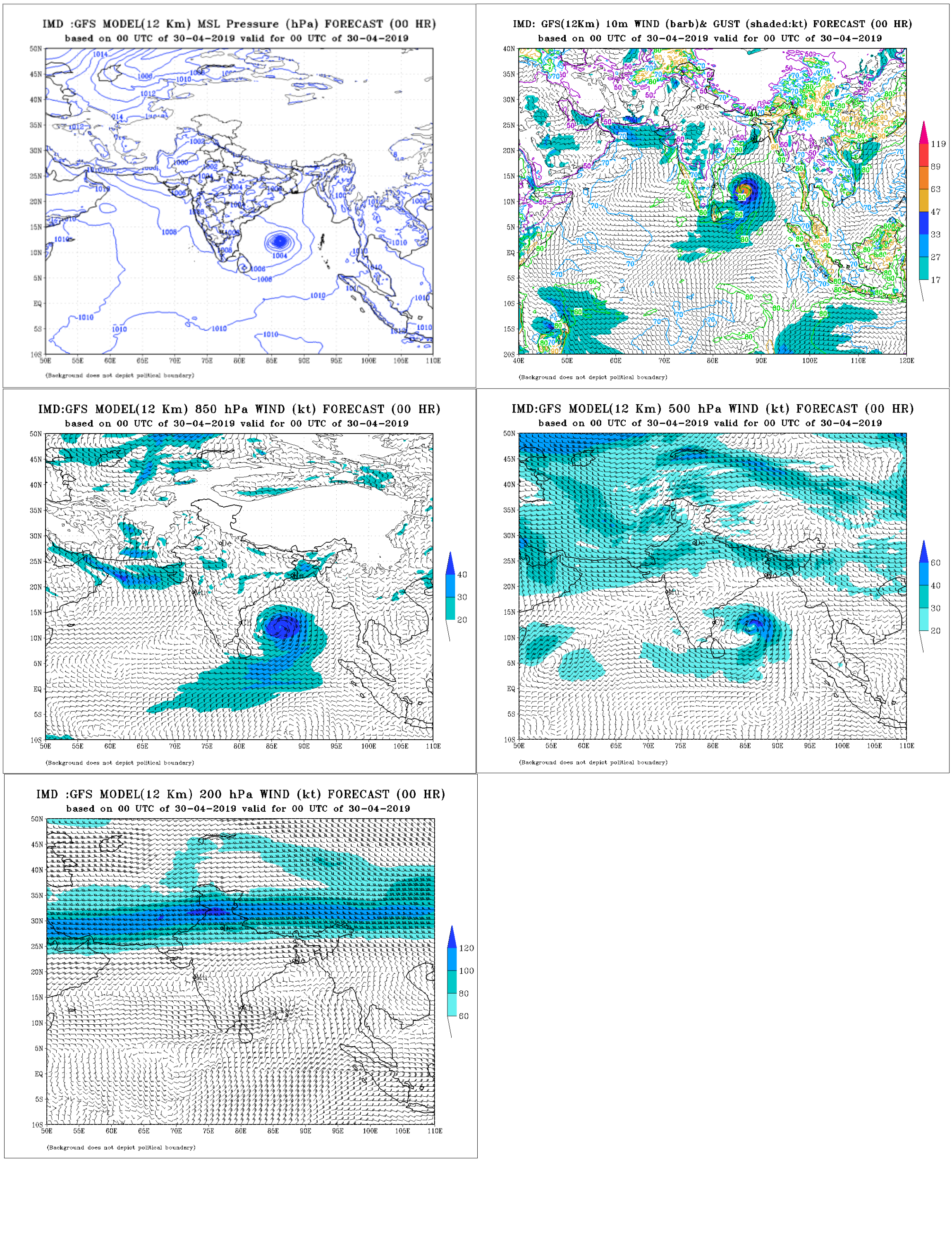


Fig. 8(e): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 30th April 2019

The analysis field based on 0000 UTC of 1st May indicated a VSCS over westcentral BoB near 14.5^0N/84.0^0E. Actually, it lay as an ESCS over westcentral BoB near 13.9^0N/84.0^0E.

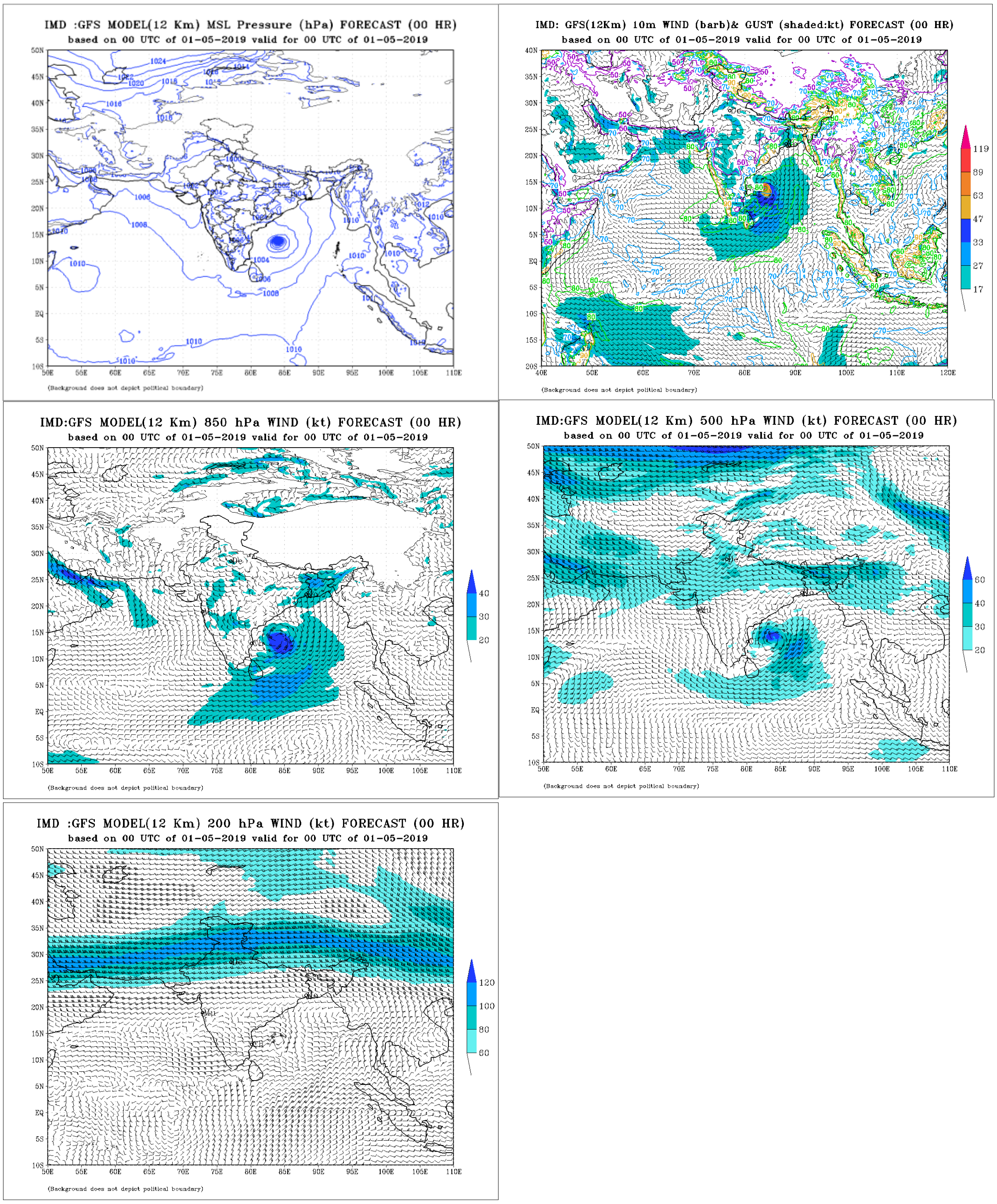


Fig. 8(f): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 01st May 2019

The analysis field based on 0000 UTC of 2nd May indicated further intensification into an ESCS over westcentral BoB near 14.5^{0}N/84.5^{0}E. Actually, it lay as an ESCS over westcentral BoB near 15.9^{0}N/84.5^{0}E.

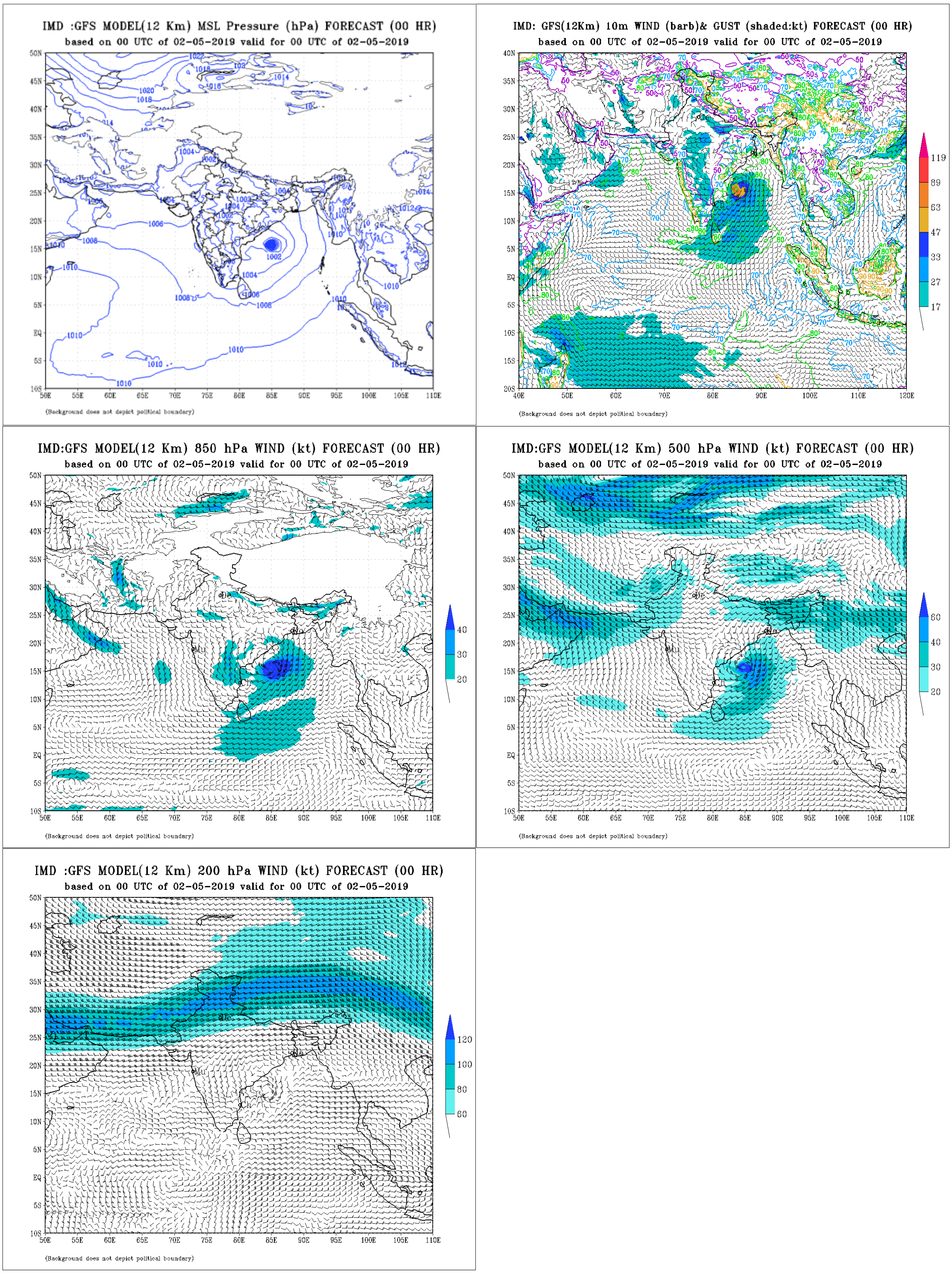


Fig. 8(g): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 02nd May 2019

The analysis field based on 0000 UTC of 3rd May indicated the system close to Odisha coast near 19.5^{0}N/85.0^{0}E. Northeastwards recurvature was also indicated. Actually, it lay as an ESCS over northwest BoB near 19.1^{0}N/85.5^{0}E.

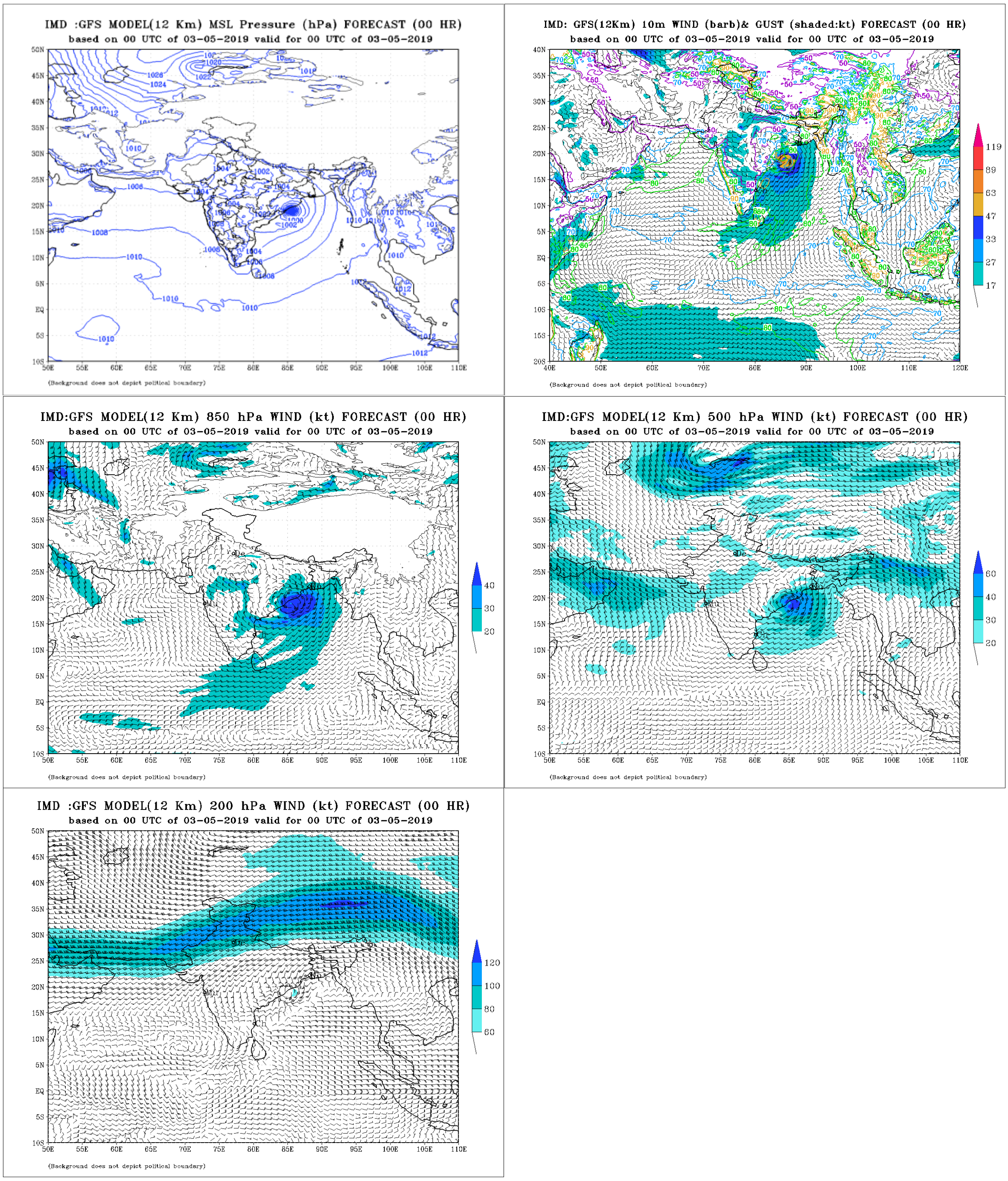


Fig. 8(h): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 03rd May 2019

The analysis field based on 0000 UTC of 4th May indicated the system over Bangladesh and adjoining West Bengal near 24.0^{0}N/88.5^{0}E. Northeastwards recurvature was also indicated. Actually, it lay as a CS over West Bengal and adjoining Bangladesh near 23.1^{0}N/88.2^{0}E.

