



Extremely Severe Cyclonic Storm TAUKTAE over the Arabian Sea (14th-19th May, 2021): A Report

1. Life History of TAUKTAE:

- A low pressure area formed over southeast Arabian Sea & adjoining Lakshadweep area in the morning (0830 hrs IST/ 0300 UTC) of 13th May 2021. It lay as a well marked low pressure area over Lakshadweep area and adjoining southeast Arabian Sea in the same evening (1730 hours IST/1200 UTC of 13th May).
- Under favourable environmental conditions, it concentrated into a depression over Lakshadweep area in the morning (0830 hrs IST) of 14th May, 2021.
- It intensified into a deep depression over Lakshadweep area and adjoining southeast & eastcentral Arabian Sea in the same afternoon (1430 hrs IST/ 0900 UTC of 14th May) and into cyclonic storm “TAUKTAE” in the same midnight (2330 hrs IST/1800 UTC) over the same region.
- It moved nearly northwards and intensified into a severe cyclonic storm in the evening (1730 hrs IST) of 15th May over eastcentral Arabian Sea.
- Continuing to move nearly northwards, it intensified into a very severe cyclonic storm over eastcentral Arabian Sea in the early hours (0230 hrs IST/2100 UTC) of 16th May over eastcentral Arabian Sea.
- It gradually started moving north-northwestwards from noon (1130 hours IST/0600 UTC) of 16th May and intensified rapidly into an extremely severe cyclonic storm in the early hours (0530 hrs IST/0000 UTC) of 17th May.
- Thereafter, it entered marginally unfavourable environment, weakened gradually and crossed Saurashtra coast near latitude 20.8°N and longitude 71.1°E, close to northeast of Diu (about 20 km northeast of Diu) during 2000-2300 hours IST of 17th May, 2021 with maximum sustained wind speed of 160-170 kmph gusting to 185 kmph.
- During the landfall, the system moved slowly nearly northward, as it started recurvature in the track. After landfall, it weakened into a very severe cyclonic storm over Saurashtra in the midnight (2330 hrs IST) of 17th May.
- Thereafter, it started moving north-northeastwards and weakened into a severe cyclonic storm in the forenoon (0830 hours IST) over Saurashtra and further into a cyclonic storm during noon (1130 hours IST) of 18th May, 2021 over Saurashtra and adjoining Gujarat region.
- Continuing to move north-northeastwards, it weakened into a deep depression over Gujarat region in the evening (1730 hrs IST) and into a depression over Gujarat region and adjoining South Rajasthan in the midnight (2330 hrs IST) of 18th May. The observed track of the system is presented in Fig. 1. The best track parameters of the system are presented in Table 1.

2. Salient features:

- i. TAUKTAE was the first cyclonic storm over the north Indian Ocean during the year 2021.
- ii. During satellite era (1961-2021), Tauktae was the most intense cyclone after Kandla cyclone in 1998. During this period, 3 extremely severe cyclonic storms crossed Gujarat coast. Tracks of tropical cyclones (TCs) crossing Gujarat coast during 1961-2020 are presented in

Fig. 2. Frequency of TCs crossing Gujarat coast is presented in Fig.3. The cyclone Tauktae had the same intensity as that of Kandla cyclone of June, 1998 at the time of landfall as both had maximum sustained surface wind speed of 160-170 kmph gusting to 185 kmph at the time of landfall. However life time maximum intensity was higher in case of Tauktae, as it had the maximum intensity of 180-190 gusting to 210 kmph over the east-central Arabian Sea during early morning to afternoon of 17th May 2021.

- iii. It was a very rare cyclone causing adverse weather and damage over entire west coast states and Union Territories and Lakshadweep as it moved parallel to west coast and crossed Gujarat.
- iv. It had a longer period of the impact of cyclone intensity over Gujarat (about 24 hrs from 1730 IST of 17th to 1730 IST/1200 UTC of 18th May).
- v. The track length of the cyclone was 1880 km.
- vi. It had rapid intensification for about 24 hrs period during 16th morning (0530 IST/0000 UTC) to 17th morning (0530 IST/0000 UTC), with increase in maximum sustained wind speed (MSW) from 65 knots at 0530 IST of 16th to 100 knots at 0530 IST of 17th.
- vii. The peak MSW of the cyclone was 180-190 kmph (100 knots) gusting to 210 kmph during 0530 IST (0000 UTC) of 17th to 1130 IST (0600 UTC) of 17th over the eastcentral AS. The lowest estimated central pressure was 950 hPa during the period with a pressure drop of about 50 hPa at the centre as compared to surrounding (Fig.2a).
- viii. The life period (D to D) of the system was 129 hours (5 days & 9 hours) against long period average (LPA) (1990-2013) of 165 hours (6 days & 21 hrs) for VSCS categories over Arabian Sea during pre-monsoon season.
- ix. It moved with 12 hour average translational speed of 14.4 kmph against LPA (1990-2013) of 11.8 kmph for VSCS category over Arabian Sea during pre-monsoon season (Fig.2b).
- x. The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 10.6×10^2 knots, 7.7×10^4 knots² and 6.11×10^6 knots³ respectively.
- xi. The operational track forecast errors for 24 and 48 hrs lead period were 73 and 113 km respectively against the average long period average (LPA) track forecast errors of 77 and 117 km during last five years (2016-20) respectively.
- xii. The operational absolute error (AE) of intensity (wind) forecast for 24 and 48 hrs lead period were 4.4 and 8.9 kt against the LPA of 7.9 and 11.4 kt respectively.
- xiii. The operational landfall point errors were 27 and 71 km for 24 and 48 hrs lead period against LPA of 32 and 62 km.
- xiv. The operational landfall time errors were 3.5 hrs and 6.5 hrs for 24 and 48 hrs lead period against LPA of 2.5 hrs and 5.0 hrs.
- xv. As the cyclone moved parallel to west coast, it caused heavy to extremely heavy rainfall activity, strong wind and tidal waves affecting Lakshadweep on 13-14th, Kerala on 14-15th, Karnataka on 15th, Goa and south coastal Maharashtra on 15-16th, north Maharashtra on 16-17th, Gujarat, Daman & Diu, Dadra & Nagar Haveli on 17th and 18th. It's remnant also impacted northwest India with heavy to very heavy rainfall activity at isolated places over Rajasthan, Haryana, Chandigarh, Delhi, Uttar Pradesh, Uttarakhand on 19th May 2021.
- xvi. It also caused strong winds along the west coast of India as well as over Lakshadweep. Agathi reported maximum sustained wind speed of 45 kts on 14th May, Panaji reported 46 kts on 16th, Diu reported 85 kts on 17th.
- xvii. A total of 41 national bulletins, 30 RSMC bulletins to WMO/ESCAP Panel member countries, 9 Press Releases, 15 hourly bulletins on the day of landfall, 18 bulletins for

International Civil Aviation, 83 lakh SMS to fishermen, farmers & coastal population, very frequent updates on social networking sites were sent to trigger mass response and sensitise masses about the impending disaster in association with the system.

xviii. While 3 hourly bulletins were issued commencing from cyclone stage, hourly updates were provided on the day of landfall

