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

HIGHLIGHTS

- The severe cyclonic storm, Nisarga originated from a Low Pressure Area which formed over southeast & adjoining eastcentral Arabian Sea and Lakshadweep area in the early morning of 31st May 2020.
- It concentrated into a depression over eastcentral and adjoining southeast Arabian Sea in the early morning of 1st June 2020.
- It intensified into deep depression over eastcentral Arabian Sea in the early morning and into cyclonic storm **"NISARGA"** in the noon of 2nd June.
- It moved northwards till evening of 2nd June and gradually recurved northeastwards and intensified into a severe cyclonic storm in the early morning of 3rd June 2020.
- Continuing to move northeastwards, it crossed Maharashtra coast close to south of Alibag as a Severe Cyclonic Storm (SCS) with a maximum sustained wind speed of 110-120 kmph gusting to 130 kmph during 0700-0900 UTC (1230-1430 hrs IST) of 03rd June.
- Continuing to move northeastwards after landfall, it weakened into a cyclonic storm in the evening over north Madhya Maharashtra and into a deep depression in the mid-night of 2nd June 2020 over the same region.
- It further weakened into a depression over western parts of Vidarbha and neighbourhood in the early morning and into a well marked low pressure area over central parts of Madhya Pradesh in the evening of 4th June.
- It lay as a low pressure area over southeast Uttar Pradesh and adjoining Bihar in the afternoon 5th June.
- 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.

Monitoring of NISARGA:

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the development of the system 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 area 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 (DWR) Goa

and Mumbai. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions, models run by other Global centres 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.

Forecast Performance:

i) 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.

ii) Cyclone warnings

- **Pre-cyclone watch:** 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 0830 UTC (1400 hrs IST) of 31st May, when the system was a low pressure area over southeast and adjoining eastcentral Arabian Sea, even before the development of depression (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:** 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 Arabian Sea and neighbourhood (about 50 hours prior to landfall of SCS NISARGA)
- **Cyclone Warning:** 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:** 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)

iii) Track, landfall and intensity forecast

- In the first bulletin issued at 0330 UTC (0855 hrs IST) of 31st May, it was indicated that the system would intensify into a cyclonic storm and reach north Maharashtra and Gujarat coasts by 3rd June, when the system formed as low pressure area over southeast Arabian Sea and neighbourhood on 31st morning (about 77 hours prior to landfall of SCS NISARGA).
- In the bulletin issued at 0400 UTC (0920 hrs IST) 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 (1130 hrs IST) 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 Alibagh with a maximum sustained wind speed of 110-120 kmph gusting to 130 kmph between 0700-0900 UTC (Afternoon) of 03rd June.

Thus, the track, landfall point & time, intensity and associated adverse weather like heavy rainfall, gale wind and storm surge were well predicted by IMD.

1. Brief Life History:

- 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 favourable 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.3a).

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.3b).

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.

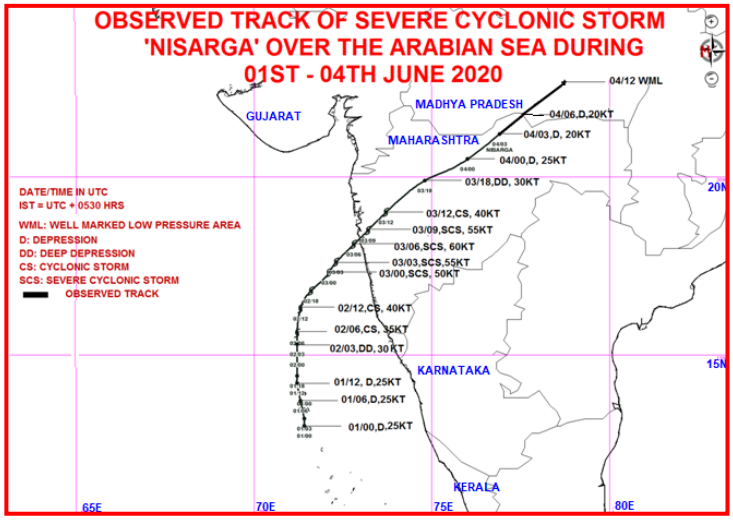


Fig.1: Observed track of SCS 'NISARGA' over the eastcentral and adjoining southeast Arabian Sea (1st-4th June, 2020)

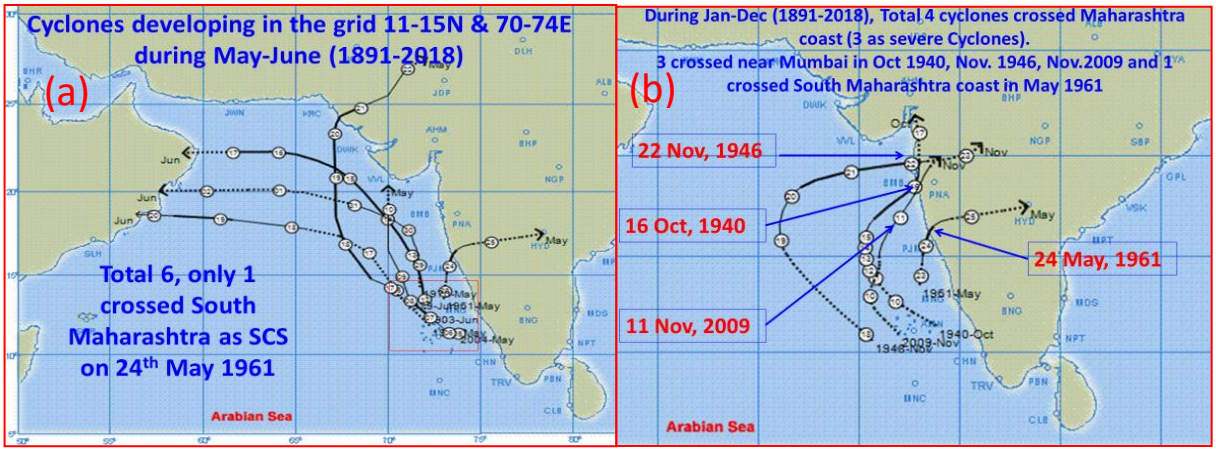


Fig.2: Tracks of severe cyclonic storms and above intensity storms (a) developing in the grid ±2.5º of genesis point and (b) crossing Maharashtra coast in the month of May and June during 1891-2018

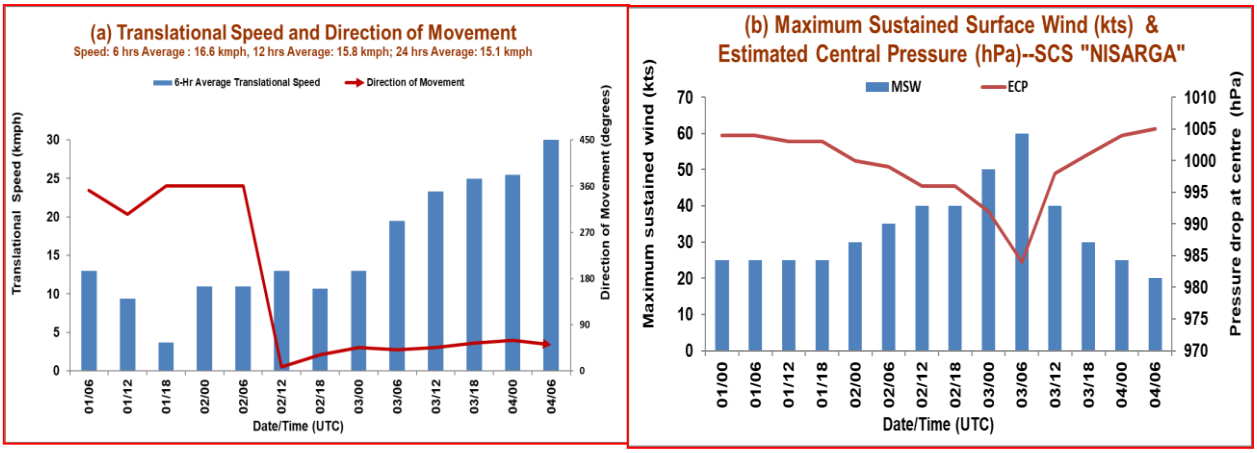


Fig. 3: (a) Translational speed & direction of movement and (b) Maximum sustained surface winds (kts) & Estimated Central Pressure

The six hourly average translational speed during the life cycle of SCS Nisarga is presented in Fig. 3a. During initial stages of it's 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. 3b. 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. Typical total precipitable water vapor imageries are placed in Annexure I.

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. Monitoring and Prediction:

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.

Typical satellite and RADAR imageries are presented in **Fig. 4**. The satellite and RADAR imageries during entire life cycle of the system are also placed at Annexure-I.