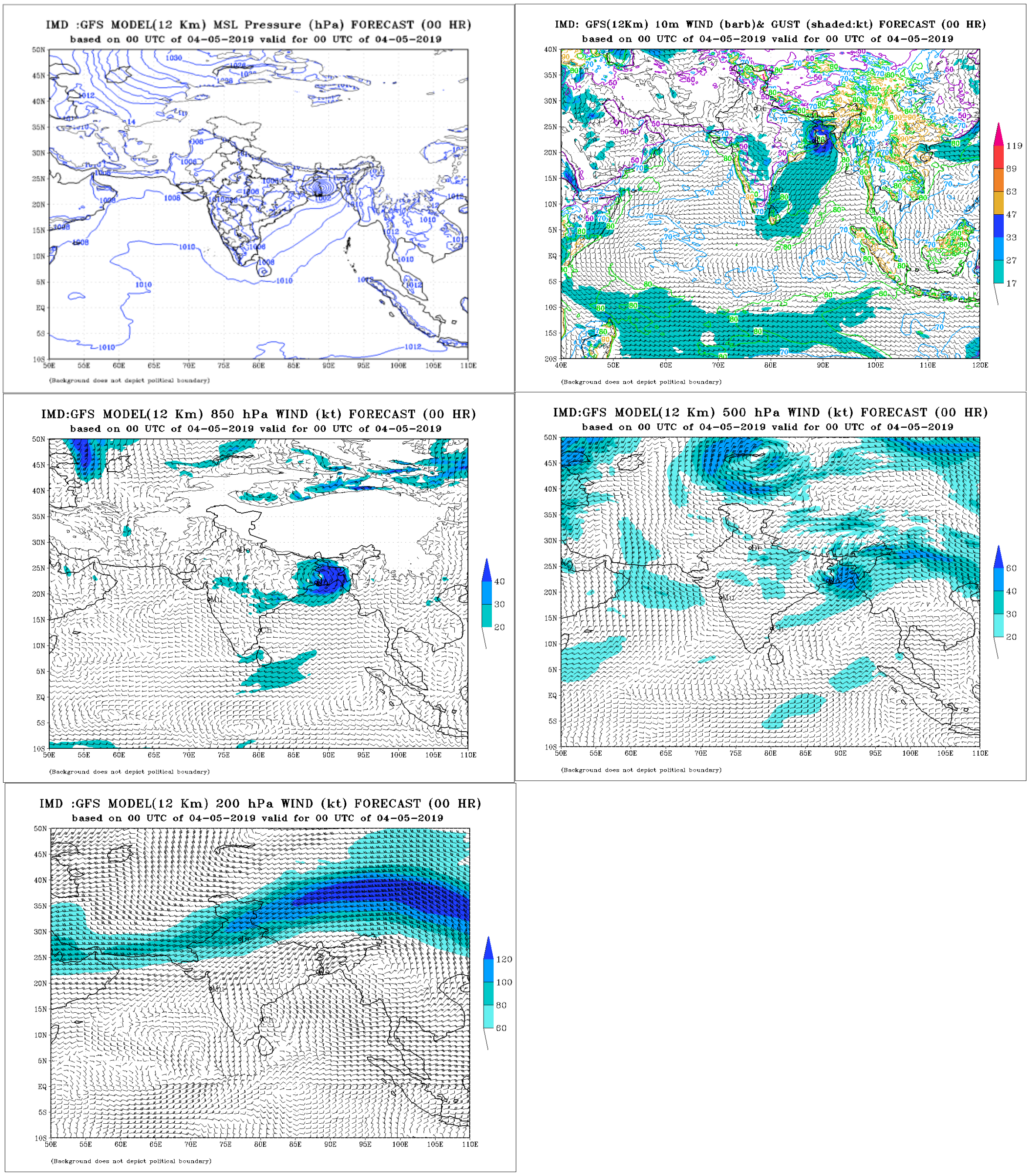


Fig. 8(i): IMD GFS (T574) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 04th May 2019

Thus overall, IMD GFS could correctly simulate the genesis, intensification and movement of the system. However in the initial 3 days, the model predicted movement towards Tamil Nadu coast and later started predicting close to the realized track.

7. Realized Weather:

Rainfall associated with ESCS FANI based on IMD-NCMRWF GPM merged gauge rainfall data is depicted in **Fig 9**.

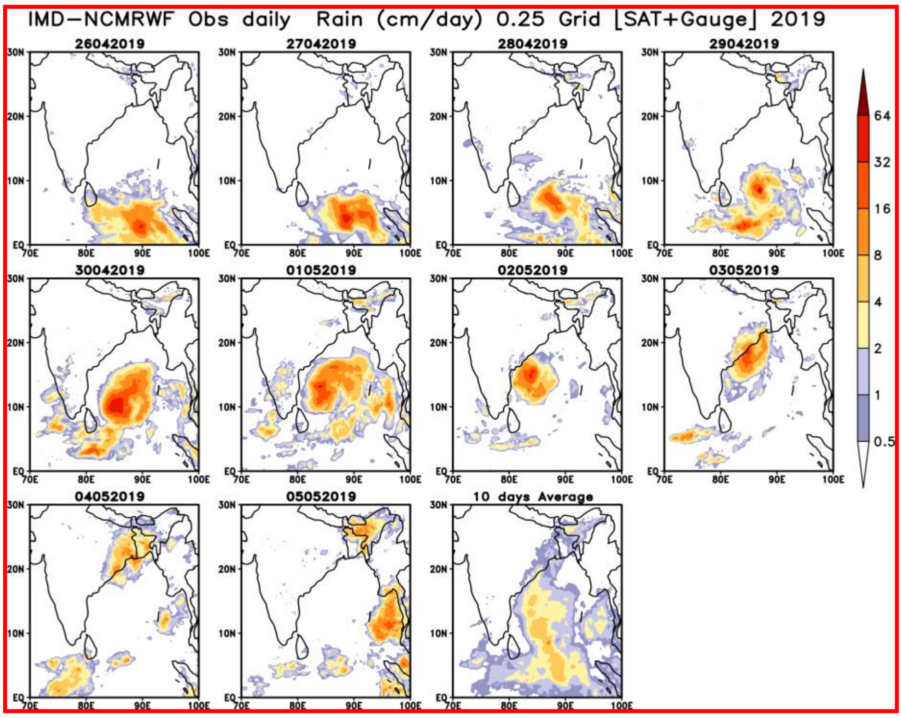


Fig.9: IMD-NCMRWF GPM merged gauge rainfall during 26th April - 5th May and 7 days average rainfall (cm/day)

It indicates occurrence of heavy to very heavy rainfall over coastal Odisha and Gangetic West Bengal on 3rd May, heavy rainfall at a few places over north coastal Odisha, Gangetic West Bengal and adjoining Bangladesh on 4th and heavy rainfall at a few places over Bangladesh and adjoining areas of northeastern states of Assam, Meghalaya & Arunachal Pradesh on 5th May.

Realized 24 hrs accumulated rainfall (≥7cm) ending at 0300 UTC of date during the life cycle of the system is presented below:

1 May 2019

Andaman & Nicobar Islands: Maya Bandar-7

2 May 2019

Arunachal Pradesh: Hawai-8.
Assam & Meghalaya: Sohra & Mawsynram-14 each, Bahalpur & Dholla Bazar-9 each, Margherita-8, Halflong, Majbat, Dillighat, Khowang, Tamulpur, & Dhubri-7 each.
Nagaland, Manipur, Mizoram & Tripura: Tizit -14 and Tuli -8

3 May 2019

Arunachal Pradesh: Hawai-8
Assam & Meghalaya: Gossaigaon-16, Kokrajhar-10, Hazuah-7
Sub-Himalayan West Bengal & Sikkim: Alipurduar (PTO) & Alipurduar (CWC)-7 each
Odisha: Berhampur-30, Gopalpur & Banki (ARG)-17 each, Chhatrapur-15, Mundali-12, Purushottampur, Mohana, Puri, Ranpur, & R.Udaigiri-11 each, Rajghat-10, Nuagada

(ARG)-9, Tirtol (ARG), Digapahandi (ARG), Balasore, & Gania (ARG)-8 each, Banpur, Aska, NH-5 Gobindpur, Khandapara, Narsinghpur, Naraj, & Niali (ARG)-7 each
Bihar: Galgalia-14
Coastal Andhra Pradesh: Ichchapuram-18, Sompeta-17, Palasa-15, Mandasa-13, Tekkali-12, Kalingapatnam-9.

4 May 2019
Arunachal Pradesh: Tuting-9
Assam & Meghalaya: Williamnagar-8, Mawsynram-7
Nagaland, Manipur, Mizoram & Tripura: Arundhutinagar-9, Sonamura-8 and Agartala AERO, Amarpur & Kamalpur-7 each.
Gangetic West Bengal: Bankura-16, Kalaikunda-15, Kansabati Dam-14, Harinkhola & Phulberia-13 each, Hetampur & Suri -12 each, Bankura, Suri & Durgapur-11 each, Rampurhat-10, Sri Niketan, Jhargram, Simula, Kharidwar, Berhampore, Asansol, & Tantloi-9 each, Midnapore, Mohanpur, Asansol & Lalgarh-8 each and Tusuma, Tilpara Barrage, Durgachack, Bagati, Purulia, Bardhman, Canning, Alipore, & Purihansa-7 each.
Odisha: Chandikhol-18, Bhuban & Bhubaneswar -16 each, Jajpur-15, Binjharpur & Samakhunta -14 each, Cuttack & Jenapur-13 each, Hindol & Remuna -12 each, Korei & Kaptipada-11 each, Keonjhargarh, Sukinda & Rairangpur-10 each, Nilgiri & Jaleswar-9 each, Soro-8 and Dhenkanal, Joshipur, & Bari-7 each.
Jharkhand: Ghatsila, Messenjor, & Maheshpur-9 each, Dhanbad-8 and Maithon, Rajmahal, Jarmindi, & Moharo-7 each.
5 May 2019
Assam & Meghalaya: Sohra-41, Mawsynram-33, Williamnagar-17, Shillong C.S.O.-13, Guwahati City-11, Kheronighat & Barapani-9 each, Guwahati, Dharamtul, Barpathar, & Kampur-8 each and Jia Bharali N T Xing, Bokajan, Karimganj, Shella, & Numaligarh-7 each.
Nagaland, Manipur, Mizoram & Tripura: Tamenglongi-13 and Sabroom-9

7.2. Realised Wind

Realised estimated maximum sustained surface wind was 175-185 kmph gusting to 205 kmph at the time of landfall close to Puri.

7.3. Realised storm surge: Storm surge height is estimated to be about 1.5 m above the astronomical tide at the time of landfall.

8. Damage due to ESCS, FANI

As per media reports (Times of India dated 13th May, 2019), Odisha Government reported 64 deaths due to ESCS FANI. There was no loss of lives in Andhra Pradesh and West Bengal. To prevent loss of human lives, a record number of 15,57,170 persons in Odisha, 17,460 persons in Andhra Pradesh and 2,34,801 persons in West Bengal were evacuated to safer places (Business Standard dated 25th June, 2019).

As per report in Business Standard dated 25th June, FANI caused damage in Andhra Pradesh, Odisha and West Bengal as per details below:

Odisha: 556,000 houses and huts were damaged, 6,281 cattle were lost, 148,663 hectare of crop land was affected and 6,416 boats & 8,828 nets were damaged. In addition, infrastructure like roads, power, railway, telecommunications etc. were also damaged in Odisha.

Andhra Pradesh: A total of 222 houses/huts were damaged, 28 cattle were lost and 1,365 hectare crop area was damaged.

West Bengal: 29,260 houses/huts were damaged and 1,12,000 hectare of crop area was affected due to the cyclone Fani.

Fig. 9: (a) Ravaged Puri (Sambad English Bureau, 6th May), (b) Debris littered train track in Puri (Dibyangshu Sarkar/AFP, SNS Web, 11 June), (c) Severely ravaged Bhubaneswar airport (ANI), (d) damaged structures in Puri (PTI) and (e) ravaged trees in Bhubaneswar (PTI)

9. Performance of operational NWP models—Inputs not received

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 ESCS FANI are presented and discussed in following sections.

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

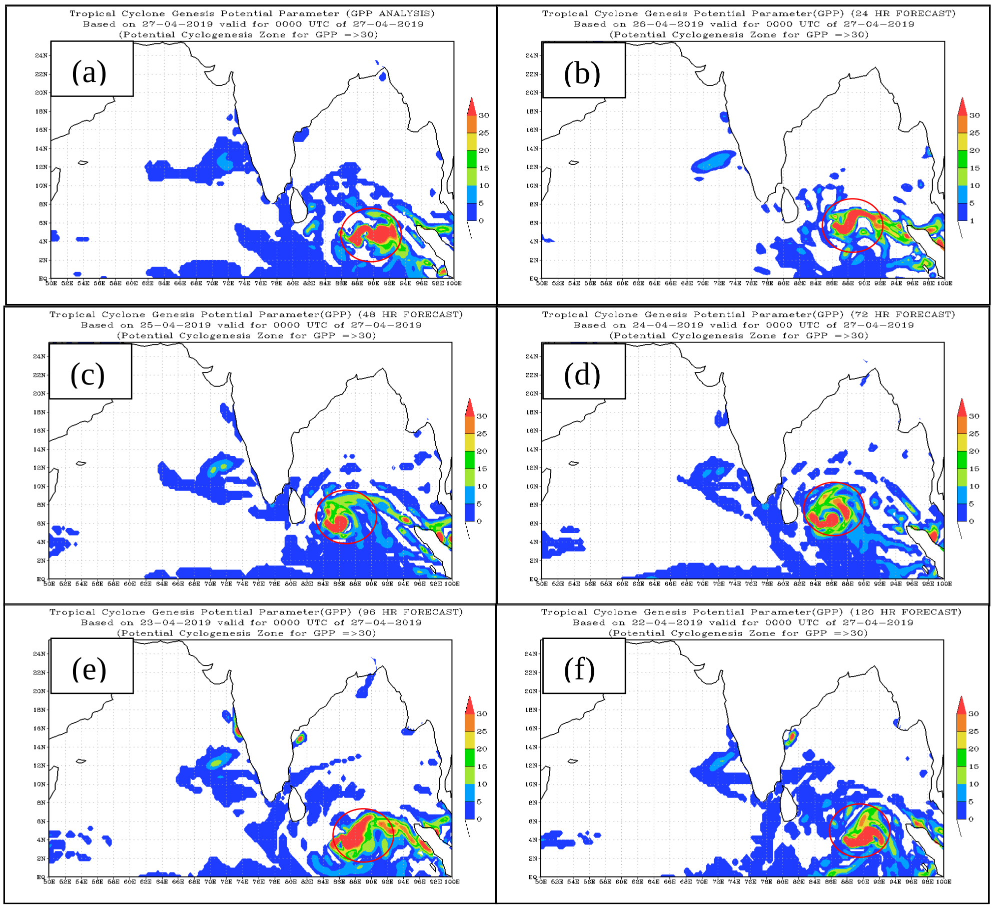


Fig.11 (a-f): Predicted zone of cyclogenesis for 0000 UTC of 27th April based on 0000 UTC of 22nd-27th April 2019

Fig. 11 (a-f) indicates that the GPP could predict the potential zone for cyclogenesis on 27th over central parts of south BoB and adjoining EIO about 120 hours in advance. However, genesis actually occurred on 26th.

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 during 25th – 27th April is presented in Fig. 12. The area average analysis was predicting the system to develop into a cyclonic storm since 25th April onwards.

