



Very Severe Cyclonic Storm YAAS over the Bay of Bengal (23rd – 28th May, 2021): A Report

1. Life History of YAAS:

- A low pressure area formed over eastcentral Bay of Bengal (BoB) in the morning (0830 IST/0300 UTC) of 22nd May. It lay as a well marked low pressure area (WML) in the same afternoon (1430 IST/0900 UTC) over eastcentral BoB.
- Under favourable environmental conditions, it concentrated into a depression over eastcentral BoB in the noon (1130 IST/0600 UTC) of 23rd May, 2021.
- It moved northwestwards and intensified into a deep depression (DD) over eastcentral BoB in the midnight (2330 IST/1800 UTC) of 23rd May and into the cyclonic storm “YAAS” in the early morning (0530 IST/0000 UTC) of 24th over the same region.
- It moved nearly north-northwestwards and intensified into a severe cyclonic storm (SCS) in the midnight (2330 IST/1800 UTC) of 24th May over eastcentral BoB.
- It started moving northwards from the morning (0830 IST/0300 UTC) of 25th and intensified into a very severe cyclonic storm (VSCS) in the evening (1730 IST/1200 UTC) over northwest BoB.
- Thereafter, it moved north-northwestwards reached peak intensity of 75 kts and lay centred over northwest BoB about 30 km east of Dhamra Port, Odisha during early morning (0530 IST/0000 UTC) of 26th May.
- Continuing to move north-northwestwards, it crossed north Odisha coast near latitude 21.35°N and longitude 86.95°E, about 20 km to the south of Balasore as a VSCS with maximum sustained wind speed (MSW) of 75 kts gusting to 85 kts (130 -140 kmph gusting to 155 kmph) between 1030-1130 IST(0500-0600 UTC) of 26th.
- Further moving north-northwestwards, it weakened rapidly into an SCS over north coastal Odisha in the afternoon (1430 IST/0900 UTC), into a CS over north Odisha in the evening (1730 IST/1200 UTC) and into a DD in the midnight (2330 IST/1800 UTC) of 26th over north interior Odisha and adjoining Jharkhand.
- It weakened into a depression over central parts of Jharkhand in the noon (1130 IST/0600 UTC) of 27th. Thereafter, it moved northwestwards and weakened into a well-marked low pressure area over Bihar and adjoining southeast Uttar Pradesh (UP) in the early morning (0530 IST/0000 UTC) of 28th May. It became a low pressure area over southeast UP and adjoining Bihar on 28th evening (1730 IST/1200 UTC) and became less marked on 29th morning (0530 IST/0000 UTC).
- 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:

- YAAS was the second cyclonic storm of the year 2021 over the north Indian Ocean.
- It developed just after 4 days of the dissipation of extremely severe cyclonic storm (ESCS) Tauktae over the Arabian Sea (14-19 May). Such back to back or simultaneous occurrence of cyclones over the BoB and Arabian Sea (AS) is not rare. Considering past 10 years statistics (2010-2020), similar back to back/simultaneous occurrence of cyclonic storms over BoB & AS has been observed in 2020 (Gati, AS-Nivar, BoB), 2019 (Maha, AS-Bulbul, BoB),

- 2018 (Luban, AS-Titli, BoB), 2018 (Sagar & Mekunu both AS), 2016 (Nada & Vardah both BoB), 2015 (Chapala & Megh both AS), 2013 (Helen, Lehar & Madi all BoB), 2010 (Laila, BoB- Bandu, AS).
- iii. During satellite era (1965-2020), 3 very severe category storms crossed Odisha coast (1 VSCS (May 1989, 65 kt), 2 ESCS (May 1982, 90 kt & Fani, May 2019, 100 kt) in the month of May. YAAS was the 4th very severe category cyclonic storm (75 kt) crossing Odisha coast in the month of May during 1965-2021.
 - iv. It affected relatively less area as compared to Tauktae causing adverse weather over Andaman & Nicobar Islands, Odisha & West Bengal (till 26th May) and Jharkhand, Bihar and East UP after landfall.
 - v. It had a straight north-northwestwards moving track (Fig. 1 & Fig. 2).
 - vi. The track length of the cyclone was 1100 km.
 - vii. It had rapid weakening after landfall with intensity falling by 35 kt in just 9 hours. The system maintained the intensity of cyclonic storm after landfall for 12 hours (0600 to 1800 UTC of 26th).
 - viii. The peak MSW of the cyclone was 130-140 kmph gusting to 155 kmph (75 kt gusting to 85 kt) during 0230 IST of 26th to 1130 IST of 26th over the northwest BoB. The lowest estimated central pressure was 970 hPa during the period with a pressure drop of 28 hPa at the centre compared to surroundings (Fig.2a).
 - ix. The life period (D to D) of the system was 114 hours (4 days & 18 hours) against long period average (LPA) (1990-2013) of 134 hours (5 days & 14 hrs) for VSCS/ESCS categories over the BoB during pre-monsoon season. Thus, it had a comparatively lower life period.
 - x. It moved with 12 hour average translational speed of 10.9 kmph against LPA (1990-2013) of 13.7 kmph for VSCS category over BoB during pre-monsoon season (Fig.2b).
 - xi. The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 0.6×10^2 kt, 3.6×10^4 kt² and 2.3×10^6 kt³ respectively.
 - xii. The track forecast errors for 24, 48 and 72 hrs lead period were 24.1, 53.1 and 81.6 km respectively against the LPA(2016-20) errors of 77, 117 and 159 km respectively
 - xiii. The landfall point forecast errors for 12, 24, 48 and 60 hrs lead period were 7.8, 7.8, 7.8 and 38.9 km respectively against the LPA (2016-20) errors of 17, 32, 62 and 61 km during 2016-20 respectively. **Thus there was almost zero landfall point forecast error 48 hrs in advance**
 - xiv. The landfall time forecast errors for 12, 24, 48 and 60 hrs lead period were 1.0, 1.0, 2.5 and 3.5 hours respectively against the LPA errors (2016-20) of 1.3, 2.5, 5.0 and 5.3 hours during 2016-20 respectively. Thus there was almost zero landfall time forecast error 48 hrs in advance
 - xv. The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 13.7, 12.9 and 14.1 knots against the LPA errors of 7.9, 11.4, and 14.1 knots during 2016-20 respectively
 - xvi. Initially in its formative stage, it caused heavy to very heavy rainfall and Squally winds and tidal waves over Andaman & Nicobar Islands on 23rd & 24th May. It caused heavy to extremely heavy rainfall activity at isolated places over coastal Odisha on 25th May and heavy to very heavy rainfall at a few places and extremely heavy rains at isolated places on 26th May over north Odisha. It caused heavy to very heavy rainfall activity at isolated places over Gangetic West Bengal on 26th May and heavy to extremely heavy rainfall over Sub-Himalayan West Bengal on 27th. It also caused heavy to extremely heavy rainfall over Jharkhand on 26th and 27th, over Bihar and east UP on 27th and 28th May. As the system

developed in the advance phase of monsoon, it had sufficient moisture and caused higher rainfall with heavy to extremely heavy rainfall activity over north Odisha, Jharkhand, West Bengal, Bihar and east UP