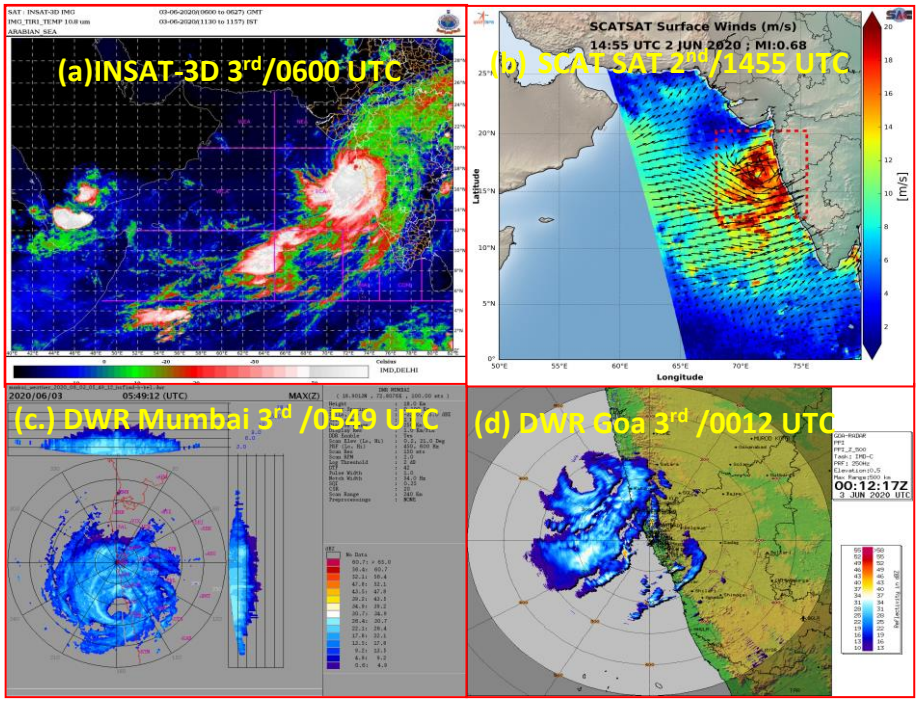


Fig.4: Typical (a) INSAT 3D imagery at 0600 UTC of 3rd June, (b) SCAT SAT imagery at 1455 UTC of 2nd June, (c) DWR Mumbai imagery at 0600 UTC of 3rd June and (d) DWR Goa imagery at 0012 UTC of 3rd June

4. Realized Weather:

4.1. Realised 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 5**.

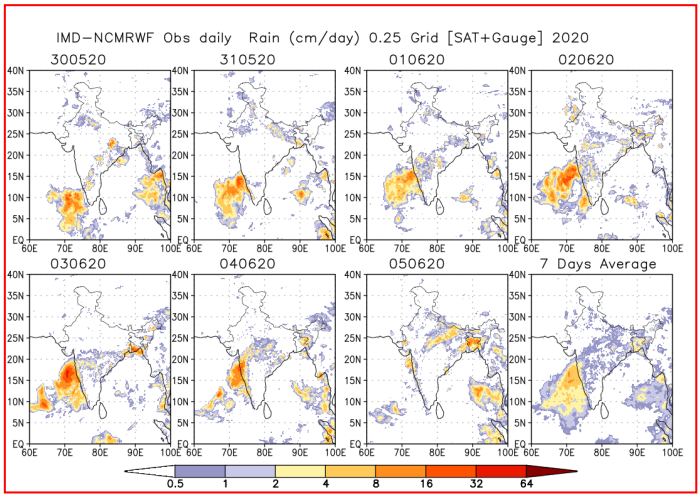


Fig.5: IMD-NCMRWF GPM merged gauge 24 hr cumulative rainfall (cm) ending at 0300 UTC of date during 30th May – 05th June and 7 days average rainfall (cm/day)

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

4.2. Realised 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

5. Forecast performance:

5.1. 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 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 0630 UTC of 29th May about **3 days prior** to the formation of depression over southeast & adjoining eastcentral Arabian Sea on 1st June morning.

5.2. Track, Intensity and Landfall 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.
- 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 1st June about 45 hours prior to landfall is presented in **Fig.6**.

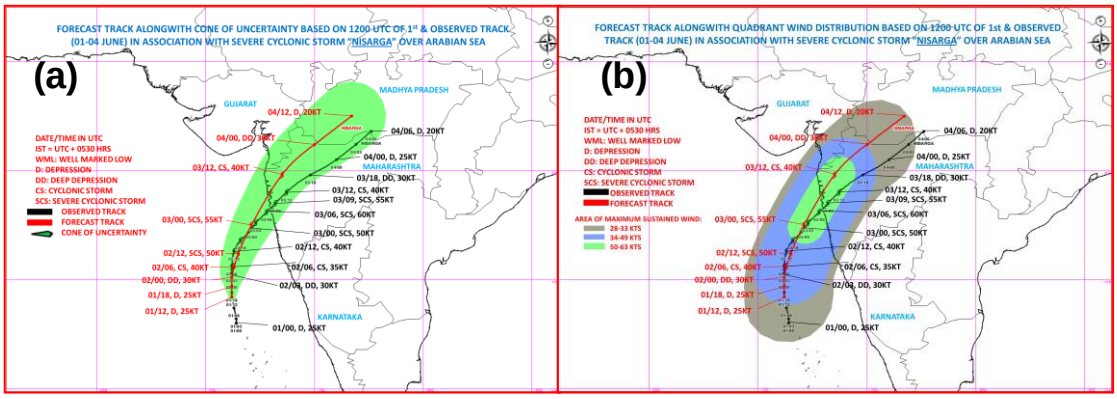


Fig.6: Typical observed and forecast track alongwith cone of uncertainty and quadrant wind distribution based on 1200 UTC of 1st June (45 hrs prior to landfall) of SCS NISARGA

5.3. 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. 7 (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. 7a).**
- 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. 7b).**

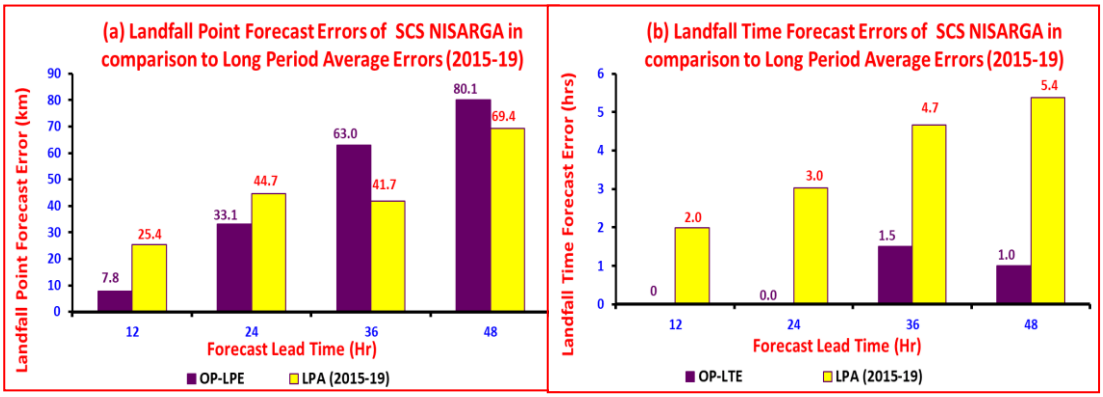


Fig. 7: Landfall (a) point and (b) time forecast errors of SCS NISARGA as compared to long period average (2015-19)

Table 3: 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

5.4. 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. 8 (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.8a)**. 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.8b)**. Thus, the track forecast skill was higher than the past five years average skill during 2015-19 for all lead periods.

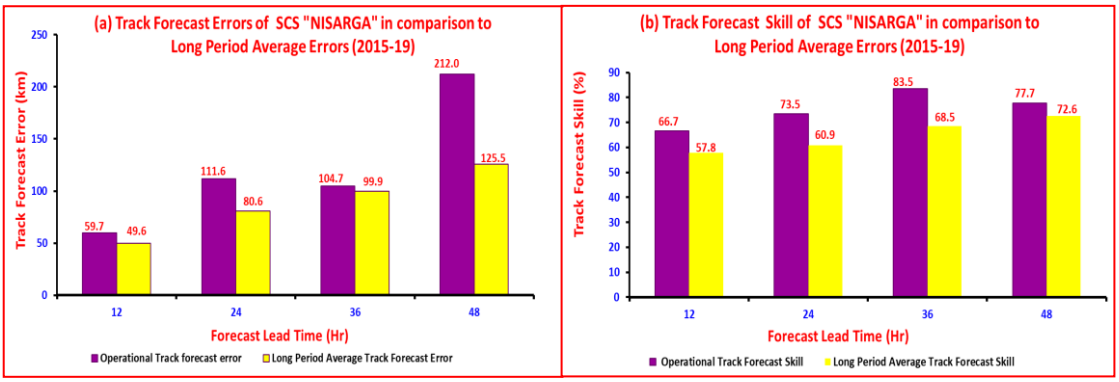


Fig. 8: Track forecast errors and skill of SCS NISARGA as compared to long period average (2015-19)

Table4: 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.