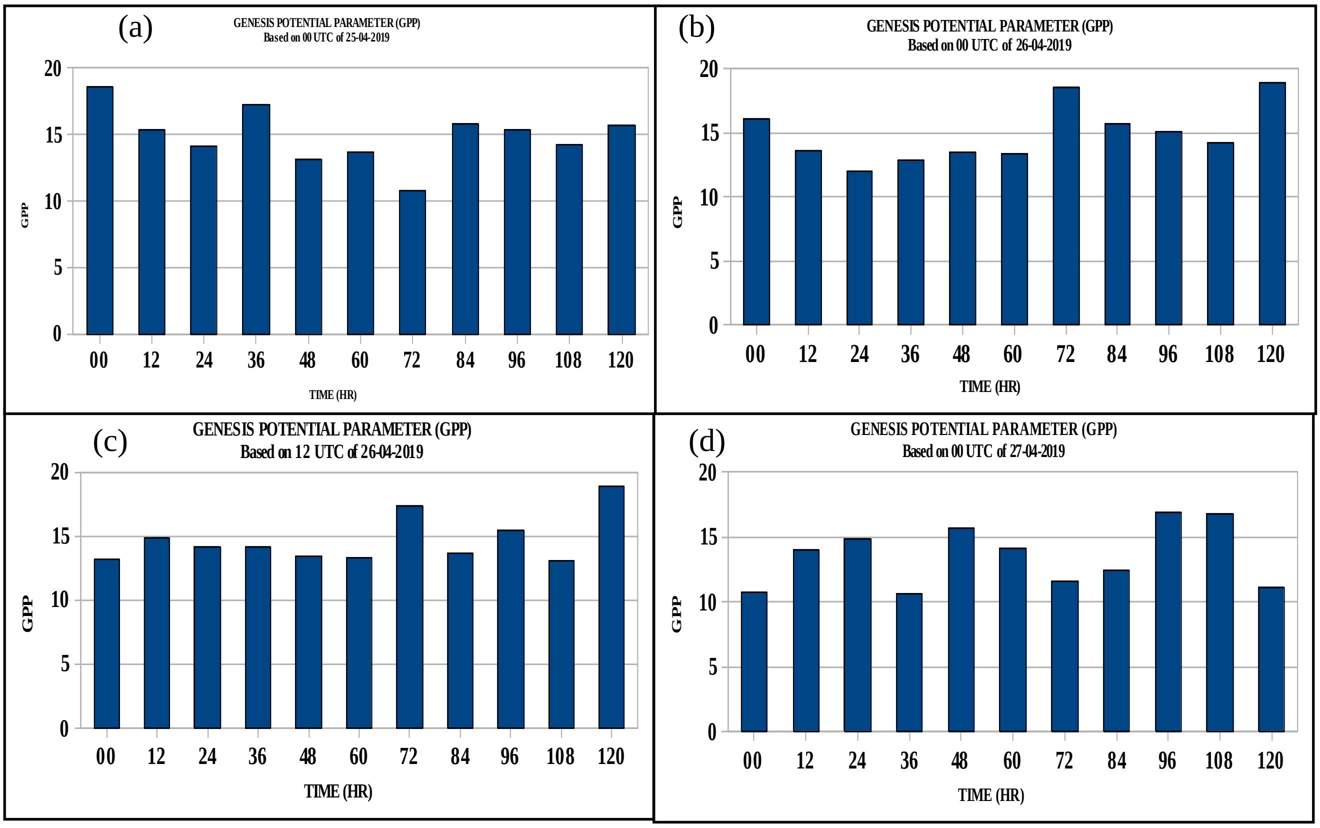
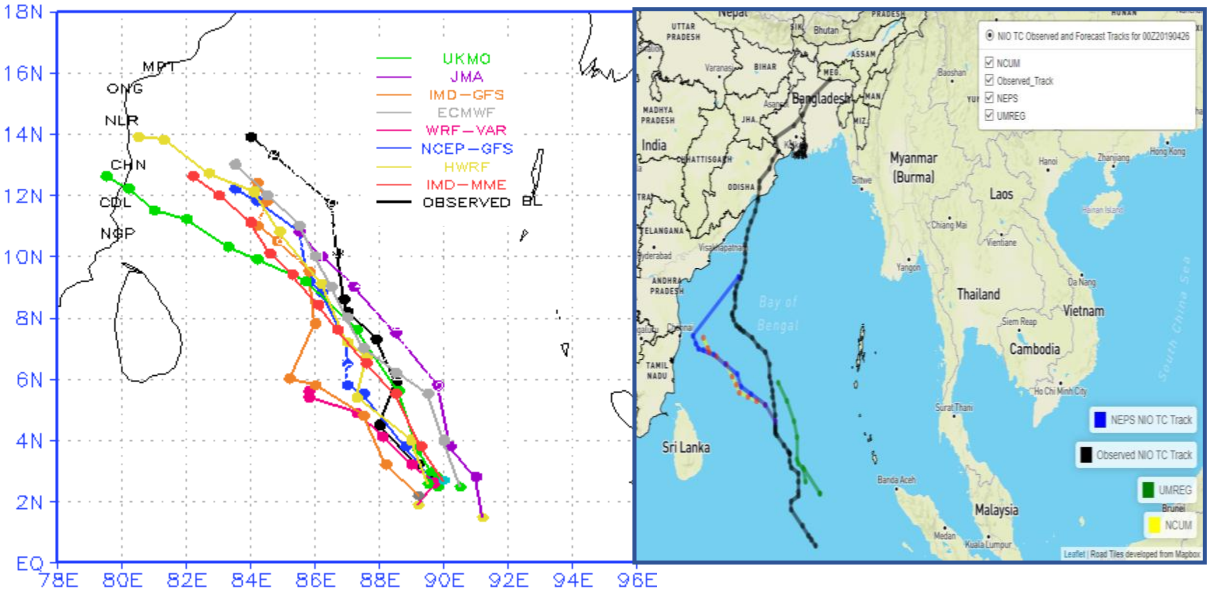
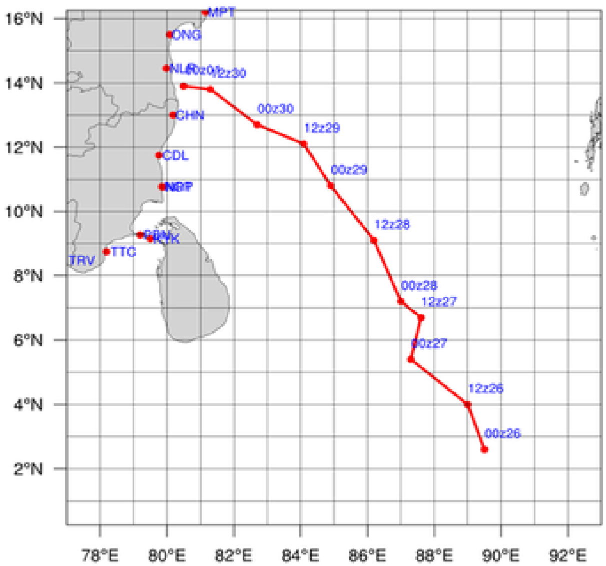


Fig. 12: Area average analysis and forecasts of GPP based on (a) 0000 of 25th, (b) 0000 UTC of 26th, (c) 1200 UTC of 26th and (d) 0000 UTC of 27th April, 2019

9.2 Track prediction by NWP models

Tracks predicted by various NWP models including IMD GFS, IMD MME, IMD HWRF, WRF-VAR, NCMRWF Unified Model (NCUM), UM Regional, NCMRWF Ensemble Prediction System (NEPS), NCEP GFS, ECMWF, UKMO and JMA during 26th April to 3rd May are presented in **Fig.13**. Based on initial conditions of 0000 UTC of 26th April, most of the models were predicting movement towards southwest BoB. UKMO was predicting landfall near Chennai. NEPS was predicting initial northwestwards movement towards Tamil Nadu with northeastwards re-curvature. IMD-HWRF was predicting movement towards south Andhra Pradesh coast and intensification upto very severe cyclonic storm stage (83 kt).

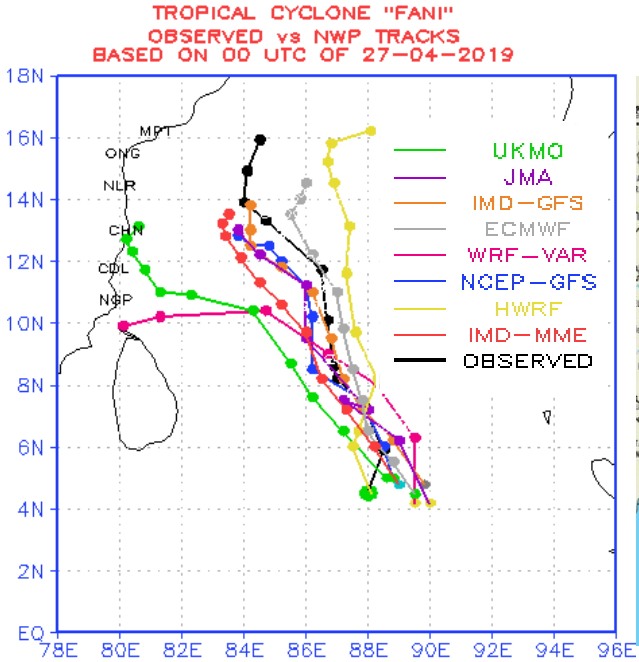


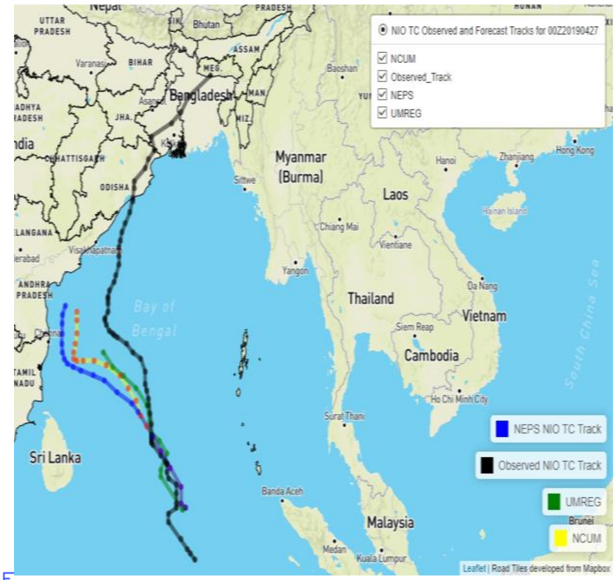


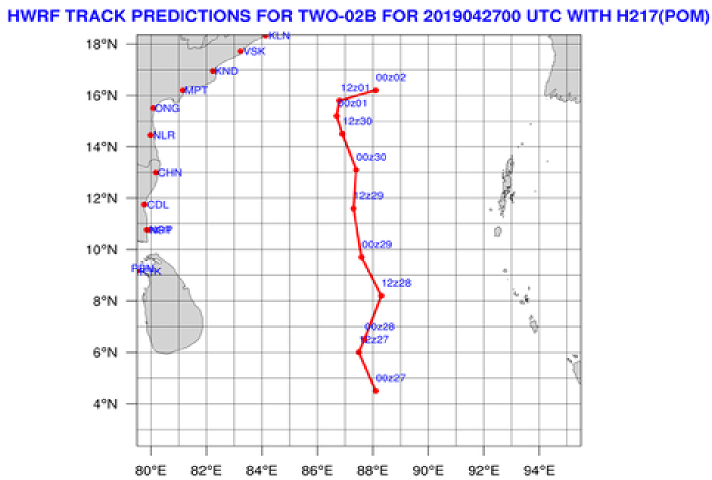
Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z26	2.60	89.5	1002.	28
12z26	4.00	89.0	1002.	39
00z27	5.40	87.3	996.0	49
12z27	6.70	87.6	1000.	48
00z28	7.20	87.0	998.0	44
12z28	9.10	86.2	999.0	45
00z29	10.8	84.9	1000.	47
12z29	12.1	84.1	994.0	42
00z30	12.7	82.7	988.0	55
12z30	13.8	81.3	976.0	82
00z01	13.9	80.5	967.0	83

Fig. 13 (a): Tracks of various models based on 0000 UTC of 26th April, 2019

Based on initial conditions of 0000 UTC of 27th April, most of the models were predicting initial north-northwestwards movement followed by northwards recurvature towards westcentral BoB. UKMO was predicting landfall near Chennai. WRF-VAR was predicting movement towards south Tamil Nadu. NCUM and NEPS were predicting initial northwestwards movement with northwards re-curvature. IMD-HWRF was predicting maximum intensification upto extremely severe cyclonic storm stage.







Dt/Hr.	Lat.	Lon.	MSLP	Vmax
00z27	4.50	88.1	1003.	29.
12z27	6.00	87.5	1001.	38.
00z28	6.50	87.7	1000.	40.
12z28	8.20	88.3	998.0	42.
00z29	9.70	87.6	993.0	42.
12z29	11.6	87.3	989.0	46.
00z30	13.1	87.4	979.0	72.
12z30	14.5	86.9	960.0	100
00z01	15.2	86.7	950.0	116
12z01	15.8	86.8	960.0	81.
00z02	16.2	88.1	965.0	82.

Fig. 13 (b): NWP model track forecast based on 0000 UTC of 27th April, 2019

Based on initial conditions of 0000 UTC of 28th April, all the models were predicting initial northwestwards movement followed by northwards/northeastwards recurvature towards westcentral BoB. IMD-HWRF was predicting maximum intensification upto super cyclonic storm stage. NEPS was indicating 40-60% strike probability near north Andhra Pradesh coast.

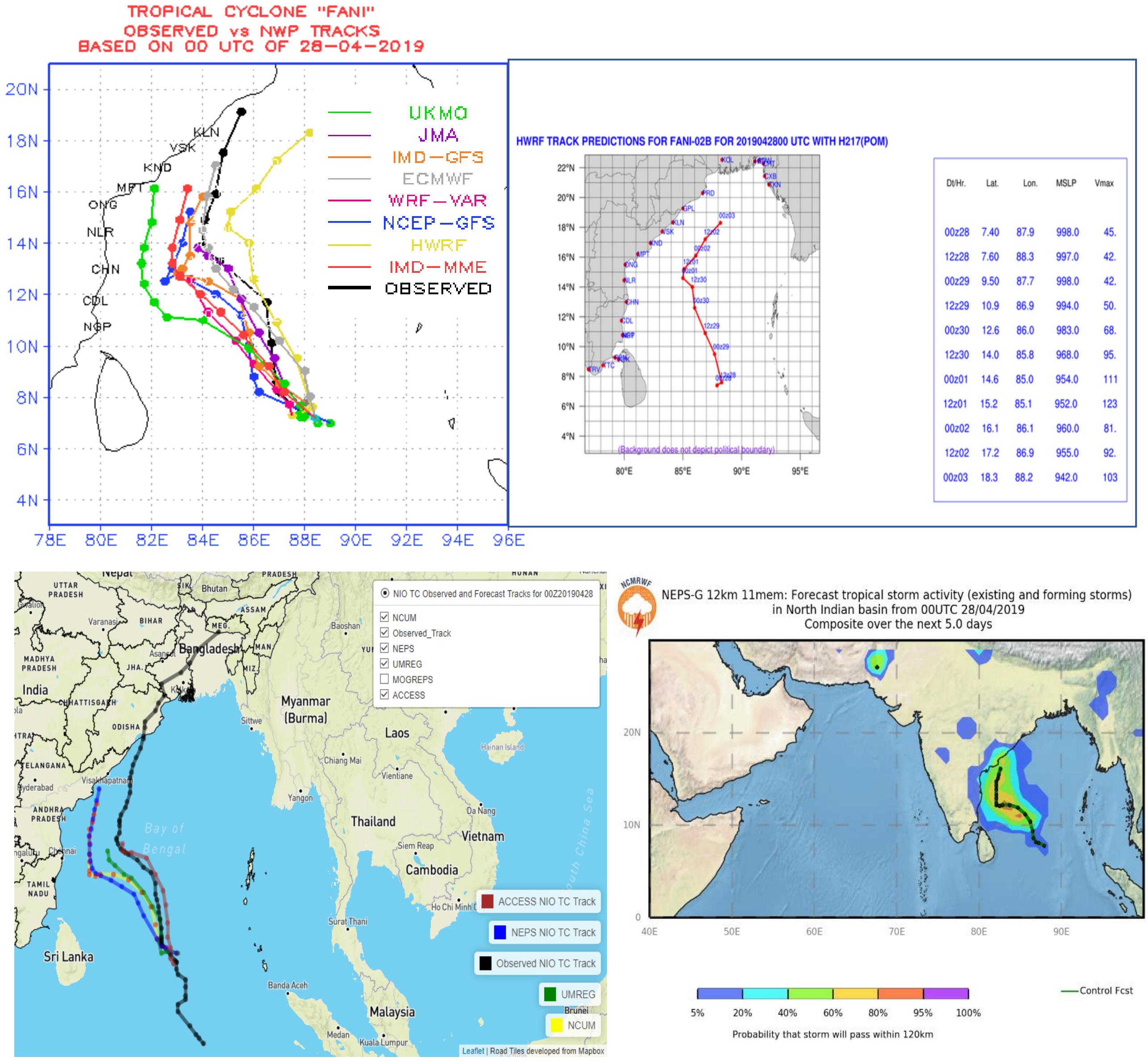


Fig. 13 (c): NWP model track forecast based on 0000 UTC of 28th April, 2019

Based on initial conditions of 0000 UTC of 29th April, most of the models were predicting initial northwestwards movement followed by north-northeastwards recurvature and landfall near Gopalpur. IMD-MME was predicting landfall near Gopalpur. ECMWF and IMD-HWRF were predicting landfall near Paradeep. NEPS was indicating 60-80% strike probability near Gopalpur. HWRF was predicting maximum intensification upto super cyclonic storm stage.

