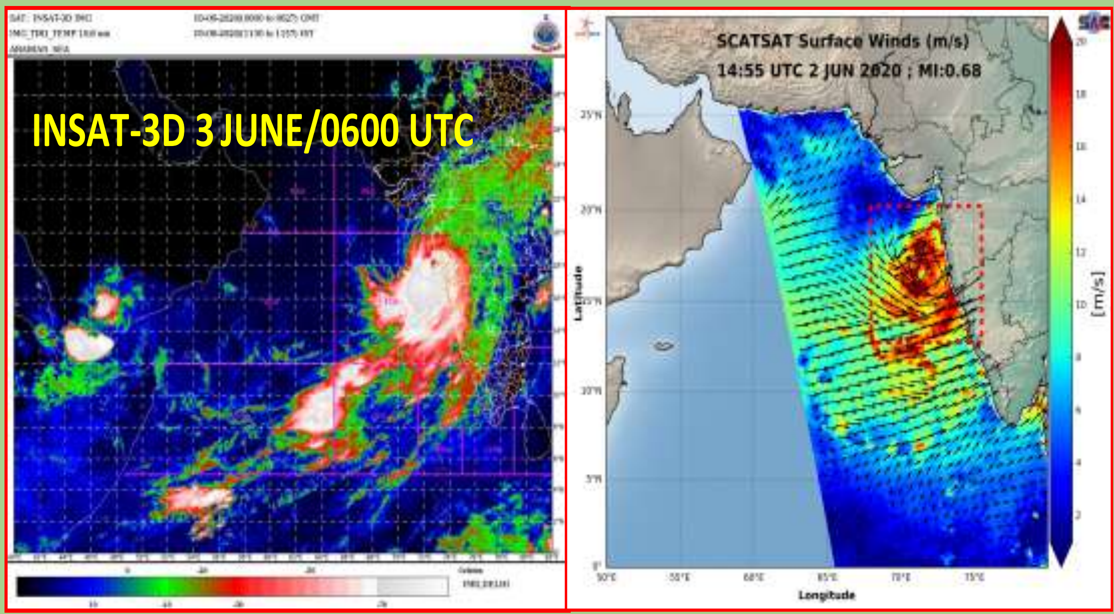
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

Severe Cyclonic Storm "NISARGA" over the Arabian Sea (01-04 June, 2020): A Report



INSAT-3D enhanced colored IR imagery of 3rd June, 2020

Cyclone Warning Division

India Meteorological Department

New Delhi

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Severe Cyclonic Storm "NISARGA" over the eastcentral and adjoining southeast Arabian Sea (01st-04th June, 2020): Detailed Report

1. Introduction

A Low-pressure area formed over southeast & adjoining eastcentral Arabian Sea and Lakshadweep area in the early morning (0000 UTC) of 31st May 2020. Under favorable environmental conditions, it concentrated into a depression over eastcentral and adjoining southeast Arabian Sea in the early morning (0000 UTC) of 1st June 2020. It intensified into deep depression over eastcentral Arabian Sea in the early morning (0000 UTC) and into cyclonic storm **"NISARGA"** in the noon (0600 UTC) of 2nd June. It moved northwards till evening (1200 UTC) of 2nd June. Thereafter, it gradually recurved northeastwards and intensified into a severe cyclonic storm in the early morning (0000 UTC) of 3rd June 2020. Further moving northeastwards, it crossed Maharashtra coast close to south of Alibag as a severe cyclonic storm with a maximum sustained wind speed of 110-120 kmph gusting to 130 kmph during 0700-0900 UTC of 03rd June. Continuing to move northeastwards after landfall, it weakened into a cyclonic storm in the evening (1200 UTC) over north Madhya Maharashtra and into a deep depression in the mid-night (1800 UTC) of 3rd June 2020 over the same region. It further weakened into a depression over western parts of Vidarbha and neighbourhood in the early morning (0000 UTC) and into a well-marked low-pressure area in the evening (1200 UTC) of 4th June over central parts of Madhya Pradesh. It lay as a low-pressure area over southeast Uttar Pradesh and adjoining Bihar in the afternoon (0900 UTC) of 5th June. The observed track of the system during 1st - 4th June is presented in Fig. 1. The best track parameters associated with the system are presented in **Table1**.

2. Salient Features:

The salient features of the system were as follows:

i. It was the first cyclonic storm over the AS during 2020. The last cyclone, which crossed Maharashtra coast was cyclonic storm, Phyan which crossed coast on 11th Nov., 2009. Prior to the SCS, Nisarga, an SCS crossed Maharashtra coast on 24th May, 1961. It was also the fourth cyclone crossing Maharashtra coast during the 1961-2020 (Fig. 2a).

ii. Climatologically, during the period 1891-2018, a total of 6 cyclonic storms and above intensity storms developed within the grid 11-15ºN and 70-74ºE about ±2.0º of the genesis point (13.0ºN/71.4ºE) of Nisarga. Out of these only 1 crossed Maharashtra coast as a severe cyclonic storm in May 1961, 3 crossed Oman coast and 1 weakened over northeast AS (Fig. 2b).

iii. It had a clockwise recurving track as it moved initially northwards till 1200 UTC of 2nd June and thereafter recurved northeastwards. The total track length of the system was 1294 km. It was mainly steered by an anticyclonic circulation in middle & upper tropospheric levels to the east of the system centre.

iv. It moved with a 12-hour average translational speed of 15.8 kmph against the Long Period Average (LPA) (1990-2013) of 10.5 kmph for SCS category over the AS during monsoon season (Fig.5a).

v. The peak MSW of the cyclone was 110-120 kmph (60 knots) gusting to 130 kmph (70 knots) during 0600 UTC of 3rd to 0900 UTC of 3rd June over the eastcentral AS. The lowest estimated central pressure was 984 hPa during the same period (Fig.5b).

vi. The system crossed Maharashtra coast close to south of Alibag near 18.35ºN/72.95ºE, as an SCS with maximum sustained wind speed of 110-120 kmph (60 knots) gusting to 130 kmph (70 knots) between 1230-1430 hrs IST (0700-0900 UTC) of 3rd June.

vii. The system maintained the cyclonic storm intensity for almost 7 hours after landfall till 1500 UTC of 3rd June.

viii. The life period (D to D) of the system was 84 hours (3 days & 12 hours) against long period average (LPA) (1990-2013) of 85 hours (3 days & 13 hrs) for SCS category over the AS during monsoon season.

ix. The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 2.65 $X10^2$ knots, 1.21 X 10^4 $knots^2$ and 0.58 $X10^6$ $knots^3$ respectively against the long period average during 1990-2013 of 2.12 $X10^2$ knots, 1.4 X 10^4 $knots^2$ and 1.0 $X10^6$ $knots^3$ respectively for tropical cyclones over the AS during monsoon season.

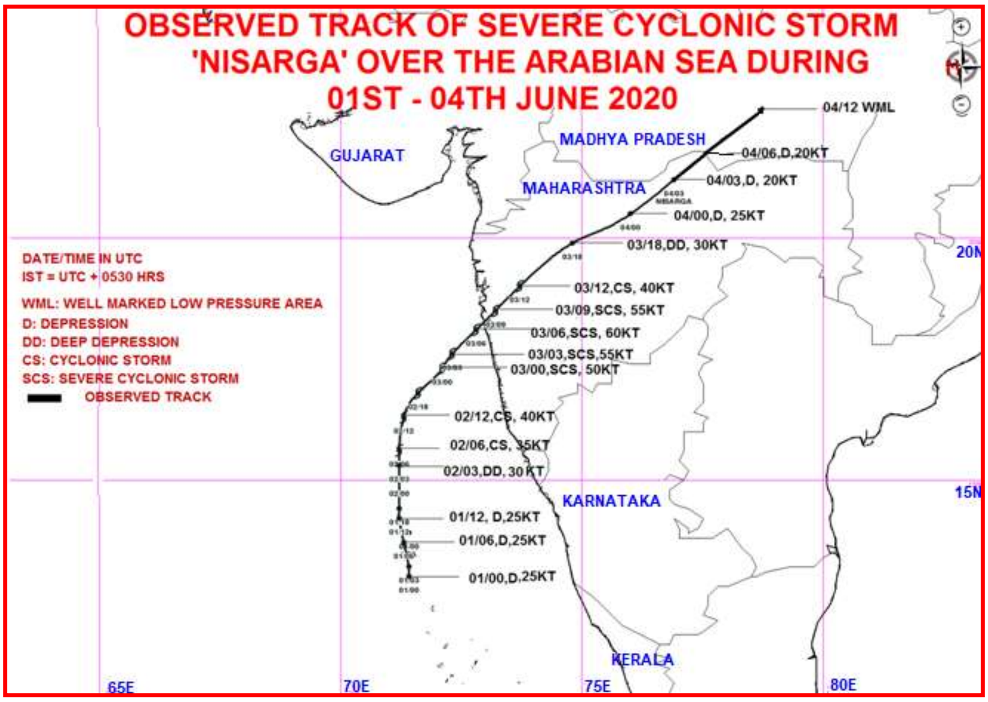

Fig. 1: Observed track of SCS 'NISARGA' over the eastcentral and adjoining southeast Arabian Sea (1st-4th June, 2020)

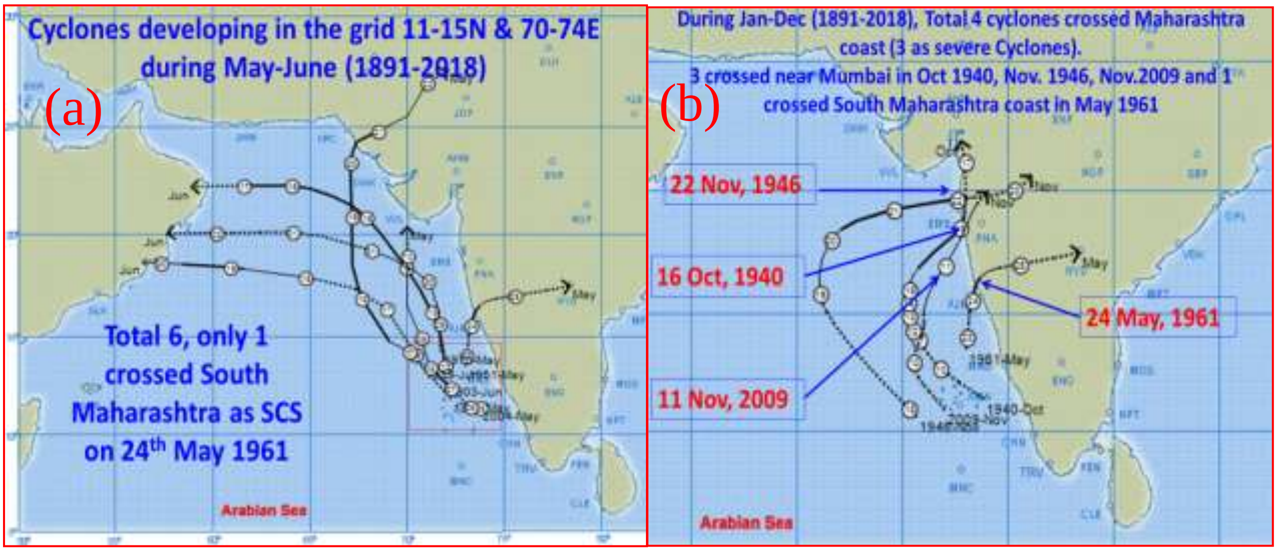

Fig.2: Past Tracks of severe cyclonic storms and above intensity storms (a) developing in the grid ±2.5⁰ of genesis point and (b) crossing Maharashtra coast in the month of May and June during 1891-2018

Table 1: Best track positions and other parameters of the Severe Cyclonic Storm, 'NISARGA' over the eastcentral and adjoining southeast Arabian Sea during 1st – 4th June, 2020

Date	Time (UTC)	Centre lat.⁰ N/ long. ⁰ E		C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
01/06/2020	0000	13.0	71.4	1.5	1004	25	3	**D**
	0300	13.2	71.4	1.5	1004	25	3	D
	0600	13.7	71.3	1.5	1004	25	3	D
	1200	14.2	71.2	1.5	1003	25	4	D
	1800	14.4	71.2	1.5	1003	25	4	D
02/06/2020	0000	15.0	71.2	2.0	1000	30	6	**DD**
	0300	15.3	71.2	2.0	1000	30	6	DD
	0600	15.6	71.2	2.5	999	35	7	**CS**
	0900	16.0	71.2	2.5	999	35	7	CS
	1200	16.3	71.3	2.5	996	40	8	CS
	1500	16.0	71.4	2.5	996	40	8	CS
	1800	16.8	71.6	2.5	996	40	8	CS
	2100	17.1	71.8	3.0	994	45	10	CS
03/06/2020	0000	17.3	72.1	3.0	992	50	12	**SCS**
	0300	17.6	72.3	3.5	988	55	16	SCS
	0600	18.1	72.8	4.0	984	60	20	SCS

		Crossed Maharashtra coast close to south of Alibag near 18.35ºN/72.95ºE, as Severe Cyclonic Storm with maximum sustained wind speed of 60 kt gusting to 70 kt between 0700-0900 UTC of 03rd June						
	0900	18.5	73.2	-	992	55	14	SCS
	1200	19.0	73.7	-	998	40	8	**CS**
	1500	19.6	74.0	-	1000	30	6	**DD**
	1800	19.8	74.8	-	1001	30	5	**DD**
04/06/2020	0000	20.5	76.0	-	1004	25	4	**D**
	0300	21.2	76.9	-	1005	20	3	D
	0600	21.8	77.6	-	1005	20	3	D
	1200	Weakened into a well marked low pressure area over central parts of Madhya Pradesh						

3. Brief life history

3.1. Genesis

At 0300 UTC of 31st May, it lay an LPA. The Madden Julian Oscillation (MJO) index lay in phase 1 with amplitude more than 1. MJO was supporting enhancement of convective activity over the west AS. The sea surface temperature (SST) was 30-32˚C over the entire AS. The tropical cyclone heat potential (TCHP) was more than 100 KJ/cm^2 over major parts of south and westcentral AS. It was about 60-80 KJ/cm^2 over central AS and was becoming negative over extreme north AS off Oman coast. Positive lower level positive vorticity (100 X10^{-6} sec $^{-1}$) lay over Comorin-Lakshadweep areas. It was extending upto 200 hPa level. The lower level convergence was around 30x10^{-5} sec $^{-1}$ over southeast Arabian Sea. The upper level divergence was 50X10^{-5}sec $^{-1}$ over southeast Arabian sea. Vertical wind shear (VWS) was moderate to high (20-30 kts) over the system centre. The upper tropospheric ridge lay near 12.0 ^{0}N over the southeast Arabian Sea.

At 1500 UTC of 31st May, the system lay as a well marked low pressure area. The MJO index lay in phase 1 with amplitude more than 1. It was forecast to remain in same phase during next 7 days with amplitude remaining more than 1. Thus MJO was supporting enhancement of convective activity over the west AS. The sea surface temperature (SST) was 30-32˚C over the entire AS. The tropical cyclone heat potential was more than 100 KJ/cm^2 over major parts of south and westcentral AS. It was about 60-80 KJ/cm ^{2} over central AS and was becoming negative over extreme north AS off Oman coast. Positive lower level vorticity was about 100 X10^{-6} sec $^{-1}$ over Lakshadweep area. It was extending upto 500 hPa level tilting southwards. The lower level convergence was around 15x10 $^{-5}$ sec $^{-1}$ over southeast AS. The upper level divergence was 30x10^{-5} sec^{-1} over southeast Arabian Sea. Vertical wind shear (VWS) was moderate to high (25-30 kts) over the system centre and was low to moderate to the east of the system.

At 0000 UTC of 1st June, similar Sea conditions prevailed. Positive lower level vorticity was about 100 x10^{-6}sec^{-1} over eastcentral Arabian Sea. It was extending upto 500 hPa level tilting southwards. The lower level convergence was around 10x10^{-5}sec^{-1} over southeast AS. The upper level divergence was 10X10^{-5} sec^{-1} over southeast Arabian sea. Vertical wind shear (VWS) was moderate to high (10-15 kts) over the system centre and was low to moderate to the southwest of the system. Under these conditions, it intensified into a depression over eastcentral and adjoining southeast Arabian Sea.

3.2. Intensification and movement

At 0000 UTC of 2nd June, it intensified into a **deep depression.** the MJO index lay in phase 1 with amplitude more than 1. The sea surface temperature (SST) was 30-31˚C over eastcentral Arabian sea. The tropical cyclone heat potential was 100-120 KJ/cm^2 over eastcentral Arabian sea and becoming 80-100 KJ/cm^2 near Karnataka, Maharashtra and Gujarat coast. Positive lower level vorticity was about 100 $x10^{-5}$ sec^{-1} over eastcentral Arabian Sea. The lower level convergence was around $10x10^{-5}$ sec^{-1} over the system center. The upper level divergence was $20X10^{-5}$ sec^{-1} to the southwest of the system center. Vertical wind shear (VWS) was low to moderate (05-10 KTS) around the system centre and was moderate (15-20 KTS) along the forecast track.

At 0600 UTC of 2nd June, the system intensified into the **cyclonic storm 'NISARGA'.** Similar Sea conditions prevailed. The lower level vorticity was about 100-150 $x10^{-5}$ sec^{-1} over eastcentral AS. The lower level convergence and the upper level divergence around the system centre were $40x10^{-5}$ sec^{-1} each. Vertical wind shear was low to moderate (15-20 kts) around the system centre and was moderate (20-30 kts) along the forecast track. All these environmental and dynamical conditions were favouring further intensification of the system into a severe cyclonic storm during next 12-hours.

At 0000 UTC of 3rd June, it intensified into a **severe cyclonic storm.** Similar Sea conditions prevailed. The lower level vorticity was about 200 to 250 $x10^{-6}$ sec^{-1} around the system center. The lower level convergence increased and was about $40x10^{-5}$ sec^{-1} to the south of the system centre. The upper level divergence also increased and was about $30x10^{-5}$ sec^{-1} to the south of the system center. The vertical wind shear was low (10-15 kts) around the system centre and also along the forecast track. Under these favourable environmental and dynamical conditions, the system had intensified into a severe cyclonic storm. The system was steered by an anticyclonic circulation to the east of the system center over peninsular India. Under it's influence, it was forecast to move gradually north-northeastwards across north-Maharashtra coast.

The system crossed Maharashtra coast as a severe cyclonic storm during 0700 to 0900 UTC of 3rd June. Thereafter, it weakened into a cyclonic storm at 1200 UTC of 3rd June, into a deep depression at 1500 UTC of 3rd June. Moving north-northeastwards, it further weakened into a depression at 0000 UTC of 4th June and further into a WML over central parts of Madhya Pradesh.

The total precipitable water (TPW) imageries (Source: TC Forecaster Website: https://rammb-data.cira.colostate.edu/tc_realtime/index.asp) during life cycle of SCS Nisarga are presented in Fig.3. These imageries indicate excessive increase in warm moist around the system centre till 0436 UTC of 3rd June. Thereafter, the system crossed Maharashtra coast.