- xvii. Gale wind speed reaching 130-140 kmph gusting to 155 kmph prevailed along and off Balasore, Bhadrak districts of north coastal Odisha and 100-120 gusting to 130 kmph prevailed along and off coastal districts of West Bengal (Purba Medinipur and south 24 Parganas district) and Kendrapara and Jagatsinghpur districts of North coastal Odisha during the time of landfall.
- xviii. Storm surge of about 2-4 meters height above astronomical tide inundated low lying areas of north coastal Odisha (Balasore and Bhadrak districts) and coastal West Bengal (South 24 Parganas, North 24 Parganas, Purba Medinipur districts) and 1-2 meters height above astronomical tide inundated low lying areas of Kendrapara and Jagatsinghpur districts of north coastal Odisha during the time of landfall.
- xix. As the cyclone crossed the coast on the full moon day, there was combined impact of astronomical tide and storm surge leading to higher tidal wave. The astronomical tidal wave over Bhadrak, Balasore, Purba Medinipur and 24 Pargana districts on this day ranged from 3 to 5 meters. In addition the extremely heavy rainfall over north coastal Odisha districts helped in enhanced inundation of coastal areas.
- xx. A total of 34 national bulletins, 32 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, 69 lakhs SMS to fishermen, farmers & coastal population, very frequent updates on social networking sites were sent to trigger mass response and to sensitise masses about the impending disaster in association with the system. DGM IMD participated in National Crisis Management Committee Meetings under the chairmanship of Cabinet Secretary, and review meetings under the chairmanship of Hon'ble Prime Minister, Hon'ble Home Minister and Hon'ble Minister for Commerce and Industry and presented updated status about the system regularly.

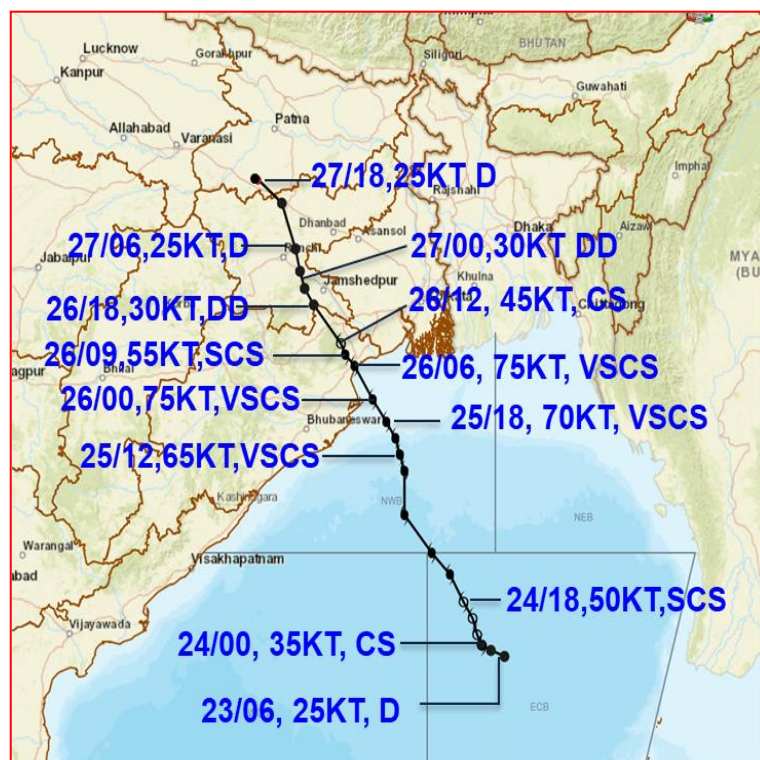


Fig.1: Observed track of VSCS YAAS during 23rd-28th May, 2021

The six hourly maximum sustained wind speed & estimated central pressure and translational speed are presented in Fig. 2(a) and 2(b). YAAS had a straight track and it moved relatively slower than long period average during 1990-2013 (Fig. 2a). After landfall, it moved relatively faster after landfall leading to rapid weakening of the system during 0600 to 1800 UTC of 26th May.

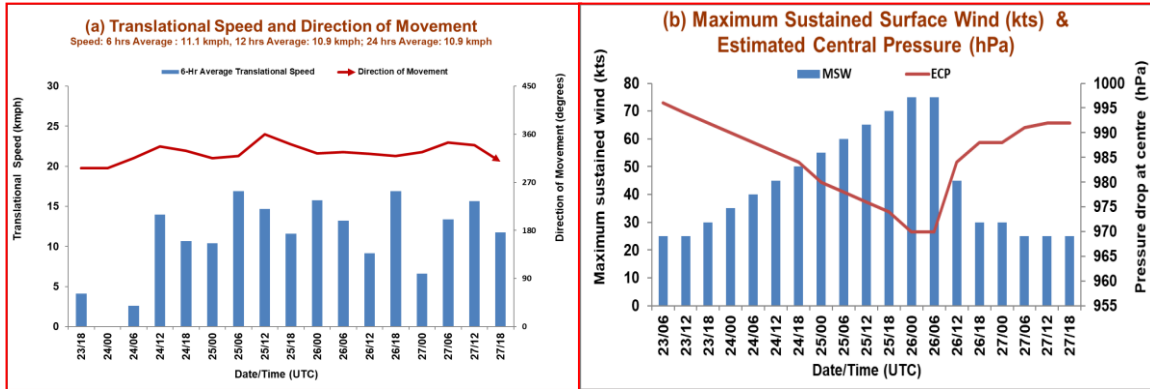


Fig. 2: (a) Translational speed & direction of movement and (b) Maximum sustained surface winds (kts) & Estimated Central Pressure

Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm, “YAAS” over the Bay of Bengal during 23 May- 28 May, 2021

| Date | Time (UTC) | Centre lat. ^o N/ long. ^o E | C.I. NO. | Estimated Central Pressure (hPa) | Estimated Maximum Sustained Surface Wind (kt) | Estimated Pressure drop at the Centre (hPa) | Grade |
|----------|--|---|-------------|---|---|---|-------|
| 23.05.21 | 0600 | 16.1 90.2 | 1.5 | 996 | 25 | 4 | D |
| | 1200 | 16.2 89.9 | 1.5 | 994 | 25 | 4 | D |
| | 1800 | 16.3 89.7 | 2.0 | 992 | 30 | 5 | DD |
| 24.05.21 | 0000 | 16.3 89.7 | 2.5 | 990 | 35 | 7 | CS |
| | 0300 | 16.5 89.6 | 2.5 | 988 | 40 | 8 | CS |
| | 0600 | 16.4 89.6 | 2.5 | 988 | 40 | 8 | CS |
| | 0900 | 16.8 89.5 | 2.5 | 988 | 40 | 8 | CS |
| | 1200 | 17.1 89.3 | 3.0 | 986 | 45 | 10 | CS |
| | 1500 | 17.4 89.2 | 3.0 | 986 | 45 | 10 | CS |
| | 1800 | 17.6 89.0 | 3.0 | 984 | 50 | 12 | SCS |
| | 2100 | 17.8 88.9 | 3.5 | 982 | 55 | 14 | SCS |
| 25.05.21 | 0000 | 18.0 88.6 | 3.5 | 980 | 55 | 16 | SCS |
| | 0300 | 18.3 88.3 | 3.5 | 980 | 55 | 16 | SCS |
| | 0600 | 18.7 88.0 | 3.5 | 978 | 60 | 18 | SCS |
| | 0900 | 19.1 88.1 | 3.5 | 978 | 60 | 18 | SCS |
| | 1200 | 19.5 88.0 | 4.0 | 976 | 65 | 20 | VSCS |
| | 1500 | 19.8 87.9 | 4.0 | 976 | 65 | 20 | VSCS |
| | 1800 | 20.1 87.8 | 4.0 | 974 | 70 | 24 | VSCS |
| | 2100 | 20.4 87.6 | 4.0 | 970 | 75 | 28 | VSCS |
| 26.05.21 | 0000 | 20.8 87.3 | 4.0 | 970 | 75 | 28 | VSCS |
| | 0300 | 21.2 87.1 | 4.0 | 970 | 75 | 28 | VSCS |
| | Crossed north Odisha coast near Latitude 21.35°N and Longitude 86.95°E, about 20 km to the south of Balasore as a VSCS with maximum sustained wind speed of 75 knots gusting to 85 knots (130 -140 kmph gusting to 155 kmph) between 0500 & 0600 UTC | | | | | | |
| | 0600 | 21.4 86.9 | - | 970 | 75 | 28 | VSCS |

| | | | | | | | | |
|------------|------|---|------|---|-----|----|----|-----|
| | 0900 | 21.6 | 86.7 | - | 978 | 55 | 16 | SCS |
| | 1200 | 21.8 | 86.6 | - | 984 | 45 | 10 | CS |
| | 1500 | 22.2 | 86.2 | - | 986 | 40 | 8 | CS |
| | 1800 | 22.5 | 86.0 | - | 988 | 30 | 6 | DD |
| 27.05.21 | 0000 | 22.8 | 85.8 | - | 988 | 30 | 6 | DD |
| | 0300 | 23.1 | 85.7 | - | 990 | 30 | 6 | DD |
| | 0600 | 23.5 | 85.6 | - | 991 | 25 | 5 | D |
| | 1200 | 24.3 | 85.3 | - | 992 | 25 | 4 | D |
| | 1800 | 24.7 | 84.8 | | 992 | 25 | 4 | D |
| 28.05.2021 | 0000 | Weakened into a well marked low pressure area over Bihar and adjoining east Uttar Pradesh | | | | | | |

D: Depression, DD: Deep Depression, CS: Cyclonic Storm, SCS, Severe Cyclonic Storm, VSCS: Very Severe Cyclonic Storm,

3. Monitoring of YAAS:

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored since 13th May, about 9 days prior to the formation of low pressure area over eastcentral BoB on 22nd May and 10 days prior to formation of depression over eastcentral BoB on 23rd 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 Radar (DWR), Paradip. 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 VSCS YAAS are presented in Fig. 3.

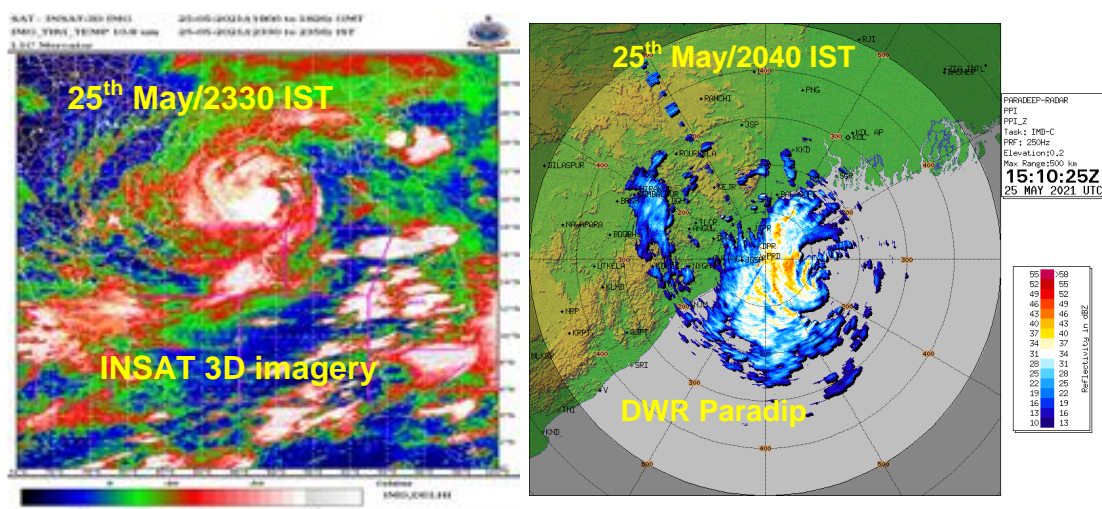


Fig. 3: Typical INSAT 3D satellite and radar imagery from Doppler Weather Radar Paradip

4. Realised weather

4.1. Rainfall:

It caused heavy to very heavy rainfall and Squally winds and tidal waves over Andaman & Nicobar Islands on 23rd & 24th May. It caused heavy to extremely heavy rainfall activity at

isolated places over coastal Odisha on 25th May and heavy to very heavy rainfall at a few places and extremely heavy rains at isolated places on 26th May. It caused heavy to very heavy rainfall activity at isolated places over Gangetic West Bengal on 26th May and heavy to extremely heavy rainfall over Sub-Himalayan West Bengal on 27th. It also caused heavy to extremely heavy rainfall over Jharkhand on 26th and 27th and over Bihar and east UP on 27th and 28th May. Rainfall associated with VSCS YAAS based on IMD-NCMRWF GPM merged gauge 24 hours cumulative rainfall ending at 0830 IST of date is depicted in **Fig 4**.