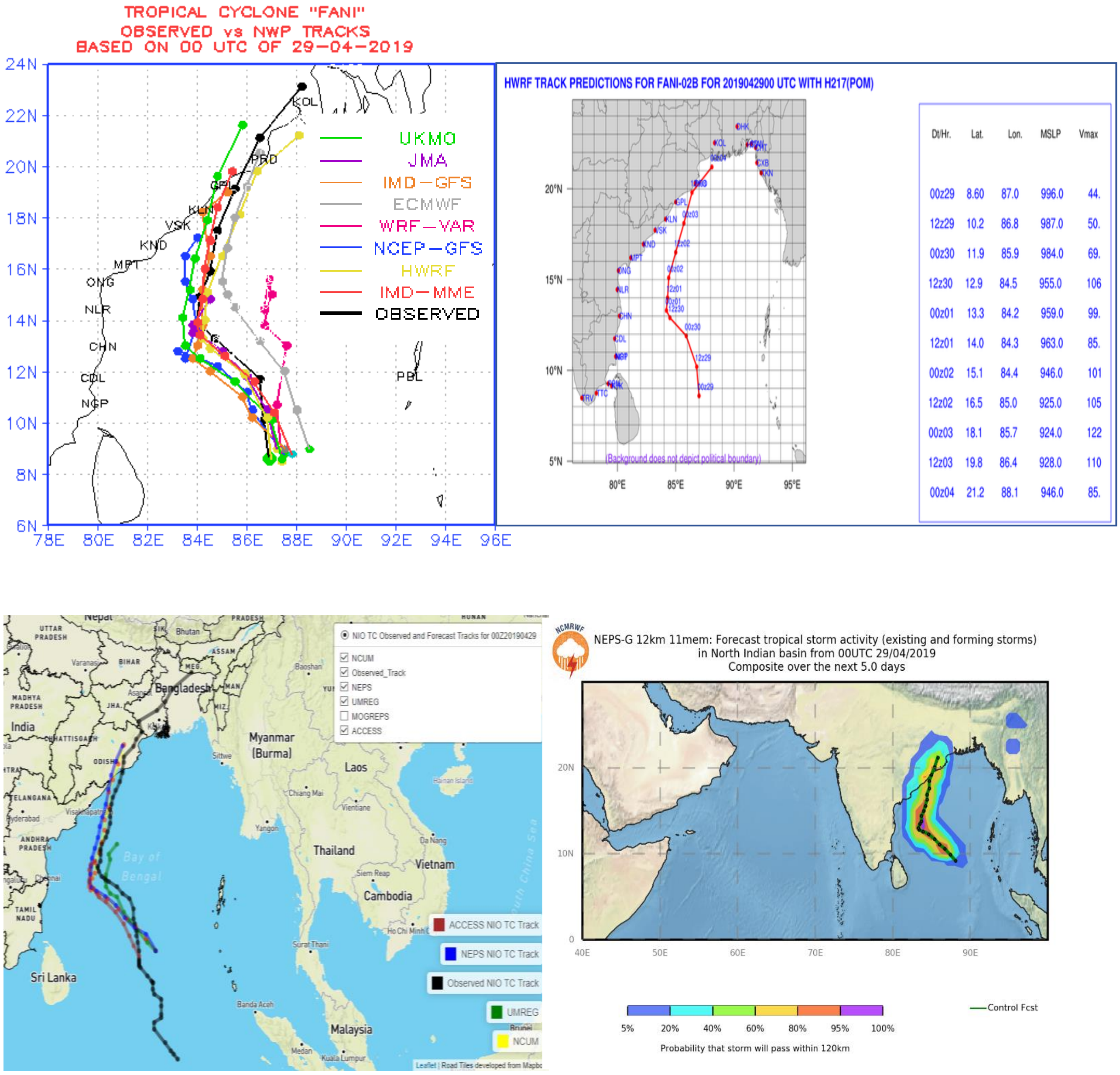


Fig. 13 (d): NWP model track forecast based on 0000 UTC of 29th April, 2019

At 0000 UTC of 30th April, models guidance converged and most of the models were predicting initial northwestwards movement followed by north-northeastwards recurvature and landfall to the north of Gopalpur. IMD-MME was predicting landfall near Gopalpur. IMD-HWRF was predicting landfall over West Bengal coast. NEPS was indicating 60-80% strike probability near Gopalpur. HWRF was predicting maximum intensification upto super cyclonic storm stage.

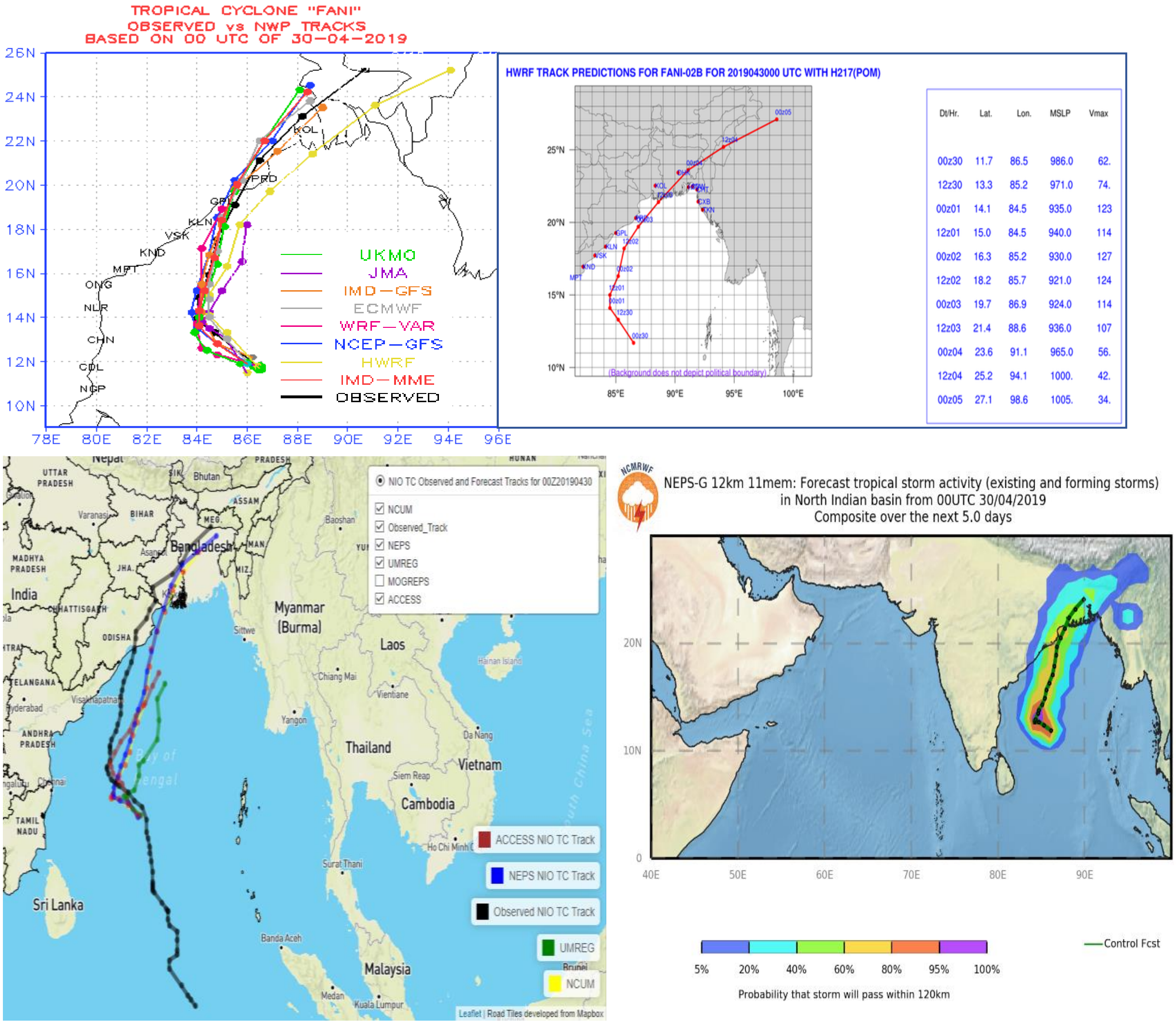


Fig. 13 (e): NWP model track forecast based on 0000 UTC of 30th April, 2019

At 0000 UTC of 1st May, most of the models were predicting landfall to the north of Gopalpur. IMD-MME was predicting landfall near Gopalpur. UKMO was predicting landfall near Kalingapatnam. IMD-HWRF was predicting landfall over West Bengal coast. JMA was predicting weakening over Sea. NEPS was indicating 60-80% strike probability near Gopalpur.

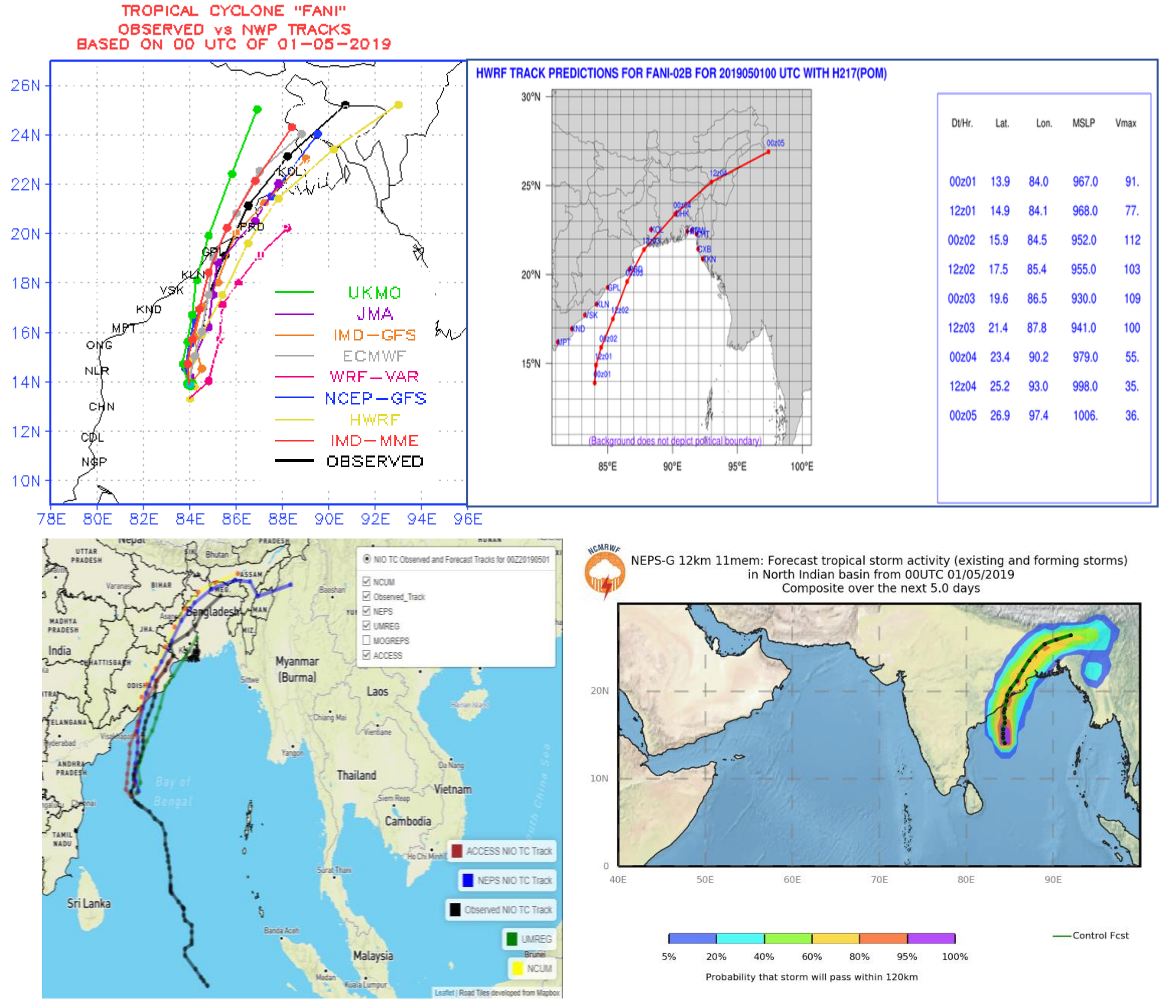


Fig. 13 (f): NWP model track forecast based on 0000 UTC of 1st May, 2019

At 0000 UTC of 2nd May, all the models were predicting landfall to the north of Gopalpur. NEPS was indicating 95-100% strike probability near Gopalpur.

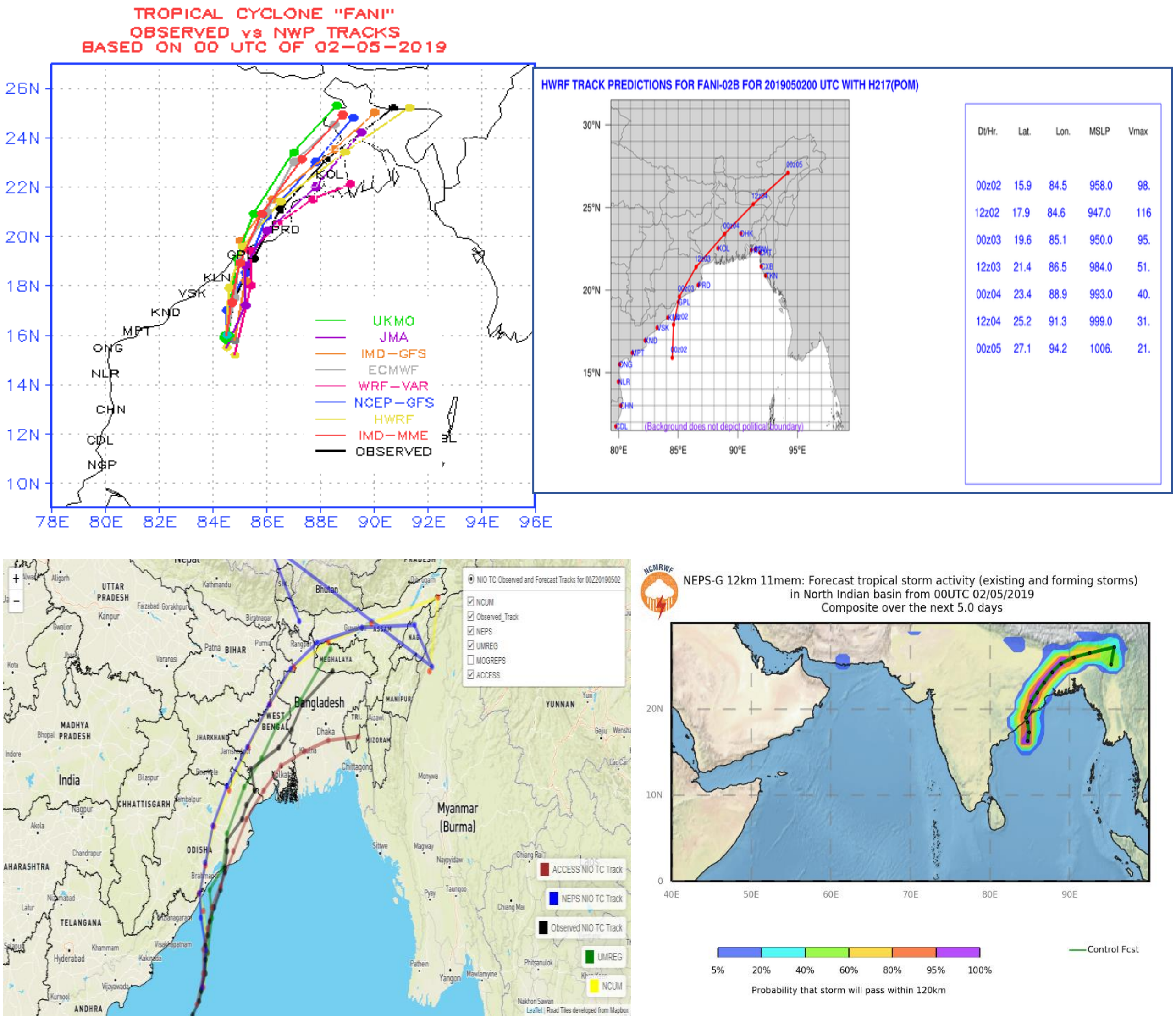


Fig. 13 (g): NWP model track forecast based on 0000 UTC of 2nd May, 2019

Thus, from 29th April onwards, models started predicting landfall near Gopalpur.