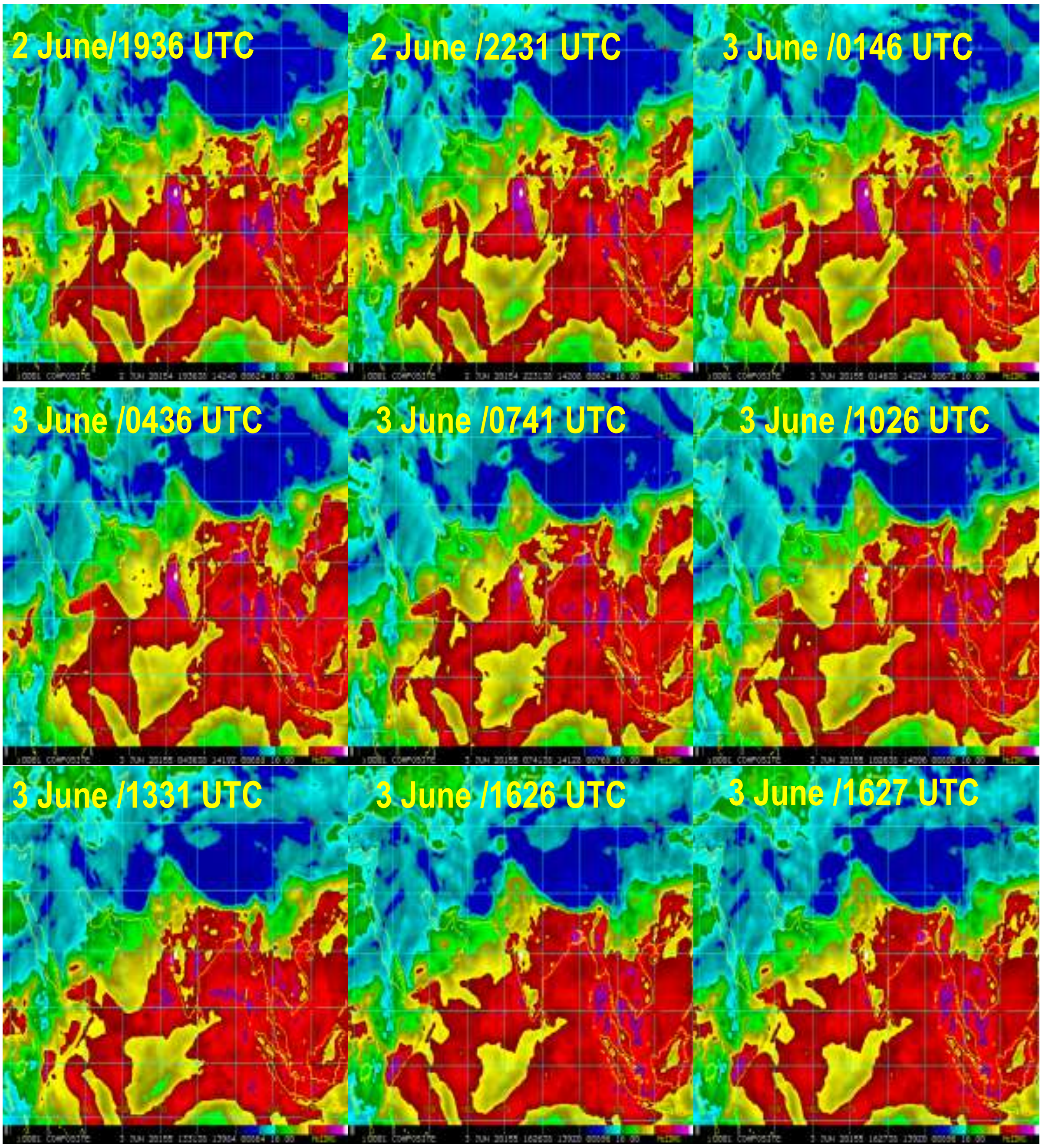

Fig.3: Total precipitable water vapour imagery during 2-3 June in association with SCS Nisarga

The mean wind speed and wind shear in middle and deep layer is presented in Fig. 4. The mean wind shear speed in the deep layer was low (10 knot) during the entire life period of the system. The mean wind shear was low (05 kt) in the middle layer during entire life cycle. The mean wind shear direction in the deep layer was east-northeastwards, thereby shearing the cloud mass to the northeast of system centre. The mean wind speed in the deep and middle layer was low (05-10 knot) during entire life cycle. The mean wind speed direction was southwesterly in both the deep and middle layer.

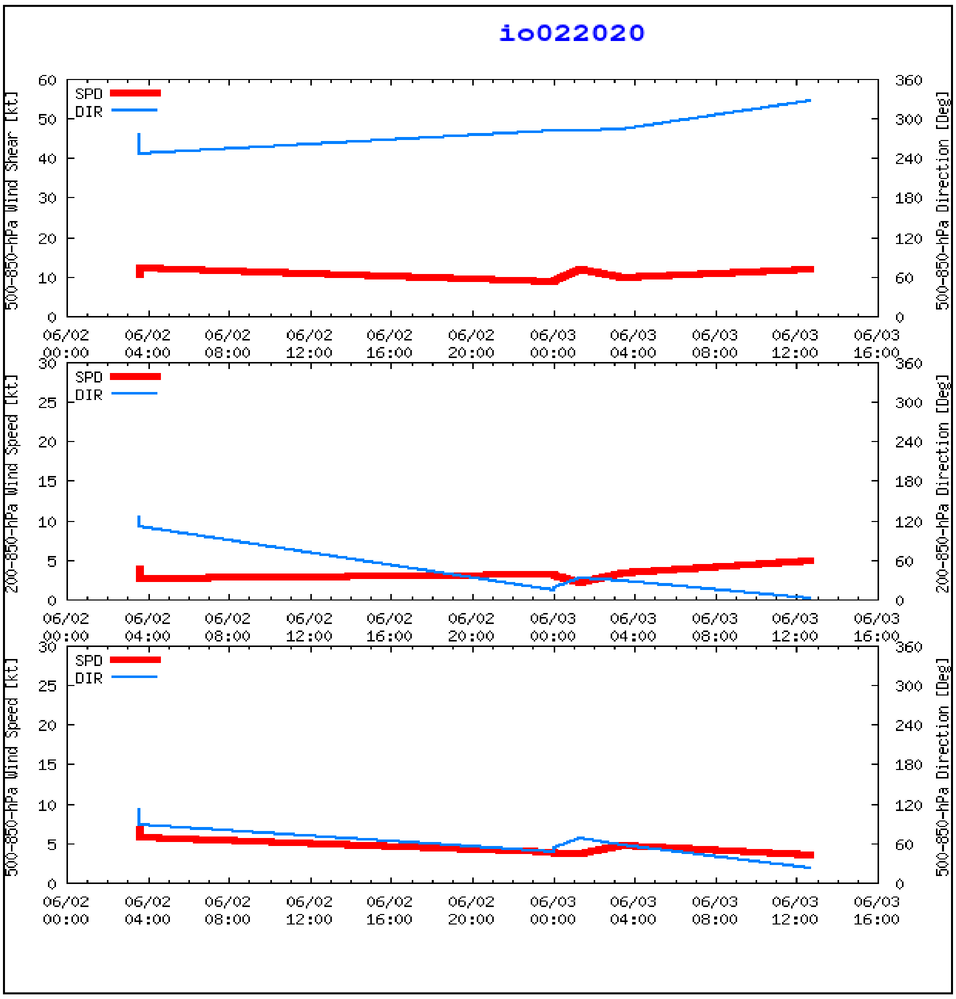

Fig.4: Wind shear and wind speed in the middle and deep layer around the system during SCS NISARGA (1st – 4th June), 2020

The six hourly average translational speed during the life cycle of SCS Nisarga is presented in Fig. 5a. During initial stages of its development (0000 UTC to 1800 UTC of 1st June), Nisarga moved slower than the average (1990-2013) speed of 10.5 kmph for SCS category over the AS during monsoon season. Thereafter the speed increased gradually till morning (0000 UTC) of 3rd June. Subsequently, it increased sharply during landfall till it's weakening into a WML at 1200 UTC of 4th June. The six hourly maximum sustained wind speed and estimated central pressure is presented in Fig. 5b. The intensity of the system increased gradually till 1800 UTC of 2nd. Thereafter, intensity increased sharply and reached it's peak of 60 kts at 0600 UTC of 3rd June. The landfall process had already started by that time and the system crossed Maharashtra coast during 0700 to 0900 UTC of 3rd with peak intensity of 60 kts gusting to 70 kts. Thereafter, due to land interactions, cut in moisture supply and increased translational speed, the system rapidly weakened into a WML at 1200 UTC of 4th June.

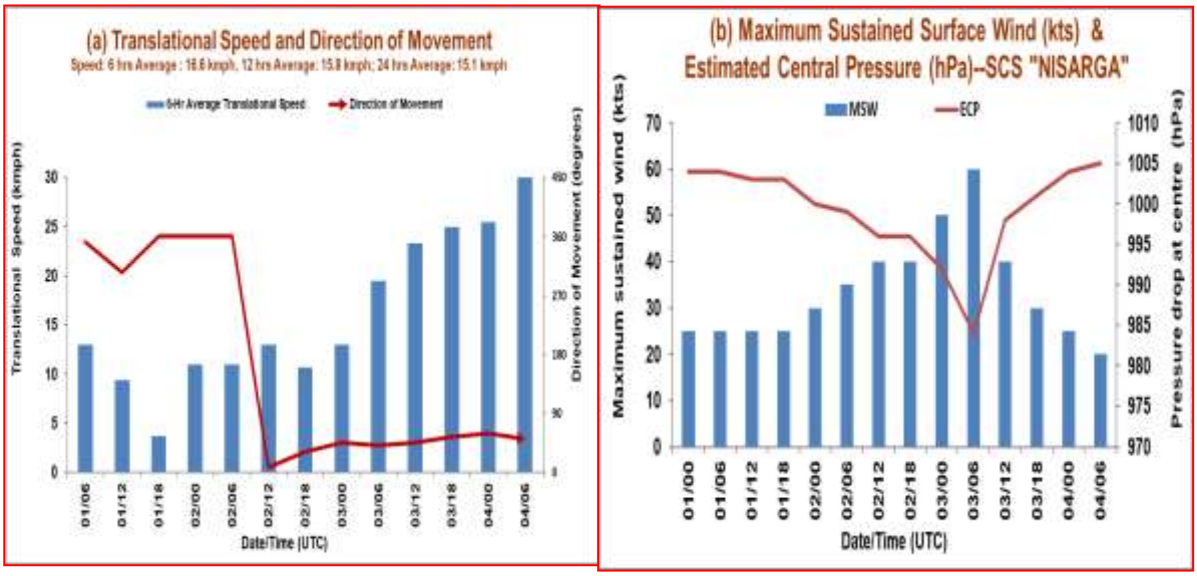

Fig. 5: (a) Translational speed & direction of movement and (b) Maximum sustained surface winds (kts) & Estimated Central Pressure

4. Monitoring and Prediction of SCS NISARGA:

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India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the genesis was monitored since 21st May, about 10 days prior to the formation of low pressure area over the southeast & adjoining eastcentral Arabian Sea and Lakshadweep on 31st May. The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, SCAT SAT, polar orbiting satellites and available ships & buoy observations in the region. The system was also monitored by Doppler Weather RADARs (DWRs) Goa and Mumbai. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions, global models and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the cyclone. A digitized forecasting system of IMD was utilized for analysis and comparison of various models' guidance, decision making process and warning products generation. The satellite and RADAR imageries during entire life cycle of the system are presented in Fig.6 & 7 respectively.

4.1. Features observed through satellite

As per satellite imagery based on 0300 UTC of today, the 29th May, the cloud mass over westcentral Arabian Sea further organized. The vortex lay over westcentral Arabian Sea & neighborhood centered within half a degree of 15.7ºN/54.8ºE. The intensity of the system was T1.0. In association with this system, broken low and medium clouds with embedded intense to very intense convection lay over westcentral Arabian Sea between latitude 13.0ºN to 21.0ºN & longitude 51.0ºE to 57.0ºE and south Oman and adjoining east Yemen. Minimum cloud top temperature is minus 93ºC. Scattered low and medium clouds with embedded intense to very intense convection also lay over southeast and westcentral Arabian Sea.

At 1200 UTC of 29th May, broken low/medium clouds with embedded intense to Very intense convection lay over westcentral Arabian Sea between Latitude 13.5°N to 19.5°N longitude 50.5°E to 57.5°E, south Oman Adjoining north Yemen. Minimum CTT is minus 93°C.

At 1200 UTC of 30th May, associated Broken low and medium clouds with embedded intense to very intense Convection lay over westcentral Arabian sea between latitude 14.5°N To 19.0°N and longitude 52.5°E to 57.0°E. Minimum cloud top temperature was minus 93°C.

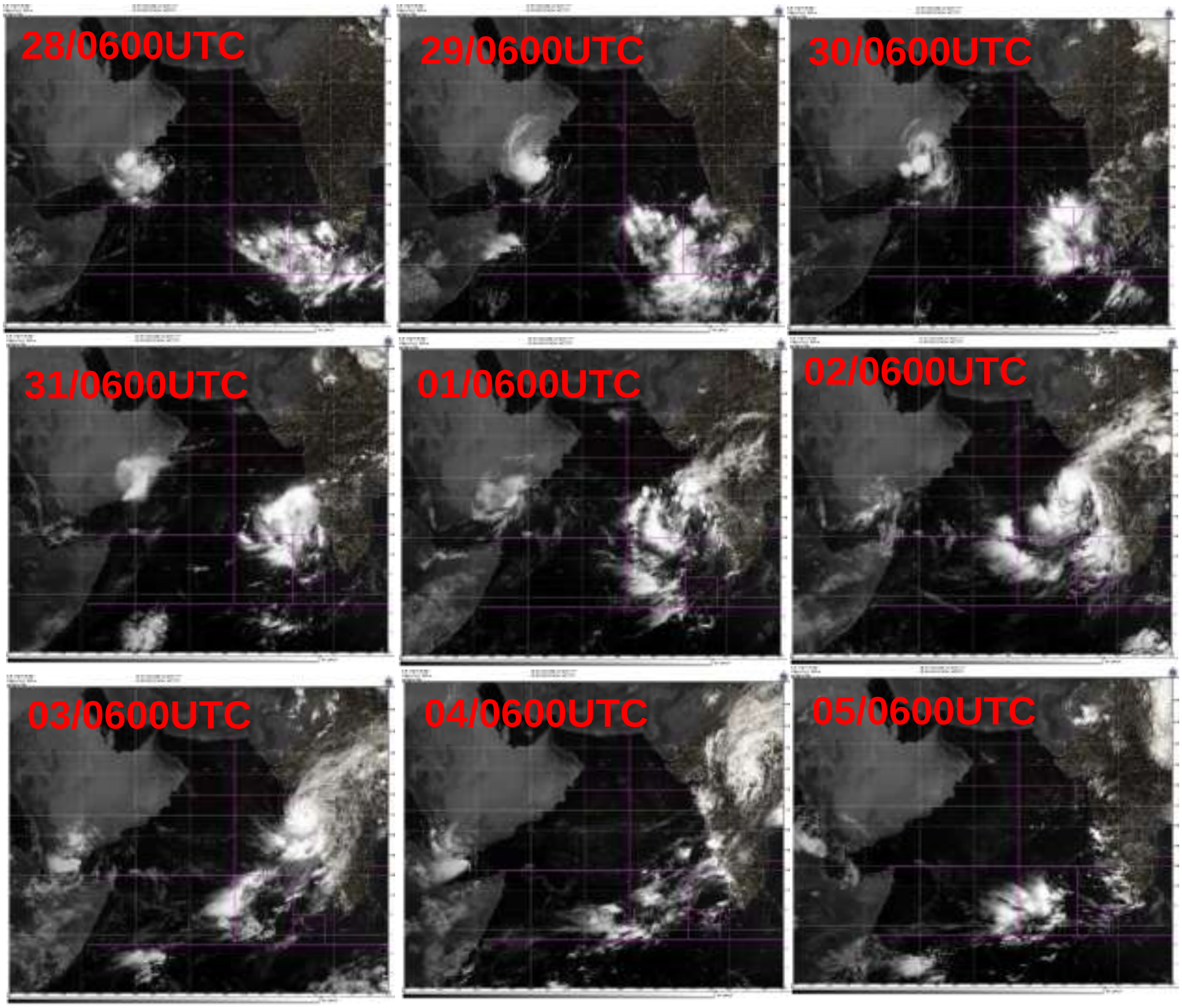


Fig. 6a: INSAT-3D Visible imageries during life cycle of SCS NISARGA (28 MAY-5 JUNE, 2020)

At 0000 UTC of 31st May, associated broken low and medium clouds with embedded intense to very intense convection lay over Lakshadweep, south east & amp; eastcentral Arabian Sea between latitude 10.0°N to 15.0°N and longitude 68.0°E. Minimum cloud top temperature was minus 93°C.

At 1200 UTC of 31st May, associated broken low and medium clouds with embedded intense to very intense convection lay over Lakshadweep, south east &

eastcentral Arabian sea between latitude 09.0°N to 16.5°N and LONGITUDE 66.0°E to 74.5°E. Minimum cloud top temperature was minus 84°C.

At 0000 UTC of 01st June, the intensity of the system was T1.5. Associated scattered to broken low/medium clouds with embedded intense to very intense convection lay over southeast and adjoining eastcentral Arabian sea between latitude 7.5^{0}N TO 17.0^{0}N and longitude 65.0^{0}E to 74.5^{0}E. Minimum cloud top temperature (CTT) was minus 93°C.

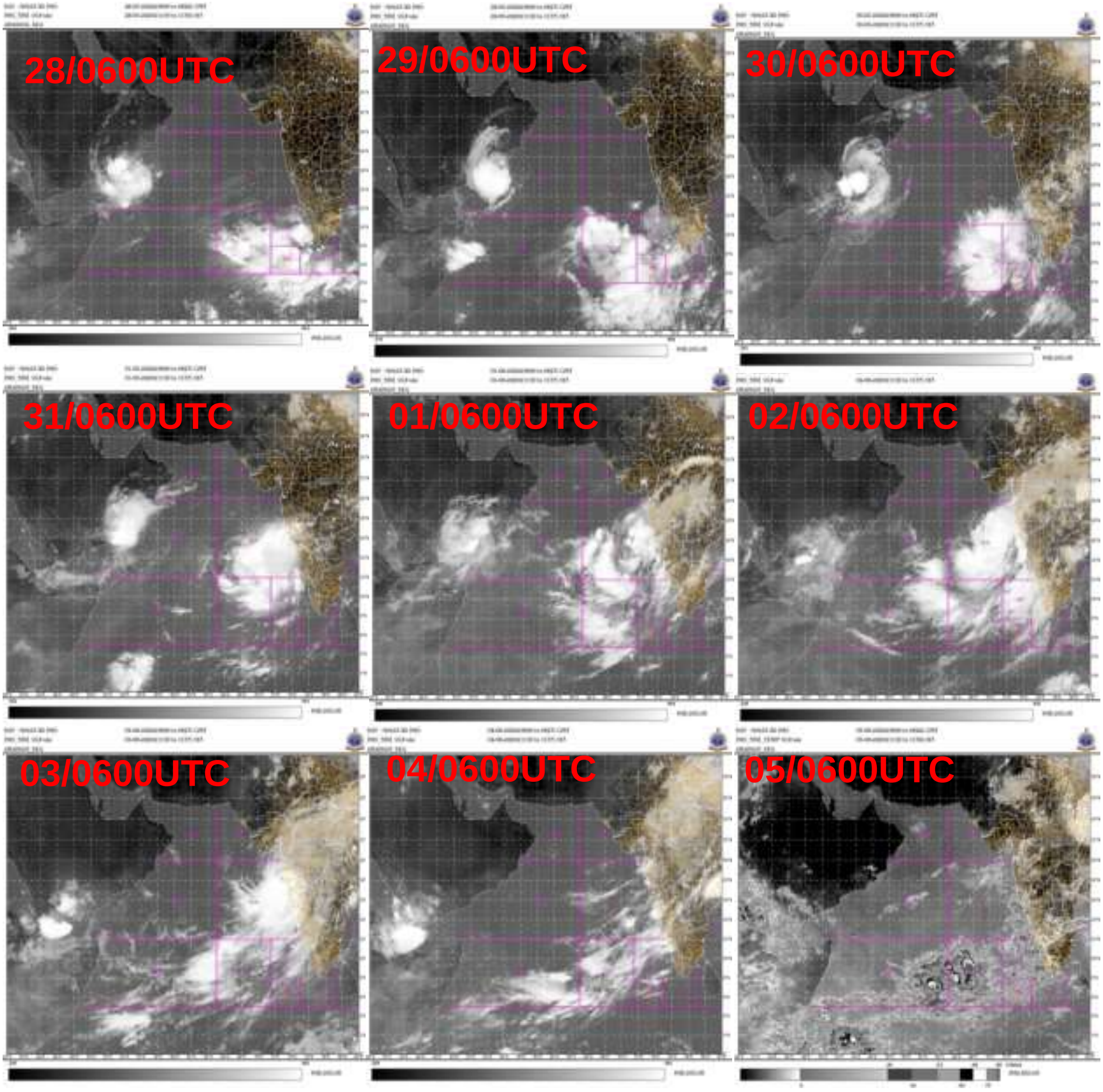


Fig. 6 b: INSAT-3D IR imageries during life cycle of SCS NISARGA (28 MAY-5 JUNE, 2020)

As per INSAT-3D satellite imagery based on 0000 UTC of 02nd June, the intensity of the system intensity is T2.0. Associated scattered to broken low/medium clouds with embedded intense to very intense convection observed over eastcentral Arabian sea between latitude 12.5^{0}N to 18.0^{0}N and longitude 67.0^{0}E TO 74.5^{0}E. Minimum cloud top temperature (CTT) was minus 93°C.