5.5. Intensity Forecast Errors:

The intensity forecast errors and skill based on absolute errors and root mean square errors are presented in Table 5 and Fig. 9 & 10 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. 9a).**
- 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. 9b).**

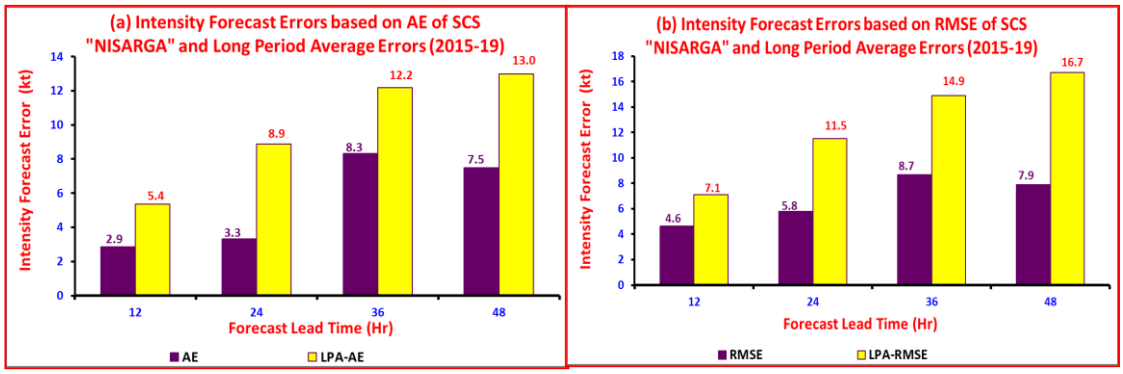


Fig. 9: (a) Absolute errors (AE) and (b) Root Mean Square errors (RMSE) in intensity forecast (winds in knots) of SCS NISARGA as compared to long period average (2015-19)

- The skill (%) in intensity forecast based on AE for 12, 24 & 48 hrs lead period was 80%, 89% and 81% against the LPA of 29%, 43% & 68% respectively **(Fig. 10a).**
- 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% & 59% respectively **(Fig. 10b).**

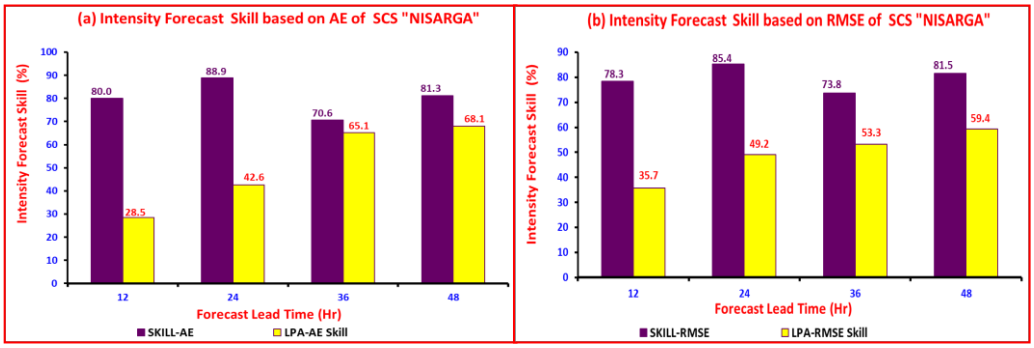


Fig. 10: Skill (%) in intensity forecast based on (a) Absolute errors (AE) and (b) Root Mean Square errors (RMSE) of SCS NISARGA as compared to long period average (2015-19)

Table 5: 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	28.5	35.7
24	6	3.3	5.8	8.9	11.5	88.9	85.4	42.6	49.2
36	3	8.3	8.7	12.2	14.9	70.6	73.8	65.1	53.3
48	2	7.5	7.9	13.0	16.7	81.3	81.5	68.1	59.4

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

5.6. 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 6-8. It is found that all the three types of adverse weather were predicted accurately and well in advance.

Table 6: Verification of Heavy Rainfall Forecast

Date/Base Time of 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 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.	**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 &
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.	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
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 7: Verification of Squally/Gale wind forecast (16-21 May)

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-	Realised wind reported on 3rd June during and after the

	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.	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 8: 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.	

6. 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. 11 & 12 respectively.

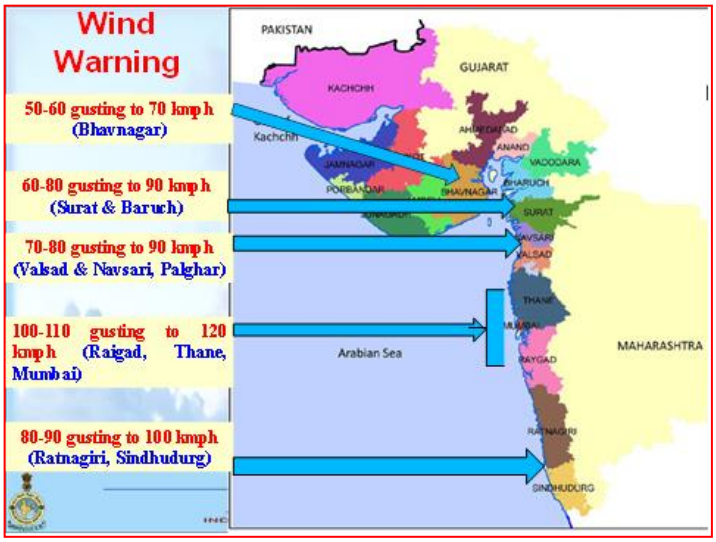
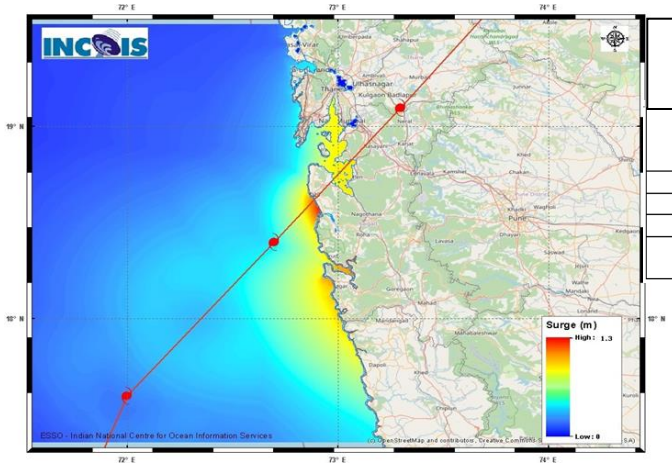


Fig. 11: Typical district level wind warning based on 0300 UTC of 2nd June



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. 12: 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 9.**

Table 9 (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.
2	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.
3	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.
4	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.
5	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)
6	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
7	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.
8	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
9	Warnings through Social Media	Daily	Cyclone Warnings were uploaded on Social networking sites (Face book, Twitter and Whatsapp) since inception to weakening of system (every time when there was change in track, intensity and landfall characteristics) and hourly on the day of landfall on 3rd June.
10	Press Release	6	Disaster Managers, Media persons by email and uploaded on website
11	Press Briefings	Daily	Regular briefing daily and frequently as and when media persons visited the National Weather Forecasting Centre
12	Hourly Updates	12	Hourly bulletins by email, websites, social media including whatsapp, facebook, twitter

Table 9 (b): Statistics of bulletins issued by CWC Thiruvanathapuram (TRV), MCs Bangaluru & Goa

S.No.	Type of Bulletin	No. of Bulletins issued		
		CWC TRV	MC Bengaluru	MC Goa
1.	Sea Area Bulletin	-	-	-
2.	Coastal Weather Bulletins	12	-	-
3.	Fishermen Warnings issued	24	04	06
4.	Port Warnings	6	02	07
5.	Heavy Rainfall warning	18	03	03

6.	Gale Wind Warning	12	-	06
7.	Storm Surge Warning	-	-	-
8.	Information & Warning issued to State Government and other Agencies	26	8	6
9.	SMS frequency	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	-	01	10

7. 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.

8. 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

9. 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 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, 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.

Annexure-1

Typical INSAT 3D imageries are presented in Fig. 1(a-e), microwave imageries in Fig. 1f, ASCAT imageries in Fig.1g and SCAT SAT imageries in Fig. 1h. Typical radar imageries from DWR Mumbai and Goa are presented in Fig.2. Total precipitable water imageries are presented in Fig. 3.

