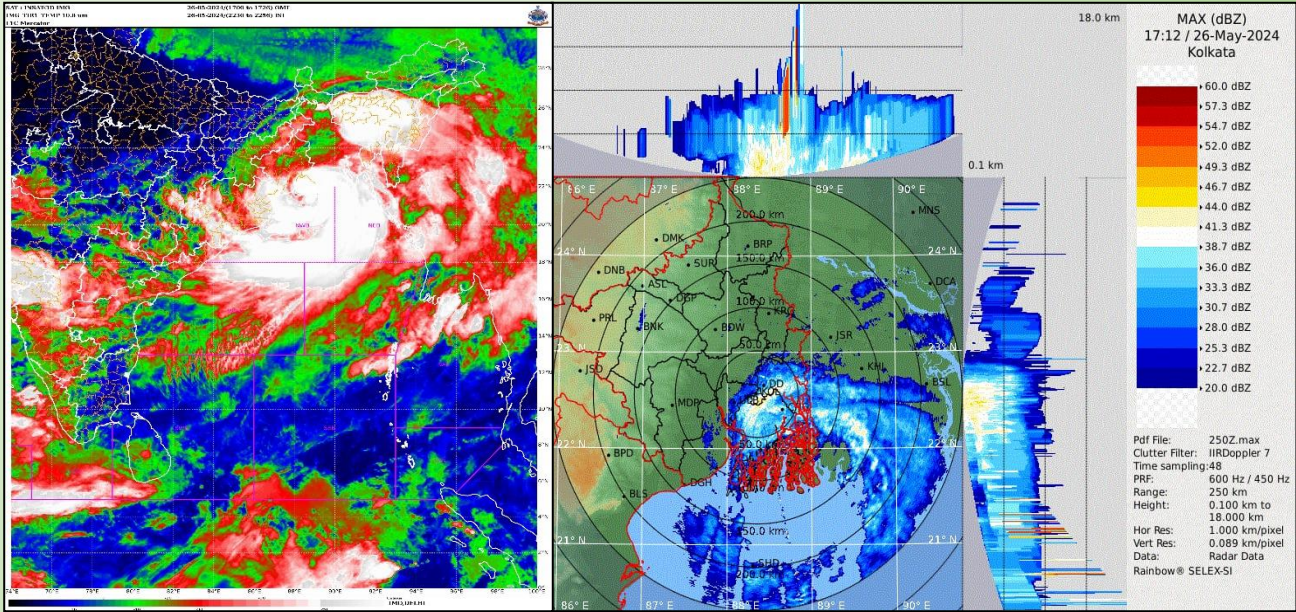




सत्यमेव जयते



Severe Cyclonic Storm “REMAL” over the Bay of Bengal (24th – 28th May, 2023): A Report



Typical (a) enhanced color imagery from INSAT 3D(R) at 2230 hrs IST/ 1700 UTC and (b) reflectivity imagery from Doppler Weather Radar, Kolkata at 2242 hrs IST/1712 UTC of 26th May, 2024 during the life cycle of severe cyclonic storm “REMAL”

Cyclone Warning Division
India Meteorological Department
New Delhi
03 June 2024

Severe Cyclonic Storm “REMAL” over the Bay of Bengal (24th-28th May, 2024): A Report

1. Life History of “REMAL”:

- An upper air cyclonic circulation developed in lower tropospheric levels over the southwest Bay of Bengal (BoB) in the early morning (0530 hours IST/0000 UTC) of 21st May, 2024, ahead of the advancing phase of southwest monsoon over the Bay of Bengal.
- Under its influence, a low pressure area (L) formed over southwest and adjoining westcentral BoB in the early morning (0530 hours IST/0000 UTC) of 22nd May, 2024.
- It lay as a well-marked low pressure area (WML) over westcentral & adjoining south BoB in the morning (0830 hours IST/ 0300 UTC) of the 23rd May.
- It concentrated into a depression (D) over central BoB in the early morning (0530 hours IST/ 0000 UTC) of the 24th May.
- It moved nearly northwards and intensified into a deep depression (DD) over the same region in the early morning (0530 hours IST/ 0000 UTC) of 25th May.
- It intensified into a cyclonic storm (CS) “REMAL” {pronounced as RE-MAL} over the north and adjoining eastcentral BoB in the same evening (1730 hours IST/ 1200 UTC of 25th May).
- Continuing to move nearly northwards it intensified further into a severe cyclonic storm(SCS) over the North BoB in the early morning (0530 hours IST/ 0000 UTC) of 26th May.
- Moving in the same direction, it crossed Bangladesh and adjoining West Bengal coasts between Sagar Islands and Khepupara close to southwest of Mongla near latitude 21.75°N and longitude 89.2°E between 2230 hrs IST of 26th May and 0030 hrs IST of 27th May 2024 (1700-1900 UTC of 26th May) as an SCS with wind speed of 110 to 120 kmph gusting to 135 kmph (60 gusting to 70 knots).
- Continuing to move northwards, it weakened into a CS over coastal Bangladesh and adjoining coastal West Bengal in the early morning (0530 hours IST/ 0000 UTC) of 27th May, 2024.
- It continued to move nearly northwards till the afternoon (1430 hours IST/ 0900 UTC) of 27th May and thereafter gradually recurved northeastwards. It weakened into a DD during the night (2030 hours IST/ 1500 UTC) of 27th May over central Bangladesh.
- Continuing to move further northeastwards, it weakened into a D over northeast Bangladesh in the early morning (0530 hours IST/ 0000 UTC) and into a WML over south Assam and neighbourhood in the evening (1730 hours IST/ 1200 UTC) of 28th May, 2024
- The observed track of the system is presented in **Fig. 1**. The best track parameters associated with the system are presented in Table 1.