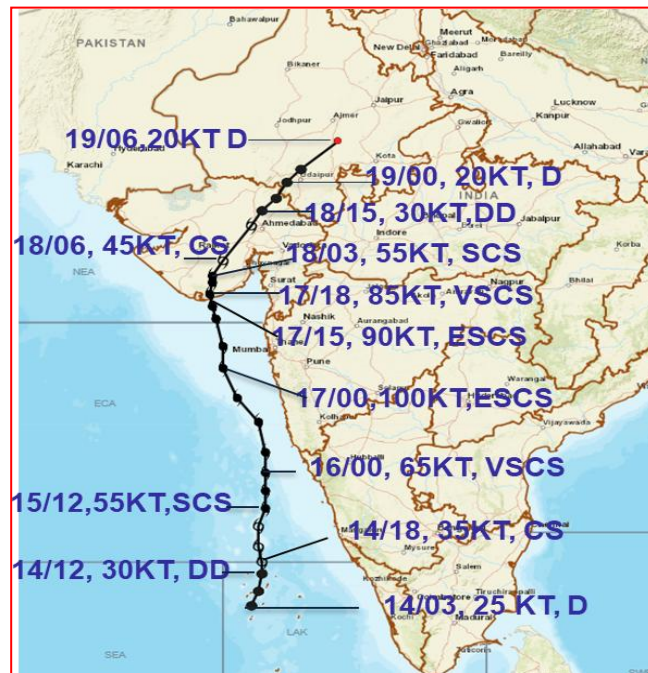


Fig.1: Observed track of ESCS TAUKTAE during 14th-19th May, 2021

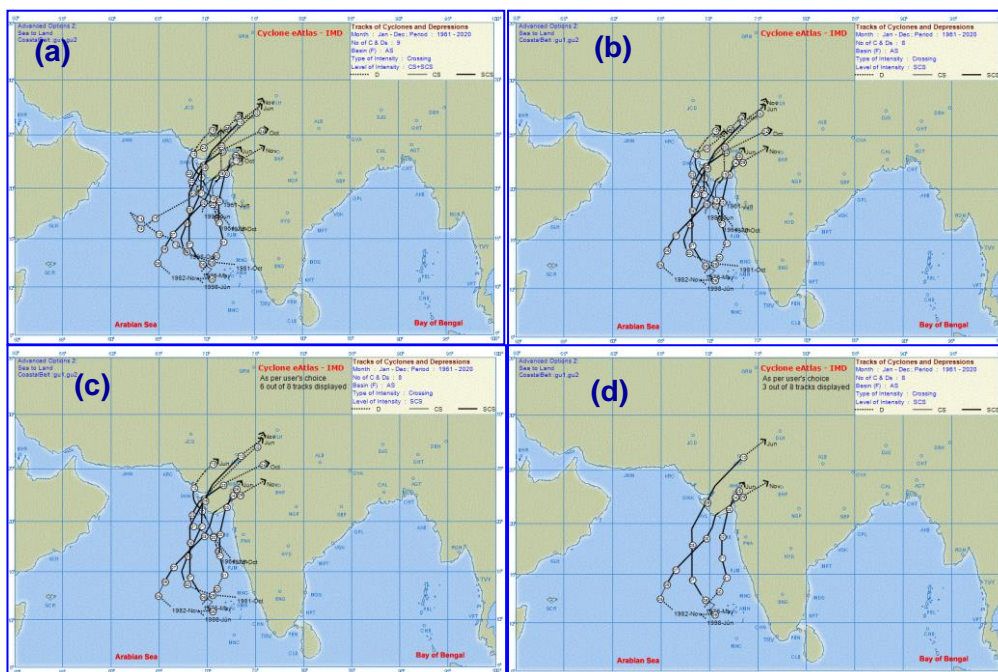


Fig.2: Tracks of (a) CS & above (Total 8), (b) SCS & above (Total 8), (c) VSCS & above (Total 6) and (d) ESCS & above (Total 3) category storms crossing Gujarat coast during 1961-2020

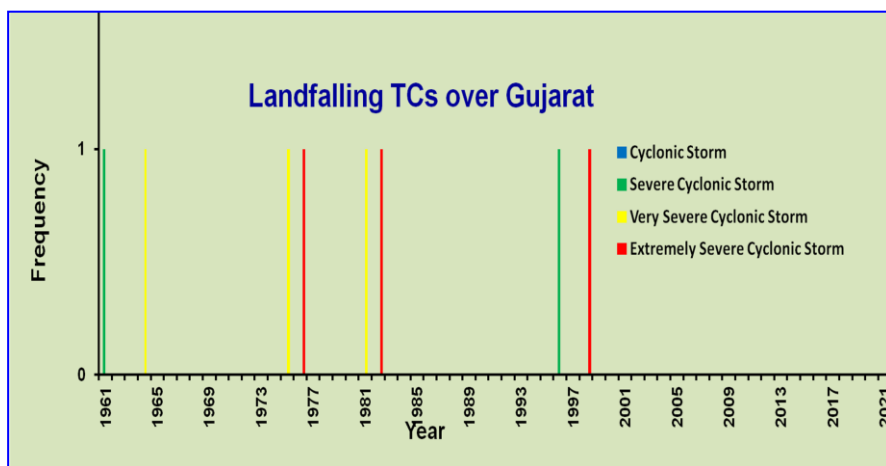


Fig.3: Frequency of landfalling TCs of Gujarat coast during 1961-2021

The six hourly maximum sustained wind speed & estimated central pressure and translational speed are presented in Fig. 4(a) and 4(b). Tauktae exhibited rapid intensification during 16/0000 UTC to 17th/0000 UTC with increase in wind speed 65 kts to 100 kts during 24 hours. It moved very slowly during and after landfall leading to maintenance of cyclonic storm intensity over Gujarat after landfall.

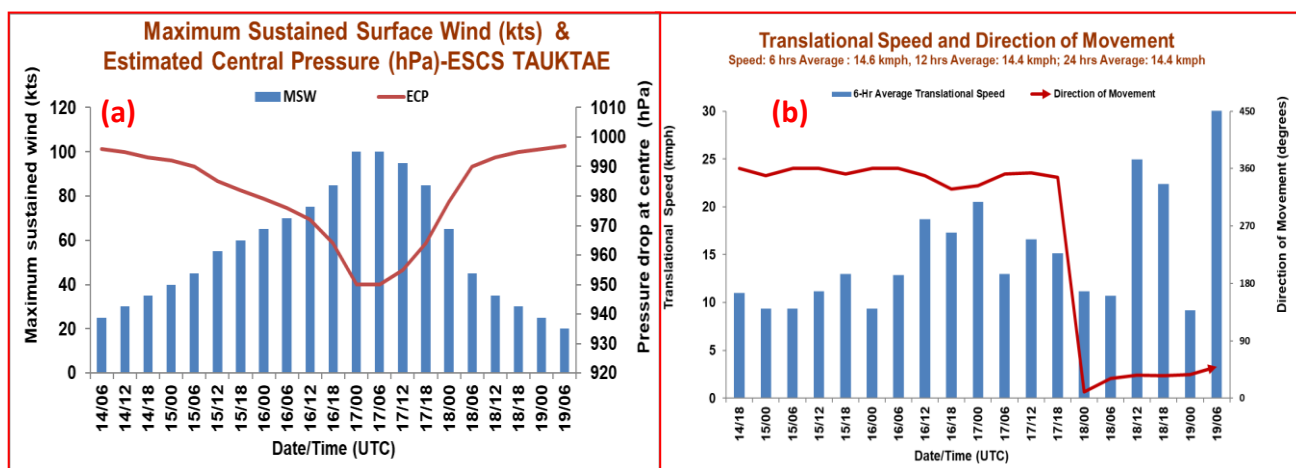


Fig. 4: (a) Translational speed & direction of movement and (b) Maximum sustained surface winds (kts) & Estimated Central Pressure