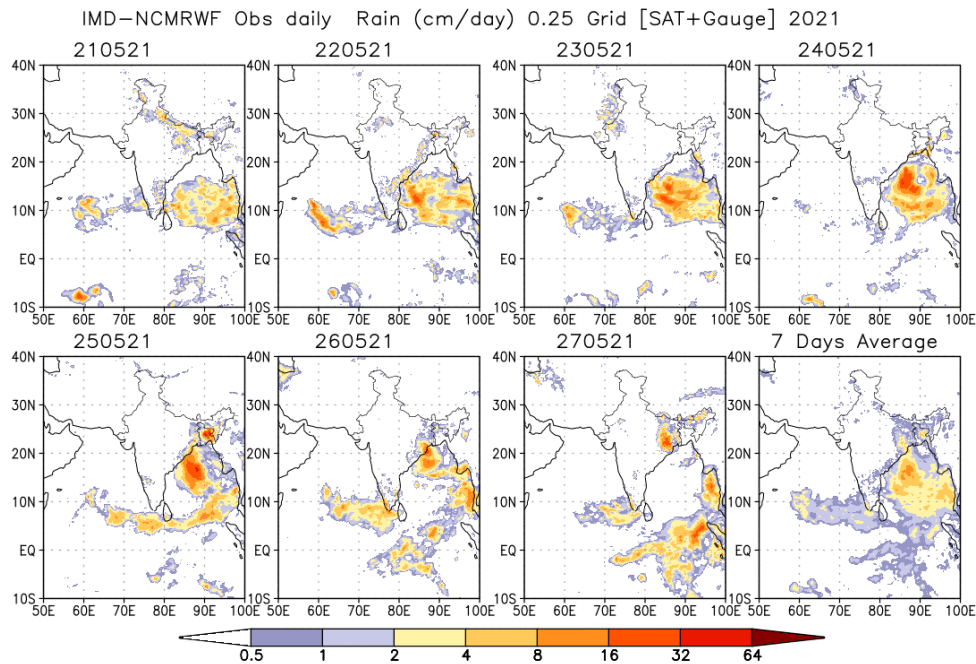


Fig.4: IMD-NCMRWF GPM merged gauge 24 hr cumulative rainfall (cm) ending at 0830 IST of date during 21st May – 27th May and 7 days average rainfall (cm/day)

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

23 May 2021:

Andaman & Nicobar Islands: Long Island-10, Maya Bandar-9

24 May 2021:

Andaman & Nicobar Islands: Port Blair-7

25 May 2021:

Andaman & Nicobar Islands: Hut Bay-11, Carnicobar-8,

Gangetic West Bengal: Contai-9

26 May 2021:

Odisha: Chandbali-29, Rajkanika & Garadapur-25 each, Marsaghai & Kujanga-23 each, Nawana & Tirtol-21 each, Paradip -20, Pattamundai, Balikuda & Derabis-19 each, Astaranga-18, Bhadrak-17, Kendrapara, Dhamnagar & Soro-16 each, Jagatsinghpur-15, Tihidi, Bari & Alipingal-14 each, Jajpur, Nilgiri, Akhuapada & Basudevpur-13 each, Chandikhol & Bonth-12 each, Korei & Kakatpur-11 each, Danagadi-10, Jenapur, Nischintakoili & Bhograi-9 each, Niali & Anandpur & Kaptipada-8 each, Joshipur, Jaleswar, Salepur, Mahanga, Chandanpur, Rairangpur, NH5 Gobindpur, Balimundali, Betanati, Balasore & Jhumpura-7 each

27 May 2021

Odisha: Nawana-28, Joda-27, Joshipur-25, Lathikata & Jhumpura-21 each, Champua, Keonjhar & Panposh-20 each, Basudevpur-19, Chandikhol & Karanjia-17 each, Rajgangpur & Mandira Dam each, Swam-Patna & Deogarh-13 each, Tiring-12, Udala, Gurundia, Barkote, Hatadihi, Tihidi & Pallahara-11 each, Ghatagaon, Lahunipara, Sharpada, Soro & Bamra-10 each, Binjharpur, Laikera, Jajpur, Kirmira & Talcher- 9 each, Sukinda & Kuchinda-8 each,

Telkoi, Kaptipada, Deogaon, Jenapur, Rairangpur, Bargaon, Kankadahad, Kolabira, Danagadi, Pattamundai & Bhadrak- 7 each

Jharkhand: Chaibasa-21, Mandar-18, Ranchi-15, Chakradharpur-13, Torpa-12, Kuru, Jamshedpur & Kharsema-11 each, Nimdih-10, Ramgarh & Jamshedpur-9 each, Chandil, Chatra, Manatu, Hariharganj & Hendigir-8 each, Shilaichak, Koner & Chandrapura-7 each,

Gangetic West Bengal: Diamond Harbour & Phulberia-11 each & Kharidwar-9, Labpur, Purihansa & Kalyani SMO-8 each, Uluberia, Mangalkote, Kangsabati Dam-7 each,

Sub-Himalayan West Bengal & Sikkim: Rongli, Damthang, Darjeeling & Gyalsing-9 each, Pedong & Pakyong-8 each, Sankalan, Mangan, Singhik & Khanitar- 7 each

Bihar: Sherghati-7

Uttar Pradesh: Light to moderate rainfall occurred over many places over East Uttar Pradesh

28 May 2021

Sub-Himalayan West Bengal & Sikkim: Malda-31, Sukiapokhri & Darjeeling-11 each, Damthang & Gyalsing-8 each,

Gangetic West Bengal: Debagram-13, Barrackpur-12, Amtala & Durgachack-10 each, Dum Dum & Alipore-9 each, MO Salt Lake, Diamond Harbour, Kalyani SMO, Bagati, Nalhati – 7 each

Jharkhand: Rajmahal-23, Koner & Tilaiya-11 each, Koderma & Hariharganj-10 each, Hazaribagh-9, Tenughat-7

Bihar: Manihari-25, Kadwa-24, Barari-23, Purnea-21, Parsa & Katihar North-18 each, Amaur-16, Banmankhi, Arwal & Sheikhpura-15 each, Vaishali, Rupauli, Saraiya & Murliganj-14 each, Siswan, Umarkhand, Ghosi, Chapra, Madhipura & Jamui-13 each, Hisua, Koilwar, Gaya Aero, Mahua, Harnaut & Islampur-12 each, Ekangersarai, Narhat, Lakhisarai, Singheshwar, Bodh Gaya, Maharajganj, Sandesh, Sherghati & Nawada-11 each, Kursela, Pachrukhi, Balrampur, Marhaura/Amnaur, Chand, Barh, Udai Kishanganj & Rajgir-10 each, Halsi, Patahi, Jandhaha, Barahara, Patna Aerodrome, Bihta, Jalalpur, Barauni, Matihani, Morwa/Tajpur, Saurbazar, Dinara, Charpokhari & Goraul/Doli-9 each, Kako, Hathwa, Barhiya, Narpatganj, Colgaon & Bihar Shrif-8 each, Hussainganj, Barauli, Tekari, Khagadia, Simrii, Bikram, Adhwara, Rajauli, Makhdumpur, Mushari, Bhore, Motihari, Tarari, Suryagadha, Jahanabad, Supaul, Marsrakh, Chandan, Bagaha, Araria & Sangrampur – 7 each.