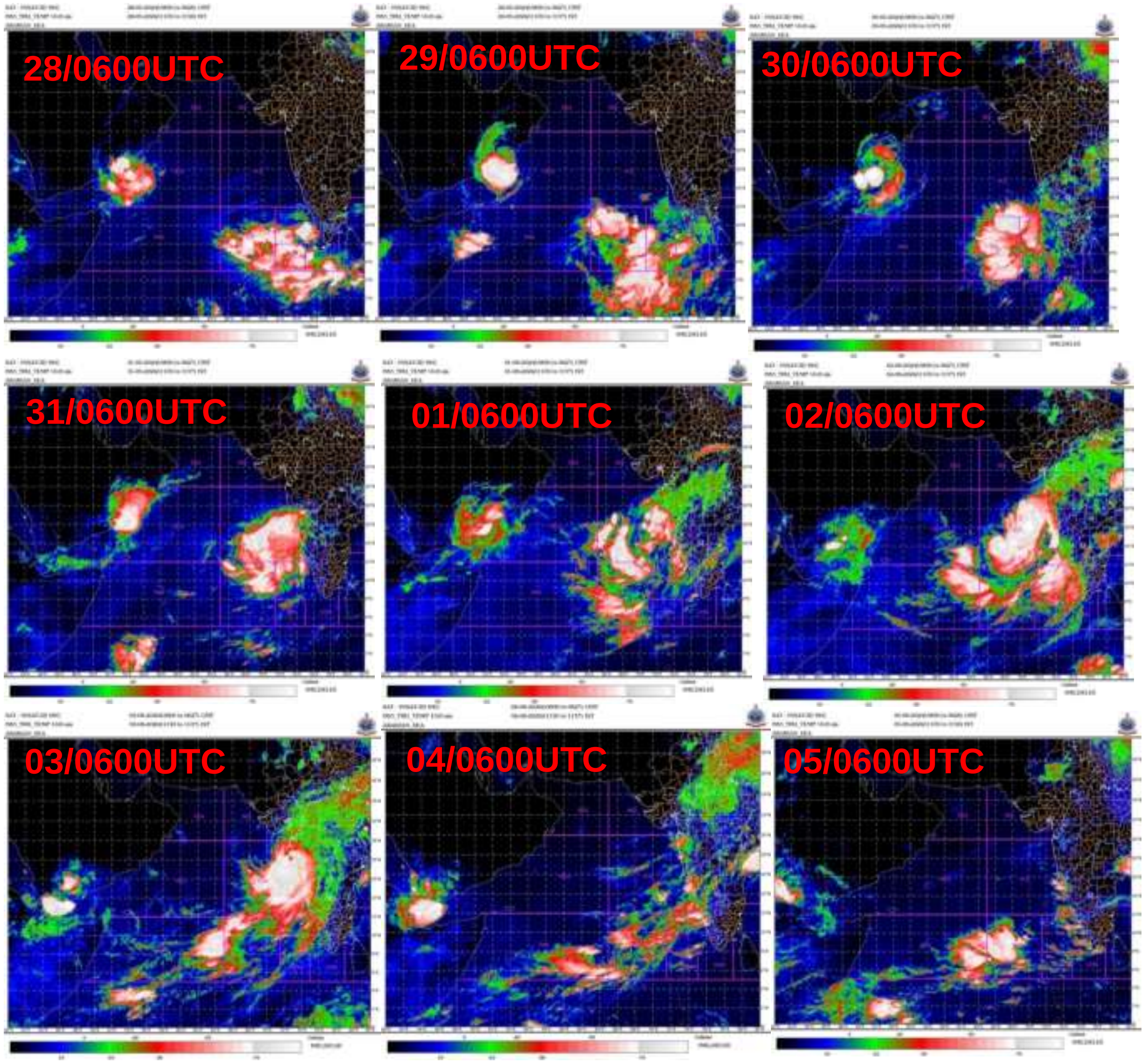


Fig. 6c: INSAT-3D enhanced color imageries during life cycle of SCS NISARGA (28 MAY-5 JUNE, 2020)

At 0600 UTC of 02nd June, the vortex further intensified. The current intensity of the system was T 2.5 associated with irregular CDO pattern. The system became further organized in last 3-hours. Associated broken low/medium clouds with embedded intense to very intense convection observed over eastcentral Arabian sea between latitude 11.1^{0}N TO 18.0^{0}N and longitude 66.0^{0}E to 74.5^{0}E. Minimum cloud top temperature (CTT) was minus 93°C.

At 0000 UTC of 03rd June, the current intensity of the system was T 3.0 associated with curved band pattern with wrap 0.5 on 10° log spiral. The system continued to organise in last 3-hours. Associated broken low/medium clouds with embedded intense to very intense convection observed over eastcentral Arabian sea between latitude 11.5^{0}N TO 19.0^{0}N and longitude 66.5^{0}E TO 75.0^{0}E. Minimum cloud top temperature (CTT) is minus 93°C.

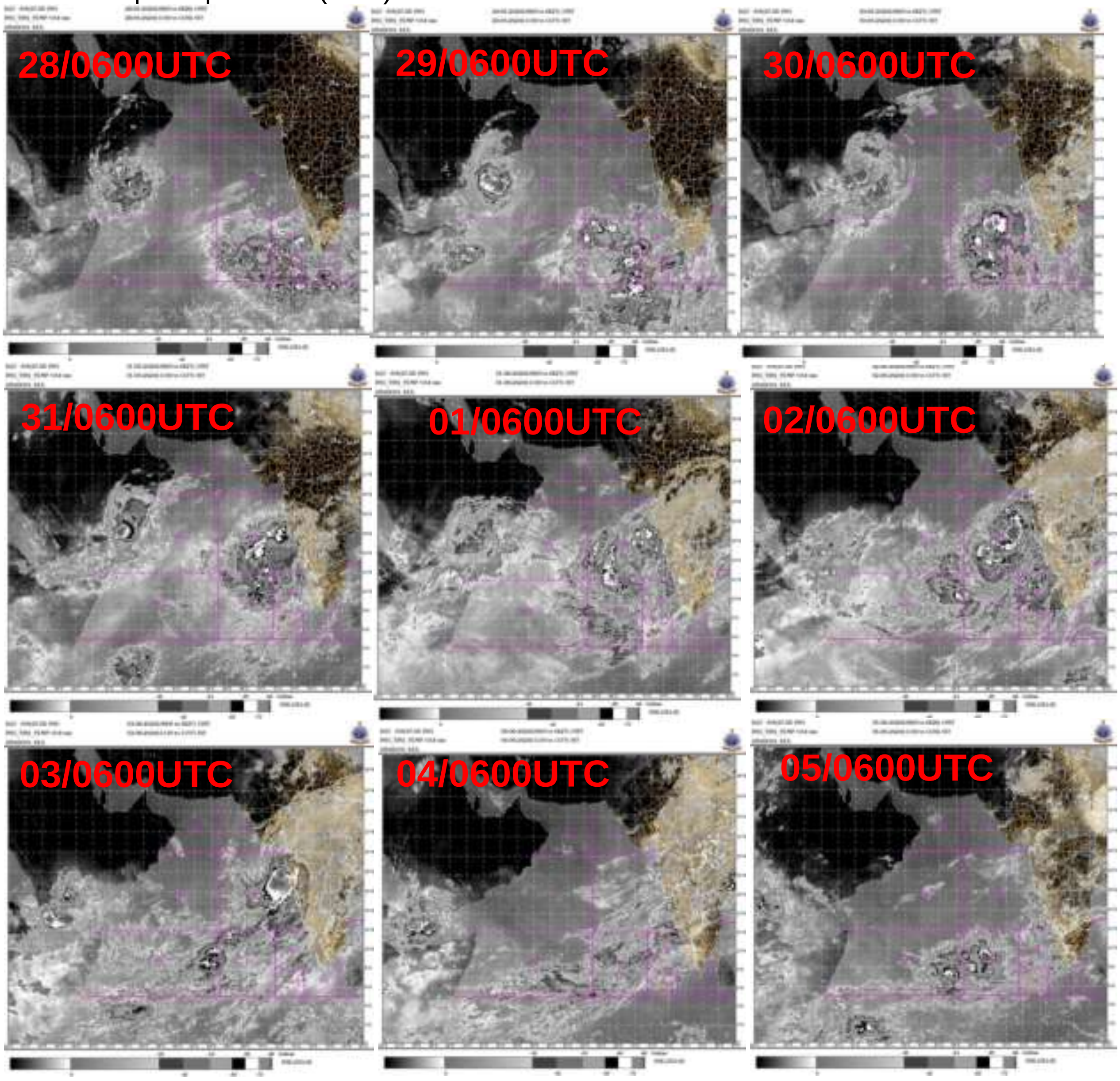


Fig. 6d: INSAT-3D BD imageries during life cycle of SCS NISARGA (28MAY-5 JUNE, 2020)

The system crossed Maharashtra coast during 0700 to 0900 UTC of 3rd June. AT 1200 UTC of 03rd June, the system further weakened over the land. Broken low/medium clouds with embedded intense to very intense convection over eastcentral Arabian Sea between latitude 13.0^0 NTO 20.0^0 N and longitude 70.0^0 E & 75.0^0.E Minimum cloud top temperature (CTT) was -86°C.

At 1500 UTC of 03rd June, the system further weakened over the land. Associated broken low/medium clouds with embedded intense to very intense convection over eastcentral Arabian Sea between latitude 13.0^{0}N to 20.0^{0}N and longitude 70.0^{0}E TO 75.0^{0}E. Minimum cloud top temperature (CTT) was -86°C.

At 0000 UTC of 04th June, the system continued to weaken over the land. INSAT 3D further showed associated broken low/medium clouds with embedded intense to very intense convection between latitude 18^{0}N to 22.0^{0}N and longitude 73.0^{0}E TO 75.0^{0}E. Minimum cloud top temperature (CTT) was minus 50°C.

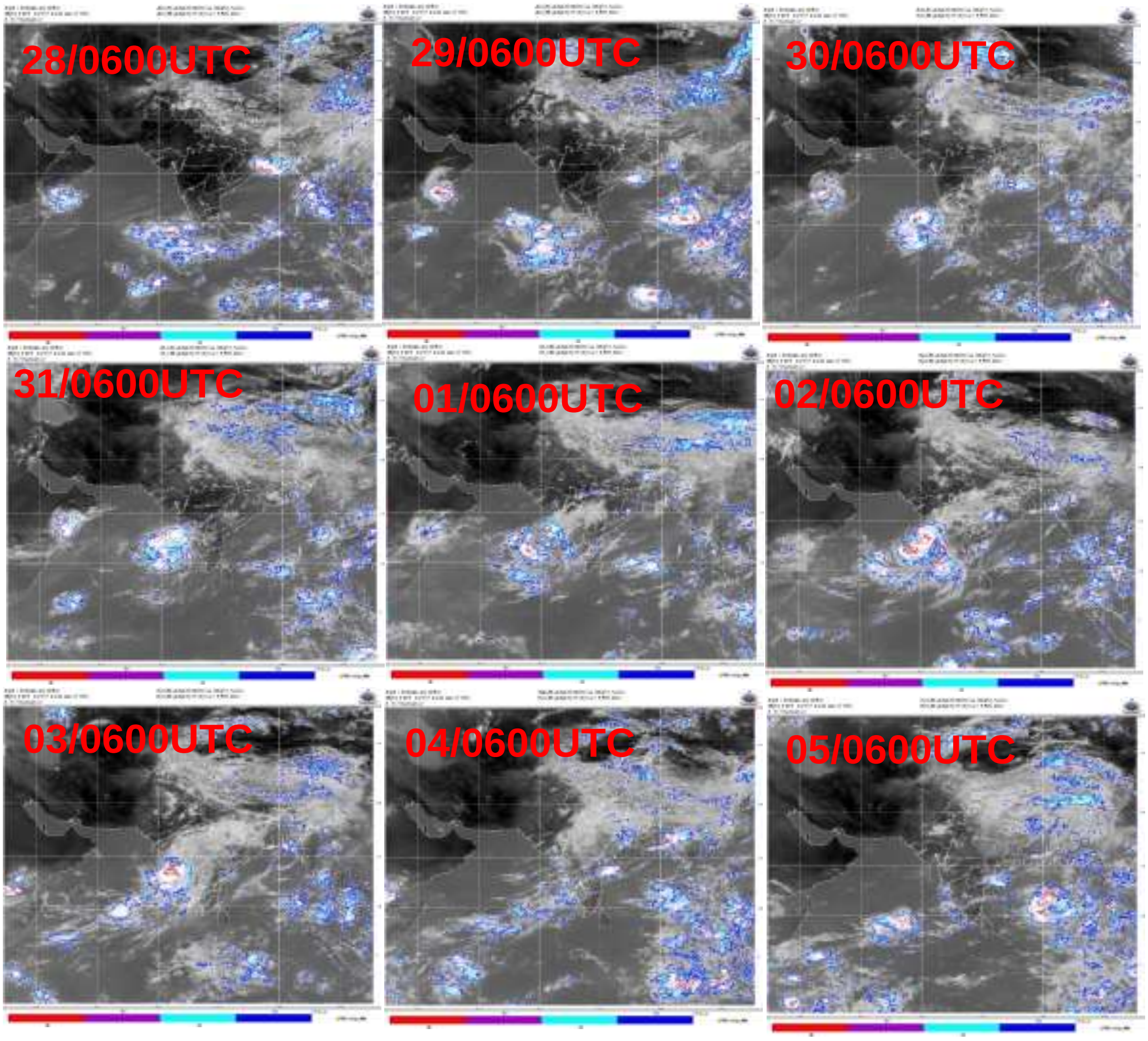


Fig. 6e: INSAT-3D cloud top brightness temperature imageries during life cycle of SCS NISARGA (28MAY-5 JUNE, 2020)

Typical microwave imageries during life cycle of SCS Nisarga are presented in Fig. 6 f.

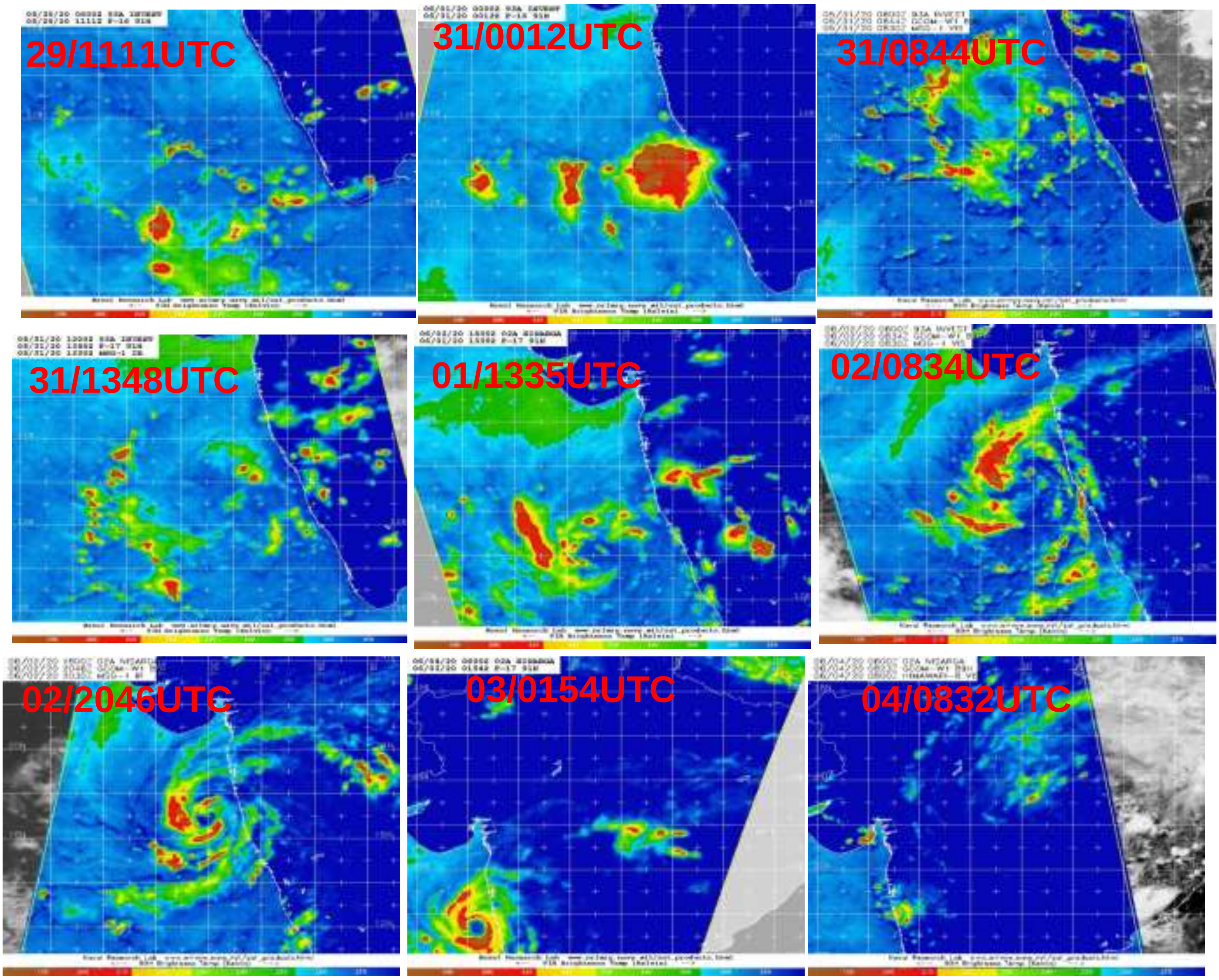


Fig. 6 f: Microwave imageries during life cycle of SCS NISARGA (29MAY-4 JUNE, 2020)

Typical ASCAT imageries during life cycle of SCS NISARGA (29MAY-4 JUNE, 2020), since inception as low pressure area are presented in 6 g.

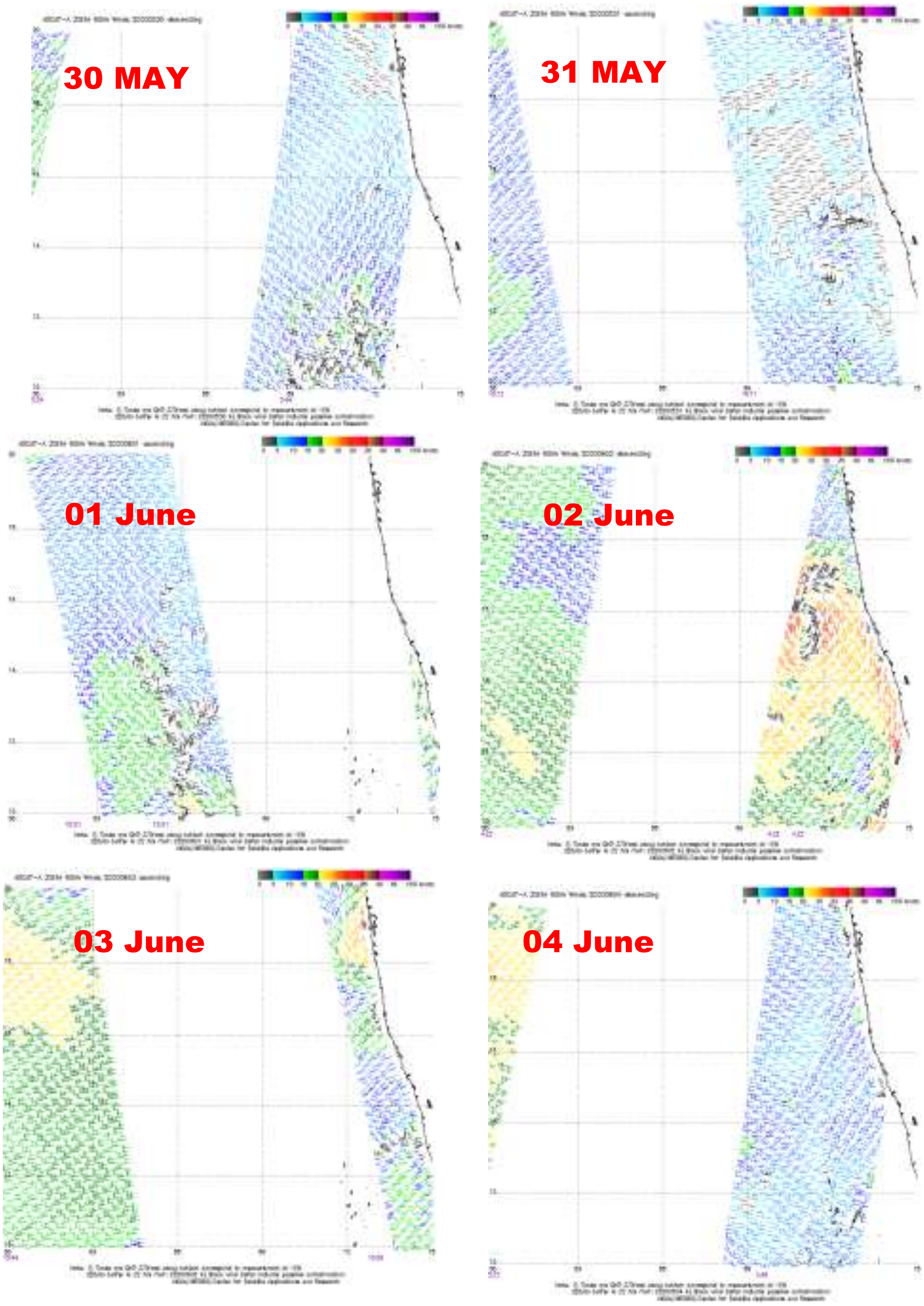


Fig. 6g: ASCAT imageries during life cycle of SCS NISARGA (29MAY-4 JUNE, 2020)

Typical SCAT SAT imageries are presented in Fig. 6h.