9.2. Track forecast errors:

Average track forecast errors by various NWP models is presented in Table 2a. For 24 hrs lead period track forecast error was the least i.r.o. MME followed by HWRF and IMD GFS. For 48 hrs lead period, the track forecast error was the least i.r.o. IMD HWRF followed by ECMWF & MME and IMD GFS. For 72 hours lead period, the error was the least i.r.o. ECMWF followed by MME, HWRF and IMD GFS. For 96 and 120 hrs lead period, error was the least in case of ECMWF and HWRF. The along track and cross track errors by different models are presented in Table 2 b & c.

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	108 H	120H
IMD-MME	50(14)	55(14)	78(14)	111(14)	136(13)	165(12)	196(11)	229(10)	276(9)	362(8)
ECMWF	93(14)	92(14)	75(14)	100(14)	101(13)	111(12)	120(11)	137(10)	180(9)	238(8)
NCEP-GFS	71(14)	79(14)	102(14)	123(14)	146(13)	168(12)	221(11)	272(10)	346(9)	477(8)
UKMO	76(14)	111(14)	160(14)	202(14)	253(13)	284(12)	318(11)	338(10)	366(9)	434(8)
JMA	75(14)	90(14)	110(14)	130(14)	166(13)	221(12)	250(11)	-	-	-
IMD-GFS	70(14)	71(14)	105(14)	129(14)	110(13)	160(12)	206(11)	235(10)	267(9)	336(8)
WRF-VAR	105(14)	112(14)	146(14)	237(14)	303(13)	335(12)	-	-	-	-
IMD-HWRF	61(29)	63(29)	70(29)	84(27)	111(25)	138(23)	146(21)	159(19)	171(17)	224 (15)
NCUM	-	88(14)	-	165(13)	-	213(12)	-	240(11)	-	312(9)
NEPS	-	96(12)	-	133(10)	-	140(8)	-	183(6)	-	302(4)
UM REG	-	95(7)	-	127(8)	-	194(7)	-	-	-	-

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

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H	120H
IMD-MME	38	33	44	65	83	113	139	167	191	235
ECMWF	74	79	64	87	65	59	66	72	84	124
NCEP-GFS	58	45	67	62	71	103	135	169	204	246
UKMO	62	70	98	146	195	233	272	297	317	369
JMA	47	47	45	40	42	63	87	-	-	-
IMD-GFS	52	36	74	78	57	83	115	113	107	125
WRF-VAR	67	59	91	150	205	216	-	-	-	-

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

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H	120H
IMD-MME	25	38	58	80	96	108	126	136	183	258
ECMWF	42	34	30	41	66	86	93	106	154	197
NCEP-GFS	28	59	64	92	123	122	159	201	270	400
UKMO	31	64	110	121	127	126	132	121	147	202
JMA	46	68	90	114	156	198	215	-	-	-
IMD-GFS	34	56	61	74	83	120	149	183	234	304
WRF-VAR	62	83	91	157	183	210	-	-	-	-

9.3. Landfall forecast errors:

Average model errors in landfall point and time are presented in Table 4 (a & b). The tables indicate that many models like NCEP GFS, JMA, IMD-GFS, WRF-VAR, IMD-HWRF didn't predict landfall till 0000 UTC of 29th April. The landfall point errors of IMD GFS and NCEP GFS were significantly less as compared to other models. The landfall time errors were the least by IMD HWRF upto 72 hours lead period.

Table- 4a: Landfall point forecast errors (km) of NWP Models at different lead time (hour)

Forecast Lead Time (hour) →	15.5 h (02May/ 12z)	27.5 h (02May/ 00z)	39.5 h (01May/ 12z)	51.5 h (01May/ 00z)	63.5 h (30April /12z)	75.5 h (30April /00z)	87.5 h (29April /12z)	99.5 h (29April /00z)
ECMWF	45	50	45	32	46	12	12	55
NCEP GFS	12	5	32	21	172	50	12	NLF
UKMO	12	95	179	172	5	21	35	149
JMA	45	5	27	45	NLF	NLF	NLF	NLF
IMD-GFS	72	74	32	32	12	21	225	NLF
WRF-VAR	35	5	NLF	NLF	NLF	NLF	NLF	NLF
IMD-MME	22	59	89	55	12	22	12	32
IMD-HWRF	42	80	64	326	366	378	282	NLF

Table-4b. Landfall time forecast errors (hour) at different lead time (hr)
('+' indicates delay landfall, '-' indicates early landfall)

Forecast Lead Time (hour) →	15.5 h (02May/ 12z)	27.5 h (02Mayl /00z)	39.5 h (01May/ 12z)	51.5 h (01May/ 00z)	63.5 h (30April /12z)	75.5 h (30April /00z)	87.5 h (29April /12z)	99.5 h (29April /00z)
ECMWF	-2.5	-0.5	-1.5	-0.5	+16.5	+4.5	+2.5	+14.5
NCEP GFS	+4.5	+2.5	+3.5	+6.5	+1.5	+4.5	+15.5	NLF
UKMO	-0.5	-1.5	-0.5	-0.5	+5.5	+8.5	+7.5	+2.5
JMA	+1.5	+3.5	+1.5	+12.5	NLF	NLF	NLF	NLF
IMD-GFS	+1.5	-6.5	-0.5	+7.5	+2.5	+8.5	-1.5	NLF
WRF-VAR	+7.5	-0.5	NLF	NLF	NLF	NLF	NLF	NLF
IMD-MME	+0.5	-0.5	-1.5	+3.5	+5.5	+7.5	+8.5	+19.5
IMD-HWRF	3	3	3	15	12	12	12	--

9.4. Intensity forecast errors by various NWP Models

The intensity forecasts errors of various models are presented in Table 5. It is seen that upto 24hrs lead period and for longer lead period (beyond 96 hrs), MME based errors were less than HWRF errors. However, for 36 to 84 hrs lead period, intensity forecast errors by IMD HWRF were lesser than MME.

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

Lead time →	12H	24H	36H	48H	60H	72H	84H	96H	108 H	120H
IMD-SCIP (AAE)	6.1 (14)	8.2 (13)	15.0 (12)	15.8 (11)	11.4 (10)	15.8 (9)	16.3 (8)	13.6 (7)	14.5 (6)	17.8 (5)
IMD-HWRF (AAE)	10.4 (29)	11.9 (29)	12.9 (29)	7.6 (27)	12.9 (25)	12.9 (23)	16.9 (21)	17.3 (19)	24.5 (17)	29.3 (15)
IMD-SCIP (RMSE)	7.5 (14)	12.2 (13)	17.5 (12)	17.4 (11)	15.0 (10)	19.7 (9)	18.6 (8)	17.9 (7)	15.4 (6)	21.6 (5)
IMD-HWRF (RMSE)	12.0 (29)	15.1 (29)	15.6 (29)	9.9 (27)	15.1 (25)	15.8 (23)	19.3 (21)	19.8 (19)	30.1 (17)	32.1 (15)

Intensity forecast by IMD Statistical Cyclone Intensity Prediction (SCIP) model is presented in Fig. 14(a). It is seen that upto 72 hrs lead period, IMD SCIP correctly predicted the intensity of the system. However, for longer lead period, it most of the times underestimated the intensity of the system. The landfall intensity forecast by IMD SCIP model is presented in Fig. 14(b). It is seen that most of the times IMD-SCIP underestimated the intensity at the time of landfall i.r.o. the system. However, at 1200 UTC of 30th (about 63 hours prior to landfall) it correctly predicted the intensity at the time of landfall.

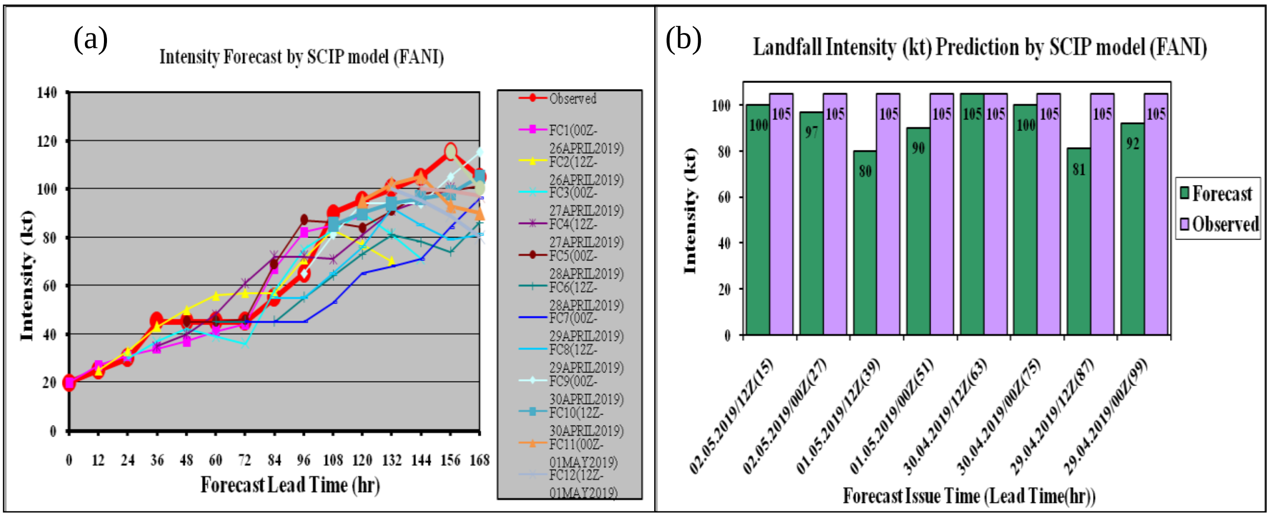


Fig.14: (a) Intensity forecast based on 0000 and 1200 UTC during 26th April to 1st May and (b) Landfall intensity prediction by SCIP Model

Predicted intensity by NCUM, NEPS, ACCESS and UM Regional Models based on 0000 UTC during 28th April to 2nd May is presented in Fig. 15. For all lead periods it is seen that these models underestimated the intensity of the system.

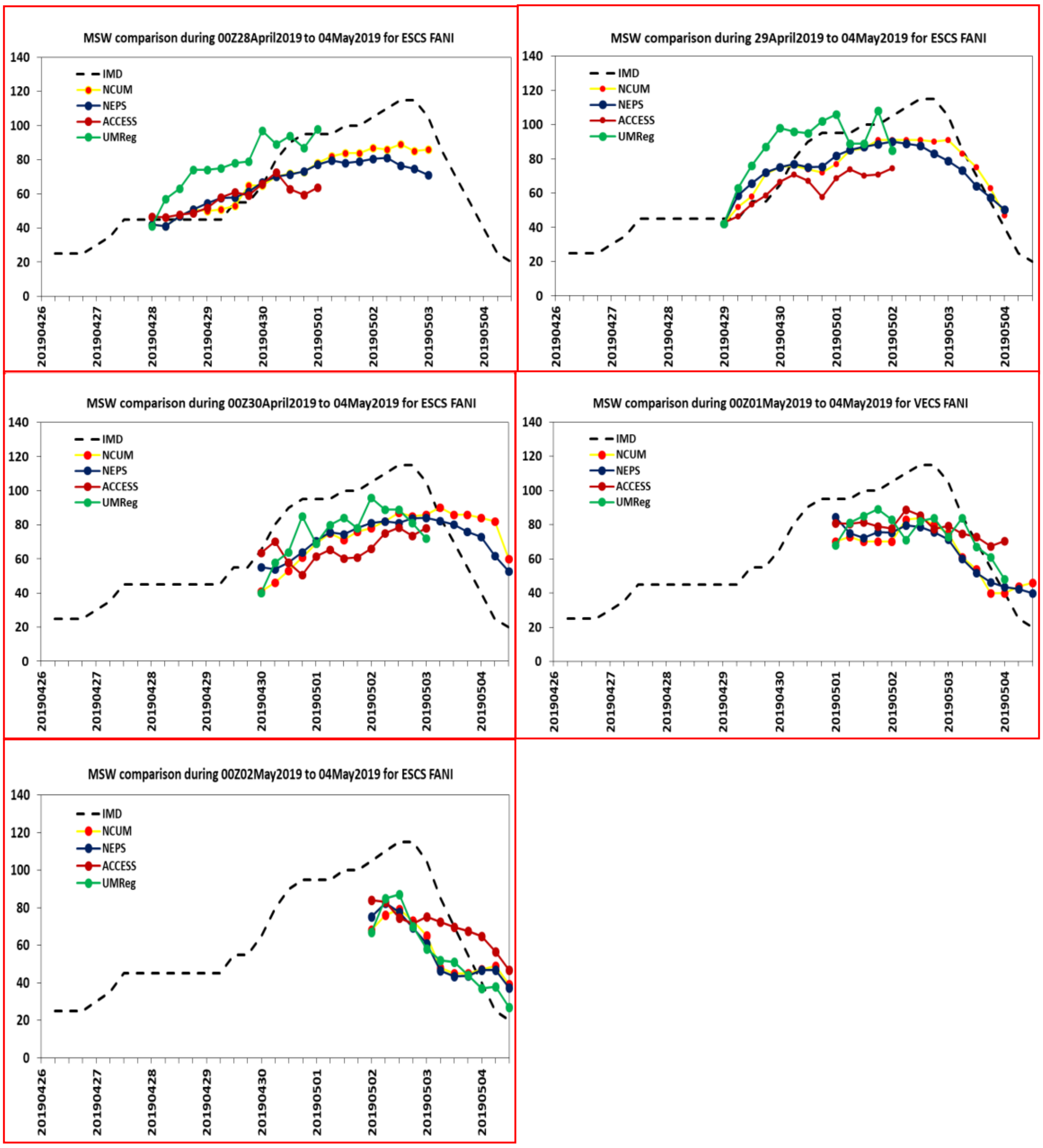


Fig.15: Intensity forecast based on 0000 UTC during 28th April to 2nd May.

10. Operational Forecast Performance

10.1. Genesis Forecast

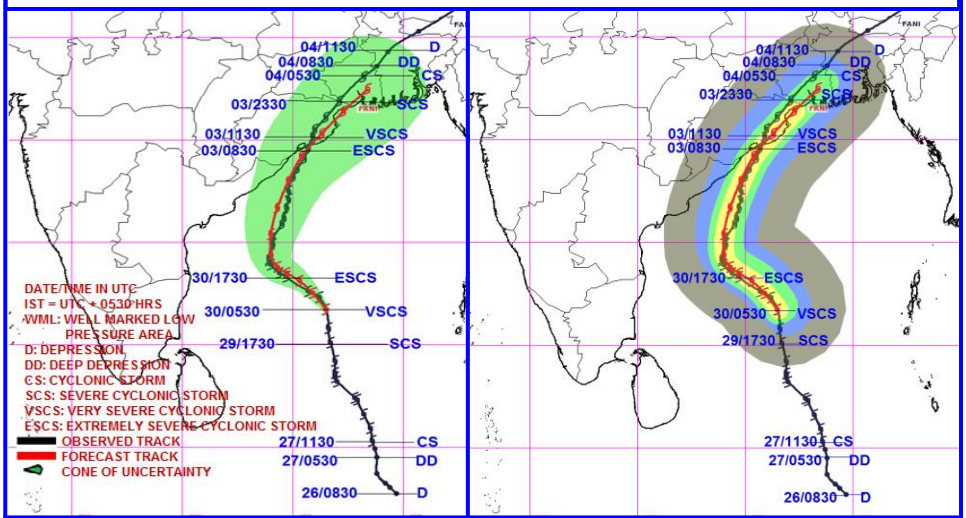
- First information about formation of LPA over EIO & adjoining south BoB during week ending 25th and beginning of week ending at 2nd May with probability of intensification into depression was indicated in the extended range forecast issued on 18th April.
- Likely formation of LPA over EIO & adjoining southwest BoB to the southeast of Sri Lanka around 26th April & intensification into D on 27th was predicted on 21st.
- The forecast was further modified on 22nd indicating an LPA over the same region on 25th April with likely intensification into a D during subsequent 48 hours.
- On 23rd, it was further informed that LPA is very likely to develop on 25th April, intensify into a depression on 26th and subsequently into a CS during next 48 hrs.
- On 25th, an LPA formed over EIO & adjoining southeast BoB. It was also predicted that it would intensify into a depression by 26th and into a CS during subsequent

48 hours. The LPA concentrated into D in morning of 26th April 2019. It was predicted that by 27th April morning it will intensify into a DD and into a CS by 27th April evening while moving northwestwards. Depression intensified into DD in early morning of 27th and into a CS by same afternoon.