East Uttar Pradesh: Chanderdeepghat-13, Gaighat -10, Ballia & Ayodhya-7 each

29 May 2021

Bihar: Tribeni/Balmikinagar-21, Darbhanga-18, Bagaha & Basua-17 each, Balrampur & Kadwa-16 each, Hayaghat-15, Gaunaha, Mushari & Kodawanpur-13 each, Ramnagar, Goraul/Doli, Rosera & Muzaffarpur-12 each, Jaley & Barh-11 each, Saraiya, Bairganja & Sonbarsa-10 each, Matihani, Minapur, Jhanjharpur, Kishanganj, Jandhaha, Sheikhpura, Tarapur, Madhwapur, Bahadurganj, Supaul, Saurbazar, Jainagar & Umarkhand-9 each, Purnea, Belsand, Morwa/Tajpur, Dhengbridge, Samastipur, Madhipura, Thakurganj, Sangrampur, Nirmali & Barauni-8 each, Harnaut, Cheria B.Pur, Parbatta, Aryari, Vaishali, Patahi, Siswan, Barbigha & Nauihatta-7 each

East Uttar Pradesh:

Bansi Tehsil-21, Nichloul-19, Nautanwa-17, Trimohanighat & Maharajganj-15 each, Kakrahi & Pharenda-14 each, Chanderdeepghat & Balrampur TEH-11 each, Balrampur-10, Bansi, Tulsipur, Uska Bazar-9 each, Gorakhpur-8 and Shoharatgarh, Domeriaganj, Ramnagar & Birdghat-7 each

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

Gale wind speed reaching 130-140 gusting to 155 kmph prevailed along and off Balasore, Bhadrak districts of north coastal Odisha and 100-120 gusting to 130 kmph prevailed along and off coastal districts of West Bengal (Purba Medinipur and south 24 Parganas district) and Kendrapara and Jagatsinghpur districts of north coastal Odisha during the time of landfall.

(c) Storm Surge:

Estimated storm surge of about 2-4 meters height above astronomical tide inundated low lying areas of Balasore and Bhadrak districts of north coastal Odisha and coastal West Bengal districts (Purba Medinipur and 24 Pargana districts) and 1-2 meters height above astronomical tide

inundated low lying areas of districts of Kendrapara and Jagatsinghpur districts of north coastal Odisha during the time of landfall.

5. Forecast Performance:

i) Genesis Forecast

- First information about development of depression over eastcentral BoB with (1-33% probability) during 21st-23rd May was given in the extended range outlook issued on 13th May (**about 10 days prior to the formation of formation of depression over eastcentral BoB on 23rd May**).
- Subsequently, in the Press Release, Tropical Weather Outlook and national weather forecast bulletin issued at 1200 hrs IST of 19th May, it was indicated that a low pressure would form over north Andaman Sea and adjoining eastcentral BoB around 22nd May and that it would intensify further into a cyclonic storm. It was also indicated that the system would move northwestwards and reach Odisha-West Bengal coasts on 26th May (**about 3 days prior to formation of low pressure area on 22nd May and 4 days prior to formation of depression on 23rd May**).
- The extended range outlook issued on 20th May (**about 3 days prior to formation of depression on 23rd May and 6 days prior to the cyclonic storm reaching near Odisha-West Bengal coasts on 26th May**) indicated with high probability (67-100%) that the system would move towards northwest BoB near Odisha-West Bengal coasts during 23rd-26th May. Accordingly, likely impact was also issued in the extended range outlook for fishermen, ships and ports along the east coast of India and adjoining Bangladesh & Myanmar coasts.
- **In the first bulletin issued at 1245 hrs IST of 22nd May on formation of low pressure area over eastcentral BoB**, it was indicated that the system would intensify upto very severe cyclonic storm and that the system would move northwestwards and reach north Odisha-West Bengal coasts around 26th morning (**about 90 hours prior to YAAS reaching Odisha-West Bengal coasts on 26th morning**).
- The first bulletin issued at 1350 IST of 23rd (**about 72 hours prior to landfall around noon of 26th**), it was indicated that the system would move north-northwestwards, reach close to north Odisha-West Bengal coasts around 26th morning and cross north Odisha coast by afternoon of 26th May.
- The bulletin issued at 0830 IST of 24th indicated that the system would cross coast close to south of Balasore, Odisha by afternoon of 26th as a very severe cyclonic storm (**about 54 hours prior to landfall) with almost zero landfall point error**.
- Actually, the very severe cyclonic storm YAAS moved nearly north-northwestwards and **lay centred over northwest BoB about 30 km east of Dhamara Port, Odisha during early morning (around 0530 IST) of 26th May**. Since first bulletin issued on 22nd May (**about 90 hours prior to landfall**) it was indicated that the system would reach north Odisha-West Bengal coasts around 26th morning.
- Also continuing to move north-northwestwards, YAAS crossed north Odisha coast near latitude 21.35°N and longitude 86.95°E, about 20 km to the south of Balasore as a VSCS with maximum sustained wind speed of 75 kts gusting to 85 kts (130 -140 kmph gusting to 155 kmph) between 0500 & 0600 UTC (103030 IST) of 26th as indicated since 24th May (**about 54 hours prior to landfall) with almost zero landfall point error (8 km) and about zero landfall time error (0.5-1.0 hour)**.
- Fig. 5-6 represent the observed and forecast track, intensity & landfall forecast issued at various lead times indicating accuracy in track, landfall and intensity forecast.