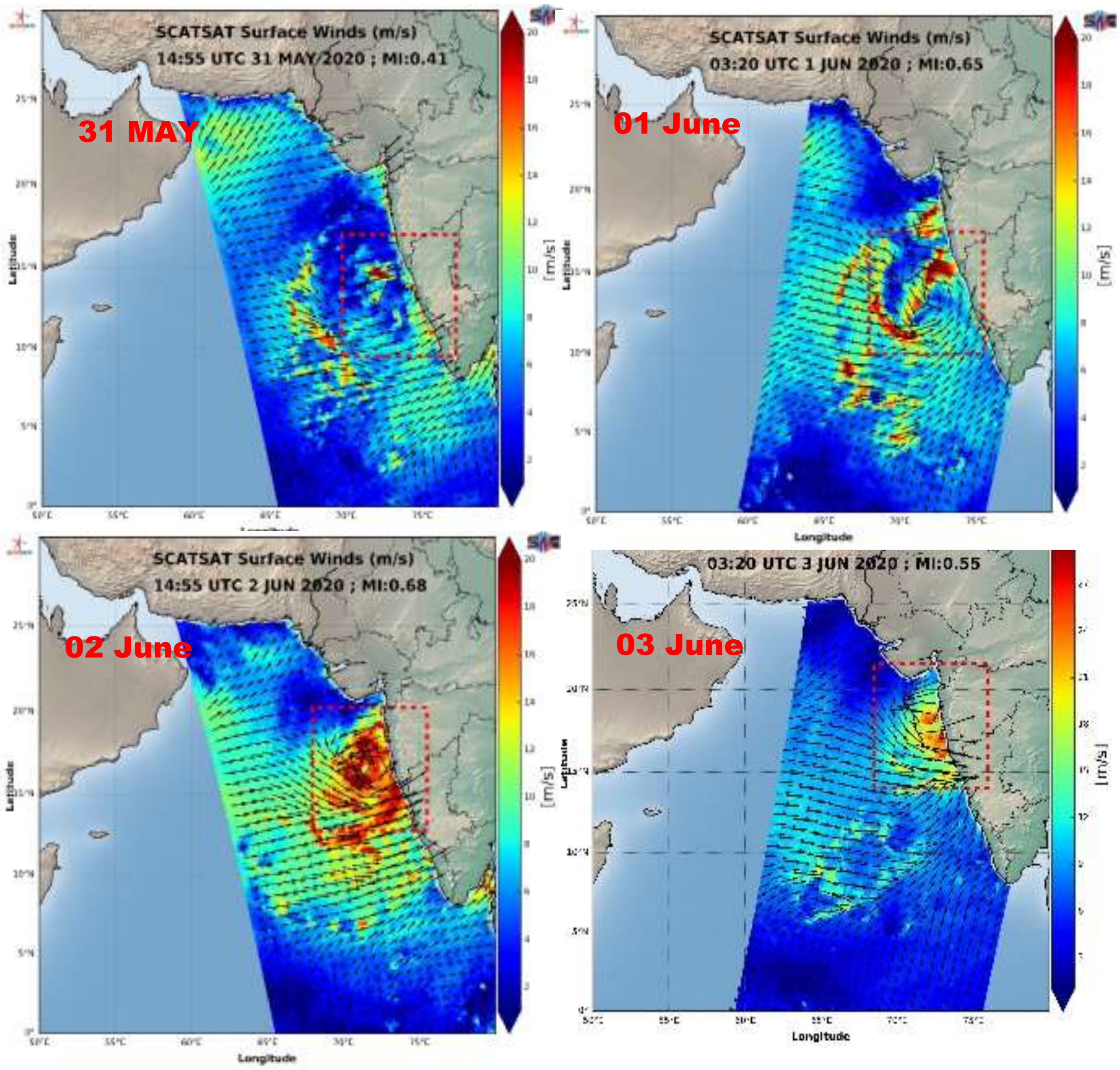


Fig. 6h: SCAT SAT imageries during life cycle of SCS NISARGA (31MAY-3 JUNE, 2020)

4.2. Features observed through Radar

The SCS NISARGA was tracked by DWRs Mumbai, GOA during its movement from southwest to north BoB. Typical DWR imageries from these radars are presented in Fig. 6.

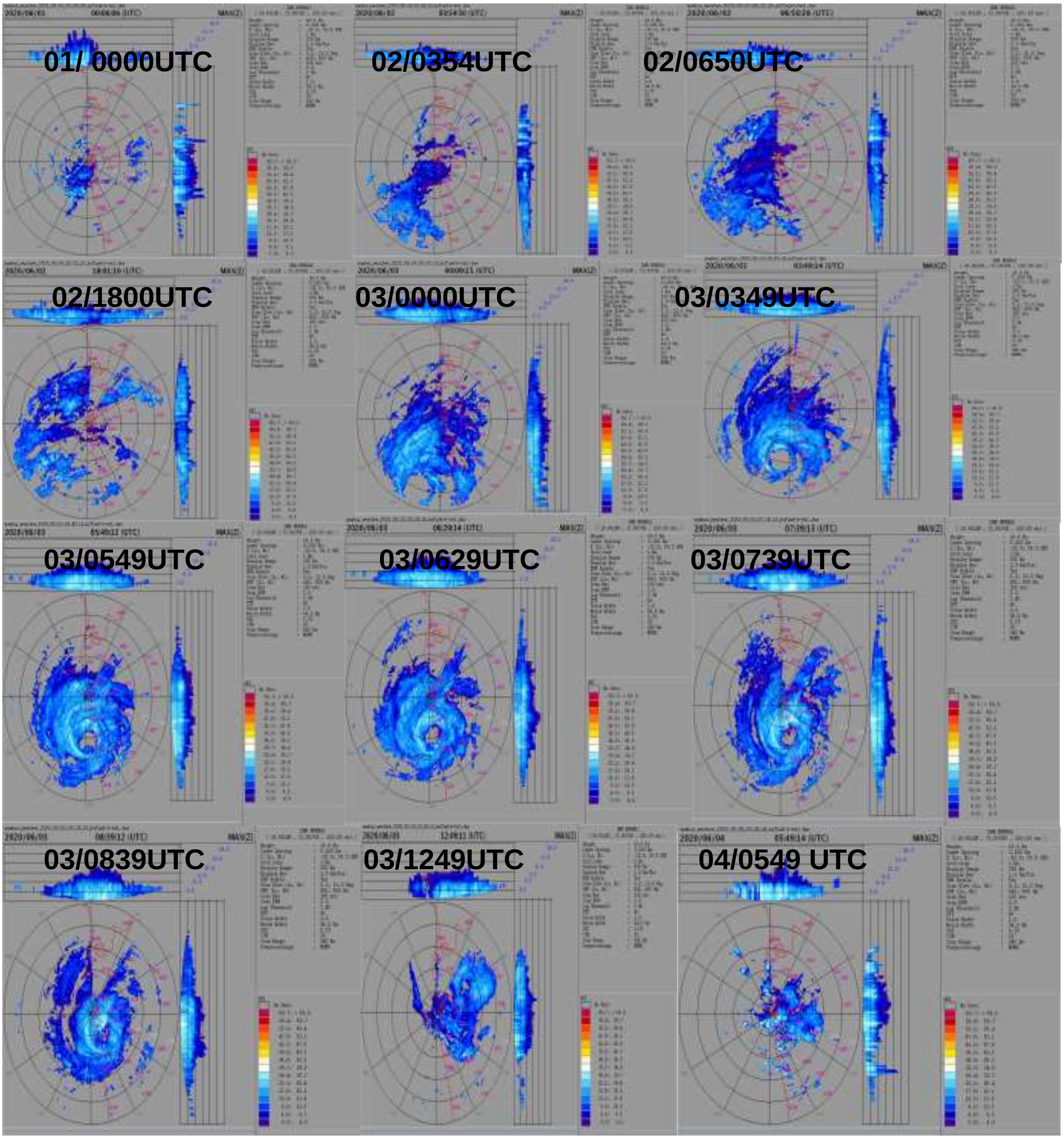


Fig. 7a: Typical Radar imagery from DWR Mumbai during 01-04 June of SCS Nisarga

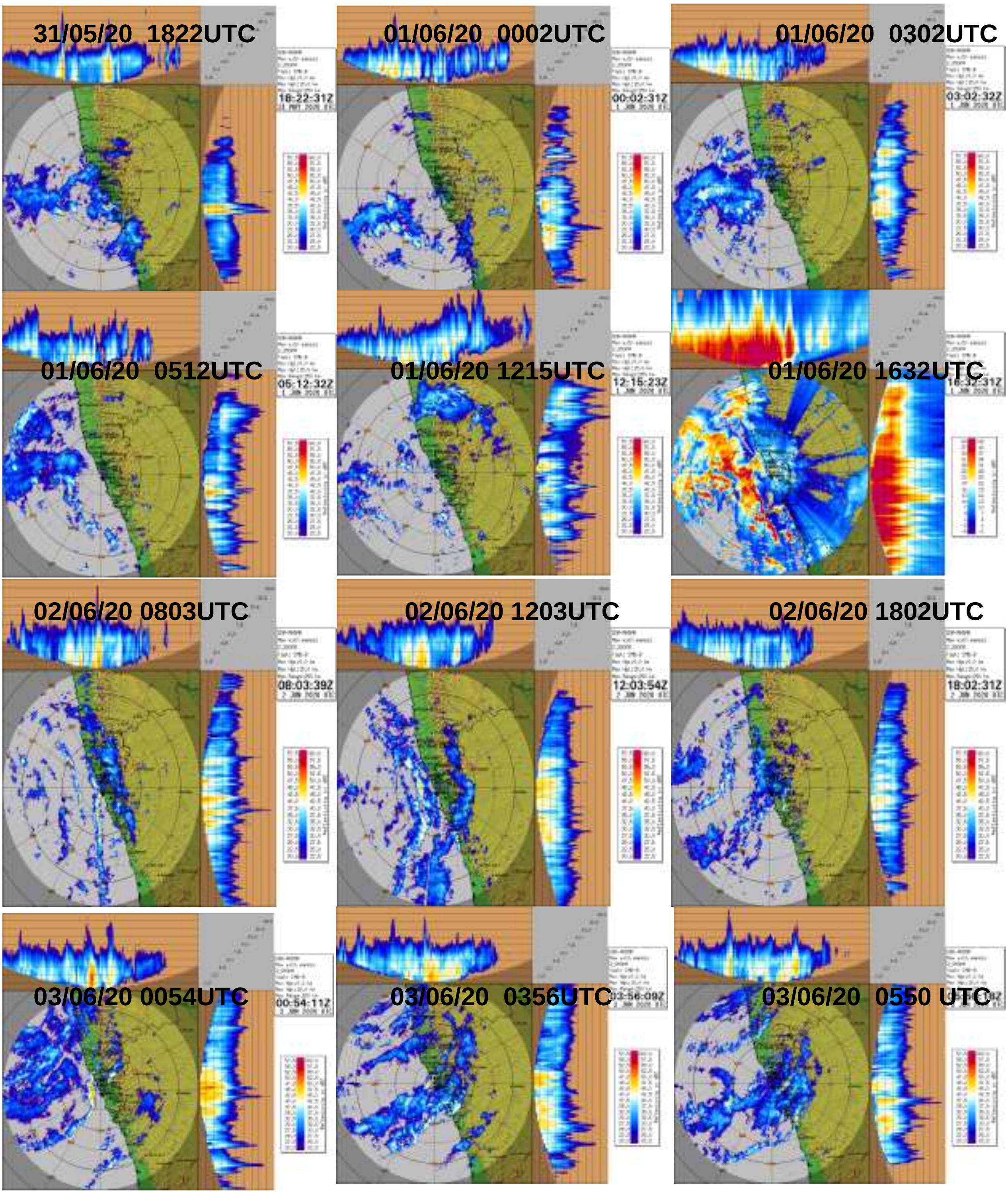


Fig.7 b: Typical Radar imagery from DWR GOA during 31May- 03 June of SCS NISARGA

5. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 01st-05th June are presented in Fig.8. At 0000 UTC of 01st June, IMD GFS was indicating a low pressure area over southeast Arabian Sea with vertical extension upto 500 hPa level. The model underestimated the intensity of the system on 1st June. However, location was correctly estimated.

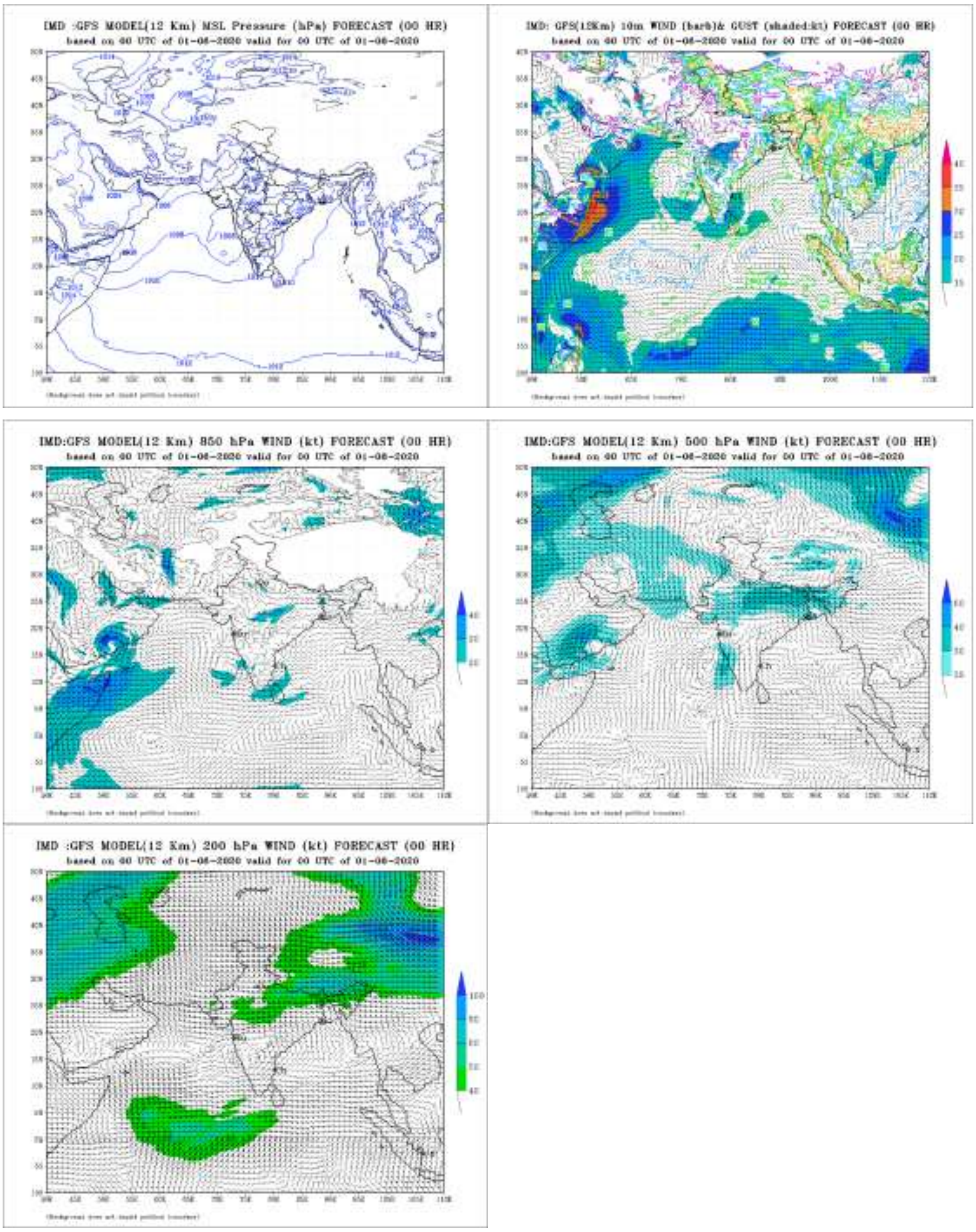


Fig 8(a): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 01st June 2020

At 0000 UTC of 2nd June, IMD GFS was indicating a deep depression over eastcentral Arabian Sea with vertical extension upto 500 hPa level. The model correctly estimated the location and intensity of the system on 2nd June.

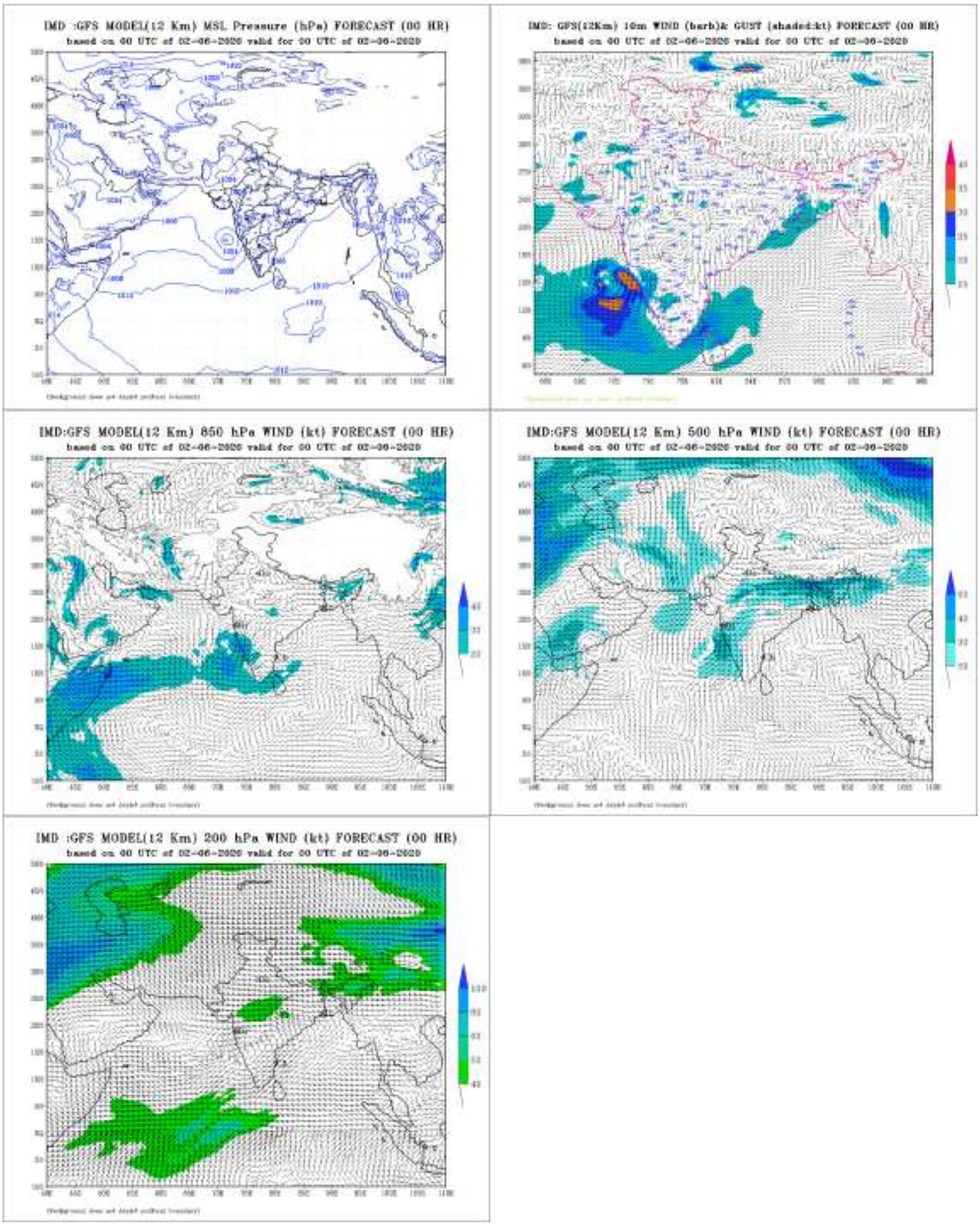


Fig 8(b): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 02nd June 2020

At 0000 UTC of 3rd June, IMD GFS was indicating a severe cyclonic storm over eastcentral Arabian Sea with vertical extension upto 500 hPa level. The model correctly estimated the location and intensity of the system on 3rd June.