10.2. Landfall Forecast

- First information issued at 0900 UTC of 29th April (about 90 hrs prior to landfall) indicated that the system would move northwestwards till 1st May and recurve north-northeastwards towards Odisha coast.
- It was further indicated at 1530 UTC of 29th that the system would cross Odisha coast around Puri in the early morning of 4th May (about 84 hrs prior to landfall) as an extremely severe cyclonic storm with maximum sustained wind speed of 160-170 kmph gusting to 190 kmph.
- The bulletin issued at 1000 UTC of 30th indicated that the system would cross Odisha coast between Gopalpur and Chandbali, to the south of Puri around 3rd May afternoon with wind speed of 175-185 kmph gusting to 205 kmph (about 66 hrs prior to landfall).
- The bulletin issued at 1500 UTC of 1st May (36 hrs prior to actual landfall) indicated that the system would cross Odisha coast between Gopalpur and Chandbali, around Puri during 3rd May afternoon. The time of landfall was revised to 3rd May forenoon at 1030 UTC of 2nd May.
- Observed & forecast track based on 0000 UTC of 30th April (72 hrs prior to landfall) of ESCS FANI indicating accurate landfall prediction near Puri is presented in **Fig.16**.

Observed Track and Forecast based on 0530 hrs IST of 30th April (72 hrs prior to landfall) with cone of uncertainty & wind distribution



MSW(knot)/kmph)	Impact	Action
28-33 /(51–62)	Very rough seas.	Total suspension of fishing operations
34-49/(63-91)	High to very high seas	Total suspension of fishing operations
50-63/(92-117)	Very High seas	Total suspension of fishing operations
≥ 64 (≥118)	Phenomenal	Total suspension of fishing operations

Fig.16: Observed and forecast track based on 0530 hrs IST (0000 UTC) of 30th April (72 hrs prior to landfall) of ESCS FANI indicating accuracy in landfall predictions near Puri (Odisha)

- Typical observed and forecast tracks based on 0000 UTC of 30th April, 1st & 2nd May, 72 hrs, 48hrs & 24 hrs prior to landfall respectively indicating the consistency in track prediction is presented in **Fig.17.** IMD continuously predicted on 30th April, 1st & 2nd May that it will cross around Puri as an extremely severe cyclonic storm (ESCS) with wind speed of 175-185 kmph gusting to 205 kmph on 3rd May. The forecast issued on 30th April, 1st & 2nd May were almost same as actual track as shown in Fig 17.

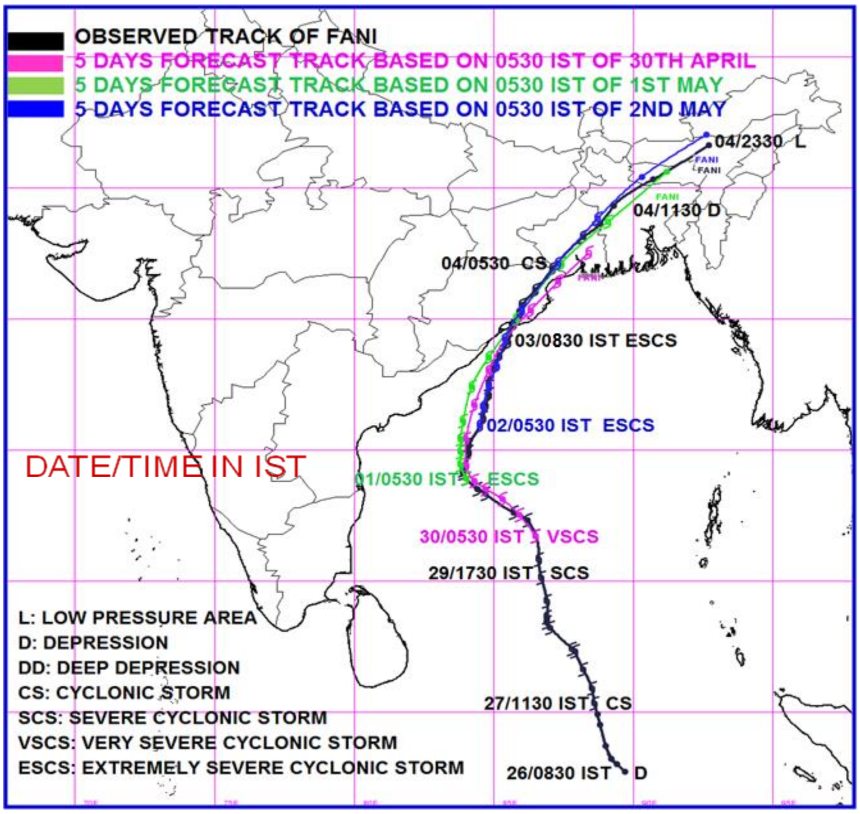


Fig. 17: Typical observed and forecast tracks based on 0000 UTC of 30th April, 1st & 2nd May, 72 hrs, 48hrs & 24 hrs prior to landfall indicating accuracy in landfall and track

10.3. Landfall Forecast Errors:

- The landfall point forecast errors for 24, 48 and 72 hrs lead period were 11.5, 11.5, and 15.0 km respectively against long period average errors of 46.6, 69.7 and 104.3 km during 2014-18.
- The landfall point forecast errors for 24, 48 and 72 hrs lead period were 1.5, 5.5, and 14.5 hours respectively against long period average errors of 2.9, 5.1 and 5.8 hours during 2014-18.
- The 120 hour landfall forecast errors of ESCS FANI in comparison to the long period average errors and skill during 2014-18 is presented in **Fig.18 and Table 6**.

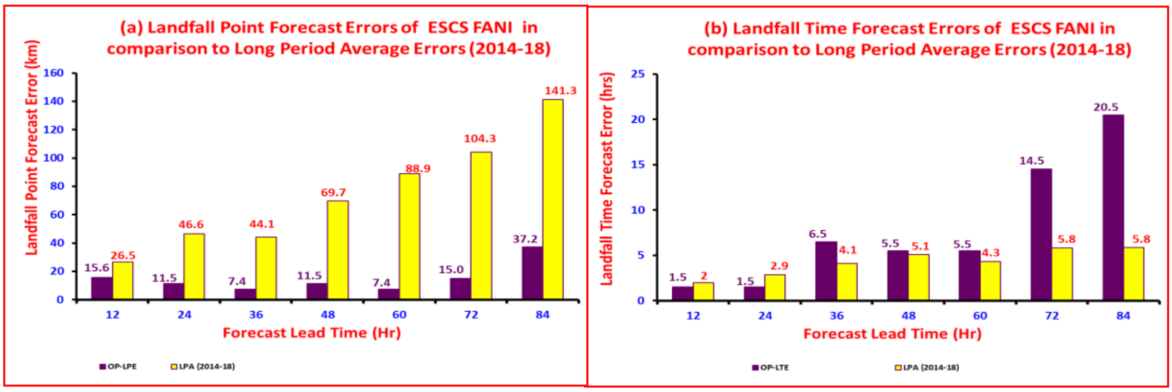


Fig. 18: Landfall forecast Errors and skill of ESCS FANI as compared to long period average (2014-18)

Table 6: Landfall point and time forecast errors of ESCS FANI as compared to long period average (LPA) errors during 2014-18

Lead Period (hrs)	Base Time	Landfall Point (^{0}N/^{0}E)		Landfall Time (hours)		Operational Error		LPA error (2014-18)	
		Forecast	Actual	Forecast	Actual	LPE (km)	LTE (hours)	LPE (km)	LTE (hours)
12	02/12	19.65/85.60	19.75/85.70	03/0500	03/0330	15.6	+1.5	26.5	2
24	02/00	19.72/85.60	19.75/85.70	03/0500	03/0330	11.5	+1.5	46.6	2.9
36	01/12	19.78/85.76	19.75/85.70	03/1000	03/0330	7.4	+6.5	44.1	4.1
48	01/00	19.72/85.60	19.75/85.70	03/0900	03/0330	11.5	+5.5	69.7	5.1
60	30/12	19.78/85.76	19.75/85.70	03/0900	03/0330	7.4	+5.5	88.9	4.3
72	30/00	19.79/85.83	19.75/85.70	03/1800	03/0330	15.0	+14.5	104.3	5.8
84	29/12	19.86/86.02	19.75/85.70	04/0000	03/0330	37.2	+20.5	141.3	5.8

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

10.4. Track Forecast Errors:

- The track forecast errors for 24, 48 and 72 hrs lead period were 77.7, 137.3, and 182.6 km respectively against the average track forecast errors of 86.1, 132.3, and 177.7 km during last five years (2014-18).
- The track forecast skill was about 57%, 61%, and 58% against the long period average (LPA) of 58%, 70%, and 74% during 2014-18 for 24, 48 and 72 hrs lead period respectively.
- The 120 hour track forecast errors and skill of ESCS FANI in comparison to the long period average errors and skill during 2014-18 is presented in **Fig.19 and Table 7**.

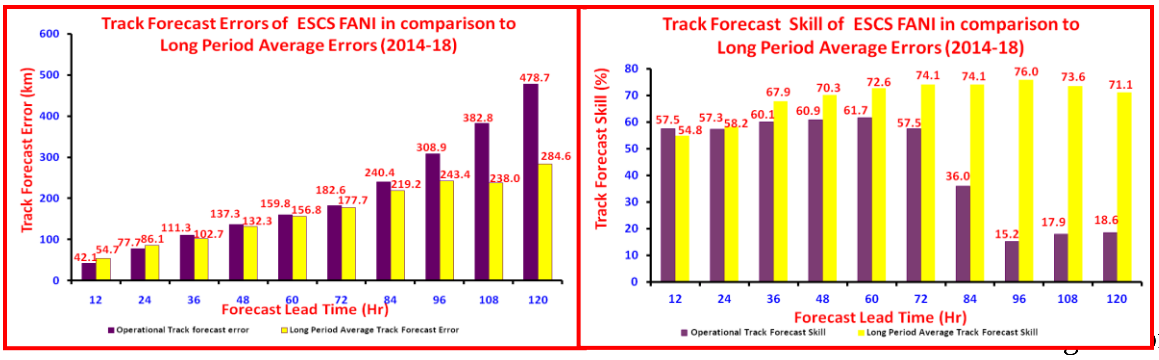


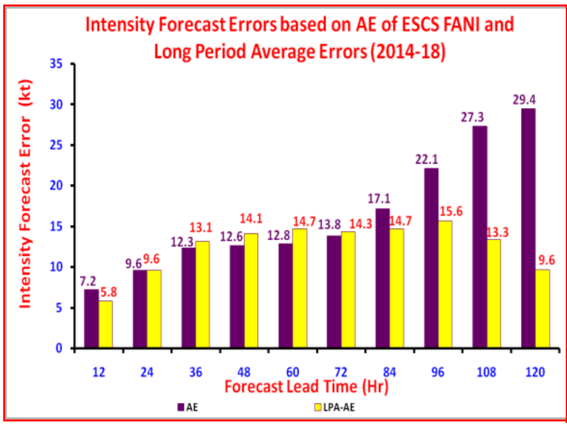
Fig. 19: Track forecast Errors and skill of ESCS FANI as compared to long period average (2014-18)

Table 7: 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	26	42.1	61.1	54.7	54.8
24	24	77.7	62.0	86.1	58.2
36	22	111.3	64.4	102.7	67.9
48	20	137.3	65.4	132.3	70.3
60	18	159.8	65.9	156.8	72.6
72	16	182.6	64.6	177.7	74.1
84	14	240.4	53.6	219.2	74.1
96	12	308.9	42.0	243.4	76.0
108	10	382.8	29.1	238.0	73.6
120	8	478.7	28.1	284.6	71.1

10.5. Intensity Forecast Errors:

- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 9.6, 12.6 and 13.8 knots against the LPA of 9.6, 14.1, and 14.3 knots respectively.
- The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 11.3, 13.5 and 14.8 knots against the LPA of 12.5, 19.0, and 19.0 knots respectively.
- The skill in intensity forecast based on AE for 24, 48 and 72 hrs lead period were 55.7, 67.0 and 77.0% against the LPA of 42.6, 68.1, and 72.3 knots respectively.
- The skill in intensity forecast based on RMSE for 24, 48 and 72 hrs lead period were 61.1, 69.7 and 80.2% against the LPA of 49.2, 59.4 and 69.2% respectively.
- The 120 hour intensity forecast errors and skill of ESCS FANI in comparison to the long period average errors and skill during 2014-18 is presented in **Fig.20 and Fig. 21** respectively.



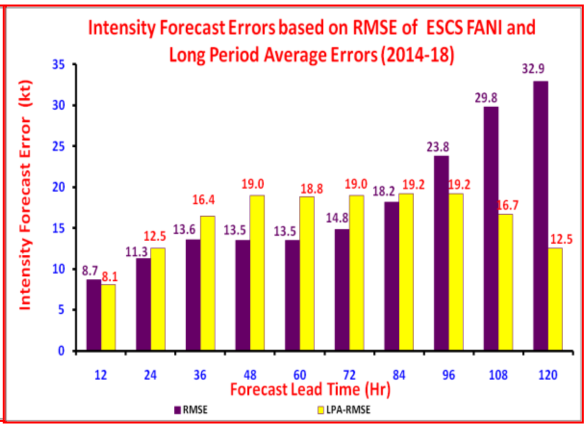


Fig. 20: Absolute errors (AE) and Root Mean Square errors (RMSE) in intensity forecast based of ESCS FANI as compared to long period average (2014-18)

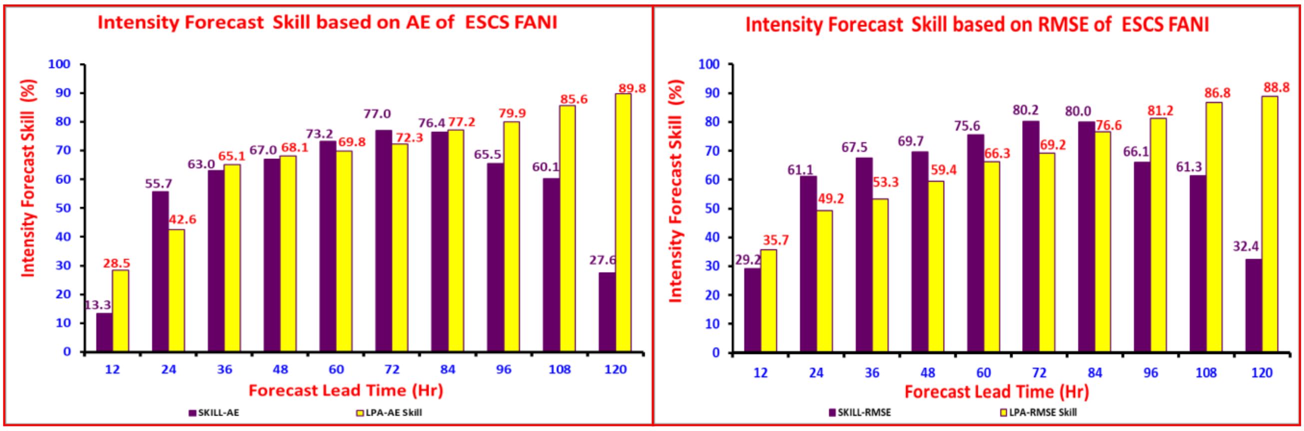


Fig. 21: Absolute errors (AE) and Root Mean Square errors (RMSE) in intensity forecast based of ESCS FANI as compared to long period average (2014-18)

Table 8: Mean Intensity forecast errors (kt) and Skill (%) in association with ESCS FANI compared to long period average errors and skill during 2014-18