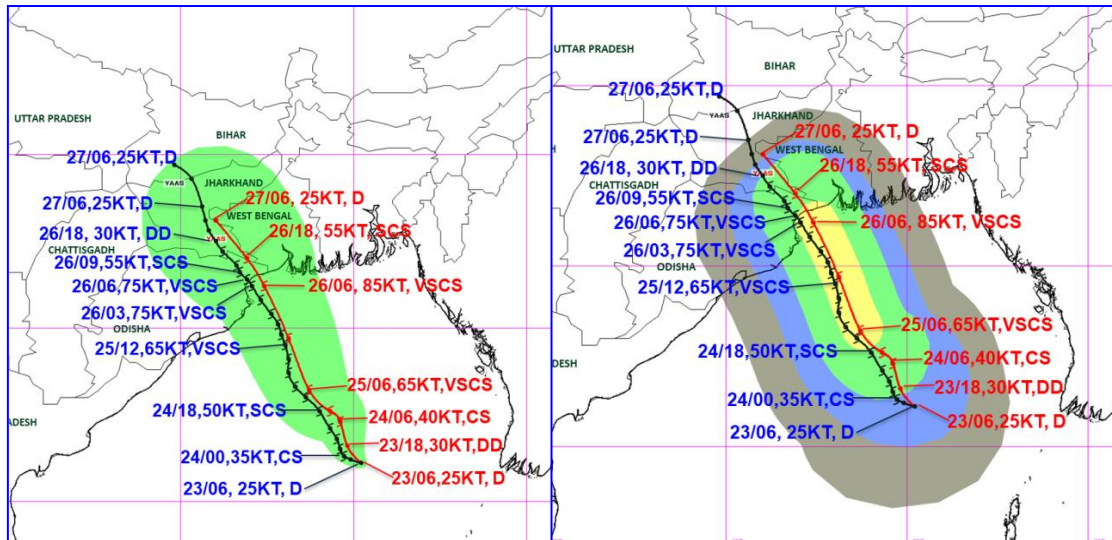


Fig.5 : Observed track (23-28 May) and first forecast track issued at 1350 hours IST of 23rd May based on 1130 hrs IST observations of 23rd May (about 72 hours prior to landfall) demonstrating accuracy in track, intensity and landfall.

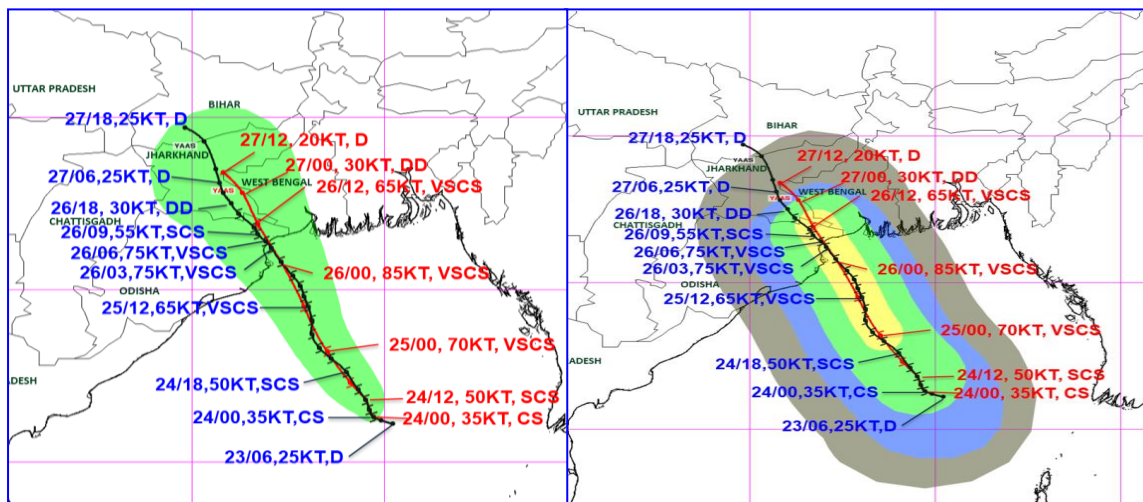


Fig.6: Observed track (23-28 May) and forecast track issued at 0830 IST based on 0530 IST observations of 24th May (about 54 hours prior to landfall) demonstrating accuracy in track, intensity and landfall

DATE/TIME IN UTC, IST = UTC + 0530 HRS, D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CYCLONIC STORM, VSCS: VERY 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, Landfall and Intensity Forecast Errors:

The operational track, intensity and landfall point & time forecast errors are presented in Fig.7.

- ❖ The track forecast errors for 24, 48 and 72 hrs lead period were 24.1, 53.1 and 81.6 km respectively against the LPA errors (2016-20) of 77, 117, and 159 km respectively

- ❖ The landfall point forecast errors for 12, 24, 48 and 60 hrs lead period were 7.8, 7.8, 7.8 and 38.9 km respectively against the LPA errors (2016-20) of 17, 32, 62 and 61 km during 2016-20 respectively.
- ❖ The landfall time forecast errors for 12, 24, 48 and 60 hrs lead period were 1.0, 1.0, 2.5 and 3.5 hours respectively against the LPA errors (2016-20) of 1.3, 2.5, 5.0 and 5.3 hours during 2016-20 respectively.
- ❖ The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 13.7, 12.9 and 14.1 knots against the LPA errors of 7.9, 11.4, and 14.1 knots during 2016-20 respectively
- ❖ The errors in track and landfall point & time were exceptionally less as compared to long period average errors during 2016-2020.