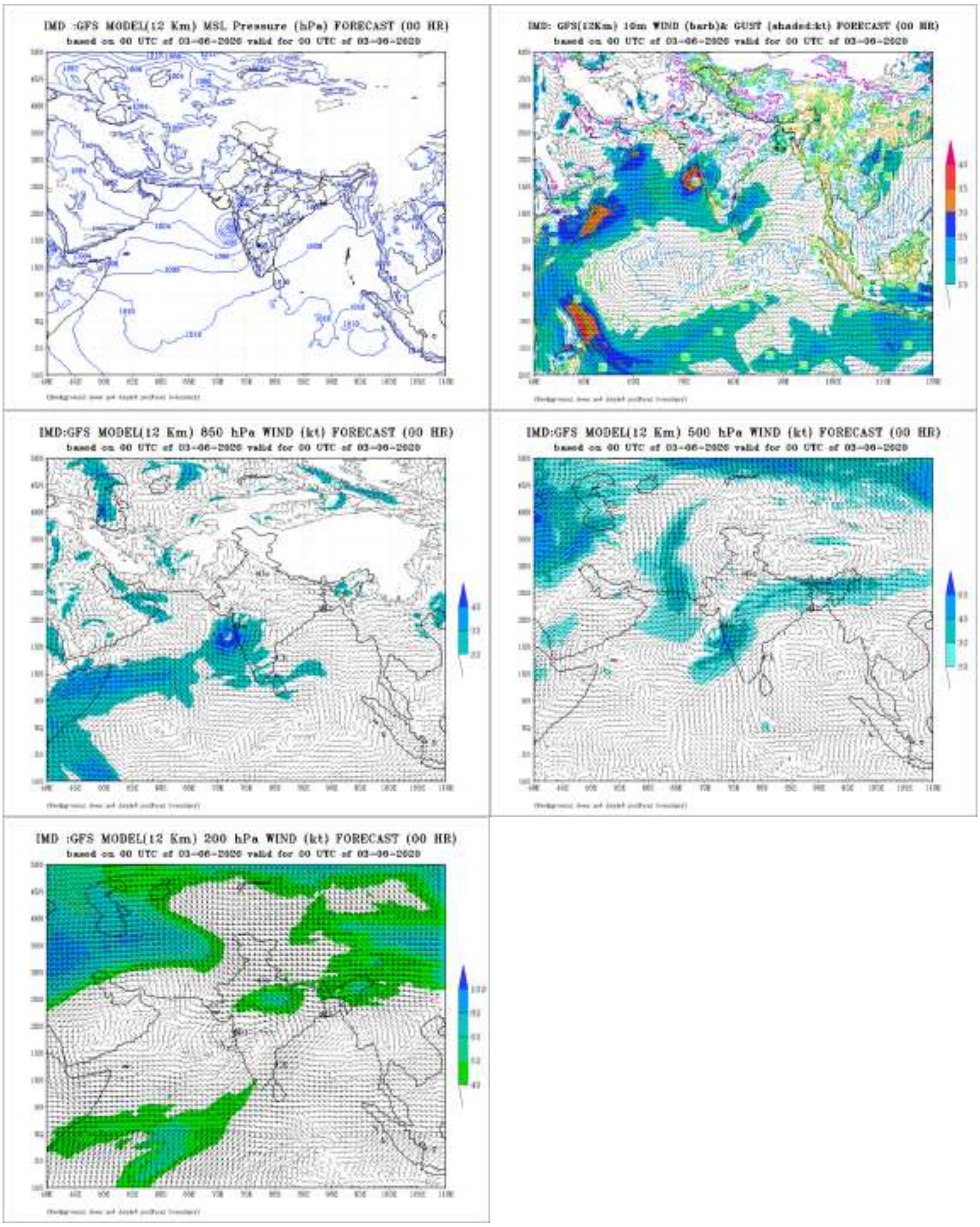


Fig. 8(c): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 03rd June 2020

At 0000 UTC of 4th June, IMD GFS was indicating a deep depression over interior Maharashtra and adjoining Madhya Pradesh with vertical extension upto 500 hPa level. The model correctly estimated the location of the system. However, intensity was slightly over estimated. At that time, system lay as a depression over Maharashtra and adjoining Madhya Pradesh.

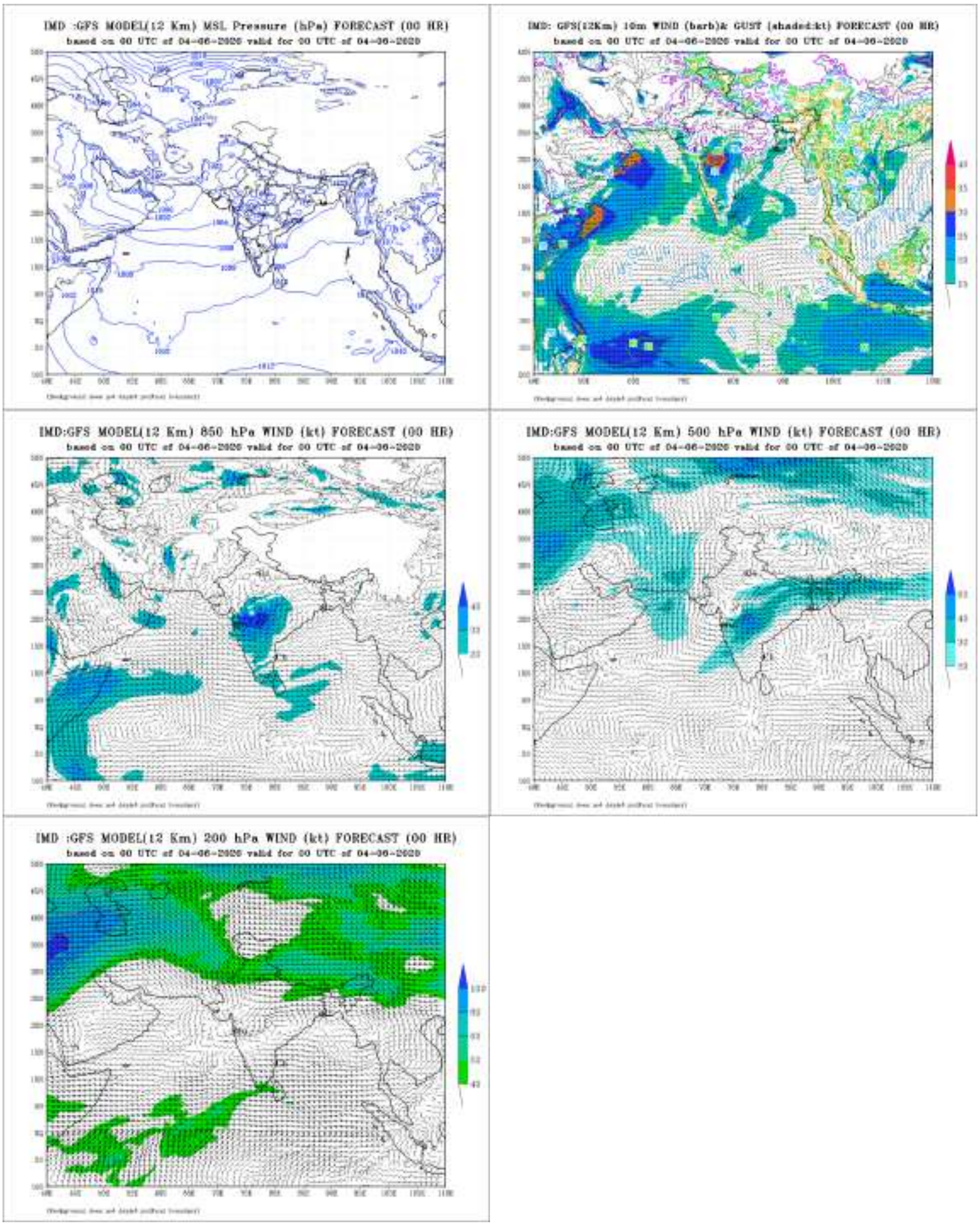


Fig. 8(d): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 04th June 2020

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

6. Realized Weather:

6.1 Realized rainfall

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

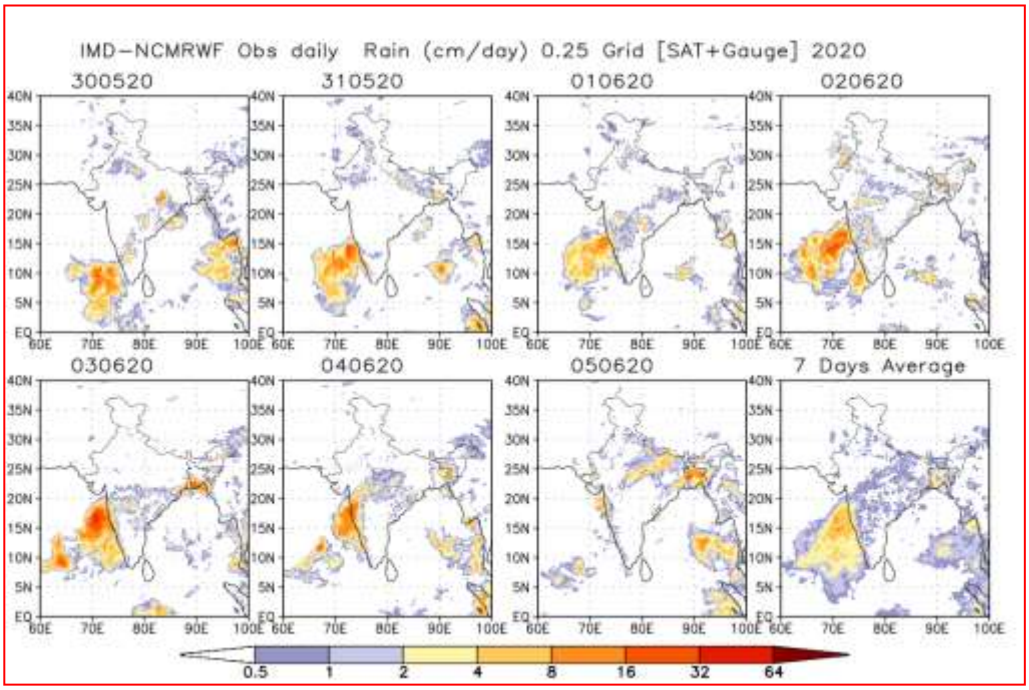


Fig.9: IMD-NCMRWF GPM merged gauge 24 hr cumulative rainfall (cm) ending at 0300 UTC of date during 30th May – 05th June and 7 days average rainfall (cm/day)

It indicates occurrence of heavy rainfall at isolated places over coastal Karnataka, Madhya Maharashtra & Marathwada on 1st June, heavy to very heavy rainfall at many places over Goa & at isolated places over Madhya Maharashtra on 3rd June, heavy to very heavy rainfall at many places over coastal Maharashtra & Goa and at isolated places over interior Maharashtra on 4th June and moderate rainfall at few places over Madhya Pradesh on 5th June.

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

1 June 2020

Coastal Karnataka: Kota-10 and Kundapur-7

3 June 2020

Konkan & Goa: Mormugao & Panjim-13 each, Quepem & Malvan-11 each, Valpoi & Sanguem-9 each, Sawantwadi, Dodamarg, Canacona & Devgad-8 each and Kudal-7

Madhya Maharashtra: Khed Rajgurunagar-7

4 June 2020

Konkan & Goa: Pen-16, Poladpur-15, Mangaon-14, Lanja, Mandangad & Dapoli -13 each, Tala-12, Vaibhavwadi & Alibag-11 each, Chiplun-10, Roha, Rajapur & Harnai -9 each, Guhagarh & Khed-8 each and Shahapur, Murud, Sangameshwar Devrukh, Khalapur, Jawhar & Ulhasnagar-7 each

Madhya Maharashtra: Mahabaleshwar-19, Gaganbawada-15, Nashik-14, Sinnar, Bhusawal & Igatpuri-11 each, Akole, Devla, Satna Baglan & Chandgad-9 each, Javali Medha, Patan & Khed Rajgurunagar-8 each and Girnadam, Malegaon Camp, Sakri, Kalvan, Dindori, Yaval, Shahuwadi, Surgana & Radhanagari-7 each
Vidarbha: Mangrulpir, Karanjalad, Jalgaon Jamod & Washim-8 each and Manora & Malegaon-7 each

6.2. Realized wind:

Peak wind speed (kmph) recorded by the meteorological observatories of IMD in association with the passage of NISARGA is presented in **Table 2**.

Table 2: Peak maximum sustained wind speed (kmph) reported by various observatories in Maharashtra on 3rd June

Station	Wind speed (kmph)	Time of observation (IST / UTC) of 3rd June 2020
Devgad	92	0530 /0000
Ratnagiri	110	1330 / 0800
Harnai	74	1230 / 0700
Alibag	102	1430 / 0900
Mumbai (Colaba)	92	1330 / 0800
Thane	75	2200 / 1700
Rajgurunagar (Pune)	65	1600 / 1030
Ahmadnagar	50	2030 / 1500
Satara	59	1730 / 1200

7. Damage and death tolls due to SCS, NISARGA

As per media reports Damage and death tolls due to SCS NISARGA in affected states are as follows -

a) Maharashtra: (https://en.gaonconnection.com/tag/helping-villagers-rebuild-their-houses-destroyed-by-cyclone-nisarga/)
A joint survey conducted by the National Fishworkers' Forum and Maharashtra Machhimar Kriti Samiti has recorded extensive damage to plantations, houses and fishing boats incurring loss of about Rs 1,000 crore in the coastal districts of Raigad and Ratnagiri. But, timely warning and evacuation helped save lives. Impact on Fishermen: (SOURCE: - Gaon connection June 18th, 2020). The damages to fishing boats alone was Rs 25 crore.

Impact on Farmers:
People living along the coast of Raigad and Ratnagiri have suffered huge losses. Majority of the houses went roofless and some houses suffered wall and slab collapse. A large number of plantations of coconut, betel, mango were flattened. Official survey by the Raigad district collector has estimated Rs 200 crore losses due to Cyclone Nisarga in 13 tehsils of the district. These include damages to 1.4 lakh houses, 1.6 lakh trees uprooted, and over 20,000 hectares farmland affected. (SOURCE: - Gaon connection dated 18th June, 2020)

b) Gujarat:

No major damage was reported.

Fig 10 (a) Uprooted trees from a road following rains and strong winds triggered by Cyclone Nisarga, at Alibag in Navi Mumbai, Wednesday, June 3, 2020. (PTI Photo) (b) & (c) Cyclone Nisarga: Strong winds pull down trees, damage property across Mumbai (Source:Deccanherald)

Fig 10 (d-g): Maharashtra: Many trees were uprooted in the Raigad district due to strong winds in view of #CycloneNisarga. The cyclone is expected to make landfall in an hour in the state and the process will be completed during the next 3 hours, as per IMD. (Source: @ANI, Twitter 3 June 12:32pm)

Fig. 10 (h-i) Houses damaged from Sindhudurg Dist. Maharashtra (Source: NDRF)

8. Performance of operational NWP models

IMD operationally runs a regional model, WRF for short-range prediction and one Global model T1534 for medium range prediction (10 days). The WRF-VAR model is run at the horizontal resolution of 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. 25ºS to 45ºN long 40ºE to 120ºE. 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 (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 multimodal ensemble (MME) for predicting the track (at 12h interval upto 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 SCS NISARGA are presented and discussed in following sections.

8.1. Prediction of cyclogenesis (Genesis Potential Parameter (GPP)) for NISARGA

Grid point analysis and forecast of GPP is used to identify potential zone of cyclogenesis. Figure 11 (a-h) shows the predicted zone of cyclogenesis. Grid point analysis and forecasts of GPP predicted the cyclogenesis zone over the Bay of Bengal since 26th May (120 hrs before actual genesis).

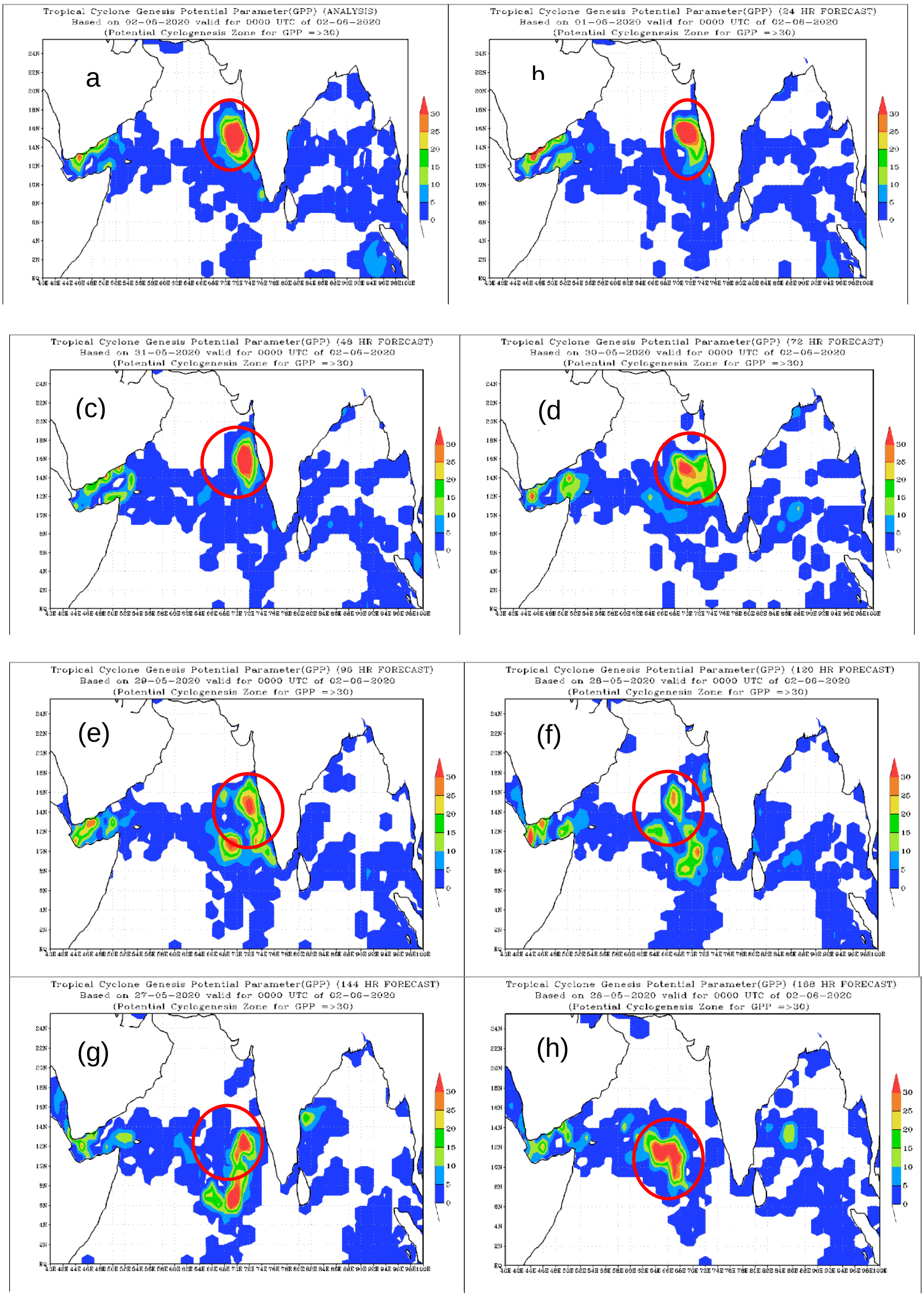


Fig.11 (a-h): Predicted zone of cyclogenesis for 0000 UTC of 2nd June based on 0000 UTC of 26th May -2nd June 2020

Since all low-pressure systems do not intensify into cyclones, it is important to identify the potential of intensification (into cyclone) of a low pressure system at the early stages (T No. 1.0, 1.5, 2.0) of development. Conditions for (i) Developed system: Threshold value of average GPP ≥ 8.0 and (ii) Non-developed system: Threshold value of GPP < 8.0. Since 31st May, the model had predicted that the system over Arabian Sea to intensify into a cyclonic storm. Area area average analysis is presented in Fig. 12.