Lead Period (hrs)	N	Average error in Intensity forecast (kt)		LPA (2014-18) Intensity forecast error (kt)		Operational Skill* (%) in intensity forecast		LPA (2014-18) Skill* (%) in intensity forecast	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	26	7.2	8.7	5.8	8.1	13.3	29.2	28.5	35.7
24	24	9.6	11.3	9.6	12.5	55.7	61.1	42.6	49.2
36	22	12.3	13.6	13.1	16.4	63.0	67.5	65.1	53.3
48	20	12.6	13.5	14.1	19.0	67.0	69.7	68.1	59.4
60	18	12.8	13.5	14.7	18.8	73.2	75.6	69.8	66.3
72	16	13.8	14.8	14.3	19.0	77.0	80.2	72.3	69.2
84	14	17.1	18.2	14.7	19.2	76.4	80.0	77.2	76.6
96	12	22.1	23.8	15.6	19.2	65.5	66.1	79.9	81.2
108	10	27.3	29.8	13.3	16.7	60.1	61.3	85.6	86.8
120	8	29.4	32.9	9.6	12.5	27.6	32.4	89.8	88.8

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 9-11. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table 9: Verification of Heavy Rainfall Forecast

Date/Base Time of observation	24 hr Heavy rainfall warning ending at 0300 UTC of next day	Realised 24-hour heavy rainfall ending at 0300 UTC of date
26.04.2019/0300	❖ **Tamil Nadu:** Heavy rainfall at isolated places over north coastal Tamil Nadu on 30th April & 1st May. ❖ **Kerala**: Heavy rainfall at isolated places on 29th & 30th April.	**<u>1st May</u>** **Andaman & Nicobar Islands**: Maya Bandar-7 **<u>2nd May</u>** **Arunachal Pradesh**: Hawai-8. **Assam & Meghalaya**: Sohra & Mawsynram-14 each, Bahalpur & Dholla Bazar-9 each, Margherita-8, Halflong, Majbat, Dillighat, Khowang, Tamulpur, & Dhubri-7 each. **Nagaland, Manipur, Mizoram & Tripura**: Tizit -14 and Tuli -8 **<u>3rd May</u>** **Arunachal Pradesh**: Hawai-8 **Assam & Meghalaya**: Gossaigaon-16, Kokrajhar-10, Hazuah-7 **Sub-Himalayan West Bengal & Sikkim**: Alipurduar (PTO) & Alipurduar (CWC)-7 each **Odisha**: Berhampur-30, Gopalpur & Banki (ARG)-17 each, Chhatrapur-15, Mundali-12, Purushottampur, Mohana, Puri, Ranpur, & R.Udaigiri-11 each, Rajghat-10, Nuagada (ARG)-9, Tirtol (ARG), Digapahandi (ARG), Balasore, & Gania (ARG)-8 each, Banpur, Aska, NH-5 Gobindpur, Khandapara, Narsinghpur, Naraj, & Niali (ARG)-7 each **Bihar**: Galgalia-14
27.04.2019/0300	❖ **Kerala:** Heavy falls at isolated places on 29th & 30th April.	
28.04.2019/0300	❖ **Kerala**: Heavy falls at isolated places on 29th & 30th April ❖ **Odisha:** Heavy rainfall over coastal Odisha from 3rd May.	
29.04.2019/0300	❖ **Kerala:** Heavy falls at isolated places on 29th & 30th April, 2019. ❖ **Odisha and Andhra Pradesh:** Heavy to very heavy rainfall at isolated places over coastal Odisha & adjoining districts of north coastal Andhra Pradesh from 3rd May.	
30.04.2019/0300	❖ **Kerala**: Heavy falls at isolated places on 30th April. ❖ **North coastal Andhra Pradesh**: Heavy to very heavy rainfall at few places on 2nd May and 3rd May. ❖ **Odisha:** Heavy to very heavy rainfall at few places over **south coastal Odisha** on 2nd May. Heavy to very heavy rainfall at a few places with extremely heavy falls at isolated places over **coastal Odisha** & its adjoining districts of **interior Odisha** on 3rd and over north Odisha on 4th May. ❖ **West Bengal:** Heavy falls at isolated places over coastal districts of **West Bengal** on 3rd. Heavy to very heavy rainfall at a few places with extremely heavy falls at isolated places over **Gangetic West Bengal** on 4th May.	
01.05.2019/0300	❖ **North Andhra Pradesh**: Heavy to very heavy rainfall and extremely heavy falls (>20 cm) at isolated places over north coastal Andhra Pradesh (Srikakulam, Visakhapatnam and Vijayanagaram Districts) on 2nd May. Heavy to very heavy rainfall at isolated places on 3rd May over the same area.	

	❖ **Odisha**: Heavy to very heavy rainfall at isolated places over south coastal Odisha on 2nd May. It is likely to increase with rainfall at most places and heavy to very heavy rainfall at a few places with extremely heavy falls (>20 cm) at isolated places over coastal Odisha & interior Odisha on 3rd and rainfall at many places with heavy to very heavy falls at isolated places over north Odisha on 4th May. ❖ **West Bengal**: Heavy falls at isolated places over coastal & adjoining districts of West Bengal on 3rd and heavy to very heavy rainfall at a few places with extremely heavy falls at isolated places over Gangetic West Bengal and heavy at isolated places over Sub-Himalayan West Bengal & Sikkim on 4th May. ❖ **Arunachal Pradesh and Assam & Meghalaya:** Isolated heavy falls over Arunachal Pradesh, Assam & Meghalaya on 4th and 5th May.	**Coastal Andhra Pradesh**: Ichchapuram-18, Sompeta-17, Palasa-15, Mandasa-13, Tekkali-12, Kalingapatnam-9. **<u>4th May</u>** **Arunachal Pradesh**: Tuting-9 **Assam & Meghalaya**: Williamnagar-8, Mawsynram-7 **Nagaland, Manipur, Mizoram & Tripura**: Arundhutinagar-9, Sonamura-8 and Agartala AERO, Amarpur & Kamalpur-7 each. **Gangetic West Bengal**: Bankura-16, Kalaikunda-15, Kansabati Dam-14, Harinkhola & Phulberia-13 each, Hetampur & Suri -12 each, Bankura, Suri & Durgapur-11 each, Rampurhat-10, Sri Niketan, Jhargram, Simula, Kharidwar, Berhampore, Asansol, & Tantloi-9 each, Midnapore, Midnapore, Mohanpur, Asansol & Lalgarh-8 each and Tusuma, Tilpara Barrage, Durgachack, Bagati, Purulia, Burdwan, Canning, Alipore, & Purihansa-7 each. **Odisha**: Chandikhol-18, Bhuban & Bhubaneswar -16 each, Jajpur-15, Binjharpur & Samakhunta -14 each, Cuttack & Jenapur-13 each, Hindol & Remuna -12 each, Korei & Kaptipada-11 each, Keonjhargarh, Sukinda & Rairangpur-10 each, Nilgiri & Jaleswar-9 each, Soro-8 and Dhenkanal, Joshipur, & Bari-7 each. **Jharkhand**: Ghatsila,
02.05.2019/0300	❖ **North Andhra Pradesh**: Isolated heavy to very heavy falls over Visakhapatnam and Vijayanagaram district and isolated heavy to extremely heavy falls (>20 cm) over Srikakulam district on 2nd May and with heavy to very heavy rainfall at isolated places over Srikakulam district on 3rd May. ❖ **Odisha:** Heavy to very heavy rainfall at few places and extremely heavy falls (over Ganjam & Gajapati districts) at isolated places over south coastal & adjoining interior Odisha on 2nd May. Heavy to very heavy rainfall at few places and extremely heavy falls at isolated places over coastal Odisha & adjoining districts of interior Odisha on 3rd. Heavy to very heavy falls at isolated places over Balasore, Mayurbhanj districts of north Odisha on 4th May. ❖ **West Bengal**: Heavy to very heavy rainfall at a few places and extremely heavy falls at isolated places over coastal & adjoining districts of West Bengal on 3rd. Heavy to very falls at isolated places over Gangetic West	

	Bengal on 4th May. ❖ **Sub-Himalayan West Bengal & Sikkim**: Heavy falls at isolated places on 4th May. ❖ **Arunachal Pradesh and Assam & Meghalaya**: Isolated heavy to very heavy falls over Arunachal Pradesh and Assam & Meghalaya on 4th & 5th May; with isolated extremely heavy falls over Assam & Meghalaya on 4th. Isolated heavy falls over Nagaland, Manipur, Mizoram & Tripura on 4th .	Messenjor, & Maheshpur-9 each, Dhanbad-8 and Maithon, Rajmahal, Jarmindi, & Moharo-7 each. **<u>5th May</u>** **Assam & Meghalaya**: Sohra -41, Mawsynram-33, Williamnagar-17, Shillong C.S.O.-13, Guwahati City-11, Kheronighat & Barapani-9 each, Guwahati, Dharamtul, Barpathar, & Kampur-8 each and Jia Bharali N T Xing, Bokajan, Karimganj, Shella, & Numaligarh-7 each. **Nagaland, Manipur, Mizoram & Tripura**: Tamenglongi-13 and Sabroom-9
03.05.2019/0300	❖ **North Andhra Pradesh**: Heavy to very heavy rainfall at isolated places over Srikakulam district on 3rd May. ❖ **Odisha**: Heavy to very heavy rainfall at a few places and extremely heavy falls at isolated places over coastal Odisha & adjoining districts of interior Odisha on 3rd May. Heavy to very heavy falls at isolated places over Balasore, Mayurbhanj districts of north Odisha on 4th May. ❖ **West Bengal**: Heavy to very heavy rainfall at a few places and extremely heavy falls at isolated places over coastal & adjoining districts of West Bengal on 3rd; and heavy to very heavy falls at isolated places over Gangetic West Bengal on 4th May. ❖ **Sub-Himalayan West Bengal & Sikkim**: Heavy falls at isolated places over on 4th. ❖ **Arunachal Pradesh, Assam & Meghalaya and Nagaland, Manipur, Mizoram & Tripura**: Isolated heavy to very heavy falls over Arunachal Pradesh and Assam & Meghalaya on 4th & 5th May. Isolated extremely heavy falls over Assam & Meghalaya on 4th. Isolated heavy falls over Nagaland, Manipur, Mizoram & Tripura on 4th .	
04.05.2019/0300	❖ **Sub-Himalayan West Bengal & Sikkim**: Heavy falls at isolated places over during next 12 hours.	

Table 10: Verification of Squally/Gale wind forecast

Date/Base Time of observation	Gale/ Squally wind Forecast at 0300 UTC of date	Realised wind
26.04.2019/0300	❖ Squally wind speed reaching 45-55 kmph gusting	

	to 65 kmph over East EIO & adjoining central parts of south BoB on 26th; gale wind speed reaching 65-75 kmph gusting to 85 kmph over Southwest BoB & adjoining EIO on 27th; 80-90 kmph gusting to 100 kmph over Southwest BoB& adjoining EIO and along & off Sri Lanka coast on 28th and 90-100 kmph gusting to 115 kmph over Southwest Bay of Bengal, along & off Sri Lanka coast and off Tamilnadu & Puducherry coast on 29th. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph likely to commence along & off Tamilnadu & Puducherry coast, Comorin area and Gulf of Mannar from 28th morning, becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph from 28th night and becoming Squally wind speed reaching 50-60 kmph gusting to 70 kmph from 29th morning. Wind speed would gradually increase further becoming 90-100 kmph gusting to 115 kmph along & off north Tamilnadu & Puducherry and adjoining south Andhra Pradesh districts coasts from 30th afternoon. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph likely to commence over Kerala from 28th morning and becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph from 29th morning.	Realised estimated maximum sustained surface wind was 175-185 kmph gusting to 205 kmph at the time of landfall close to Puri.
27.04.2019/0300	❖ Squally wind speed reaching 55-65 kmph gusting to 75 kmph prevailing over East EIO & adjoining central parts of south Bay of Bengal; is very likely to become gale wind speed reaching 60-70 kmph gusting to 80 kmph over Southeast BoB & adjoining EIO from 27th noon; 90-100 kmph gusting to 115 kmph over Southwest BoB and off Sri Lanka coast from 28th evening; 120-130 kmph gusting to 145 kmph over Southwest Bay of Bengal, off north Tamilnadu & Puducherry coast from 30th morning and 135-145 kmph gusting to 160 kmph over southwest & adjoining westcentral BoB off north Tamilnadu, Puducherry and south Andhra Pradesh Coasts from 1st May morning. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph likely to commence along & off Tamilnadu & Puducherry coast, Comorin area and Gulf of Mannar from 28th morning, becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph from 29th morning. It is very likely to become squally wind speed reaching 50-60 kmph gusting to 70 kmph from 30th morning along Tamilnadu, Puducherry and south Andhra Pradesh Coasts. ❖ Strong wind speed reaching 30-40 kmph gusting	

	to 50 kmph likely to commence over Kerala from 28th morning and becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph on 29th & 30th .	
28.04.2019/0300	❖ Gale wind speed reaching 80-90 kmph gusting to 100 kmph is prevailing over Southeast BoB & neighbourhood. It is very likely to become 90-100 kmph gusting to 115 kmph from 28th evening over the same area; 120-130 kmph gusting to 145 kmph over Southwest BoB from 30th morning and 150-160 kmph gusting to 175 kmph over southwest & adjoining westcentral BoB off north Tamilnadu, Puducherry and south Andhra Pradesh Coasts from 01st May evening. It is likely to become 130-140 kmph gusting to 150 kmph over westcentral BoB off Andhra Pradesh Coast on 3rd May 2019. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph likely to commence along & off Tamilnadu & Puducherry coast, Comorin area and Gulf of Mannar from 28th morning, becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph from 29th morning. It is very likely to become squally wind speed reaching 50-60 kmph gusting to 70 kmph from 30th morning along north Tamilnadu, Puducherry and south Andhra Pradesh Coasts. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph likely to commence along & off Kerala coast from 28th evening and becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph on 29th & 30th . ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely to commence along & off north Andhra Pradesh & Odisha Coasts from 2nd and likely to become 50-60 kmph gusting to 70 kmph from 3rd May onwards over the same area.	
29.04.2019/0300	❖ Gale wind speed reaching 80-90 kmph gusting to 100 kmph is prevailing over Southeast BoB & neighbourhood. It is very likely to increase gradually becoming 120-130 kmph gusting to 145 kmph over Southwest BoB from 30th morning and 160-170 kmph gusting to 185 kmph over southwest & adjoining westcentral BoB off north Tamilnadu, Puducherry and south Andhra Pradesh Coasts from 01st May evening. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph very likely along & off Tamilnadu & Puducherry coast, Comorin area and Gulf of Mannar on today the 29th April, becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph from 30th morning. It is very likely to	

	become squally wind speed reaching 50-60 kmph gusting to 70 kmph from 30th evening along north Tamilnadu, Puducherry and south Andhra Pradesh Coasts. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph very likely along & off Kerala coast on today the 29thApril and becoming squally wind speed reaching 40-50 kmph gusting to 60 kmph on 30th . ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely to commence along & off north Andhra Pradesh & Odisha Coasts from 2nd May and likely to become 50- 60 kmph gusting to 70 kmph from 3rd May onwards over the same area.	
30.04.2019/0300	❖ Gale wind speed reaching 135-145 kmph gusting to 160 kmph is prevailing over Southeast & adjoining Southwest Bay of Bengal. It is very likely to increase gradually becoming 165-175 kmph gusting to 195 kmph over Westcentral & adjoining Southwest BoB off north Tamilnadu, Puducherry and south Andhra Pradesh Coast from 30th night onwards. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph very likely along & off Tamilnadu & Puducherry coast, Comorin area, Gulf of Mannar and Kerala on 30th. ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely to commence along & off north Andhra Pradesh & Odisha Coasts from 2nd May and very likely to become gale wind, speed reaching 60-70 kmph gusting to 85 kmph from 3rd May morning and become 170-180 gusting 200 kmph over Odisha Coast and 90-100 gusting to 115 kmph over adjoining districts of north Andhra Pradesh by 3rd May evening. ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely along & off West Bengal coast on 2nd May. It would become gale wind speed reaching 60-70 kmph gusting to 85 kmph from 3rd May evening and become 90-100 gusting to 115 kmph from 4th May morning.	
01.05.2019/0300	❖ Gale wind speed reaching 180-190 kmph gusting to 210 kmph is prevailing over westcentral Bay of Bengal, off north Tamilnadu, Puducherry and south Andhra Pradesh Coast during next 24 hours and decrease thereafter. ❖ Strong wind speed reaching 30-40 kmph gusting to 50 kmph very likely along & off Tamilnadu coast, Comorin area, Gulf of Mannar and Kerala during next 12 hours. ❖ Squally wind speed reaching 40-50 kmph gusting	