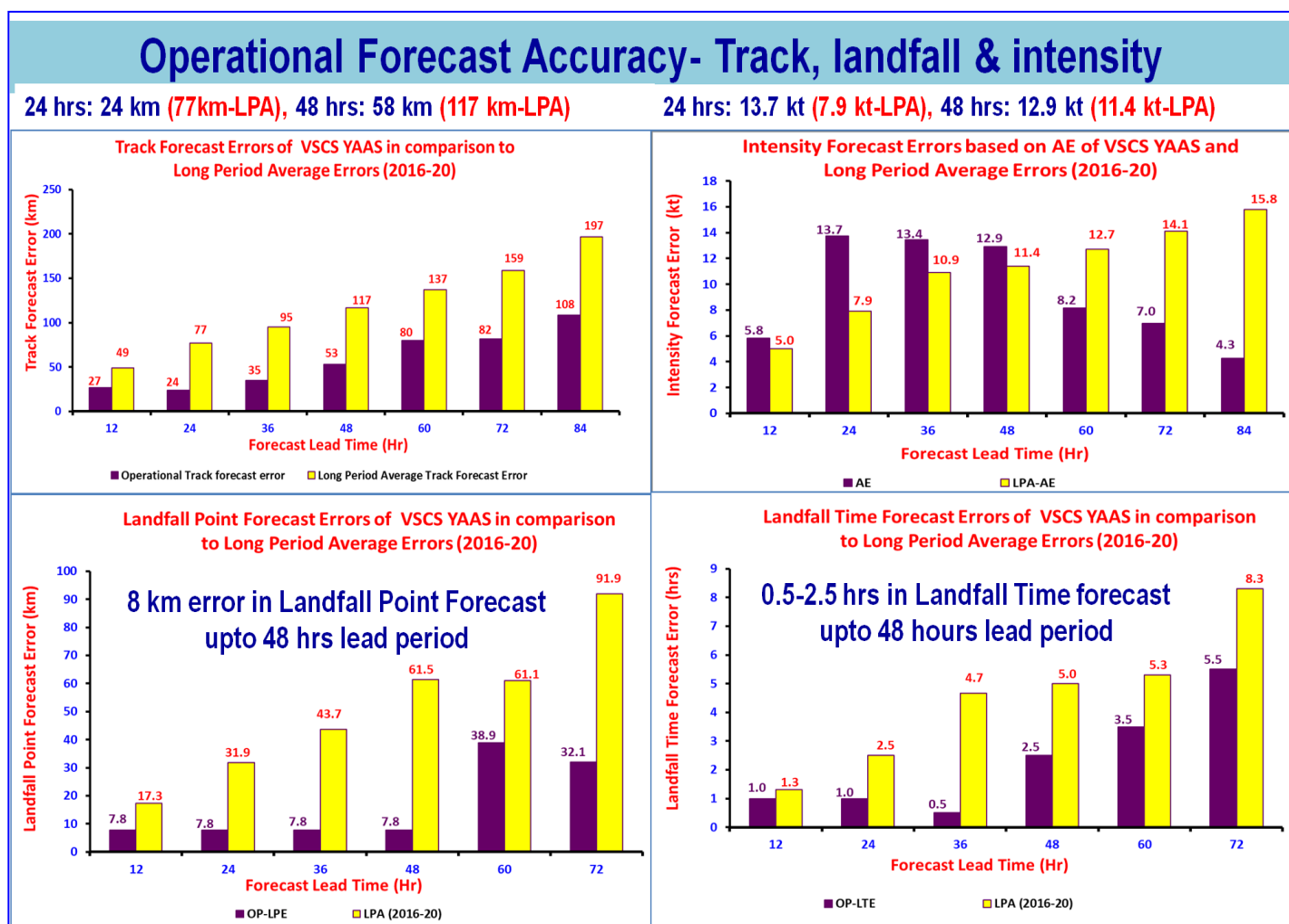


Fig. 7: Operational track, intensity, landfall point and time forecast errors during YAAS as compared to long period average (LPA) errors based on 2016-20

(iv) Forecast verification of Gale wind

| Forecast Winds (kmph) | Realised wind (kmph) |
|---|--|
| <p>➤ Gale wind speed reaching 155-165 gusting to 185 kmph over north coastal districts of Balasore, Bhadrak Jagatsinghpur, Kendrapara of Odisha. It</p> | <p>❖ Gale wind speed reaching 130-140 gusting to 155 kmph prevailed over north coastal districts of Balasore, Bhadrak and 100-120 kmph gusting to 130 kmph along and off</p> |

| | |
|--|---|
| <p>was modified to 130-140 gusting to 155 kmph on 25th night.</p> <p>➤ Gale wind speed reaching 110-120 gusting to 130 kmph over coastal districts of West Bengal (Purba Medinipur and south 24 Parganas district) and during the time of landfall.</p> | <p>Kebdrapara and Jagatsinghpur districts of Odisha.</p> <p>❖ Gale wind speed reaching 110-120 gusting to 130 kmph prevailed over coastal districts of West Bengal (Purba Medinipur and south 24 Parganas district) during the time of landfall</p> |
|--|---|

(v) Verification of Heavy Rainfall Warning

| Forecast Rainfall | Realised 24 hr cumulative heavy rainfall ending at 0830 IST of date |
|---|---|
| <p>❖ Heavy to very heavy rainfall over Andaman & Nicobar Islands on 23rd & 24th May.</p> <p>❖ Heavy to extremely heavy rainfall activity at isolated places over coastal Odisha on 25th May and heavy to very heavy rainfall at a few places and extremely heavy rains at isolated places on 26th May over North Odisha.</p> <p>❖ Heavy to very heavy rainfall activity at isolated places over Gangetic West Bengal on 26th May and heavy to extremely heavy rainfall over Sub-Himalayan West Bengal on 27th.</p> <p>❖ Heavy to extremely heavy rainfall over Jharkhand on 26th and 27th, over Bihar and east UP on 27th and 28th May.</p> | <p>❖ Heavy to very heavy rainfall over Andaman & Nicobar Islands on 23rd & 24th May.</p> <p>❖ Heavy to extremely heavy rainfall at isolated places over coastal Odisha on 25th May and heavy to very heavy rainfall at a few places and extremely heavy rains at isolated places on 26th May over North Odisha.</p> <p>❖ Heavy to very heavy rainfall at isolated places over Gangetic West Bengal on 26th May and heavy to extremely heavy rainfall over Sub-Himalayan West Bengal on 27th.</p> <p>❖ Heavy to extremely heavy rainfall over Jharkhand on 26th and 27th, over Bihar and east UP on 27th and 28th May.</p> |

(vi) Verification of storm surge warning

| Forecast Storm Surge (m) | Realised Storm Surge (m) |
|--|--|
| <p>Tidal waves of height 2-4 meters above astronomical tide to inundate low lying areas of Balasore, Bhadrak Medinipur, South 24 Parganas, and about 1-2 meters above astronomical tide to inundate low lying areas of Kendrapara & Jagatsinghpur Districts around the time of landfall.</p> | <p>Estimated storm surge of about 2-4 meters height above astronomical tide inundated low lying areas of Balasore and Bhadrak districts of north Odisha and West Bengal (South 24 parganas, North 24 parganas, Purba Medinipur districts) and 1-2 meters height above astronomical tide inundated low lying areas of Kendrapara and Jagatsinghpur districts of north Odisha during time of landfall.</p> |

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

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... +84 hrs lead period commencing from 23rd May noon till the

system weakened into a low pressure area in the morning of 28th. 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 15 hours prior to landfall till the system maintained the intensity of cyclonic storm over Odisha.