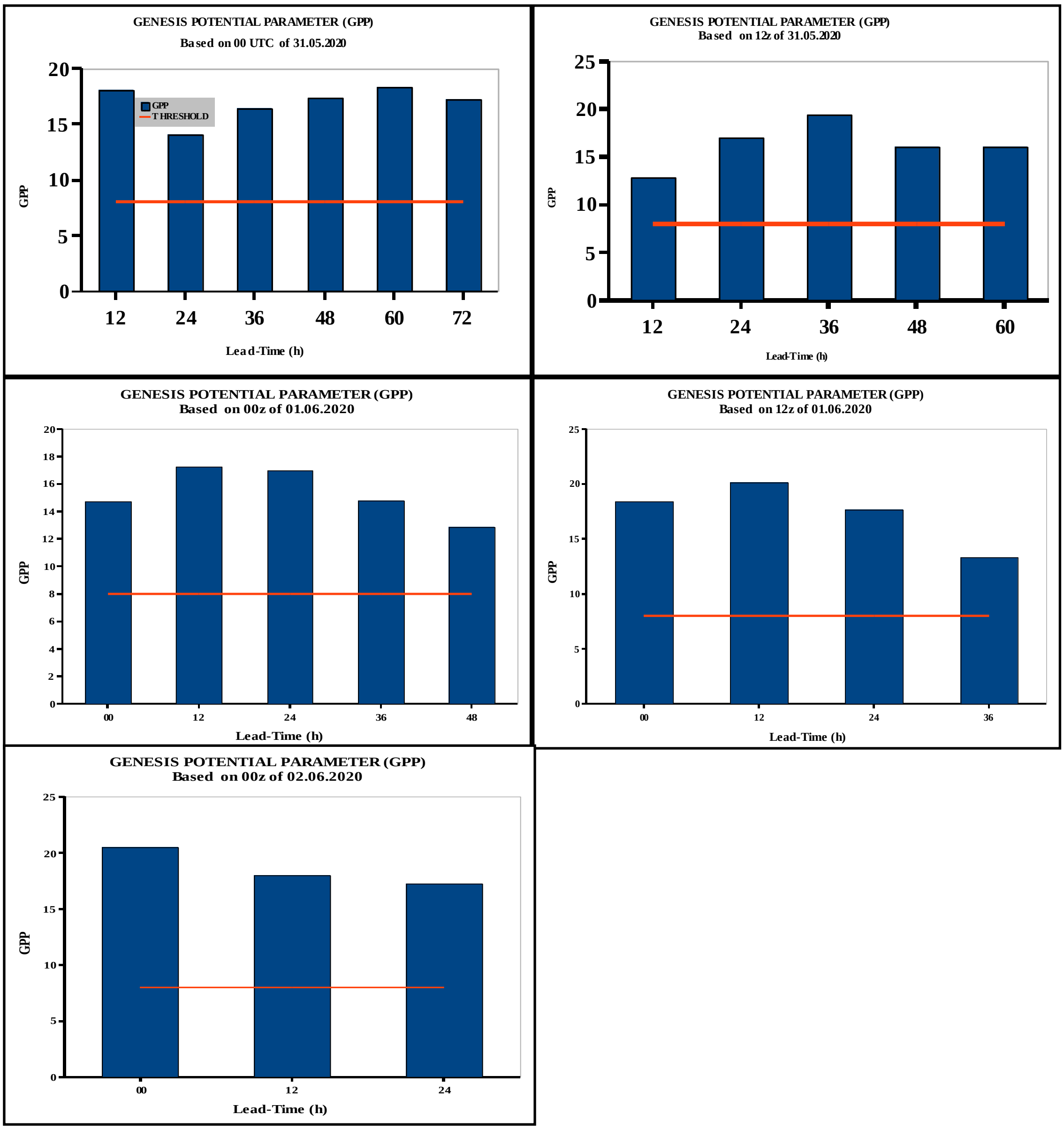


Fig. 12: (i) Area average analysis and forecasts of GPP based on 0000 UTC of 31.05.2020 (ii) 1200 UTC of 31.05.2020 (iii) 0000 UTC of 01.06.2020 (iv) 1200 UTC of 01.06.2020 and (v) 0000 UTC of 02.06.2020

9.2 Track prediction by NWP models

Track prediction by various NWP models is presented in **Fig.13**. Based on initial conditions of 0000 UTC of 1^{st} June, most of the models indicated initial northwards movement followed by north-northeastwards re-curvature and crossing near 18^{0}N. However, the landfall time varied largely. HWRF predicted intensification upto very severe cyclonic storm stage and MME indicated upto cyclonic storm stage.

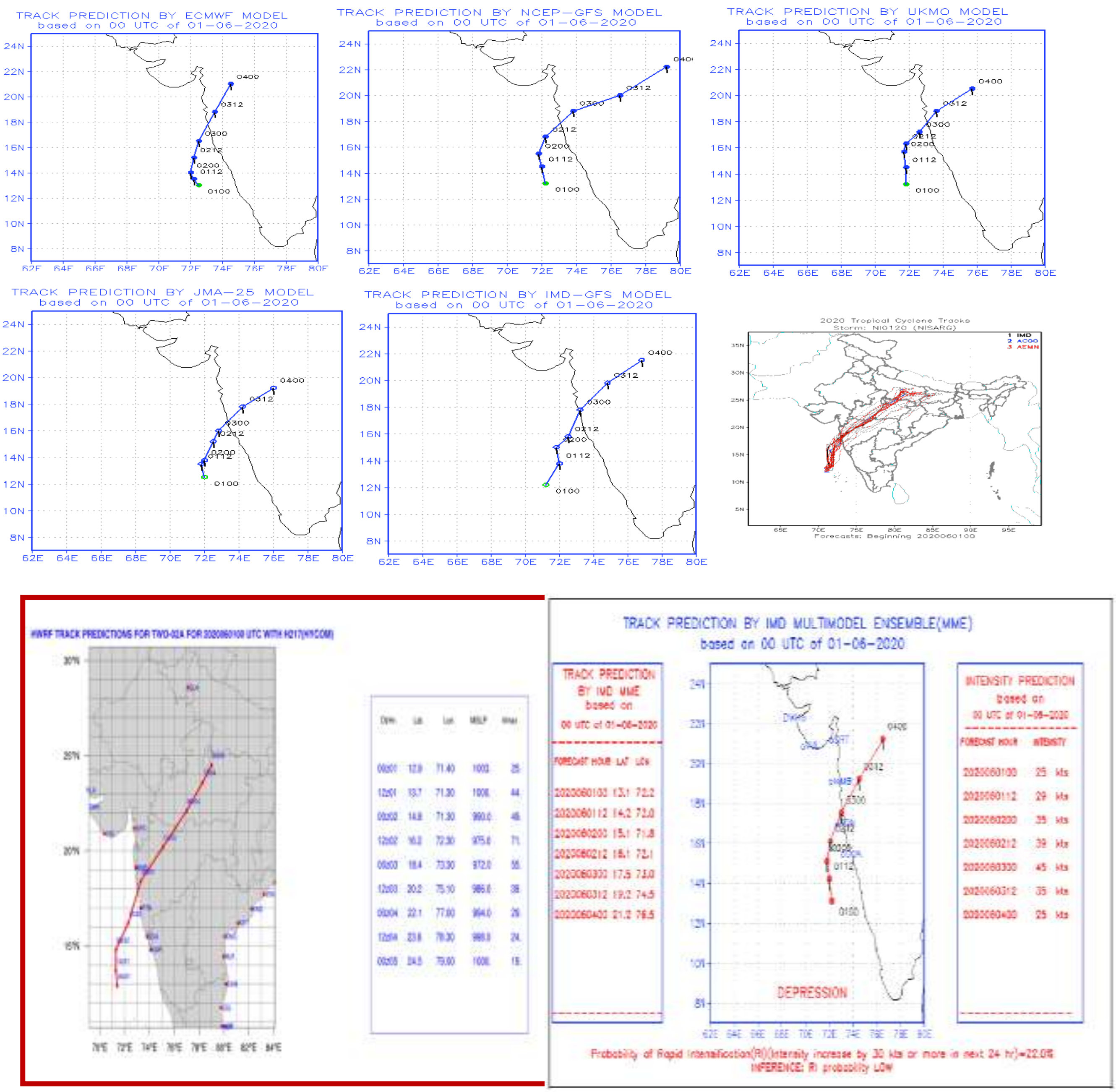


Fig. 13 (a): NWP model track forecast based on 0000 UTC of 01.06.2020

Based on initial conditions of 0000 UTC of 2nd June, most of the models indicated initial northwards movement followed by north-northeastwards re-curvature and crossing near 18^0N. Both HWRF and MME correctly picked up the intensity at the time of landfall.

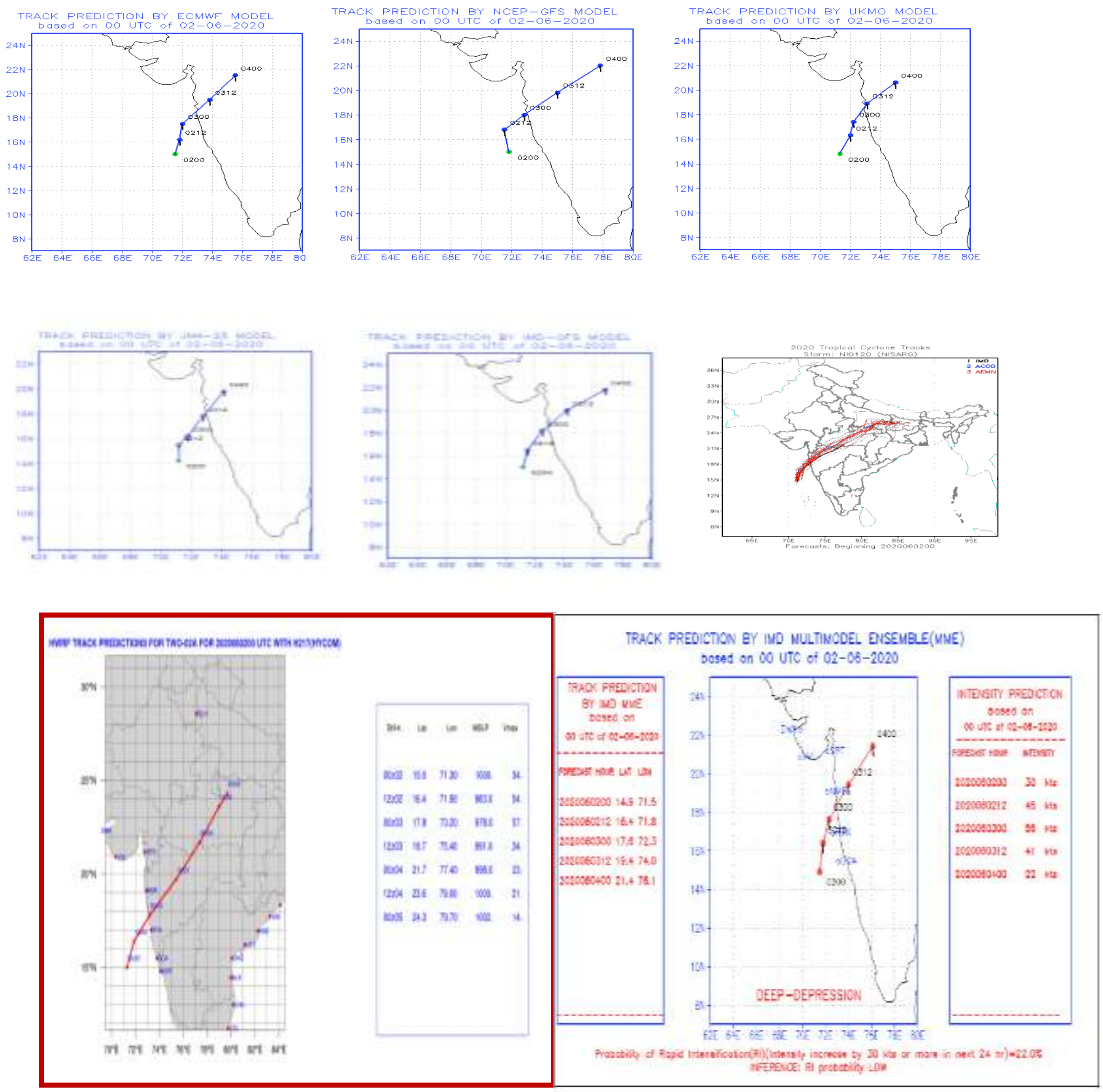


Fig. 13 (b): NWP model track forecast based on 0000 UTC of 02.06.2020

Based on initial conditions of 0000 UTC of 4th June, most of the models indicated crossing near 18.5^{0}N. Both HWRF and MME underestimated the intensity at the time of landfall.

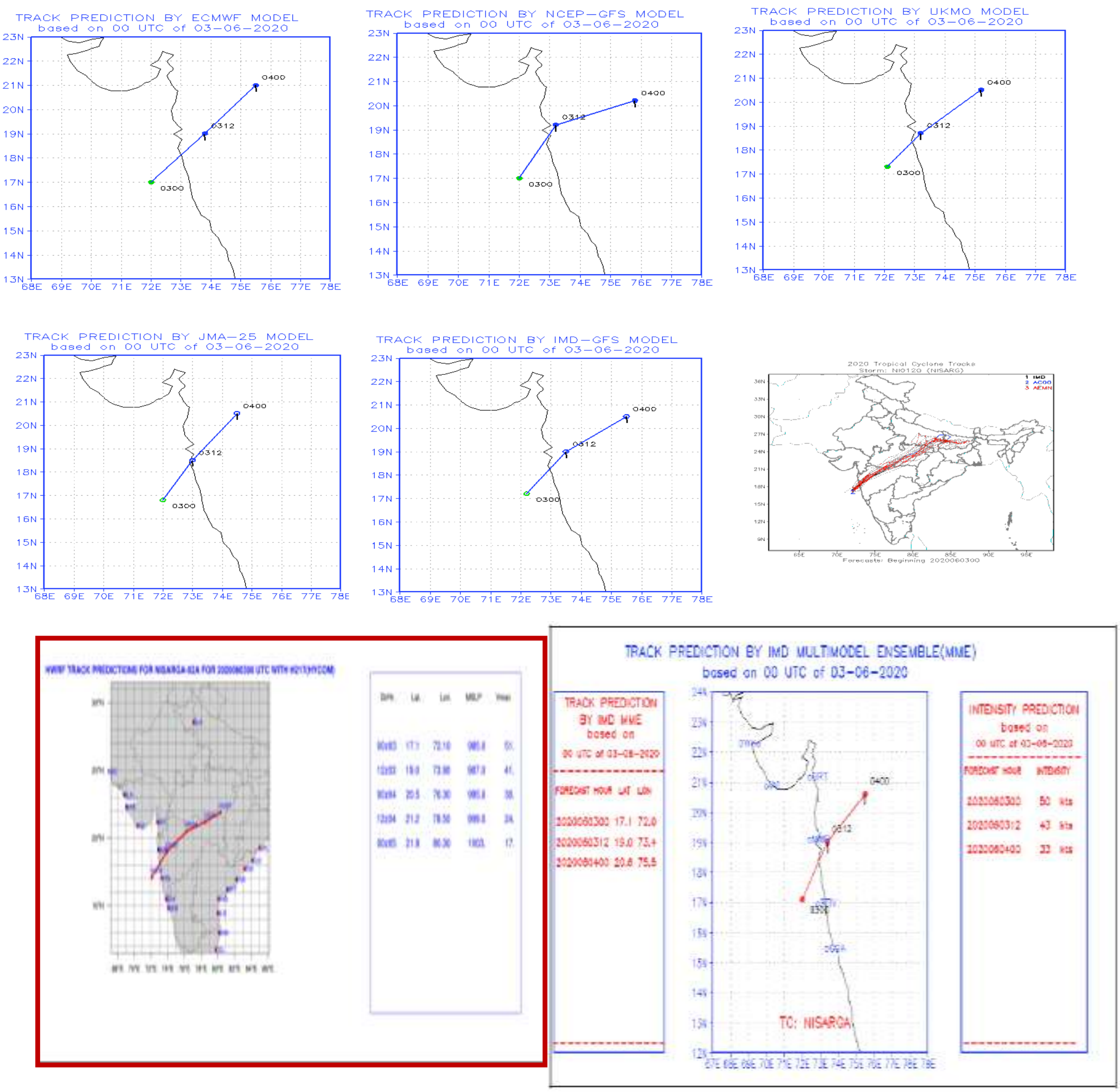


Fig 13 (c): NWP model track forecast based on 0000 UTC of 03.06.2020

9.3. Track forecast errors by various NWP Models

The average track forecast errors (Direct Position Error) in km at different lead period (hr) of various models are presented in **Table 3**. From the verification of the forecast guidance available from various NWP models, it is found that the average track forecast errors of MME was the least followed by IMD GFS, ECMWF, IMD HWRF & UKMO model was minimum for 24 and 48 hr and 72 hours forecast.

Table-3: Average Track Forecast Error (Direct Position Error) in km of various models (Number of forecasts verified is given in the parentheses):

Lead time →	12h	24h	36h	48h	60h	72h
IMD-MME	52(5)	47(5)	47(4)	70(3)	80(2)	94(1)
ECMWF	58(5)	68(5)	83(4)	116(3)	123(2)	165(1)
NCEP-GFS	67(5)	72(5)	102(4)	214(3)	209(2)	381(1)
UKMO	62(5)	64(5)	50(4)	74(3)	81(2)	31(1)
JMA	95(5)	136(5)	154(4)	167(3)	148(2)	144(1)
IMD-GFS	53(5)	68(5)	101(4)	124(3)	156(2)	139(1)
HWRF	43 (10)	69 (10)	123 (8)	171 (6)	165 (4)	150 (2)
NCUM-G	64 (5)	36(5)	61(6)	91(5)	156(6)	184(5)
NEPS-G	75 (7)	66 (7)	78 (7)	101 (7)	129(6)	165(5)
NCUM-R	73(6)	103(7)	131(6)	199(7)	174(6)	249(5)
NEPS-R	78(3)	83(4)	139(3)	164(4)	137(3)	124(2)

9.4. Landfall forecast errors by various NWP Models

Landfall point and time forecast errors by various models run at NCMRWF are presented in Table 4.

Table 4: Error in the forecast landfall time and point by various models run at NCMRWF

(forecast time – Observed time) **[-ve early +ve delay]**

IC	NCUM-G		NEPS-G		NCUM-R		NEPS-R	
	Time error hh:mm	Point error (km)	Time error hh:mm	Point error (km)	Time error hh:mm	Point error (km)	Time error hh:mm	Point error (km)
12Z29052020			04:00	8				
00Z30052020	16:00	96	13:00	117				
12Z30052020	09:00	11	11:30	90				
00Z31052020	17:00	118	10:00	72				
12Z31052020	17:00	28	14:00	96				
00Z01062020	07:00	47	09:30	22			01:00	59
12Z01062020	03:30	28	03:30	28	03:30	39		
00Z02062020	-02:00	70	-02:00	70	06:00	26	02:00	29
12Z02062020	-02:00	52	-02:00	39	01:00	81		
00Z03062020	00:30	11	00:00	12	-03:00	62	00:00	12

The landfall point and time errors for different lead periods by IMD MME are presented in Fig. 14. The landfall point errors was 17 km for lead period of 44 hrs and 8 km for the lead period of 20 hrs. The landfall time error also varied between 1-2 hrs for various lead periods.