	to 60 kmph is very likely to commence along & off north Andhra Pradesh & Odisha Coasts from 2nd May and very likely to become gale wind speed reaching 60-70 kmph gusting to 85 kmph from 3rd May morning and become 170-180 kmph gusting to 200 kmph over Odisha Coast and 90-100 kmph gusting to 115 kmph over adjoining districts of north Andhra Pradesh (Srikakulam, Visakhapatnam and Vijayanagaram Districts) by 3rd May for subsequent 12 hours and significant decrease thereafter. ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely along & off West Bengal coast on 2 nd May. It would become gale wind speed reaching 60-70 kmph gusting to 85 kmph from 3 rd May evening and become 90-100 kmph gusting to 115 kmph from 4th May early morning for subsequent 12 hours and decrease thereafter.	
02.05.2019/0300	❖ Gale wind speed reaching 180-190 kmph gusting to 210 kmph is very likely to prevail over westcentral BoB around system centre during next 24 hours and decrease thereafter. ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely to prevail along & off north Andhra Pradesh & Odisha Coasts and become gale wind speed reaching 60-70 kmph gusting to 85 kmph from 2nd May night. It is very likely to become 170-180 kmph gusting to 200 kmph along & off south Odisha & adjoining north Andhra Pradesh (Srikakulam District) coasts; and 90-100 kmph gusting to 115 kmph along & off remaining districts of coastal Odisha and north Andhra Pradesh (Visakhapatnam and Vijayanagaram Districts) by 3rd May forenoon for subsequent 12 hours and decrease thereafter. ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely along & off West Bengal coast from 2nd May evening. It is very likely become gale wind speed reaching 60- 70 kmph gusting to 85 kmph from 3rd May afternoon and become 90-100 kmph gusting to 115 kmph from 4th May early morning for subsequent 12 hours and decrease thereafter.	
03.05.2019/0300	❖ Gale wind speed reaching 140-150 kmph gusting to 165 kmph is prevailing along & off Puri and Jagatsighpur districts of Odisha coast. It is very likely to increase gradually and become 170-180 kmph gusting to 200 kmph during next 06 hours and 150-160 kmph gusting to 180 kmph along & off remaining districts of coastal Odisha and north Andhra Pradesh (Srikakulam and Vijayanagaram districts) during next 6 hours and decrease	

	thereafter. ❖ Squally wind speed reaching 40-50 kmph gusting to 60 kmph is very likely along & off West Bengal coast during next 12 hours. It is very likely become gale wind speed reaching 60-70 kmph gusting to 85 kmph from 3rd May afternoon and become 90-100 kmph gusting to 115 kmph from 4th May early morning for subsequent 12 hours and decrease thereafter.	
04.05.2019/0300	❖ Squally wind speed reaching 50-60 kmph gusting to 70 kmph likely over West Bengal districts adjoining to Bangladesh during next 6 hours. Squally wind speed reaching 45-55 kmph gusting to 65 kmph is also likely along & off West Bengal coast during the same period.	

Table 11: Verification of Storm Surge Forecast

Date/Base Time of observation	Storm Surge Forecast at 0300 UTC of date	Realized surge
01.05.2019/0300	❖ Storm surge of about 1.5 meter height above astronomical tide is very likely to inundate low lying areas of Ganjam, Khurda, Puri & Jagatsinghpur districts of Odisha at the time of landfall.	Storm surge height is estimated to be about 1.5 m above the astronomical tide at the time of landfall.
02.05.2019/0300	-do-	
03.05.2019/0300	-do-	

11. Warning Services

Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track, intensity, and landfall forecast for +06, +12, +18, +24, +36 and +48… +120 hrs lead period till the system weakened into a low pressure area. The above forecasts were issued from the stage of depression onwards along with the cone of uncertainty in the track forecast five times a day and every three hours during the cyclone period. The hourly updates were also provided 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 knots and ≥34 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36 and +120 hrs lead period.

- **Four stage Warning:**
  - **Cyclone Watch:** Cyclone watch for Odisha and adjoining AP coasts was issued at 0900 UTC of 29th April when the system was a CS over southwest BoB (90 hrs prior to landfall). Extended for West Bengal coast at 0630 UTC of 30th April.
  - **Cyclone Alert:** 66 hrs prior to actual landfall issued for Odisha, West Bengal & Srikakulam and Vijayanagaram Districts of Andhra Pradesh coasts in the update issued at 1000 UTC of 30th April.
  - **Cyclone Warning:** Issued on 1st May 1500 UTC (about 36 hrs prior to actual landfall) for Odisha, West Bengal and Srikakulam, Vijayanagaram & Visakhapatnam Districts of Andhra Pradesh Coasts:
  - **Post landfall Outlook** for interior districts of south coastal Odisha, north Odisha and interior districts of Gangetic West Bengal indicating expected winds, damage and action suggested after landfall of the system was issued at 1500 UTC of 2nd May (about 12 hrs prior to actual landfall).
- **Adverse weather warning bulletins:** Adverse weather warning bulletins: The tropical cyclone forecasts along with expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update to central, state and district level disaster management agencies including MHA NDRF, NDMA for all concerned states along the east coast of India including Kerala, 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 along with colour codes in the website.
- **Warning and advisory through social media:** Daily updates (every six hourly or whenever there was any significant change in intensity/track/landfall) were uploaded on face book and twitter regularly during the life period of the system. From 2nd evening onwards, hourly updates were posted on Facebook and twitter till the system maintained the intensity of cyclonic storm.
- **Press release and press briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services division at New Delhi and bulletins for maritime interest were issued by Area cyclone warning centres of IMD at 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 of east equatorial Indian Ocean and adjoining south BoB and the states of West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Andaman & Nicobar Islands were issued since 25th April.
- **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 and tropical cyclone advisory bulletins.
- **Hourly Bulletin:** Hourly updates on the location, distance from recognised station, intensity and landfall commenced from 2nd evening onwards till the system maintained the intensity of cyclonic storm.

Statistics of bulletins issued by RSMC New Delhi and Area Cyclone Warning Centre Kolkata, Cyclone Warning Centre Bhubaneswar and Visakhapatnam in association with the ESCS FANI are given in **Table 12.**

Table 12 (a): Bulletins issued by RSMC New Delhi

S.N	Bulletin type	No. of Bulletins	Issued to
1	National Bulletin	65	1. IMD's website, RSMC New Delhi website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defense Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Chief Secretary, Government of Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Assam, Meghalaya, Arunachal Pradesh.
2	RSMC Bulletin	64	1. IMD's website 2. WMO/ESCAP member countries through GTS and E-mail.
3	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)
4	Tropical Cyclone Advisory Centre Bulletin	30	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
5	Tropical Cyclone Vital Statistics	29	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.

6	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) 4,29,357 to General Public by IMD Headquarters (ii) 2,140 to disaster managers by IMD Headquarters (iii) SMS to fishermen by INCOIS (iv) 59,37,365 to farmers by Kisaan Portal
7	Warnings through Social Media	Daily	Cyclone Warnings were uploaded on Social networking sites (Face book and Tweeter) since inception to weakening of system (every time when there was change in track, intensity and landfall characteristics).
8	Press Release	12	Disaster Managers, Media persons by email and uploaded on website
9	Press Briefings	Daily	Regular briefing daily
10	Hourly Updates	36	Hourly bulletins by email, website, social media

Table 12 (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	46	-	-
2.	Coastal Weather Bulletins	30	32	31
3.	Fishermen Warnings issued	74	32	29
4.	Port Warnings	53	34	20
5.	Heavy Rainfall warning	31	31	8
6.	Gale Wind Warning	23	25	8
7.	Storm Surge Warning	4	24	-
8.	Information & Warning issued to State Government and other Agencies	37	35	13 (Bulletins for All India Radio)
9.	SMS	10,000	22,150	396

12. Initiatives during ESCS FANI:

(i) Rapid scanning of cyclone by INSAT-3DR was carried out during life cycle of ESCS FANI.

(ii) The lightning data was superimposed on the satellite and radar image.

(iii) The cyclone was continuously monitored and tracked by all the DWRs along the east coast commencing from radar at Chennai, Visakhapatnam, Gopalpur, Paradeep, Kolkata and Agartala. The DWR based specific products like wind speed at the height of 1 km was used to find out the intensity of cyclone.

(iv) Both versions namely Princeton Ocean Model (POM) and Hybrid Co-ordinate Model (Hy-Com) of cyclone specific Hurricane Weather Research & Forecast Model (HWRF) were run simultaneously and six hourly forecast was provided with latest data assimilation tools.

(v) HWRF model forecast products were made available through IMD website, RSMC website and also NCEP, USA website.

(vi) IMD issued Extended Range Outlook giving 15 days probabilistic cyclogenesis forecast **(Fig. 22)**. The product is available at http://www.rsmcnewdelhi.imd.gov.in/images/bulletin/eroc.pdf

(vii) Prediction of intensity of cyclone even prior to genesis. On 23rd April, it was predicted that the system would intensify into a cyclonic storm, while low pressure area formed on 25th April.

(viii) Cone of uncertainty representing uncertainty in track was reduced by 20-30% for different lead periods due to reduction in track forecast errors during 2014-18 as compared to that during 2009-13. The last revision of COU was carried out in 2013 **(Fig.23).**

(ix) Impact over sea area and suggested action was given in the warning graphics alongwith wind distribution around the system centre **(Fig.16).**

(x) Fishermen warning in graphical form was issued daily valid upto 5 days from 25th April, 2019 onwards **(Fig.24).** The product is available at http://www.rsmcnewdelhi.imd.gov.in/images/bulletin/gfisherman.png

(xi) Hourly updates based on Radar observations were provided from 9:30 PM of 1st of May.

(xii) Hourly bulletins were issued from 2nd morning (10:30 A.M.) till the system maintained the intensity of cyclonic storm. These bulletins were uploaded on Facebook & twitter hourly and SMS to disaster managers and general public were sent hourly.

(xiii) To facilitate easy access to cyclone warning bulletins and graphics, the products were also uploaded on INCOIS website on 2nd & 3rd May.

(xiv) Information and warning products on cyclone along with storm surge guidance were also provided to United Nations through WMO.

(xv) During cyclone FANI the number of unique visitors and hits on IMD & RSMC website were exceptionally higher **(Fig.25).**

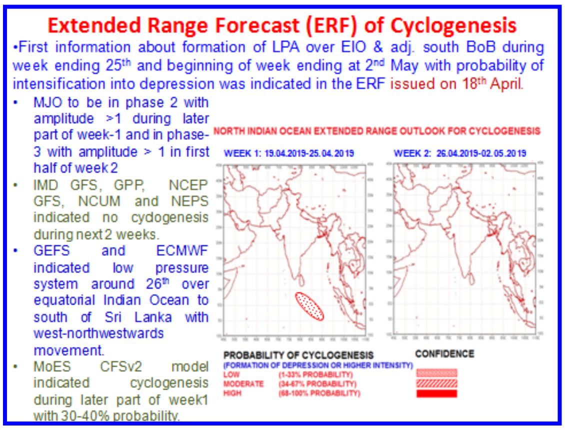


Fig.22: Extended Range Outlook issued on 18th April for next 15 days indicating cyclogenesis around 26th.

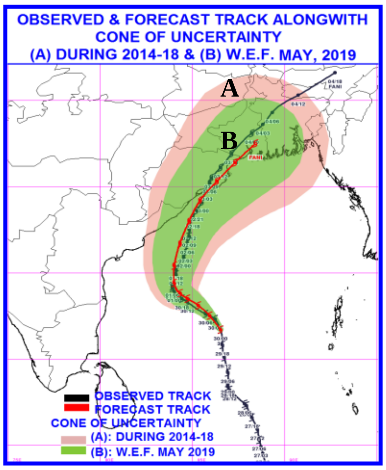


Fig. 23: Observed & Forecast Track along with cone of uncertainty (A) during 2014-18 and (B) w.e.f. May, 2019

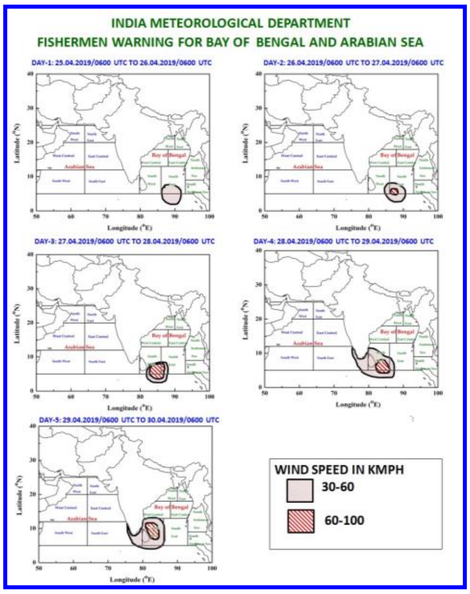


Fig. 24: 5 days fishermen warning in graphical form for entire north Indian Ocean issued at 0600 UTC (1130 IST) of 25th April 2019

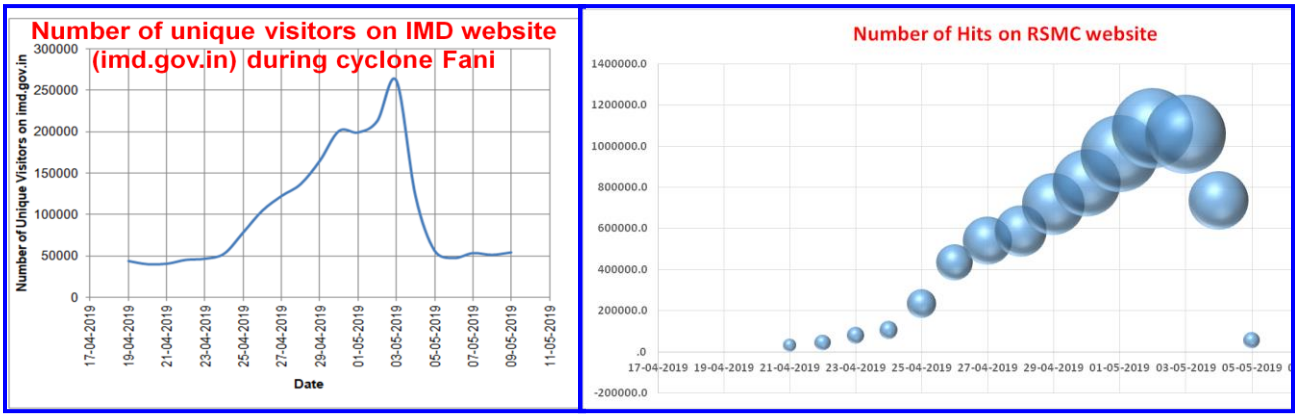


Fig. 25: No. of unique visitors in IMD website and No. of Hits on RSMC website during ESCS FANI

13. Appreciations earned for accurate forecast of ESCS FANI:

- ❖ Cyclone warning services of IMD were appreciated world-wide by scientific, research and Govt. & non-governmental disaster management communities.
- ❖ IMD received appreciation from UNDRR, WMO and other national & international scientific community and media for pin point accuracy during recent cyclone FANI (26 April-04 May 2019).

Excerpt of Appreciation from United Nations Office for Disaster Risk Reduction

The government's zero casualty policy for natural disasters and the near accuracy of the India Meteorological Department's early warning system have helped reduce the possibility of deaths from cyclone "FANI".

14. Acknowledgement:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge the contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of ESCS FANI. We acknowledge the contribution of all sister organisations of Ministry of Earth Sciences including National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), Indian Institute of Tropical Meteorology (IITM) Pune, research institutes including IIT Bhubaneswar, IIT Delhi and Space Application Centre, Indian Space Research 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 Chennai, Machilipatnam, Visakhapatnam, Gopalpur, Paradeep, Kolkata & Agartala and coastal observatories of Odisha & north Andhra Pradesh. The contribution from Numerical Weather Prediction Division, Satellite and Radar Division, Surface & Upper air instruments Divisions, New Delhi and Information System and Services Division at IMD is also duly acknowledged.