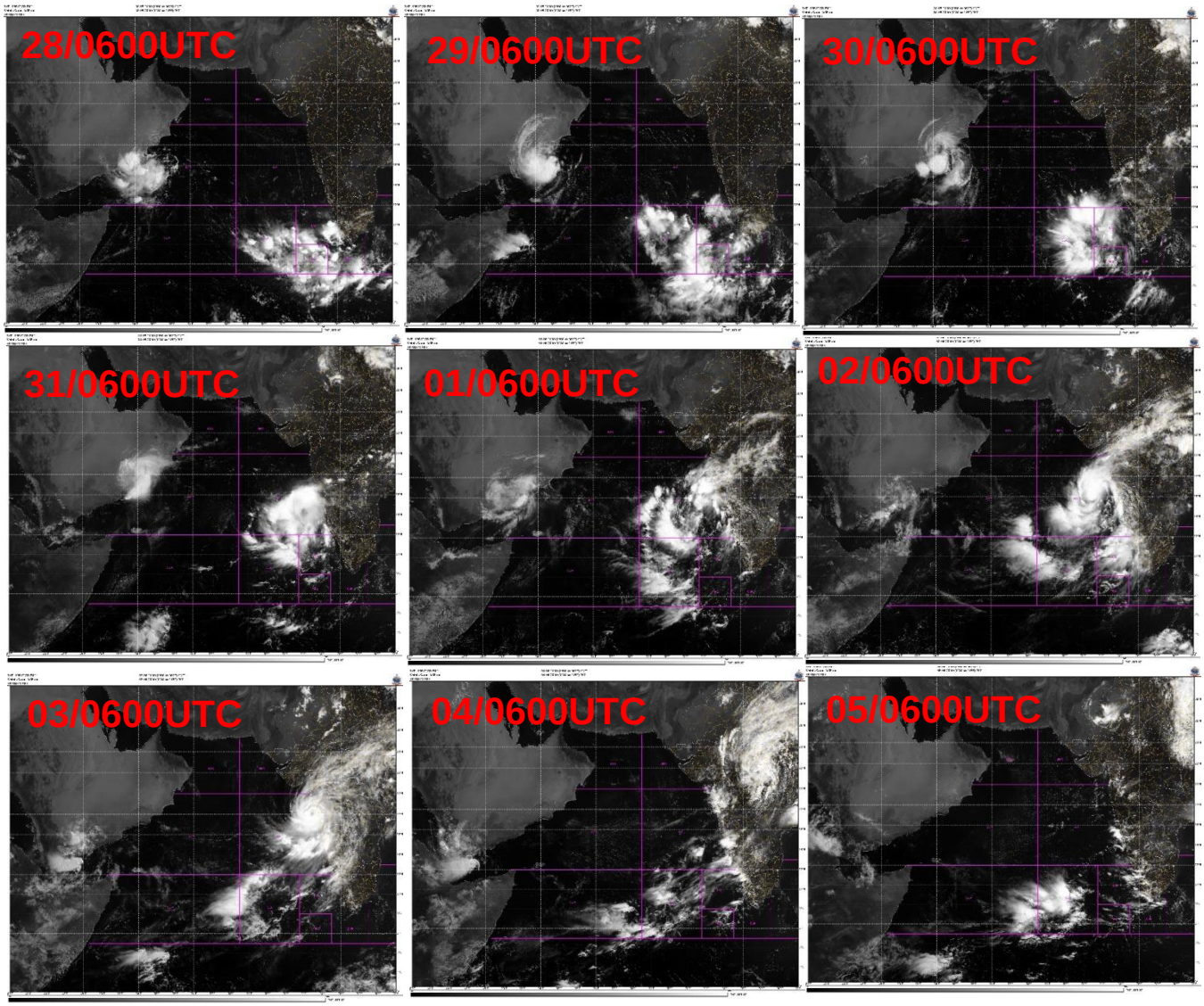


Fig. 1a: INSAT-3D Visible imageries during life cycle of SCS NISARGA (28 MAY-5 JUNE, 2020)

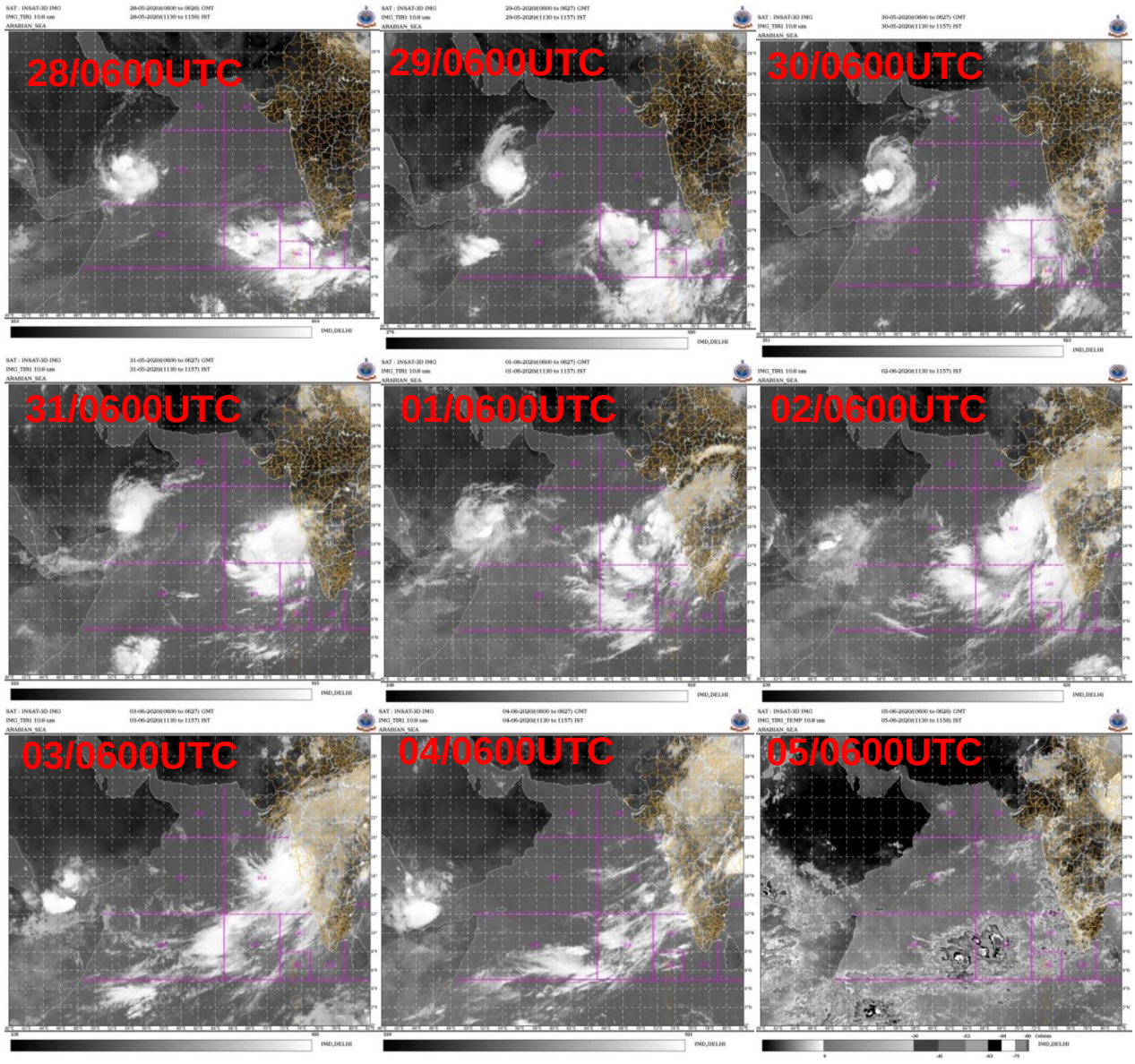


Fig. 1b: INSAT-3D IR imageries during life cycle of SCS NISARGA (28 MAY-5 JUNE, 2020)