Table1: Best track positions and other parameters of the Extremely Severe Cyclonic Storm, “Tauktae” over the Arabian Sea during 14 May- 19 May, 2021

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
14/05/2021	0300	10.5 72.3	1.5	997	25	3	D
	0600	11.0 72.5	1.5	996	25	4	D
	0900	11.5 72.5	2.0	995	30	5	D
	1200	11.6 72.6	2.0	995	30	6	DD
	1800	12.2 72.6	2.5	993	35	7	CS
	2100	12.2 72.6	2.5	992	40	8	CS

15/05/2021	0000	12.7	72.5	2.5	992	40	8	CS	
	0300	12.8	72.5	2.5	992	40	8	CS	
	0600	13.2	72.6	2.5	990	45	10	CS	
	0900	13.5	72.7	2.5	990	45	10	CS	
	1200	13.8	72.7	3.0	985	55	15	SCS	
	1500	14.2	72.7	3.0	984	55	16	SCS	
	1800	14.5	72.6	3.0	982	60	18	SCS	
	2100	14.7	72.7	3.0	982	60	18	SCS	
16/05/2021	0000	15.0	72.7	4.0	979	65	21	VSCS	
	0300	15.3	72.7	4.0	976	70	24	VSCS	
	0600	15.7	72.7	4.0	976	70	24	VSCS	
	0900	16.2	72.6	4.0	976	70	24	VSCS	
	1200	16.7	72.5	4.5	972	75	28	VSCS	
	1500	17.2	72.3	4.5	978	80	32	VSCS	
	1800	17.5	72.0	4.5	964	85	36	VSCS	
	2100	18.0	71.7	5.0	960	90	40	ESCS	
17/05/2021	0000	18.5	71.5	5.5	950	100	50	ESCS	
	0300	18.8	71.5	5.5	950	100	50	ESCS	
	0600	19.2	71.4	5.5	950	100	50	ESCS	
	0900	19.6	71.4	5.5	950	100	50	ESCS	
	1200	20.1	71.3	5.0	955	95	45	ESCS	
	1500	20.5	71.2	5.0	960	90	40	ESCS	
	Crossed Saurashtra coast about 20 km northeast of Diu, near Lat.20.8°N and Long. 71.1°E during 1530-1730 UTC of 17 th May 2021 with maximum sustained wind speed of 90 knots gusting to 100 knots.								
	1800	20.9	71.1	-	964	85	36	VSCS	
	2100	21.3	71.2	-	972	75	28	VSCS	
	18/05/2021	0000	21.5	71.2	-	978	65	22	VSCS
0300		21.6	71.3	-	984	55	16	SCS	
0600		22.0	71.5	-	990	45	10	CS	
0900		22.5	71.8	-	992	40	8	CS	
1200		23.1	72.3	-	993	35	7	CS	
1500		23.6	72.6	-	994	30	6	DD	
1800		24.1	73.0	-	995	30	5	DD	
19/05/2021		0000	24.5	73.3	-	996	25	4	D
	0300	24.9	73.7	-	997	20	3	D	
	0600	25.8	74.8	-	997	20	3	D	
	1200	Weakened into a Well-Marked Low Pressure Area over Northeast Rajasthan.							

3. Monitoring of TAUKTAE:

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored since 6th May, about 7 days prior to the formation of low pressure area over southeast Arabian Sea & adjoining Lakshadweep area on 13th May and 8 days prior to formation of depression over Lakshadweep area. 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) Thiruvananthapuram, Kochi and Goa. 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 during ESCS TAUKTAE are presented in Fig. 5.

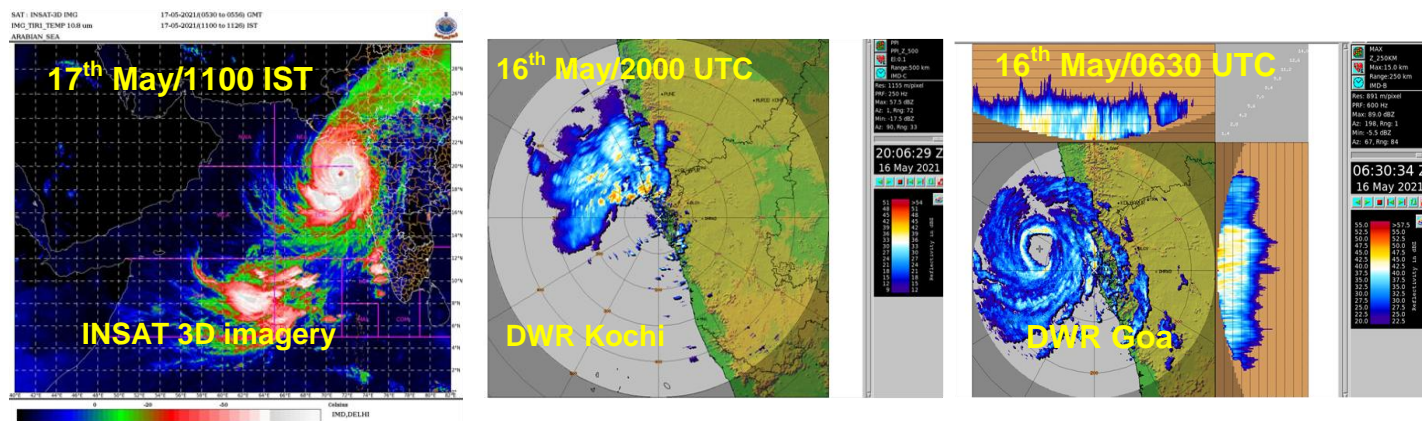


Fig. 5: Typical INSAT 3D satellite and radar imageries from Doppler Weather Radars Kochi and Goa

4. Realised weather

4.1. Rainfall:

It caused heavy to extremely heavy rainfall activity, strong wind and tidal waves affecting Lakshadweep on 13-14th, Kerala on 14-15th, Karnataka on 15th, Goa and south coastal Maharashtra on 15-16th, north Maharashtra on 16-17th, Gujarat, Daman & Diu, Dadra & Nagar Haveli on 17th and 18th. It's remnant also impacted northwest India with heavy rainfall at isolated places. Rainfall associated with ESCS Tauktae based on IMD-NCMRWF GPM merged gauge 24 hours cumulative rainfall ending at 0830 IST of date is depicted in **Fig 6**.