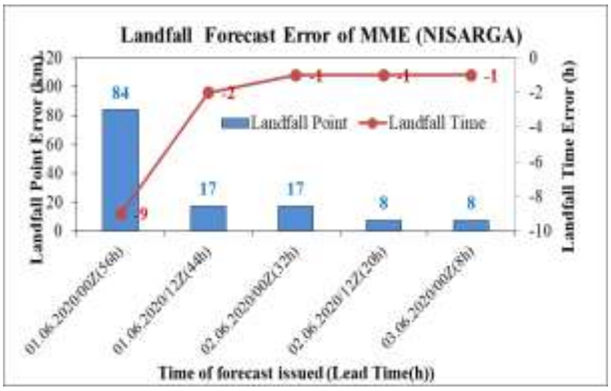


Fig. 14: Landfall point and time errors by IMD MME

The landfall point and time errors by IMD HWRF are presented in Table 5.

Table 5: Landfall point (in km) and time (in hrs) errors of IMD HWRF model
(Number of forecasts verified is given in the parentheses)

Lead Time	12 Hr	24 Hr	36 Hr	48 Hr	60 Hr
Landfall Point	39	49	63	79	72
Landfall Time	-3	-3	-9	-12	-15

Landfall Errors for Cyclone Nisarg (From GEFS mean and control)

The landfall point and time errors by GEFS mean and GEFS control are presented in Table 6.

Table 6: Landfall point and time errors by GEFS mean and GEFS control

IC	GEFS Mean				GEFS Control			
	Lat	Lon	landfall error(km)	landfall time	lat	lon	landfall error(km)	landfall time
IMD	**18.35**	**72.95**	**--**	**bet 07-09Z03June**				
IC:00Z30May	21.27	72.09	335	06Z04June	19.57	72.71	138	bet 18-00Z 04June
IC:00Z31May	21.64	72.49	365	06Z04June	21.15	72.63	310	00Z04june
IC:00Z01June	18	73.05	40	bet 00-06Z03June	17.66	73.09	77	bet 00-06Z03June
IC:00Z02June	18.48	72.9	15	bet 00-06Z03June	18.73	72.84	44	bet 00-06Z03June
IC:00Z03June	17.94	73	45	06Z03June	18.53	72.86	22	bet 06-12Z03June

9.5. Intensity prediction

The intensity forecast by IMD SCIP during life cycle and intensity at the time of landfall compared to observed intensity are presented in Fig.15. Based on 1200 UTC of 12th June, SCIP Model correctly picked up the intensity. Intensity at the time of landfall was underestimated by the model on 1st. However, based on 0000 & 1200 UTC conditions, model could capture intensity almost correctly.

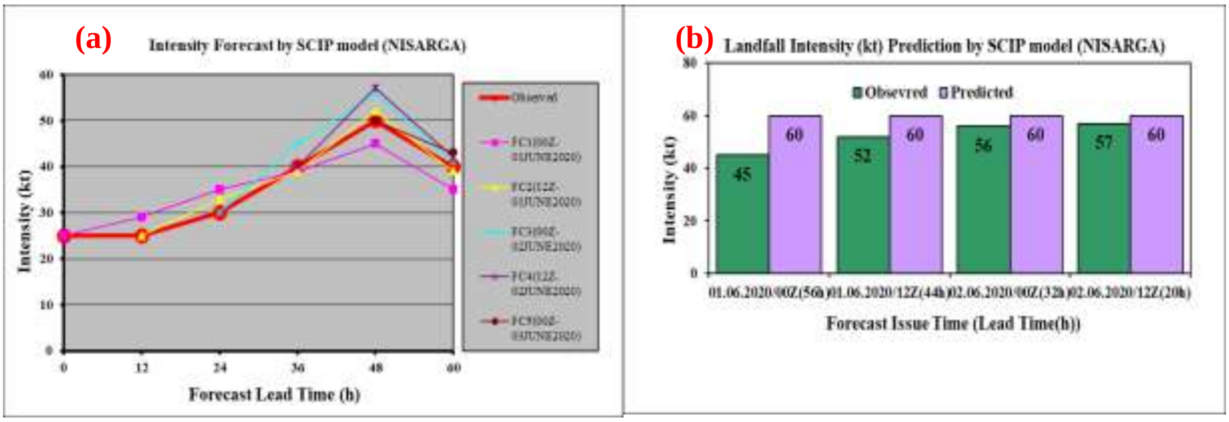


Fig. 15: (a) SCIP Intensity Forecast (NISARGA) at different lead periods and (b) intensity prediction at the time of landfall

The intensity forecast errors are presented in Table 7. The intensity forecast errors by IMD MME were the least followed by IMD HWRF.

Table-7 Average absolute errors (AAE) and Root Mean Square (RMSE) errors in knots (Number of forecasts verified is given in the parentheses)

Lead time →	**12H**	**24H**	**36H**	**48H**	**60H**	**72H**
IMD-SCIP (AAE)	4.4(5)	3.5(4)	1.3(3)	3.0(2)	5.0(1)	
IMD-HWRF (AAE)	8.4 (10)	11.0 (10)	13.0 (8)	15.0 (6)	7.8 (4)	11.0 (2)
IMD-SCIP (RMSE)	4.6	4.1	1.4	3.6	5.0	
IMD-HWRF (RMSE)	11.4 (10)	12.9 (10)	14.8 (8)	15.7 (6)	8.8 (4)	11.2 (2)

10. Operational Forecast Performance

10.1 Genesis Forecast

- First information about development of low pressure area over southeast Arabian Sea was given in the extended range outlook issued on 21st May about 10 days prior to the formation of low pressure area over the southeast & adjoining eastcentral Arabian Sea and Lakshadweep area on 31st May.
- First information about development of depression over southeast Arabian Sea was issued in the tropical weather outlook and national weather forecast bulletin issued at 1200 noon of 29th May about 3 days prior to the formation of depression over southeast & adjoining eastcentral Arabian Sea on 1st June morning.

10.2. Track, landfall and intensity forecast

• **With the formation of** low pressure area over southeast & adjoining eastcentral Arabian Sea on 31st May morning, IMD **issued first bulletin at 0630 UTC of 31st May and** indicated that the system would intensify into a cyclonic storm and reach north Maharashtra and Gujarat coasts by 3rd June, **(about 77 hours prior to landfall of SCS NISARGA)**.

• **In the bulletin issued at 0400 UTC of 1st June,** it was indicated that the system would intensify upto severe cyclonic storm stage with maximum sustained wind speed of 105-115 kmph gusting to 125 kmph and cross north Maharashtra and south Gujarat coasts between Harihareshwar (Raigad), Maharashtra and Daman during evening/ night of 3rd June **(about 52 hours prior to landfall of SCS NISARGA)**.

• **In the bulletin issued at 0600 UTC of 2nd June, it was indicated that the system would cross** close to Alibag (Raigad District, Maharashtra) during the afternoon of 03rd June as a Severe Cyclonic Storm with a maximum sustained wind speed of 100-110 kmph gusting to 120 kmph (**about 28 hours prior to landfall of SCS NISARGA)**.

• **Actually, the severe cyclonic storm Nisarga** crossed north Maharashtra coast close to south of Alibag with a maximum sustained wind speed of 110-120 kmph gusting to 130 kmph between 0700 & 0900 UTC of 03rd June

Actually, the severe cyclonic storm Nisarga crossed north Maharashtra coast close to south of Alibag with a maximum sustained wind speed of 110-120 kmph gusting to 130 kmph between 0700 & 0900 UTC of 03rd June.

Thus, the track, landfall point & time, intensity and associated adverse weather like heavy rainfall, gale wind and storm surge were predicted well in advance by IMD. Typical observed & forecast track along with cone of uncertainty and quadrant wind distribution based on 1200 UTC of 2nd June about 20 hours prior to landfall is presented in **Fig.16**.

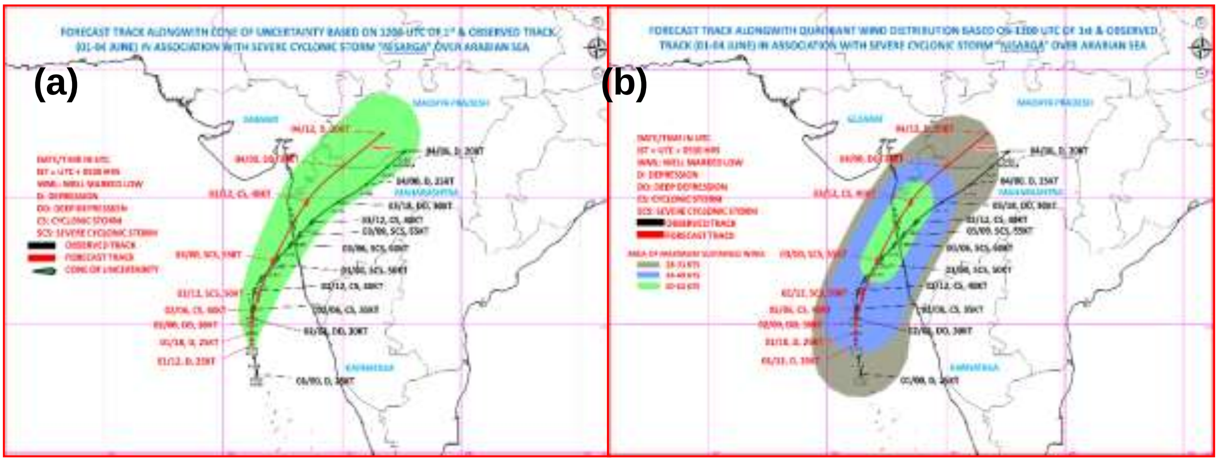


Fig.16: Typical observed and forecast track alongwith cone of uncertainty and quadrant wind distribution based on 1200 UTC of 1st June (45 hrs prior to landfall) of SCS NISARGA

10.2. Landfall Forecast Errors:

The landfall point and time errors during SCS Nisarga compared to long period average (LPA) errors during 2015-19 are presented in Table 3 and Fig. 16 (a-b).

- The landfall point forecast errors for 12, 24 and 48 hrs lead period were 7.8, 33.1 and 80.1 km respectively against the LPA errors of 25.4, 44.7 and 69.4 km during 2015-19 respectively **(Fig. 17 a).**

➢ The landfall time forecast errors for 12, 24 and 48 & 72 hrs lead period were 0, 0.5, 0 & 1.0 hours respectively against the LPA errors of 2.0, 3.0 & 5.4 hours during 2015-19 respectively **(Fig. 17 b).**

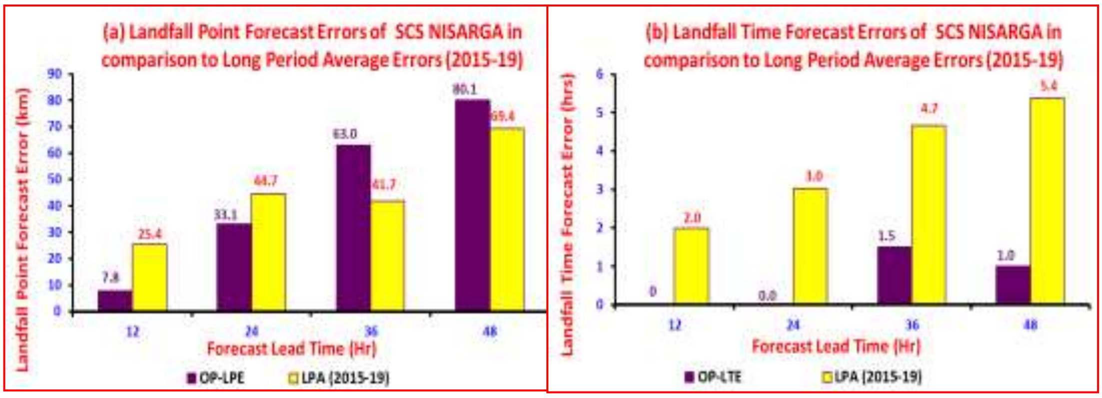


Fig. 17: Landfall (a) point and (b) time forecast errors of SCS NISARGA as compared to long period average (2015-19)

Table 8: Landfall point and time errors of SCS NISARGA compared to long period average errors during 2015-19

Lead Period (hrs)	Base Time	Landfall Point (^{0}N/^{0}E)		Landfall Time (hours)		Operational Error		LPA error (2015-19)	
		Forecast	Actual	Forecast	Actual	LPE (km)	LTE (hours)	LPE (km)	LTE (hours)
12	02/18	18.40/72.90	18.35/72.95	03/0800	03/0800	7.8	0	25.4	2.0
24	02/06	18.64/72.87	18.35/72.95	03/0800	03/0800	33.1	0	44.7	3.0
36	01/18	18.92/72.89	18.35/72.95	03/0930	03/0800	63.0	+1.5	41.7	4.7
48	01/06	19.06/72.79	18.35/72.95	03/0700	03/0800	80.1	-1.0	69.4	5.4

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

9.3. Track Forecast Errors:

The track forecast errors and skill compared to long period average errors during 2015-19 are presented in Table 4 and Fig. 17 (a-b).

➢ The track forecast errors for 12, 24 & 48 hrs lead period were 59.7, 111.6, and 212.0 km respectively against the LPA errors of 49.6, 80.6 & 125.5 km respectively (**Fig.18a)**. The relatively higher forecast error was due to recurving nature of the track.

➢ The track forecast skill was about 67%, 73%, and 78% against the LPA skill of 58%, 61% & 73% for 12, 24 & 48 hrs lead period respectively (**Fig.18b)**. Thus, the track forecast skill was higher than the past five years average skill during 2015-19 for all lead periods.

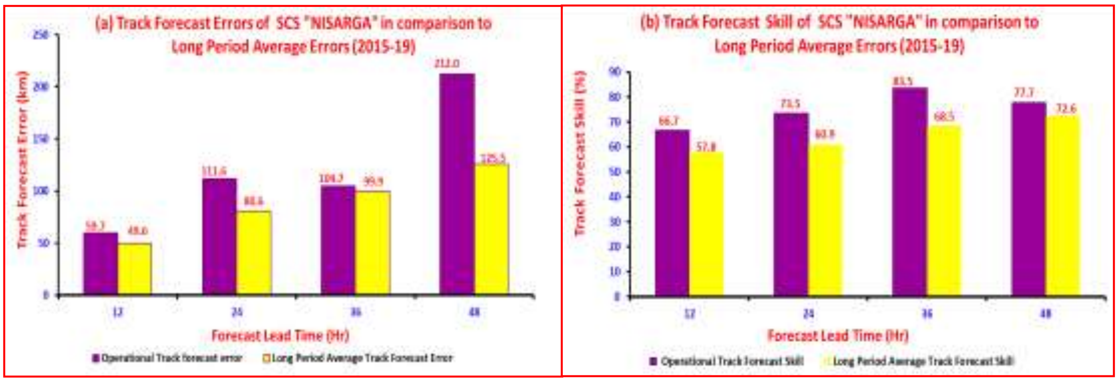


Fig. 18: Track forecast errors and skill of SCS NISARGA as compared to long period average (2015-19)

Table 9: 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	7	59.7	66.7	49.6	57.8
24	6	111.6	73.5	80.6	60.9
36	3	104.7	83.5	99.9	68.5
48	2	212.0	77.7	125.5	72.6

* Skill is calculated by comparing the operational track forecast error with the forecast error based on climatology and persistence (CLIPER) model.

10.4. Intensity Forecast Errors:

The intensity forecast errors and skill based on absolute errors and root mean square errors are presented in Table 9 and Fig. 18 & 19 respectively.

- The absolute error (AE) of intensity (wind) forecast for 12, 24 & 48 hrs lead period were 2.9, 3.3 and 7.5 knots against the LPA errors of 5.4, 8.9 & 13.0 knots during 2015-19 respectively **(Fig. 19).**
- The root mean square error (RMSE) of intensity (wind) forecast for 12, 24 & 48 hrs lead period were 4.6, 5.8 & 7.9 knots against the LPA errors of 7.1, 11.5 & 16.7 knots respectively **(Fig. 19).**

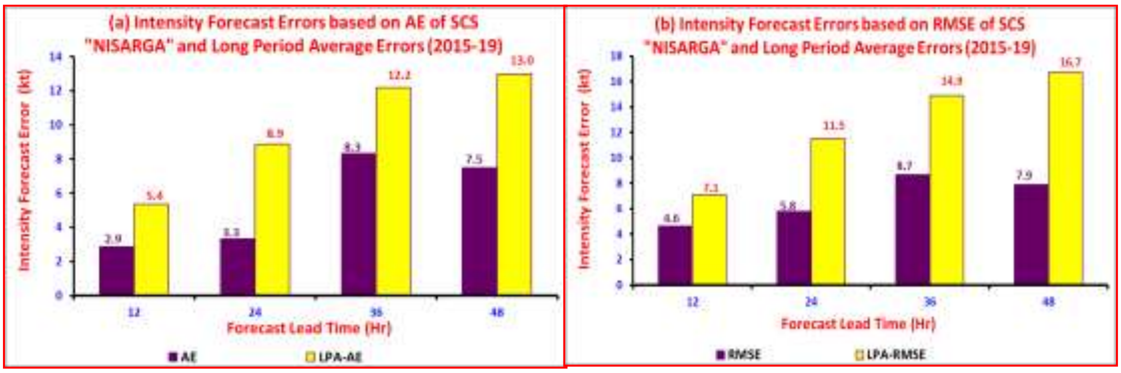


Fig. 19: Absolute errors (AE) and Root Mean Square errors (RMSE) in intensity forecast (winds in knots) of SCS NISARGA as compared to long period average (2015-19)

- The skill (%) in intensity forecast based on AE for 12, 24 & 48 hrs lead period was 80%, 89% and 81% against the LPA of 28%, 45% & 69% respectively **(Fig. 20a).**
- The skill (%) in intensity forecast based on RMSE for 12, 24 & 48 hrs lead period was 78%, 85% and 82% against the LPA of 36%, 49% & 63% respectively **(Fig. 20b).**

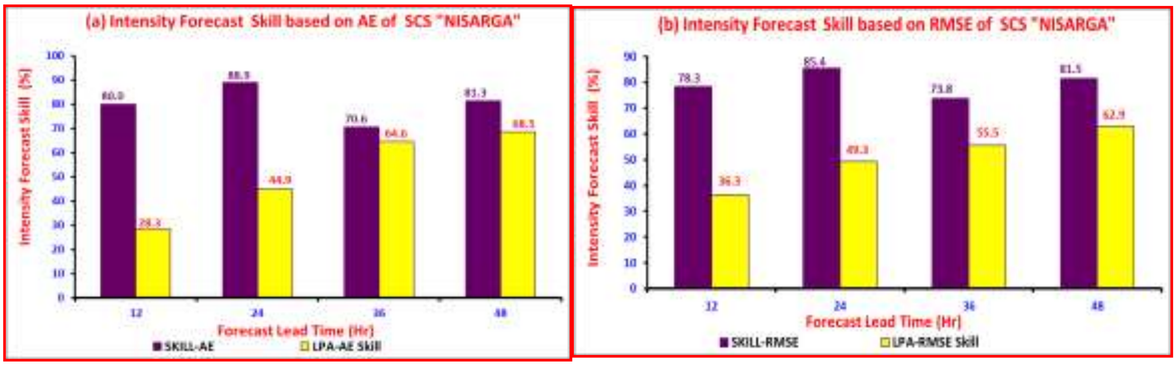


Fig. 20: Skill (%) in intensity forecast based on (a) Absolute errors (AE) and (b) Root Mean Square errors (RMSE) of SCS NISARGA as compared to long period average (2015-19)

Table 10: Mean Intensity forecast errors (kt) and Skill (%) in association with SCS NISARGA compared to long period average errors and skill during 2015-19

Lead Period (hrs)	N	Average error in Intensity forecast (kts)		LPA (2015-19) Intensity forecast error (kts)		Operational Skill* (%) in intensity forecast		LPA (2015-19) Skill* (%) in intensity forecast	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
12	7	2.9	4.6	5.4	7.1	80.0	78.3	28.3	36.3
24	6	3.3	5.8	8.9	11.5	88.9	85.4	44.9	49.3
36	3	8.3	8.7	12.2	14.9	70.6	73.8	64.6	55.5
48	2	7.5	7.9	13.0	16.7	81.3	81.5	68.5	62.9

N: No. of observations verified; AE: Absolute Error; RMSE: Root Mean Square Error, LPA: Long Period Average (2015-19). * Skill of forecast is calculated by comparing the operational forecast error with the forecast error based on persistence method

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 Table 11-13. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table 10: Verification of Heavy Rainfall Forecast