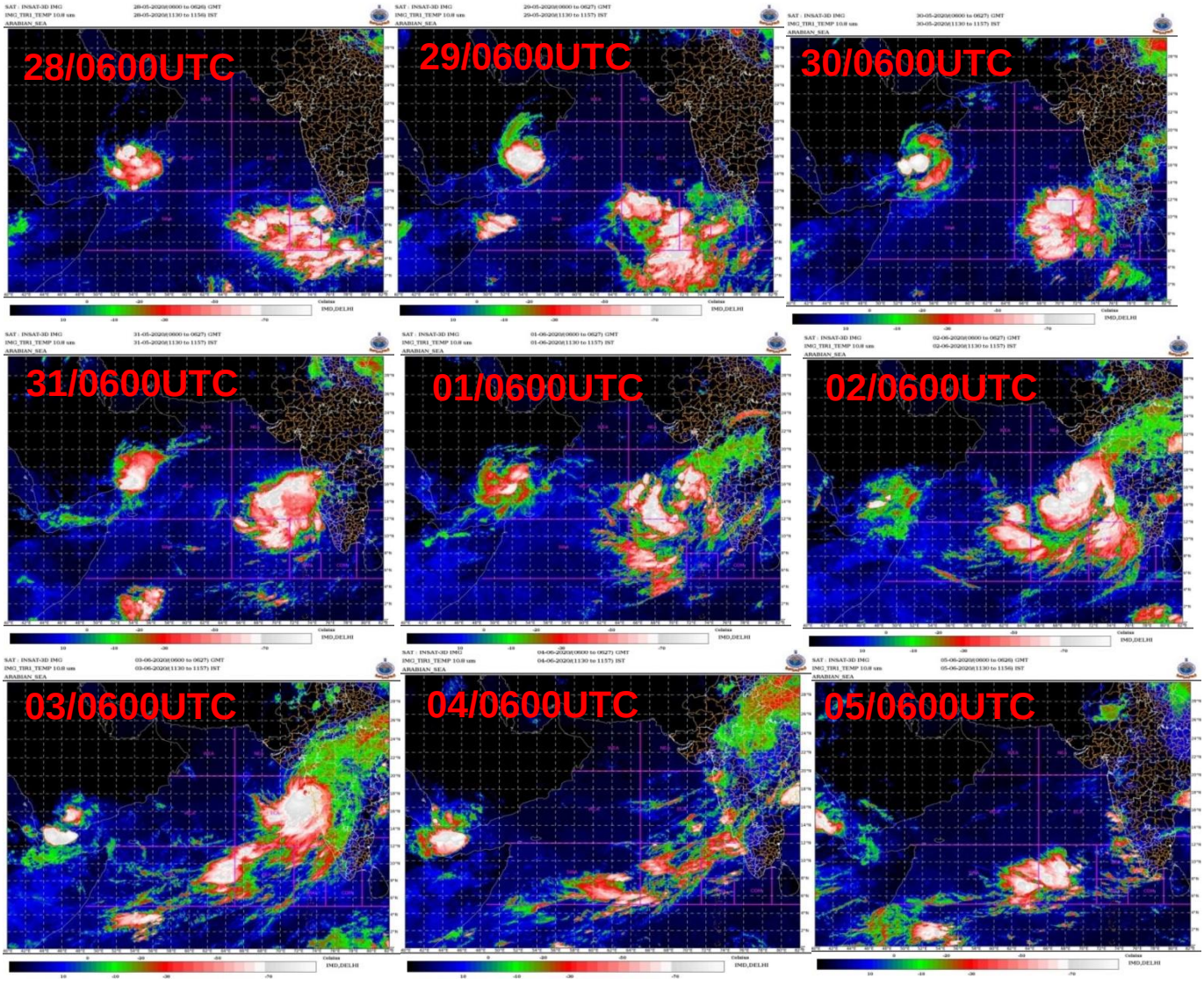


Fig. 1c: INSAT-3D enhanced color imageries during life cycle of SCS NISARGA (28 MAY-5 JUNE, 2020)

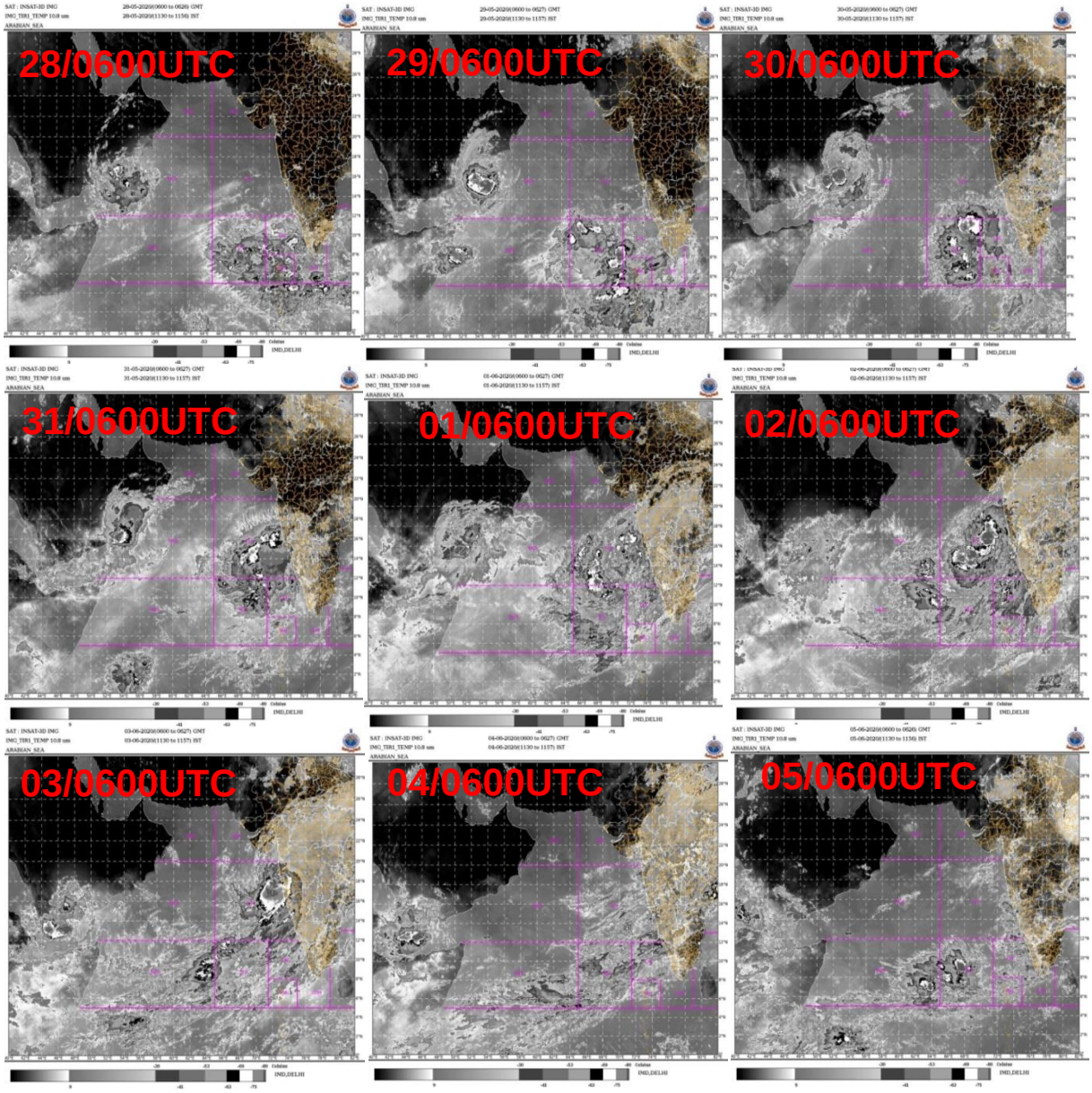


Fig. 1d: INSAT-3D BD imageries during life cycle of SCS NISARGA (28MAY-5 JUNE, 2020)