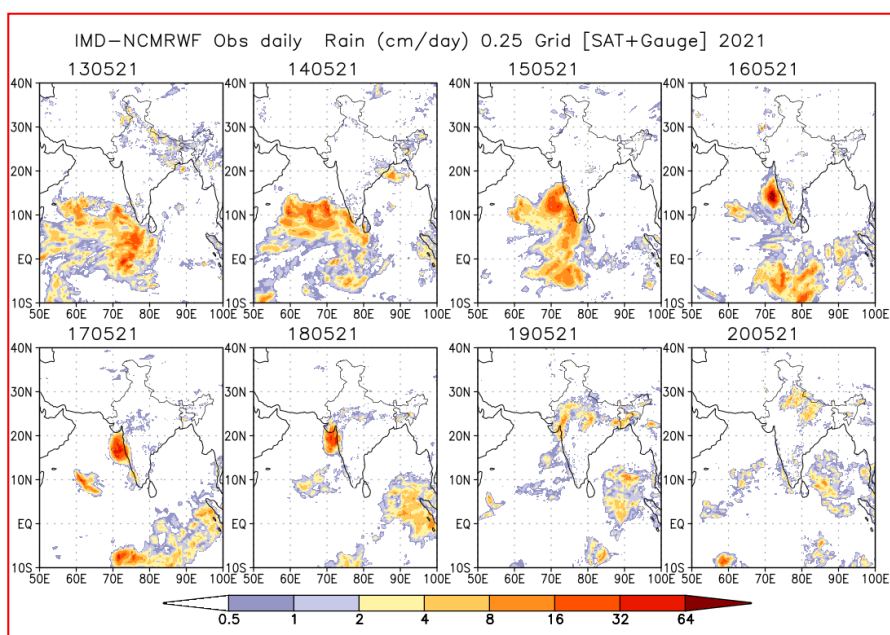


Fig.6: IMD-NCMRWF GPM merged gauge 24 hr cumulative rainfall (cm) ending at 0830 IST of date during 13th May – 18th May and 7 days average rainfall (cm/day)

Rainfall (cm) reported (realised during the past 24 hours ending at 0830 hrs IST of date) along the west coast during 12th-20th May, 2021

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

12 May

LAKSHADWEEP: Agathi-8, Minicoy-1.

13 May

LAKSHADWEEP: Agathi-17, Amini-8, Minicoy-5.

14 May

KERALA & MAHE: Mavelikara-15, Konni-14, Kayamkulam-14, Kayamkulam Agri-13, Neyyattinkara-11, Nedumangad-11, Kottayam-11, Kurudamannil-10, Varkala-10, Mancompu-9, Kozha-9, Vaikom-9, Haripad-9, Kumarakam-9, Chalakudi-8, Aluva-8, Thritala-7, Kochi C.I.A.L.-7, Ernakulam South-7

LAKSHADWEEP: Agathi-12.

SOUTH INTERIOR KARNATAKA: Balehonnur-7

15 May

COASTAL KARNATAKA: Mangaluru AP - 8, Panambur - 7, Mangaluru-7,

KERALA & MAHE: Kochi-21, Peermade-21, Kodungallur-20, Enamakkal-19, Ernakulam South-17, Kumarakam-16, Kannur-16, Kollam-16, Alapuzha-16, Chalakudi-15, Irinjalakuda-15, Ponnani-14, Pattambi-14, Vaikom-14, Cherthala-13, Kozhikode-13, Varkala-13, Mancompu-13, Thritala-13, Mavelikara-12, Aluva-12, Kayamkulam-12, Kurudamannil-11, Konni-11, Quilandi-11, Perumpavur-11, Taliparamba-11, Vellanikkara-11, Kochi C.I.A.L.-11, Kottayam-11, Haripad-11, Vadakkancherry-11, Kozha-11, Kanjirappally-10, Munnar KSEB-10, Manjeri-10, Mahe-9, Perinthalmanna-9, Vadakara-9, Ottapalam-9, Punalur-9, Talassery-9, Hosdurg-9, Piravam-8, Nilambur-8, Angadipuram-8, Vyttiri-8, Karipur -7, Thodupuzha-7, Kudulu-7, Neyyattinkara-7

LAKSHADWEEP: Agathi-10, Amini-8

16 May

KONKAN & GOA: Canacona-7, Pernem-7

COASTAL KARNATAKA: Kollur-24, Manki-19, Kota-19, Puttur -19, Kundapur-17, Bhatkal-16, Udupi-15, Dharmasthala-14, Mani-13, Mulki-12, Karkala-11, Shirali -11, Mangaluru -11, Kadra-11, Panambur -10, Karwar -10, Mudubidre-10, Belthangadi-9, Honavar -9, Gokarna-9, Vitla ARG-9, Sulya-8, Siddapur-8

NORTH INTERIOR KARNATAKA: Vijayapura-8

SOUTH INTERIOR KARNATAKA: Hosanagara-19, Bhagamandala-17, Kalasa-13, Virajpet-13, Linganamakki -9, Thalaguppa-7, Sagar-7

KERALA & MAHE: Mahe-24, Vadakara-23, Vyttiri-21, Taliparamba-17, Talassery-17, Quilandi-16, Ernakulam South-14, Kochi I.A.F.-14, Kochi C.I.A.L.-13, Aluva -13, Manantoddy-13, Irikur-13, Kannur-12, Piravam-11, Perumpavur-11, Enamakkal-11, Kudulu-10, Thodupuzha-10, Karipur.-10, Munnar KSEB-10, Varkala-10, Kozha-9, Vaikom-9, Nilambur-9, Neyyattinkara-9, Idukki-9, Vadakkancherry-8, Nedumangad-8, Parambikulam-8, Irinjalakuda-8, Perinthalamanna-8, Pattambi-8, Angadipuram-8, Kozhikode-8, Ottapalam-8, Peermade -8, Chalakudi-7, Ponnani-7, Thiruvananthapuram-7, Ambalavayal-7, Mannarkkad-7, Myladumpara Agri-7, Thritala-7

17 May

KONKAN & GOA: Sawantwadi-37, Ratnagiri -36, Dodamarg-25, Panjim -23, Malvan-21, Kudal-20, Devgad-20, Kankavli-19, Vengurla -18, Mapusa-17, Lanja-16, Dabolim- Navy-15, Vaibhavwadi-15, Sangameshwar Devrukh-14, Guhagarh-12, Margao-12, Dapoli Agri-8, Harnai -8, Sanguem-7

COASTAL KARNATAKA: Kadra-11, Honavar -7, Kollur-7

18 May

GUJARAT REGION: Umergam-18, Daman-15, Daman FMO-13, Surat City-9, Khanvel-8, Valsad-8, Silvassa-7

SAURASHTRA & KUTCH: Bagasra-21, Gir Gadhada-19, Una-17, Savarkundla-17, Palitana-16, Amreli-13, Mahuva-13, Rajula-13, Khambha-13, Babra-13, Gadhda-11, Visavadar-10, Diu-9, Umralla-9, Bhavnagar-8, Dhari-7, Jesar-7

KONKAN & GOA: Palghar Agri-30, Dahanu -28, Santacruz -23, Devgad-23, Sawantwadi-21, Colaba -21, Talasari-17, Canacona-9, Tbia -9, Kankavli-9, Murud-8, Wada-8

19 May

GUJARAT REGION: Nadiad-23, Mahudha-16, Anand-16, Daman FMO-15, Umergam-15, Matar-15, Pardi-14, Daman-14, Khambhat-13, Kheda-13, Tarapur-13, Vaso-13, Olpad-12, Khergam-12, Mahemdavad-12, Dhansura-11, Ahmedabad City-11, Jalalpor-11, Sojitra-11, Kathalal-11, Prantij-10, Wanakbori-10, Borsad-10, Navsari-10, Kapadvanj-10, Virpur-10, Modasa-10, Balasinor-9, Dahegam-9, Bayad-9, Bardoli-9, Talod-9, Madhban-9, Valsad-9, Hansot-9, Vadodara-9, Vagra-9, Meghraj-9, Bhiloda-8, Himatanagar-8, Kamrej-8, Anklav-8, Silvassa-8, Padra-8, Palsana-7, Gandevi-7, Thasra-7, Galteshwar-7, Idar-7, Vapi-7, Poshina-7, Chikhli-7, Sanand-7, Vijapur-7, Khanpur-7, Kaprada-7, Kalol-7, Dascroi-7, Mahuva-7, Lunawada-7, Danta-7, Malpur-7, Petlad-7,