- **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 23rd May noon giving forecast for +06, +12, +18, +24, +36 and +84 hrs lead period.
- **Four stage Warning:**
- **Considering the development of cyclonic storm over Bay of Bengal, 1st Press Release** was issued on 19th May (3 days prior to formation of LPA on 22nd May). Adverse weather warnings and advisories for fishermen issued.
- **2nd Press Release & Special Message were issued on 22nd May on formation of LPA (4 days prior to landfall)** indicating formation of cyclonic storm over Bay of Bengal and system to reach northwest BoB near north Odisha-West Bengal coasts around 26th morning.
- **Pre cyclone watch** for Odisha-West Bengal coasts was issued at 1350 hrs IST of 23rd May, on development of depression over eastcentral BoB (**about 70 hours prior to landfall**).
- **Cyclone alert** for Odisha-West Bengal coasts was issued at 0830 hrs IST of 24th May, on intensification of the system into the cyclonic storm YAAS (**about 54 hours prior to landfall**).
- **Cyclone Warning** for Odisha-West Bengal coasts was issued at 2030 hrs IST of 24th May, when the system was a cyclonic storm over eastcentral BoB (**about 39 hours prior to landfall**).
- **Post landfall outlook for interior districts of Odisha and West Bengal** was issued at 1700 hrs IST of 25th, when system was a severe cyclonic storm over northwest and adjoining areas of BoB (**about 18 hours prior to landfall**).
- **Adverse weather warning bulletins:** The tropical cyclone forecasts alongwith expected adverse weather like heavy rain, gale wind and storm surge was issued with every three hourly update to central, state and district level disaster management agencies including MHA NDRF, NDMA for all concerned states along the east coast of India and interior parts of north India across which the system moved including Tamilnadu, Andhra Pradesh, Andaman & Nicobar Islands, Puducherry, Odisha, West Bengal, Jharkhand, Assam, Sikkim, Bihar, Meghalaya, Uttar Pradesh. 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 & 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 Bay of Bengal. However, from 25th night (2030 IST/1500 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 over Odisha.
- **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 capsules by DGM, Media Briefings by all concerned Officials at Hqrs as well as in Odisha & West Bengal 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 Kolkata, Chennai and Cyclone warning centres at Visakhapatnam and Bhubaneswar to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen for deep Sea of BoB and the states of Tamilnadu, Andhra Pradesh, Odisha, West Bengal and Andaman & Nicobar Islands were issued since 19th 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 25th night (1500 UTC/2030 IST) onwards till the system maintained the intensity of cyclonic storm.
- **Important Briefing Meetings attended by DGM IMD**
 - ❖ High Level meeting chaired by Secretary, NDMA on 21st May.
 - ❖ NCMC Meeting chaired by Cabinet Secretary on 22nd May
 - ❖ Briefing meeting under Chairmanship of Hon'ble Prime Minister on 23rd May.
 - ❖ Preparedness Meeting chaired by Union Home Minister on 24th May.
 - ❖ Review Meeting under joint Chairmanship of Hon'ble Ministers of State for Ports, Shipping & Waterways (I/C), Commerce & Industry and Petroleum and Natural Gas on 24th May.
 - ❖ Review meeting under chairmanship of Hon'ble Prime Minister on 27th May.

Statistics of bulletins issued by RSMC New Delhi, Area Cyclone Warning Centre Kolkata and CWC Visakhapatnam & Bhubaneswar in association with the VSCS YAAS are given in **Table 2-3**.

Table2: Bulletins issued by Cyclone Warning Division, New Delhi

| S.N | Bulletin | No. of Bulletins | Issued to |
|-----|---|------------------|---|
| 1 | Bulletin from DGM IMD | 6 | 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, Andhra Pradesh, Andaman & Nicobar Islands, Puducherry, Odisha, West Bengal, Jharkhand, Assam, Sikkim, Bihar, Meghalaya, Uttar Pradesh. |
| 2. | National Bulletins | 34 | 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 Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, UNI, Chief Secretary-Tamilnadu, Andhra Pradesh, Andaman & Nicobar Islands, Puducherry, Odisha, West Bengal, Jharkhand, Assam, Sikkim, Bihar, Meghalaya, Uttar Pradesh. |
| 2 | RSMC Bulletins | 32 | 1. IMD's website 2. WMO/ESCAP member countries including Somalia and WMO through GTS and E-mail. |
| 3 | GMDSS Bulletins | 32 | 1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM) |
| 4 | Tropical Cyclone Advisory Centre Bulletin (Text & Graphics) | 13 | 1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation. 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website |
| 5 | Tropical Cyclone Vital Statistics | 14 | 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 |
| 6 | Warnings through SMS | 69,52,040 | To disaster managers at national level and concerned states (every time when there was change in intensity)-130 To general public registered with RSMC website from the states of Odisha, West Bengal, Andhra Pradesh, Andaman & Nicobar Islands and National level disaster managers—2,97,785 To Fishermen through INCOIS on Ocean State Forecast- |

| | | | |
|-----|---------------------------------|---|---|
| | | | 36,69,472 To farmers of Andaman & Nicobar Islands, Odisha & West Bengal, Bihar & Jharkhand through Kisaan Portal-29,84,653 |
| 7. | CAP Feeds | 6.66 crores | Notifications were issued through Common Alerting Protocol |
| 8. | Notifications through Umang App | 2,45,740 | Notifications through Umang App |
| 9. | 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) |
| 10. | Hourly Bulletin | 27 | 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. |
| 11. | Press Release | 10 | Disaster Managers, Media persons by email and uploaded on website |
| 12. | Press Briefings | Frequently | Regular briefing daily |

Table3: Statistics of bulletins issued by Area Cyclone Warning Centre Kolkata, Cyclone Warning Centre (CWC) Visakhapatnam and Bhubaneswar

| S.N. | Type of Bulletin | ACWC Kolkata | CWC Bhubaneswar | CWC Visakhapatnam |
|------|------------------------------------|--------------|-----------------|-------------------|
| 1. | Sea Area Bulletins | 16 | - | - |
| 2. | Coastal Weather Bulletins | 16 | 31 | 13 |
| 3. | Fishermen Warnings | 16 | 38 | 10 |
| 4. | Port Warnings | 19 | 33 | 10 |
| 5. | Heavy Rainfall Warning | 26 | 30 | - |
| 6. | Gale Wind Warning | 18 | 23 | - |
| 7. | Storm Surge Warning | 15 | 18 | - |
| 8. | Warning issued to State Government | 28 | 36 | 5 |
| 9. | SMS | NIL | - | 60 |
| 10. | No. of Press releases | 26 | 10 | 5 |
| 11. | Impact based warnings | 56 | 20 | 30 |
| 12. | Whatsapp messages | 3,50,830 | 1,01,479 | 20 |
| 13. | Facebook updates | 24 | 42 | 20 |
| 14. | No. of updates on tweeter | 26 | 110 | 1 |

| | | | | |
|-----|------------------------|---|----|---|
| 15. | Warning video released | 1 | 12 | - |
|-----|------------------------|---|----|---|

7. Acknowledgement:

IMD acknowledges contribution from all the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of VSCS YAAS. India Meteorological Department (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, Kolkata, Cyclone Warning Centre (CWC) Bhubaneswar & Visakhapatnam, Meteorological Centre (MC) Patna, Lucknow, Raipur, Ranchi, Regional Meteorological Centre Guwahati, Doppler Weather Radar Station at Paradip 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.