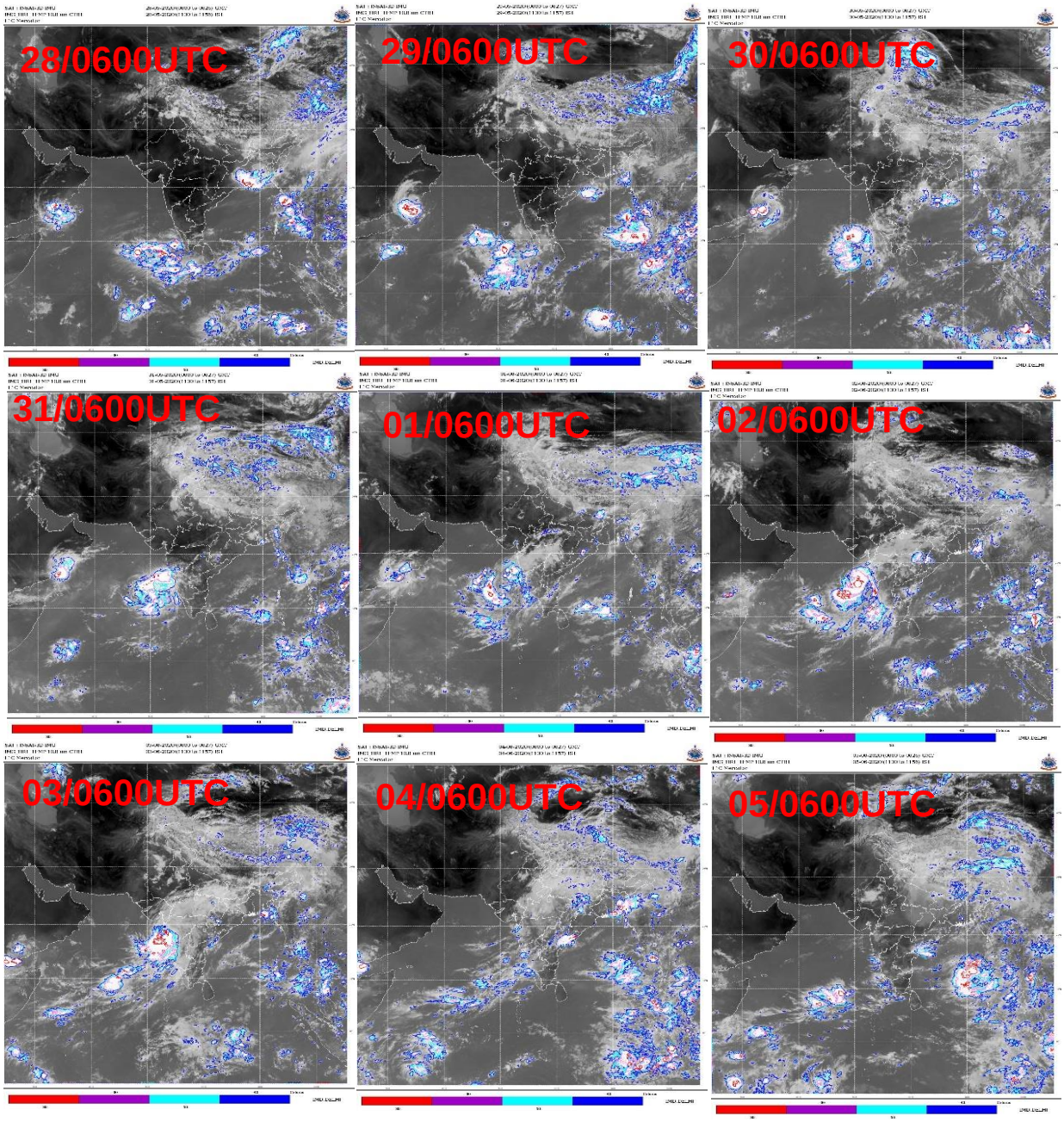


Fig. 1e: INSAT-3D cloud top brightness temperature imageries during life cycle of SCS NISARGA (28MAY-5 JUNE, 2020)

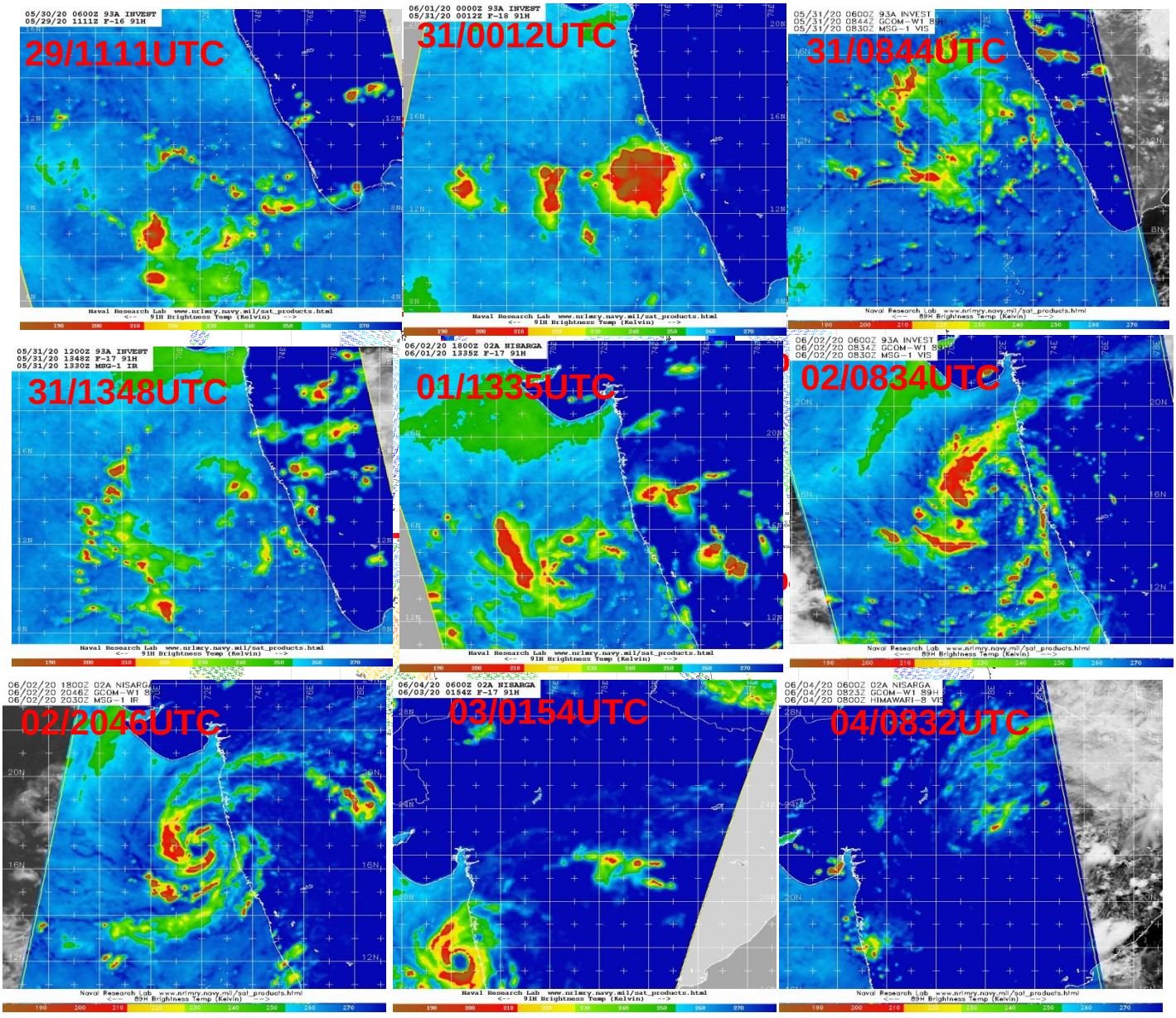


Fig. 1f: Microwave imageries during life cycle of SCS NISARGA (29MAY-4 JUNE, 2020)