SAURASHTRA & KUTCH: Gir Gadhada-19, Una-18, Bhavnagar-11, Rajula-10, Botad-9, Shihor-9, Visavadar-8, Palitana-8, Vallabhipur-8, Umralla-7,

EAST RAJASTHAN: Veja-23, Kanva-14, Devel-14, Dungarpur Tehsil-14, Dhambola-13, Sarara-13, Girva-11, Aspur-11, Gogunda-10, Ganeshpur-10, Ajmer Tehsil-9, Railmagra-9, Dungla-9, Sagwara-8, Jhadol-8, Udaipur/D-Aero-8, Ajmer-7, Tatgarh-7, Salumber-7, Nithuwa-7, Bari-Sadri-7, Loharia-7, Dhariabad-7, Badesar-7,

20th May:

UTTARAKHAND: Nainital-12; Mussoorie-10; Mukteshwar-9; Haldwani-8

HARYANA, CHANDIGARH & DELHI: Jhajjar-12; Gurgaon-11; Mewat-8; Faridabad-8; Narnaul-8

WEST UTTAR PRADESH: Bareilly-15; Meerut-9; Aligarh-7; Muzzafarnagar-7

EAST UTTAR PRADESH: Gorakhpur-8; Varanasi-8; Sultanpur-7; Mirzapur-7, Jaunpur-7,

WEST RAJASTHAN: Nagaur-7

EAST RAJASTHAN: Dholpur-10; Alwar-9; Jaipur-8, Dausa-7; Sikar-7

(b) Peak wind speed (kmph) recorded by the Meteorological Observatories in association with the passage of TAUKTAE

Agathi reported maximum sustained wind speed of 45 kts on 14th May, Panaji reported 46 kts on 16th. The maximum wind at the time of landfall over Gujarat and Diu was 90 kts gusting to 100 kts (160-170 kmph gusting to 185 kmph) on 17th May.

(c) Storm Surge:

- 3-4 meters of storm surge above the astronomical tide inundated the low lying areas of coastal districts of Saurashtra around the time of landfall.

5. Forecast Performance:

i) Genesis Forecast

- First information about development of low pressure area over southeast Arabian Sea and adjoining areas was given in the extended range outlook issued on 6th May (**about 7 days prior to the formation of low pressure area** over southeast Arabian Sea & adjoining Lakshadweep area on 13th May and **8 days prior to formation of depression** over Lakshadweep area on 14th May).
- Subsequently, in the Tropical Weather Outlook issued on 10th May and national weather forecast bulletin issued at 1200 hrs IST, it was indicated that a low pressure would form over southeast Arabian Sea around 14th May and would intensify further into a cyclonic storm. (**about 4 days prior to formation of cyclonic storm** on 14th May).
- The extended range outlook issued on 13th May (**about 4 days prior to landfall over Gujarat coast**) indicated that the system would move towards Gujarat coast and would impact the areas including southeast, eastcentral & northeast Arabian Sea, Lakshadweep – Maldives area, Lakshadweep Islands, areas along & off Kerala, Karnataka, Goa, Maharashtra, Gujarat & south Pakistan coasts and also the coastal & adjoining districts of all these States. Accordingly, likely impact was also issued in the extended range outlook for fishermen, ships and ports along the west coast of India.

ii) Track, landfall and intensity forecast

- The Press Release updated on 13th May (**5 days prior to landfall**) on development of low pressure area over southeast Arabian Sea. It indicated that the cyclonic storm over southeast Arabian Sea and adjoining Lakshadweep area would reach Gujarat coast on 18th May.
- **In the first bulletin issued at 1245 hrs IST of 14th May**, it was indicated that the system would intensify into a very severe cyclonic storm and reach Gujarat coast by 18th May morning (**about 80 hours prior to landfall of TAUKTAE**). (Fig.7)
- In the bulletin issued at 2030 hrs IST of 14th May (**about 75 hours prior to landfall**), it was indicated that the system would reach near Gujarat coast in the morning of 18th May and that winds as high as 150-160 kmph gusting to 180 kmph would prevail along & off south Gujarat since late night of 17th.

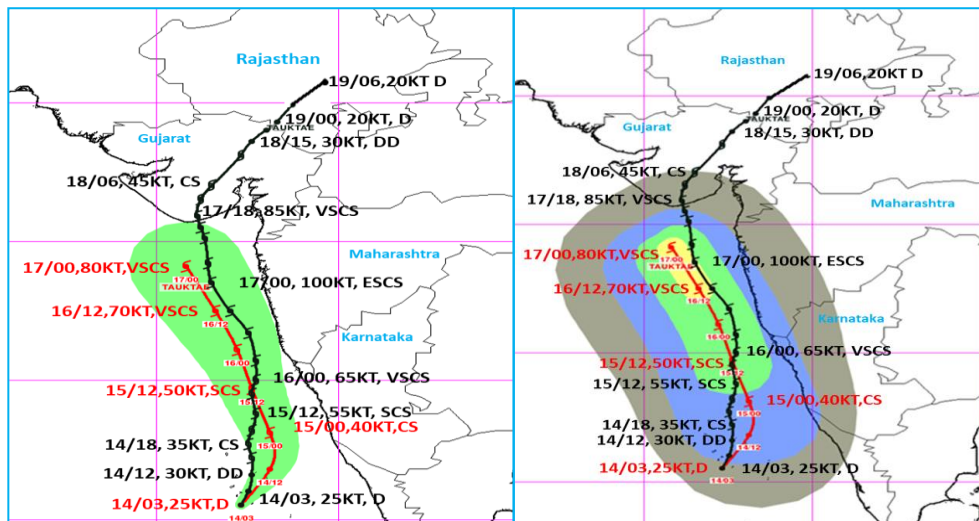


Fig7 (a-b): Observed track (14-19 May) and forecast track issued at 1245 hours IST of 14th May based on 0830 hrs IST observations of 14th May (**80 hours prior to landfall**).

- The landfall point & time was further updated in the bulletin issued at 0330 hours IST of 16th May (**about 45 hours prior to landfall**) that the system would reach Gujarat coast in the evening hours of 17th & cross Gujarat coast between Porbandar & Mahuva (Bhavnagar district) around 18th May early morning with wind speed of 150-160 kmph gusting to 180 kmph.

- In the bulletin issued at 0815 hrs IST of 17th May (**about 15 hours prior to landfall**), the warnings were further specified and it was informed that the system would reach Gujarat coast in the evening hours of 17th & cross Gujarat coast between Porbandar & Mahuva (Bhavnagar district) during the night (2000 – 2300 hrs IST) of 17th May as a Very Severe Cyclonic Storm with a maximum sustained wind speed 155-165 kmph gusting to 185 kmph.
- Actually, the extremely severe cyclonic storm TAUKTAE crossed Saurashtra coast close to about 20 km northeast of Diu near latitude 20.8°N and longitude 71.1°E during 2000-2300 hrs IST of 17th May with wind speed of 160-170 kmph gusting to 185 kmph.
- Thus, the track, landfall point & time, intensity and associated adverse weather like heavy rainfall, gale wind and storm surge were well predicted by IMD.
- Fig. 7-9 represent the observed and forecast track, intensity & landfall forecast issued at various lead times indicating accuracy in track, landfall and intensity forecast.