Table 11: 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
01.06.2020/0300	- Isolated heavy falls very likely over Lakshadweep area, north Kerala and coastal Karnataka on 1st June. Isolated heavy to very	**1 June 2020** **Coastal Karnataka:**

	heavy falls over south Konkan & Goa on 1st June. Isolated heavy to very heavy falls very over Konkan & Goa on 02nd June and over south Konkan & Goa on 03rd June. ➢ Heavy to very heavy falls at a few places and extremely heavy falls at isolated places over north Konkan and north Madhya Maharashtra on 03rd & 04th June. ➢ Isolated heavy to very heavy falls very likely over south Gujarat state, Daman, Diu, Dadra & Nagar Haveli on 03rd June and with heavy to very heavy falls at a few places and extremely heavy falls at isolated places over south Gujarat state, Daman, Diu, Dadra & Nagar Haveli and on 04th June.	Kota-10 and Kundapur-7 **3 June 2020** **Konkan & Goa:** Mormugao & Panjim-13 each, Quepem & Malvan-11 each, Valpoi & Sanguem-9 each, Sawantwadi, Dodamarg, Canacona & Devgad-8 each and Kudal-7 **Madhya Maharashtra:** Khed Rajgurunagar-7 **4 June 2020** **Konkan & Goa:** Pen-16, Poladpur-15, Mangaon-14, Lanja, Mandangad & Dapoli -13 each, Tala-12, Vaibhavwadi & Alibag-11 each, Chiplun-10, Roha, Rajapur & Harnai -9 each, Guhagarh & Khed-8 each and Shahapur, Murud, Sangameshwar Devrukh, Khalapur, Jawhar & Ulhasnagar-7 each **Madhya Maharashtra:** Mahabaleshwar-19, Gaganbawada-15, Nashik-14, Sinnar, Bhusawal & Igatpuri-11 each, Akole, Devla, Satna Baglan & Chandgad-9 each, Javali Medha, Patan & Khed Rajgurunagar-8 each and Girnadam, Malegaon Camp, Sakri, Kalvan, Dindori, Yaval, Shahuwadi, Surgana & Radhanagari-7 each **Vidarbha:** Mangrulpir, Karanjalad, Jalgaon Jamod & Washim-8 each and Manora & Malegaon-7 each
02.06.2020/0300	➢ Heavy to very heavy falls at isolated places over Konkan & Goa during next 24 hours. Isolated heavy falls over Coastal Karnataka, Madhya Maharashtra and Marathwada during next 24 hours. ➢ Heavy to very heavy falls at a few places and **extremely heavy falls (≥ 20 cm in 24 hours)** at isolated places over north Konkan (Mumbai, Palghar, Thane, Raigad districts) and north Madhya Maharashtra ➢ Heavy to very heavy falls at isolated places over south Konkan (Ratnagiri & Sindhudurg districts) & Goa and south Gujarat region (Valsad, Navsari, Dang, Daman, Dadra & Nagar Haveli and Surat districts) ➢ Heavy falls at isolated places over west Madhya Pradesh on 03rd June.	
03.06.2020/0300	➢ Heavy to very heavy falls at a few places and **extremely heavy falls (≥ 20 cm in 24 hours)** at isolated places very likely over north Konkan (Mumbai, Palghar, Thane, Raigad districts) and north Madhya Maharashtra during next 24 hours. ➢ Heavy to very heavy falls at isolated places over south Konkan (Ratnagiri & Sindhudurg districts) & Goa and south Gujarat region (Valsad, Navsari, Dang, Daman, Dadra & Nagar Haveli and Surat districts) during next 24 hours. ➢ Heavy falls at isolated places over west Madhya Pradesh and Vidarbha during	

	next 24 hours.	
04.06.2020/0300	➢ Heavy to very heavy falls at isolated places very likely over east Madhya Pradesh and Chhattisgarh. ➢ Heavy falls at isolated places very likely over Vidarbha and west Madhya Pradesh during next 24 hours.	

Table 12: Verification of Squally/Gale wind forecast

Date/Base Time of observation	Gale/ Squally wind Forecast at 0300 UTC of date	Realised wind (kmph)
01.06.2020/0300	➢ Squally wind, speed reaching 40-50 kmph gusting to 60 kmph, is prevailing over Eastcentral and adjoining southeast Arabian Sea. It is very likely to become 50-60 kmph gusting to 70kmph over Eastcentral and adjoining southeast Arabian Sea during next 48 hours. It will gradually increase becoming Gale wind speed reaching 60-70 kmph gusting to 80 kmph over eastcentral Arabian Sea and along and off south Maharashtra coast from 2nd June morning and further becoming 105-115 kmph gusting to 125 kmph over eastcentral and northeast Arabian Sea along & off Maharashtra coast (Raigad, Mumbai, Palghar, Thane), 90-100 kmph gusting to 110 kmph along & off Valsad, Navsari districts of Gujarat, and 80-90 kmph gusting to 100 kmph along & off Ratnagiri, Sindhudurg districts of Maharashtra, 70-80 kmph gusting to 90 kmph along & off Surat & Bharuch districts of south Gujarat from 3rd June evening. ➢ Squally wind, speed reaching 50-60 kmph gusting to 70 kmph is likely prevail over eastcentral Arabian Sea along and off Karnataka-Goa coasts during next 48 hours. ➢ Squally wind, speed reaching 40-50 kmph gusting to 60 kmph is likely to prevail over Lakshadweep area and along & off Kerala coast during next 48 hours.	Reported on 3rd June during and after the landfall in kmph are as given below: Devgad -92, Ratnagiri – 110, Harnai – 74, Alibag – 102, Mumbai (Colaba) – 92, Thane – 75, Rajgurunagar (Pune) – 65, Ahmadnagar – 50, Satara - 59
02.06.2020/0300	➢ Squally wind speed reaching 55-65 kmph gusting to 75 kmph, is prevailing over Eastcentral Arabian Sea. To increase becoming gale wind, speed reaching 60-70 kmph gusting to 80 kmph, over eastcentral Arabian Sea off south Maharashtra & Goa coasts from 2nd afternoon and further becoming 100-110 kmph gusting to 120 kmph over eastcentral Arabian Sea along	

	& off Maharashtra (Raigad, Mumbai, Palghar, Thane) coast from 03rd June morning. Gale wind, speed reaching 80-90 kmph gusting to 100 kmph, likely along & off Valsad, Navsari districts of Gujarat, Daman ad along & off northeast Arabian Sea, Ratnagiri, Sindhudurg districts of Maharashtra and 70-80 kmph gusting to 90 kmph along & off Surat & Bharuch districts of south Gujarat, Dadra & Nagar Haveli from 03rd June noon. ➢ Squally wind, speed reaching 50-60 kmph gusting to 70 kmph is likely to prevail over northeast Arabian Sea along & off remaining districts of south Gujarat coast on 03rd June. ➢ Squally wind, speed reaching 50-60 kmph gusting to 70 kmph is likely prevail over eastcentral Arabian Sea along and off Karnataka-Goa coasts during next 24 hours.	
03.06.2020/0300	➢ Gale wind, speed reaching 100-110 kmph gusting to 120 kmph, is prevailing over Eastcentral Arabian Sea. From the Noon of today, the 3rd June, it will become Gale wind, speed reaching 100-110 kmph gusting to 120 kmph over eastcentral Arabian Sea along & off north Maharashtra coast (Raigad, Mumbai and adjoining Thane), 85-95 kmph gusting to 105 kmph along & off Ratnagiri, Sindhudurg, Palghar and remaining areas of Thane. Gale wind, speed reaching 60-80 kmph gusting to 90 kmph, likely along & off Valsad, Navsari districts of Gujarat, Daman, Dadra & Nagar Haveli and along & off northeast Arabian Sea and 60-70 kmph gusting to 80 kmph along & off Surat & Bharuch districts of south Gujarat from today the 03rd June noon. ➢ Squally wind, speed reaching 50-60 kmph gusting to 70 kmph is likely to prevail over northeast Arabian Sea along & off remaining districts of south Gujarat coast on 03rd June. ➢ Squally wind, speed reaching 50-60 kmph gusting to 70 kmph is likely prevail over eastcentral Arabian Sea along and off Karnataka-Goa coasts during next 12	

	hours.	
04.06.2020/0300	➢ Squally wind, speed reaching 35-45 kmph gusting to 55 kmph, is prevailing over western Districts of Vidarbha and adjoining Madhya Pradesh. ➢ It is likely reduce gradually during next 12 hours.	

Table 13: Verification of Storm Surge Forecast

Date/Base Time of observation	Storm Surge Forecast at 0300 UTC of date	Realised surge
02.06.2020/0300	Storm surge of about 1-2 meters height above astronomical tide to inundate low lying areas of Mumbai up to about 1.0 to 1.5 km, Thane and Raigad districts and 0.5-1.0 meter height above the astronomical tide likely to inundate low lying areas of Ratnagiri district during the time of landfall.	Storm surge of 0.5 – 1.0 m height occurred over the low lying areas of Raigad District during the time of landfall.
03.06.2020/0300	Storm surge of about 1-2 meters height above astronomical tide to inundate low lying areas of Mumbai, Thane and Raigad districts and 0.5-1.0 meter height above the astronomical tide likely to inundate low lying areas of Ratnagiri district during the time of landfall.	

11. Warning Services

Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track, intensity and landfall forecast for +06, +12, +18, +24, +36, +48 and +60 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 during the Depression period and every three hours during the cyclone period. The hourly updates were also provided 12 hours prior to landfall till the system maintained the intensity of cyclonic storm over Maharashtra.
- **Cyclone structure forecast for shipping and coastal hazard management:** The radius of maximum wind and radii of MSW ≥28, ≥34, ≥50 and ≥64 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36, +48 and +60 hrs lead period.
- **Four stage Warning:**

- **Considering the expected short life of the system and it's intensification into a cyclonic storm with predicted landfall over north Maharashtra and south Gujarat coasts on 3rd June, the Pre cyclone watch** was issued for north Maharashtra and south Gujarat coasts in the bulletin issued at 1400 hrs IST of 31st May, when the system was a low pressure area over southeast and adjoining eastcentral Arabian Sea **(about 80 hours prior to landfall of SCS NISARGA)**. This is for the first time that **Pre cyclone watch** was issued by IMD in the low pressure area stage. Usually, the pre cyclone watch is issued from depression/deep depression stage as per the Standard Operating Procedure.
- **Cyclone alert** was issued for north Maharashtra and south Gujarat coasts in the bulletin issued at 1150 hrs IST of 1st June, when the system was a depression over eastcentral & adjoining southeast Arabian Sea **(about 50 hours prior to landfall of SCS NISARGA)**
- **Cyclone warning** was issued for north Maharashtra and south Gujarat coasts in the bulletin issued at 0900 UTC (1430 hrs IST) of 2nd June, when the system was a cyclonic storm over eastcentral Arabian Sea **(about 24 hours prior to landfall of SCS NISARGA)**
- **Post landfall outlook** indicating expected severe weather over interior districts of Maharashtra was given in the bulletin issued at 2150 hrs IST of 2nd June, when the system was a cyclonic storm over eastcentral Arabian Sea **(about 16 hours prior to landfall of SCS NISARGA)**

- **Adverse weather warning bulletins:** Adverse weather warning bulletins: The tropical cyclone forecasts alongwith expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update to central, state and district level disaster management agencies including MHA, NDRF, NDMA for all concerned states along the west coast of India including Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman & Diu and Lakshadweep. The bulletins also contained the suggested action for disaster managers and general public in particular for fishermen. These bulletins were also issued to Defence including Indian Navy & Indian Air Force.
- **Warning graphics:** The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The adverse weather warnings related to heavy rain, gale/squally wind & storm surge were also presented in graphics alongwith colour codes in the website. Typical wind and storm surge graphical products are presented in Fig. 21 & 22 respectively.

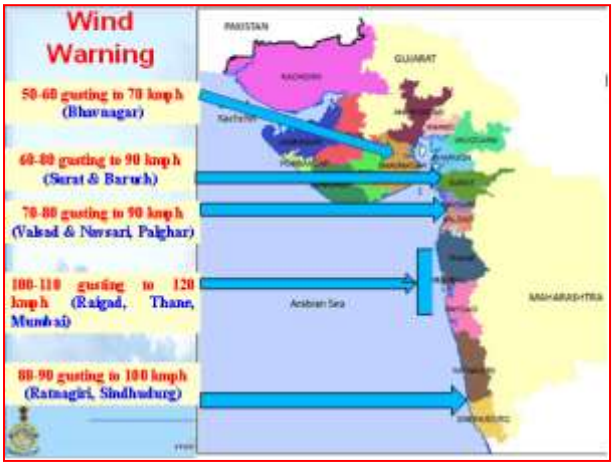
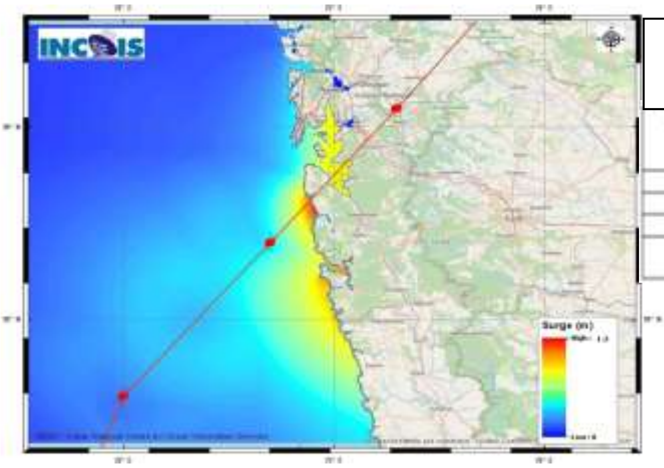


Fig. 21: Typical district level wind warning based on 0300 UTC of 2nd June



Surge heights above astronomical tide and inundation

MANDAL/TALUK	DISTRICT	STATE / UNION TERRITORY	NEAREST PLACE OF HABITATION	* STORM SURGE (m)	* EXPECTED INUNDATION EXTENT (km)
ALIBAG	RAIGAD	MAHARASHTRA	ALIBAG	0.5-1.3	Around 1.4
DAPOLI	RATNAGIRI	MAHARASHTRA	DAPOLI	0.6-0.9	Around 0.3
PEN	RAIGAD	MAHARASHTRA	PEN	0.7-0.9	Around 2.2
THANE	GREATER BOMBAY	MAHARASHTRA	THANE	0.7-0.9	Around 0.3

Fig. 22: typical storm surge warning graphics based on 0000 UTC of 2nd June

- **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, whatsapp and twitter regularly during the life period of the system since the development of low pressure area over the Arabian Sea. From 3rd morning (0000 UTC) onwards, hourly updates were issued and sent to disaster managers by email, uploaded on websites, posted on face book, whatsapp 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 the 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, Mumbai and cyclone warning centres at Thiruvananthapuram & Ahmedabad to ports, fishermen, coastal and high Sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen for deep Sea areas of the Arabian Sea (AS) and the states of Kerala, Karnataka, Goa,

Maharashtra, Gujarat, Daman & Diu and Lakshadweep were issued since 31st May on the development of low pressure area over southeast & adjoining eastcentral AS and adjoining Lakshadweep.

- **Advisory for international Civil Aviation:** The Tropical Cyclone Advisory Centre (TCAC) bulletin for International Civil Aviation were issued every six hourly to all meteorological watch offices in Asia Pacific region for issue of significant meteorological information (SIGMET). It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong.
- **Diagnostic and prognostic features of cyclone:** The prognostics and diagnostics of the systems were described in the RSMC bulletins.
- **Hourly Bulletin:** Hourly updates on the location, distance from recognised station, intensity and landfall commenced from 3rd June morning (0000 UTC) onwards till the system maintained the intensity of cyclonic storm.

Statistics of bulletins issued by RSMC New Delhi and Cyclone Warning Centre (CWC) Thiruvananthapuram, Meteorological Centres Bengaluru & Goa in association with the SCS NISARGA are given in **Table 14.**

Table 14 (a): Bulletins issued by RSMC New Delhi

S.N	Bulletin type	No. of Bulletins	Issued to
1	Informatory Message during 29th-31st May	8	1. IMD website, RSMC New Delhi website and Mausam website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Press Information Bureau, Chief Secretary to Government of Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman & Diu and Lakshadweep.
	National Bulletin	24	1. IMD website, RSMC New Delhi website and Mausam website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Press Information Bureau, Chief Secretary to Government of Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman & Diu and Lakshadweep.

2	Bulletin from DGM, IMD	5 daily during 31st May to 4th June	1. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Press Information Bureau, Ministry of Railways, Shipping & Surface Transport, Chief Secretary to Government of Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman & Diu and Lakshadweep.
3	RSMC Bulletin	24	1. IMD's website, RSMC website and Mausam website 2. WMO/ESCAP member countries including Bangladesh and Myanmar through GTS and E-mail.
4	GMDSS Bulletins	24	1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)
5	Tropical Cyclone Advisory Centre Bulletin	8	1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website
6	Tropical Cyclone Vital Statistics	12	Modelling group of IMD, National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc.
7	Warnings through SMS	Frequently	SMS to disaster managers at national level and concerned states (every time when there was change in track, intensity and landfall characteristics) (i) 1,07,043 SMS to General Public of the states of India along the west coast, senior level disaster managers by IMD Headquarters to users registered at RSMC website www.rsmcnewdelhi.imd.gov.in (ii) 1,305 SMS to senior level disaster managers at centre and affected states along the west coast by IMD Headquarters (iii) 12,02,602 SMS to registered users including fishermen by INCOIS (iv) INCOIS also issued IMD-INCOIS joint bulletins to 10,206 emails to 1776 users. (v) 38,43,874 SMS to farmers in the affected regions of Maharashtra, Gujarat and Goa by Kisaan Portal
8	Warnings through Social	Daily	Cyclone Warnings were uploaded on Social networking sites (Face book, Twitter and Whatsapp) since inception to weakening of system (every time when

	Media		there was change in track, intensity and landfall characteristics) and hourly on the day of landfall on 3rd June.
9	Press Release	6	Disaster Managers, Media persons by email and uploaded on website
10	Press Briefings	Daily	Regular briefing daily and frequently as and when media persons visited the National Weather Forecasting Centre
11	Hourly Updates	12	Hourly bulletins by email, websites, social media including whatsapp, facebook, twitter

Table 14 (b): Statistics of bulletins issued by ACWC Mumbai, CWC Thiruvanathapuram (TRV), MCs Bangaluru & Goa

S.No.	Type of Bulletin	No. of Bulletins issued			
		ACWC Mumbai	CWC TRV	MC Bengaluru	MC Goa
1.	Sea Area Bulletin	08	-	-	-
2.	Coastal Weather Bulletins	12	12	-	-
3.	Fishermen Warnings issued	12	24	04	06
4.	Port Warnings	08	6	02	07
5.	Heavy Rainfall warning	20	18	03	03
6.	Gale Wind Warning	18	12	-	06
7.	Storm Surge Warning	2	-	-	-
8.	Information & Warning issued to State Government and other Agencies	50	26	8	6
9.	SMS frequency	120 Whatsapp-98 Facebook/ Twitter: 33/33	28 Whatsapp-15 Facebook/ Twitter: 3/3	18 Whatsapp-18 Facebook/ Twitter: 10/10	SMS 75 Whatsapp-12 Facebook/ Twitter: 6/5
10.	Press Conference/Briefing/All India Radio	4	-	01	10

12. Major challenges during monitoring and prediction of SCS NISARGA:

There were 2 main challenges while monitoring NISARGA.

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

ii. **Considering the expected short life of the system and it's intensification into a cyclonic storm with predicted landfall over north Maharashtra and south Gujarat coasts on 3rd June, it was a challenge to issue the Pre cyclone watch** when the system was a low pressure area over southeast and adjoining eastcentral Arabian Sea **(about 80 hours prior to landfall of severe cyclonic storm NISARGA)**. Pre cyclone watch was issued on 31st May for north Maharashtra and south Gujarat coasts in the bulletin issued at 1400 hrs IST of 31st May. This is for the first time that **Pre cyclone watch** was issued by IMD in the low pressure area stage. Usually, the pre cyclone watch is issued from depression/deep depression stage as per the Standard Operating Procedure.

13. Initiatives during SCS NISARGA:

(i) For the first time, during Nisarga district wise wind warning graphics was issued.

(ii) Cyclone track with cone of uncertainty and wind distribution in four geographical quadrants around the centre of system on GIS platform was made live on RSMC website

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 SCS NISARGA. We acknowledge the contribution of all sister organizations 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, 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 & Mumbai, Cyclone Warning Centre (CWC) Thiruvananthapuram & Ahmedabad, Meteorological Centre (MC) Goa & Bengaluru, Doppler Weather Radar Stations at Mumbai & Goa and coastal observatories of Maharashtra & Goa. 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.