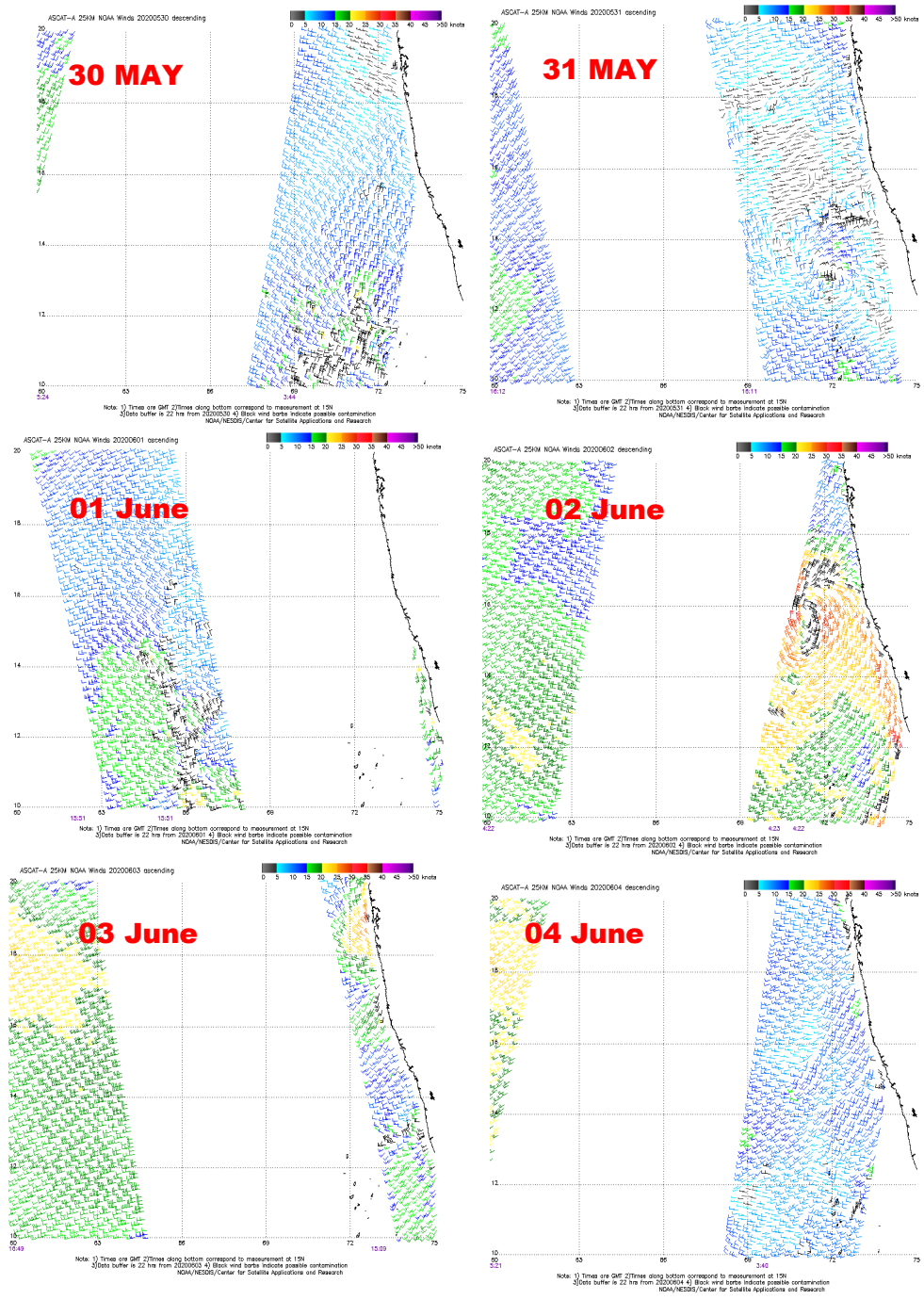


Fig. 1g: ASCAT imageries during life cycle of SCS NISARGA (30MAY-4 JUNE, 2020)

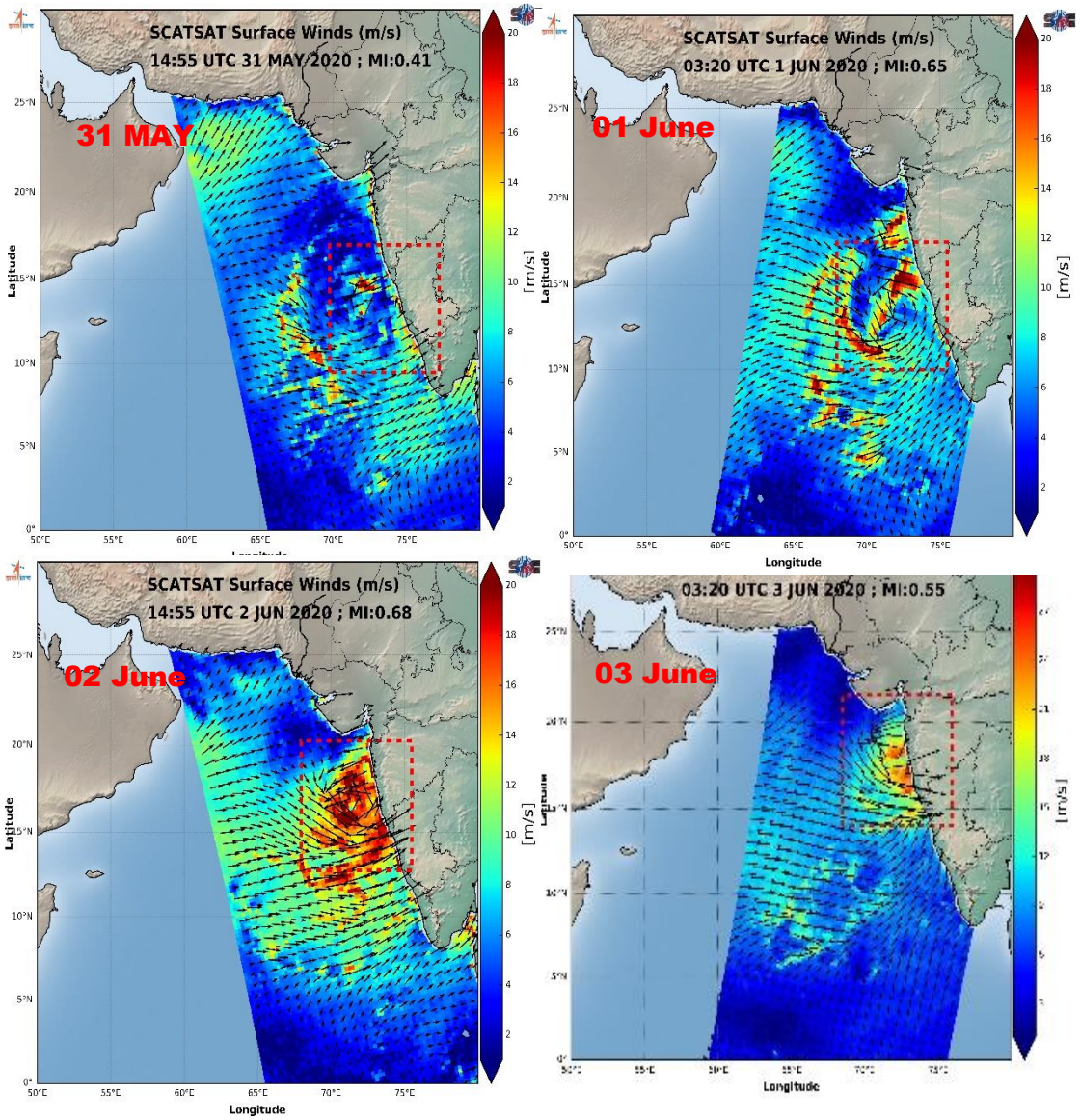


Fig. 1h: SCAT SAT imageries during life cycle of SCS NISARGA (31MAY-3 JUNE, 2020)