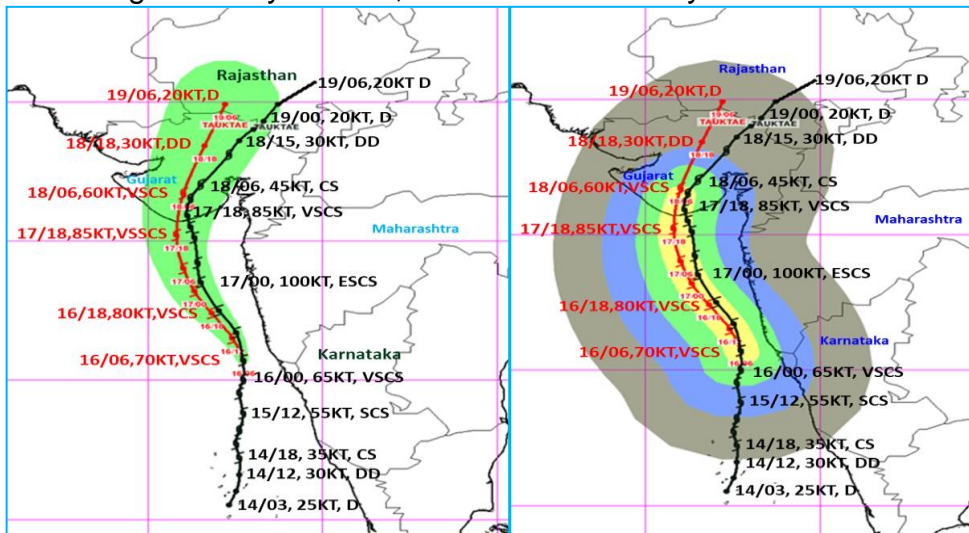


Fig.8 (a-b): Observed track (14-19 May) and forecast track issued at 1430 hours IST of 16th May based on 1130 hrs IST observations of 16th May (**about 36 hours prior to landfall**) demonstrating accuracy in track, intensity and landfall.

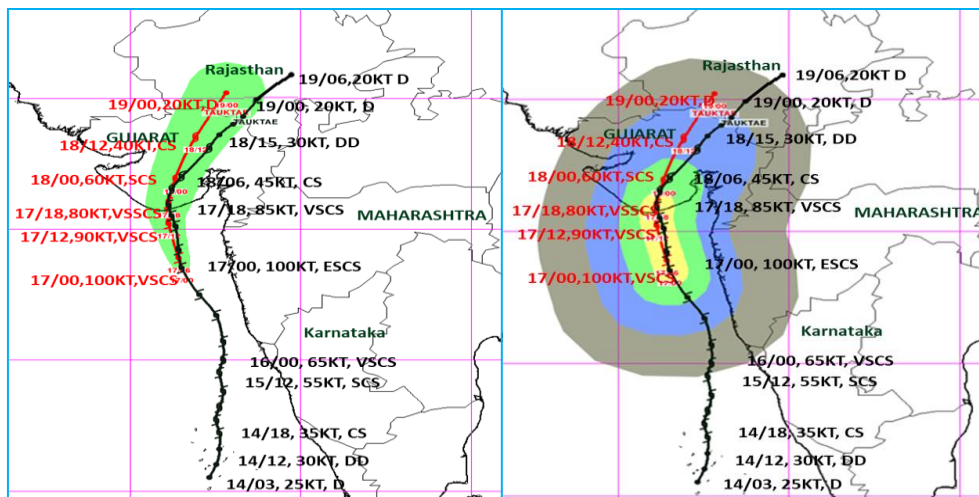


Fig.9 (a-b): Observed track (14-19 May) and forecast track issued at 0830 hours IST of 17th May based on 0530 hrs IST observations of 17th May (**about 15 hours prior to landfall**) demonstrating accuracy in track, intensity and landfall.

DATE/TIME IN UTC, IST = UTC + 0530 HRS, D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CYCLONIC STORM, VSSCS: VERY SEVERE CYCLONIC STORM, ESCS: EXTREMELY SEVERE CYCLONIC STORM

█ OBSERVED TRACK, █ FORECAST TRACK, █ CONE OF UNCERTAINTY

MSW(knot)/kmph)	Impact	Action
28-33 (52-61)	Very rough seas.	Total suspension of fishing operations
34-40(62-74)	High to very high seas	Total suspension of fishing operations
41-63/(75-117)	Very High seas	Total suspension of fishing operations
≥ 64 (≥118)	Phenomenal	Total suspension of fishing operations

iii) Operational Track, Intensity and Landfall Point & Time Forecast Errors:

The operational track, intensity and landfall errors as compared to long period average errors during 2016-20 are presented in Fig. 10.

- The track forecast errors for 24, 48 and 72 hrs lead period were 73, 118, and 224 km respectively against the LPA errors of 77, 117, and 159 km respectively (**Fig.10a**).
- The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 4.4, 8.9 and 15.5 knots against the LPA errors of 7.9, 11.4, and 14.1 knots during 2015-19 respectively.
- The landfall point forecast errors for 24 and 48 hrs lead period were 27 and 71km respectively against the LPA errors of 32 and 62 km during 2016-20 respectively.
- The landfall time forecast errors for 24 and 48 hrs lead period were 3.5 and 6.5 hours respectively against the LPA errors of 2.5 and 6.5 hours during 2016-20 respectively.

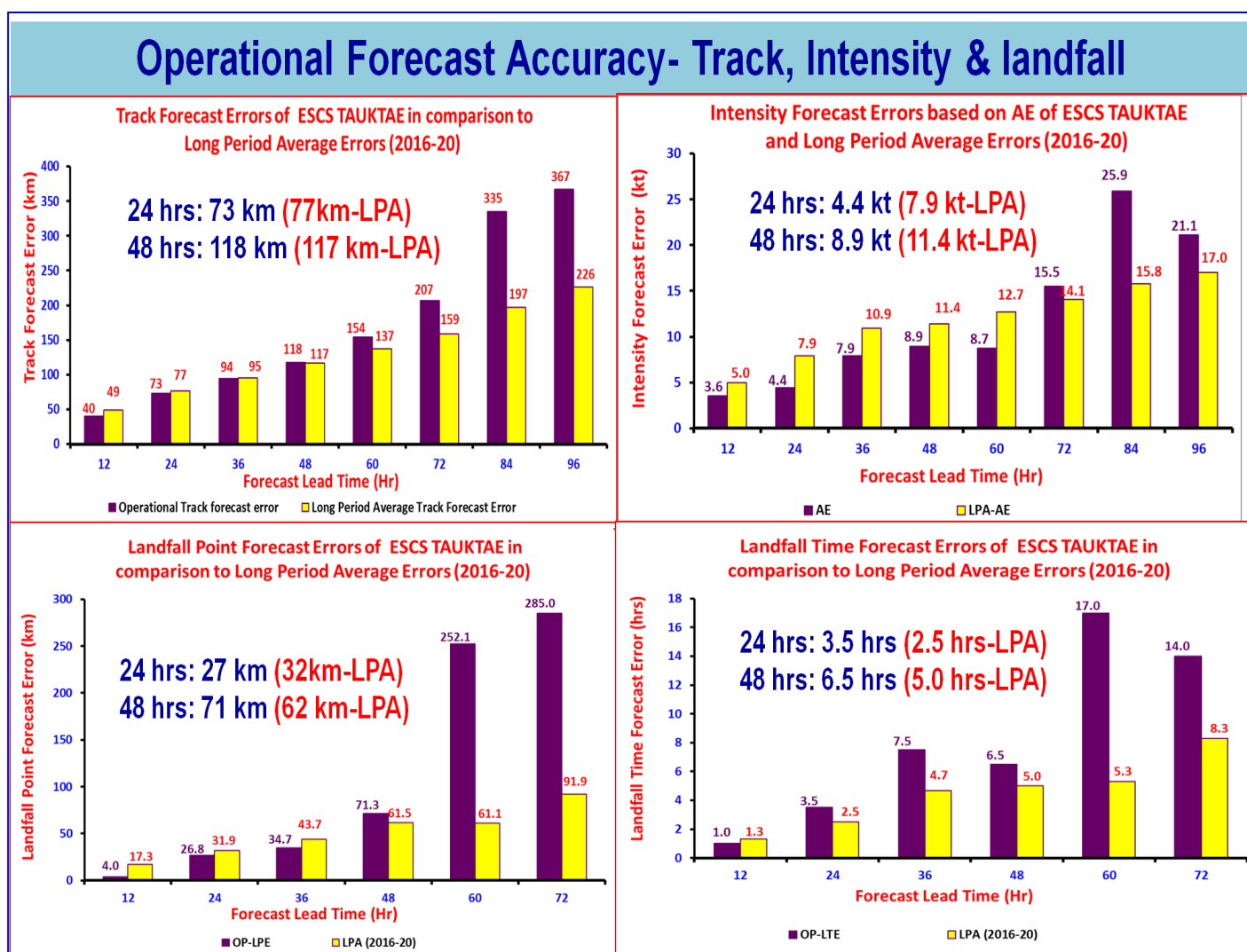


Fig. 10: Operational track, intensity and landfall errors of extremely severe cyclonic storm Tauktae as compared to long period average errors during 2016-2020

(vi) Verification of wind warnings issued

Forecast Winds (kmph)	Realised wind (kmph)
<ul style="list-style-type: none"> ➤ Lakshadweep & Maldives area: 55-65kmph gusting to 75 kmph on 14th, ➤ Kerala-Karnataka coast: 45-55 gusting to 65 kmph on 15th & 16th, ➤ Maharashtra coast: 80-90 gusting to 100 kmph on 17th & 18th, ➤ Gujarat coast: 155-165 kmph gusting to 185 kmph at the time of landfall. 	<p>Agathi reported maximum sustained wind speed of 85 kmph, Minicoy-50 kmph, Amini Divi-38 kmph kts on 14th May.</p> <p>Coastal Karnata reported 55 kmph on 15th May.</p> <p>Mumbai City reported 114 kmph on 18th May. Gujarat coast reported 160-170 gusting to 185 kmph at the time of landfall on 18th</p>

(vii) Verification of heavy rainfall warning issued

Forecast Rainfall	Realised 24 hr cumulative heavy rainfall ending at 0830 IST of date
<ul style="list-style-type: none"> • Lakshadweep Islands: Heavy to very heavy falls over northern Islands on 15th May and heavy falls on 16th May. • Kerala: Heavy to very heavy falls and extremely heavy falls places on 15th, heavy to very heavy falls at on 16th and heavy on 17th May. • Tamil Nadu (Ghat districts) heavy to very heavy falls on 15th May. • Karnataka (coastal & adjoining Ghat districts): Heavy to very heavy falls and extremely heavy falls on 15th and heavy to very heavy falls on 16th. • Konkan & Goa: heavy to very heavy falls at a few places over south Konkan & Goa and heavy to very heavy falls over north Konkan on 15th and heavy to very heavy falls over Konkan & Goa & adjoining Ghat areas on 16th and heavy falls at isolated places on 17th May over north Konkan. • Gujarat: Heavy to very heavy falls at isolated places over Saurashtra & Kutch and extremely heavy falls on 17th and with heavy to very heavy falls at a few places over Saurashtra & Kutch with extremely heavy falls on 18th. • West Rajasthan: Heavy to very heavy falls at isolated places on 18th & 19th 	<p>Heavy to extremely heavy rainfall activity, over Lakshadweep on 13-14th, Kerala on 14-15th, Karnataka on 15th, Goa and south coastal Maharashtra on 15-16th north Maharashtra on 16-17th, Gujarat, Daman & Diu, Dadra Nagar and Haveli on 17th and 18th and West Rajasthan on 18th & 19th</p>

(viii) Verification of storm surge warning issued

Forecast Storm Surge (m)	Realised Storm Surge (m)
Tidal wave of about 3-4 meters above astronomical tide is likely to inundate coastal areas of Anand, Amreli, Gir Somenath, Bhavnagar & Diu.	About 3-4 m above astronomical tide over Diu and of coastal districts of Saurashtra.

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 and +48... +96 hrs lead period commencing from 14th May morning till the system weakened into a low pressure area. The above forecasts were issued from the stage of depression onwards along with the cone of uncertainty in the track forecast five times a day and every three hours during the cyclone period. The hourly updates were also provided 12 hours prior to landfall till the system maintained the intensity of cyclonic storm over Gujarat.
- **Cyclone structure forecast for shipping and coastal hazard management:** The radius of maximum wind and radii of MSW ≥ 28 , ≥ 34 , ≥ 50 and ≥ 64 knots wind in four quadrants of cyclone was issued every six hourly, commencing from 16th May morning giving forecast for +06, +12, +18, +24, +36 and +96 hrs lead period.
- **Four stage Warning:**
- **Considering the development of cyclonic storm over southeast Arabian Sea and Lakshadweep area,** IMD issued first Press Release at 1400 hours IST of 11th May (**2 days in advance of formation of low pressure area on 13th May**). Heavy rainfall, strong wind and tidal waves warnings were issued alongwith advisories for fishermen.
- The Press Release was further updated on 13th May (**5 days prior to landfall**) on development of low pressure area over southeast Arabian Sea. It indicated that the cyclonic storm over southeast Arabian Sea and adjoining Lakshadweep area would reach Gujarat coast on 18th May.
- **Considering the expected development of a cyclonic storm the Pre cyclone watch** was issued for south Gujarat and Diu coasts in the first bulletin issued at 1245 hrs IST of 14st May, when the system was a depression over Lakshadweep (**about 80 hours prior to landfall of extremely severe cyclonic storm TAUKTAE**).
- **Warnings were further upgraded and Cyclone alert** for Gujarat & Diu coasts was given in the bulletin issued at 0920 hrs IST of 15th May, on intensification of the system into a cyclonic storm (**about 62 hours prior to landfall of extremely severe cyclonic storm TAUKTAE**)
- **Warnings were further upgraded and Cyclone Warning** for Gujarat and Diu coasts was issued at 1730 hrs IST of 16th May, when the system was a very severe over eastcentral Arabian Sea (**about 30 hours prior to landfall of TAUKTAE**)
- **Post landfall outlook for interior districts of Gujarat and southern districts of Rajasthan** indicating expected severe weather over interior districts of Gujarat and southern parts of Rajasthan was issued at 0815 hrs IST of 17th May, when the system was an extremely severe cyclonic storm over eastcentral Arabian Sea (**about 15 hours prior to landfall of TAUKTAE**)
- **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 Lakshadweep Islands, Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman & Diu, Dadra and Nagar Haveli and Rajasthan. 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, NDRF, Indian Coast Guard, ports, Shipping, fishery, Railways, surface transport and aviation authorities.