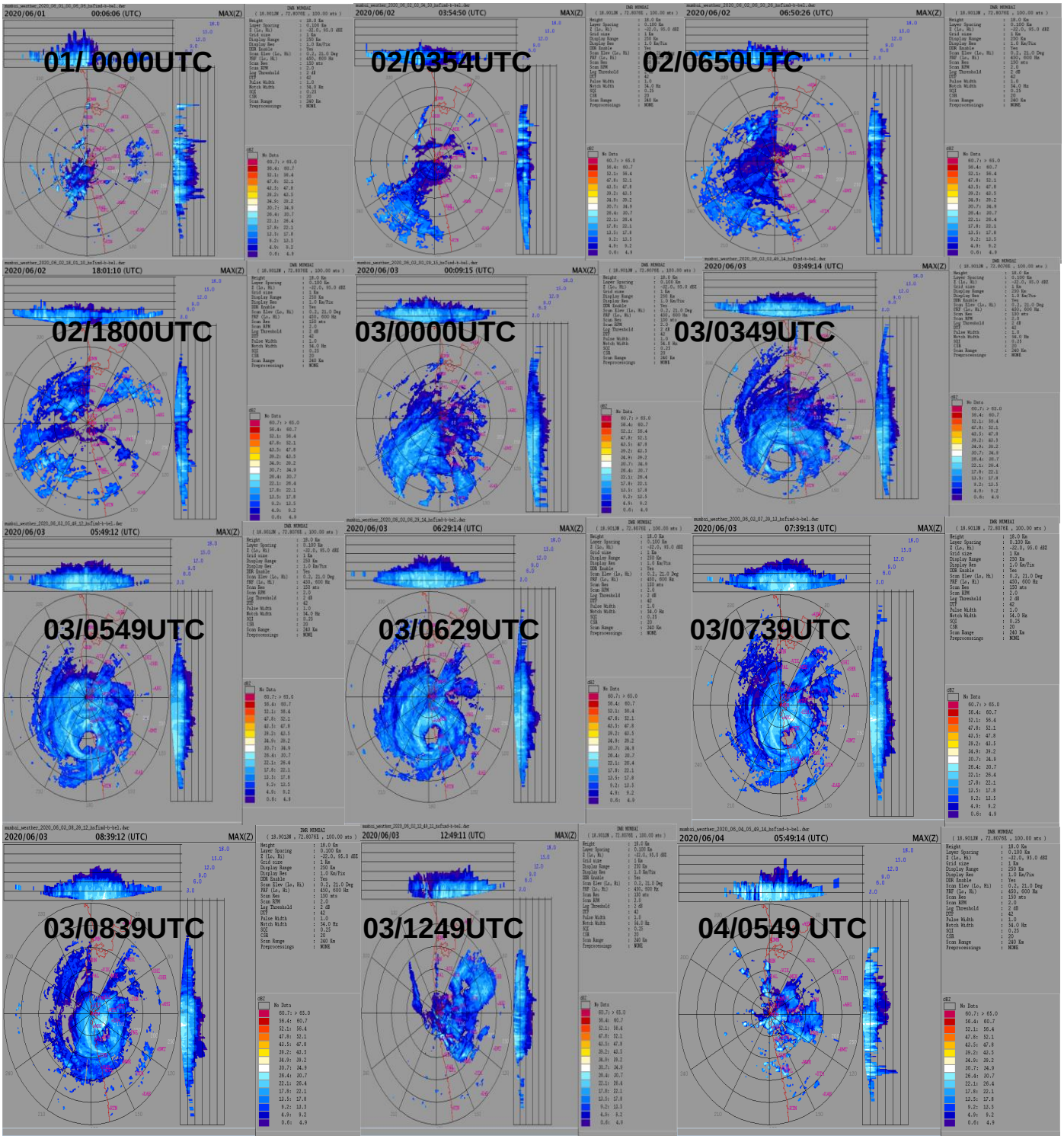


Fig2a: Typical Radar imagery from DWR Mumbai during 01-04 June of SCS Nisarga

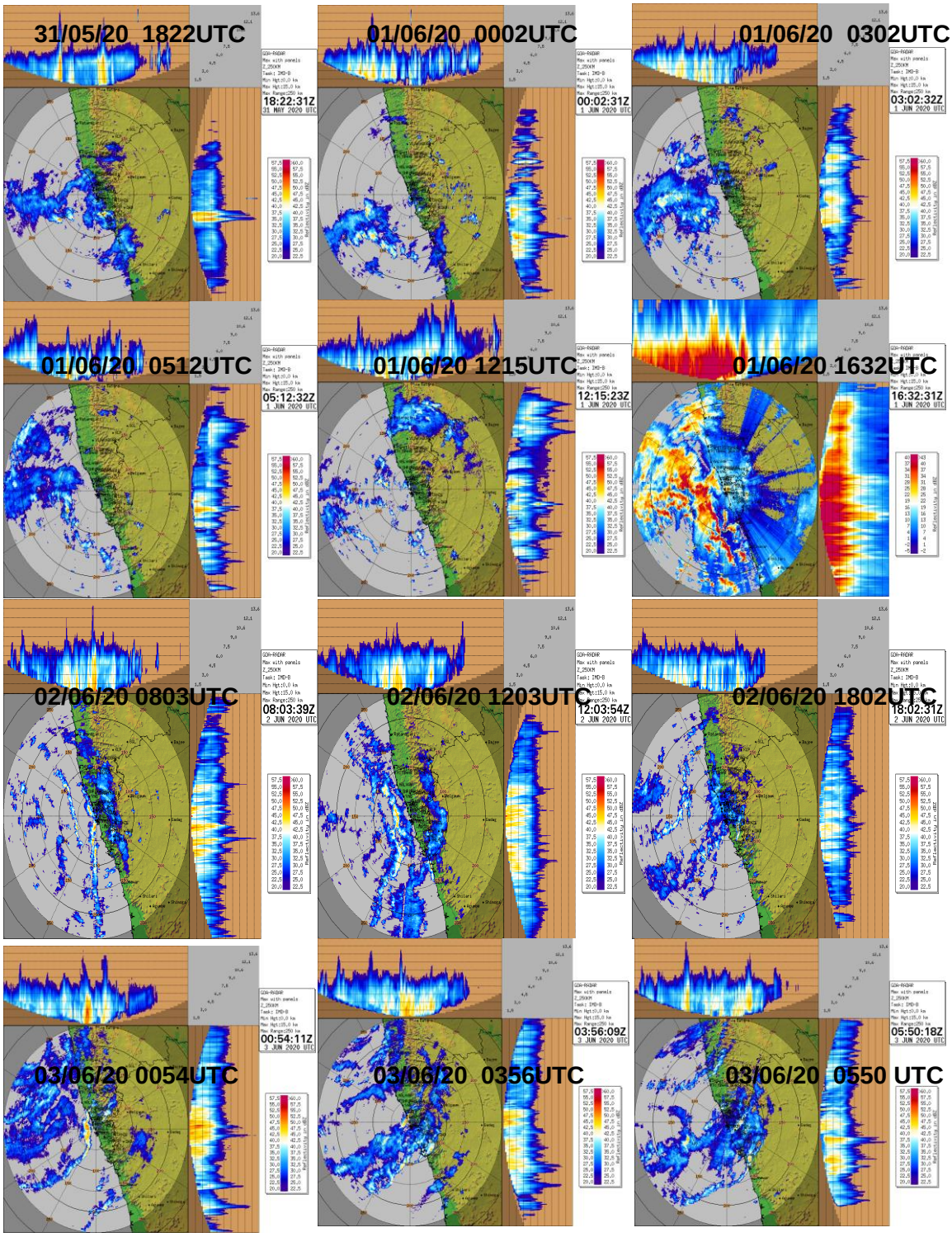


Fig:2 Typical Radar imagery from DWR GOA during 31May- 03 June of SCS NISARGA

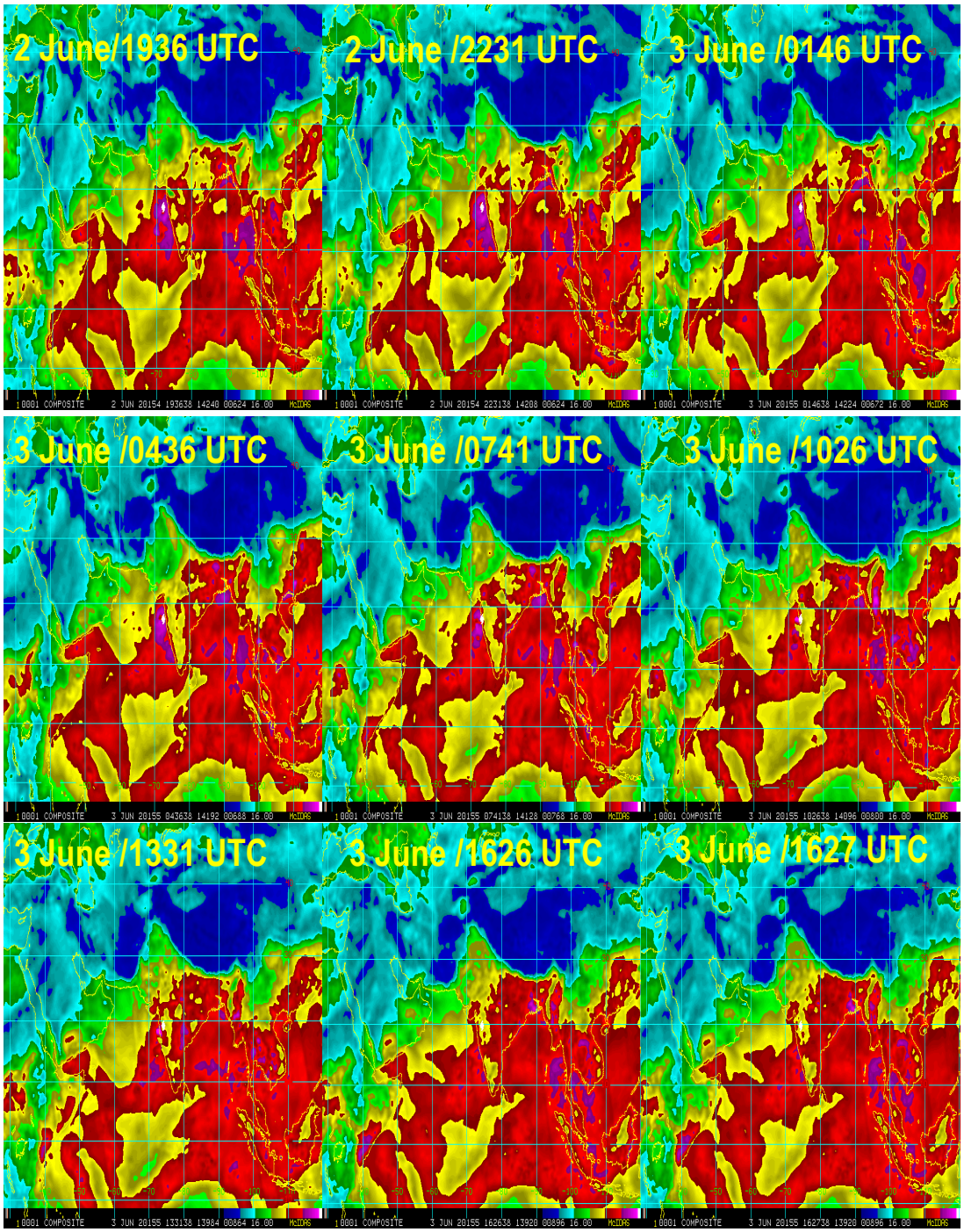


Fig.3: Total precipitable water vapour imagery during 2-3 June in association with SCS Nisarga