- **Warning graphics:** The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the RSMC, New Delhi website (<http://rsmcnewdelhi.imd.gov.in/>) regularly. The adverse weather warnings related to heavy rain, gale/squally wind & storm surge were also presented in graphics alongwith colour codes in the website.
- **Warning and advisory through social media:** Daily updates (every three hourly or whenever there was any significant change in intensity/track/landfall) were uploaded on Facebook and Twitter during the life period of the system since the development of low pressure area over the Arabian Sea. However, from 17th afternoon (0700 UTC) onwards, hourly updates were issued and sent to disaster managers by email, uploaded on websites, posted on Facebook and Twitter till the system maintained the intensity of cyclonic storm.
- **Press Conference, Press release and Media briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website, video capsule by DGM 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 Mumbai, Chennai 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 of Arabian Sea and the states of Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra & Gujarat, the Union Territories along the west coast & Lakshadweep Islands were issued since 11th May.
- **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 17th afternoon (0700 UTC) onwards till the system maintained the intensity of cyclonic storm.

High level briefing meetings attended by the Director General of Meteorology, India Meteorological Department:

- ❖ Meeting on impending Cyclone Scenario in Arabian Sea under the Chairmanship of Member Secretary, NDMA on 13th May and Hon'ble Cabinet secretary on 14th May.
- ❖ National Crisis Management Committee Meeting chaired by Hon'ble Prime Minister and Cabinet Secretary on 16th.
- ❖ Review Meeting under the joint Chairmanship of Hon'ble Minister of State for Ports, Shipping & Waterways (I/C), Hon'ble Minister of Commerce & Industry on 16th May.

- ❖ National Crisis Management Committee (NCCM) Meeting on 20th May.
- ❖ Frequent Press Briefings

Statistics of bulletins issued by RSMC New Delhi, Area Cyclone Warning Centres Chennai, Mumbai, CWCs Thiruvananthapuram, Ahmedabad, Meteorological Centres Bengaluru & Goa in association with the ESCS Tauktae are given in **Table 2-3**.

Table2: Bulletins issued by Cyclone Warning Division, New Delhi

S.N	Bulletin	No. of Bulletins	Issued to
1	Bulletins from DGM IMD	7	To senior level Govt. Officials including Cabinet Secretary, Principal Secretary to Prime Minister, Secretary Ministry of Home Affairs, Ministry of Agriculture, Defence, Information & Broadcasting, Ministry of Earth Sciences, Deptt. of Science & Technology, Shipping & Surface Transport, Ministry of Home Affairs, Director Punctuality, Indian Railways, Director All India Radio, Doordarshan, Secretary NDMA, Director General NDRF, Chief Secretaries of Tamilnadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat, Administrator Lakshadweep Islands, Dadra & Nagar Haveli, Daman & Diu.
2	National Bulletins	41 + 1 informatory message on 13 th May	1. IMD's website, RSMC New Delhi website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, PIB MoES, Headquarter Integrated Defense Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, UNI, Chief Secretary- Kerala, Karnataka, Goa, Dadra & Nagar Haveli, Gujarat and Maharashtra and Administrator Lakshadweep Islands, Dadra & Nagar Haveli, Daman & Diu.
3	RSMC Bulletins	30	1. IMD's website 2. WMO/ESCAP member countries including Somalia and WMO through GTS and E-mail.
4	GMDSS Bulletins	27	1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)

5	Tropical Cyclone Advisory Centre Bulletin (Text & Graphics)	18	1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation. 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website
6	Tropical Cyclone Vital Statistics	18	Modelling group of IMD, National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc
7.	Warnings through SMS	82,80,446	SMS to disaster managers at national level and concerned states (every time when there was change in intensity)--1780 To general public to users registered with RSMC website from the states of Kerala, Karnataka, Goa, Gujarat and Maharashtra and National level disaster managers—1,39,378 Through INCOIS on Ocean State Forecast- 12,53,449 To farmers of Tamilnadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat, Rajasthan, Haryana, Uttar Pradesh, Uttrakhand through Kisaan Portal-68,85,839
8.	Warnings through Social Media	Daily four times and when intensity changed	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)
9.	Hourly Bulletin	15	IMD's website, RSMC New Delhi website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, PIB MoES, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, UNI, Chief Secretary- Kerala, Karnataka, Goa, Dadra & Nagar Haveli, Gujarat and Maharashtra and Administrator Lakshadweep Islands.
10.	Press Release	9	Disaster Managers, Media persons by email and uploaded on website
11.	Press Briefings	Frequently	Regular briefing daily

Table3: Statistics of bulletins issued by Area Cyclone Warning Centre Mumbai, CWC Thiruvananthapuram, Ahmedabad, Meteorological Centre Bengaluru

S.N.	Type of Bulletin	CWC TRV	MC BNG	MC Goa	ACWC Mumbai	CWC AHM
1.	Sea Area Bulletins	Nil	Nil	0	20	Nil
2.	Coastal Weather Bulletins	8	Nil	0	20	19
3.	Fishermen Warnings issued	16	4	22	12	21
4.	Port Warnings	8	Nil	13	NIL	21
5.	Heavy Rainfall Warning	12	6	9	4	10
6.	Gale Wind Warning	7	01	9	24	16
7.	Storm Surge Warning	-	Nil	5	5	12
8.	Information & Warning issued to State Government & other Agencies	25	7	22	Frequently	18
9.	SMS	-	469	77	-	-
10.	No. of Press releases	5	4	4	5	5
11.	No. of impact based warnings for District and City	94	1	14	-	11
12.	No. of whatsapp messages	108	469	360	-	800
13.	No. of updates on facebook	57	150	32	-	39
14.	No. of updates on tweeter	38	125	48	-	05
15.	No. of Forecast / Warning video released	2	8	6	-	2

8. Acknowledgement:

India Meteorological Department (IMD) acknowledge contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of ESCS TAUKTAE. IMD and RSMC New Delhi duly acknowledge the contribution from the World Meteorological Organisation and all the 13 WMO/ESCAP Panel

member countries. We acknowledge the contribution of all sister organisations of Ministry of Earth Sciences including National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), National Institute of Ocean Technology (NIOT), Indian Institute of Tropical Meteorology (IITM) Pune, research institutes including IIT Bhubaneswar, IIT Delhi and Space Application Centre, Indian Space Research Organisation (SAC-ISRO) for their valuable support. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai, Mumbai, Cyclone Warning Centre (CWC) Thiruvananthapuram, Ahmedabad, Meteorological Centre (MC) Bengaluru, Jaipur, Doppler Weather Radar Stations at Thiruvananthapuram, Kochi & Goa and coastal observatories. The contribution from Numerical Weather Prediction Division, Satellite and Radar Divisions, Surface & Upper air instruments Divisions, New Delhi, Agromet Advisory Division and Information System and Services Division at IMD is also duly acknowledged. IMD also acknowledges the support and cooperation from all national and state level disaster management agencies, various stakeholders and press and electronic media.