2. Salient Features

(i) Salient features compared to climatology:

It was the first cyclonic disturbance (CD) over the North Indian Ocean during 2024. During the last 62 years (1961-2023), about 38 cyclones (MSW \geq 34 knots) developed over the BoB in the month of May. Out of these 18 crossed Bangladesh, 9 crossed Myanmar, 3 crossed West Bengal, 2 crossed Odisha, 5 crossed Andhra Pradesh and 1 crossed Tamil Nadu coast. Further out of 38 cyclones developing over BoB in the month of May, 28 intensified into SCS & above category (MSW \geq 48 knots) with 10 crossed Bangladesh, 6 Myanmar, 3 West

Bengal, 2 Odisha & 3 Andhra Pradesh as an SCS and remaining 4 crossed coast as cyclonic storms (**Fig. 2**). Considering the development in the grid (13-18N/86-90E) within $\pm 2.5^\circ$ of point of genesis of SCS, REMAL, a total of 6 cyclones developed over the region in the month of May and out of these 4 crossed Bangladesh coast and 1 each crossed West Bengal and Andhra Pradesh coasts (**Fig. 3a**). The analogous tracks are presented in **Fig. 3b**. Thus climatologically, there was 67% probability for the SCS REMAL to cross Bangladesh coast and 83% probability for the SCS REMAL to cross Bangladesh and adjoining West Bengal coasts.

(ii) Movement :

The six hourly average translational speed of “REMAL” was 12.2 kmph against the normal speed of 15 kmph for SCS category over the BoB during the pre-monsoon season (March-June) (**Fig. 4a**). It initially moved north-northeastwards till morning (0000 UTC of 25th May) and then nearly northwards till noon of 27th May and thereafter it gradually recurved northeastwards from 27th evening (1200 UTC) towards the northeastern states of India. It weakened into a WML over northeast Assam and neighbourhood in the evening (1200 UTC) of 28th May.

(ii) Maximum sustained wind speed (MSW) and estimated central pressure(ECP):

No rapid intensification was observed during the life cycle of REMAL. The system reached its peak intensity of maximum sustained wind speed of 60 knots gusting to 70 knots (110-120 kmph gusting to 135 kmph) at 1200 UTC (1730 IST) of 26th May with estimated central pressure (ECP) of 978 hPa and pressure drop of about 18 hPa. It was moving in a favourable environment with high sea surface temperature, high low level positive vorticity, low to moderate anticyclonic vertical wind shear (5-15 knots), enhanced warm moist air incursion into the core region of the system from southeast and favourable Madden Julian Oscillation and convectively coupled equatorial waves (**Fig. 4b**).

(iii) Landfall and dissipation characteristics:

It maintained its intensity of SCS and crossed Bangladesh & adjoining West Bengal coasts between Sagar islands and Khepupara close to southwest of Mongla around 1800 UTC (2330 IST) of 26th May 2024 with maximum sustained wind speed of 60 knots gusting to 70 knots (110-120 gusting to 135 kmph). It maintained the intensity of cyclonic storm for next 18 hours after landfall as the system was getting moist air from Bay of Bengal. However, there was rapid weakening during 1800 UTC (2330 IST) of 26th to 1800 UTC(2330 IST) of 27th with system experiencing a fall in MSW by 30 knots (55 kmph) in 24 hours due to decrease in moisture supply and interaction with orography over northern part of Bangladesh and Northeastern states of India.

(iv) Track length:

The total track length of “REMAL” was 1294 km against average track length of 1032 km for all CDs developed over the BoB during pre-monsoon season based on data of 1990-2020.

(v) Life Period:

The total life period (D to D) of “REMAL” was 4 days & 12 hours against the normal of 3 days & 8 hours for SCS category developed over the BoB in pre-monsoon season based on the data of 1990-2013.

(vi) Accumulated Cyclone Energy and Power Dissipation Index:

The Velocity Flux, Accumulated Cyclone Energy (a measure of damage potential) and Power Dissipation Index (a measure of loss) were 4.1×10^2 knots, 1.95×10^4 knots² and 0.97×10^6 knots³ respectively against normal of 4.12×10^2 knots, 1.96×10^4 knots² and 0.96×10^6 knots³ for SCS category over the BoB developed in pre-monsoon season based on data of 1990-2020.

(vii) Adverse weather:

The cyclone “REMAL” caused, torrential rains (heavy to extremely heavy rainfall) and gale-force winds over coastal districts of Bangladesh and West Bengal on 26th and 27th May. While moving northeastwards, outer rainbands reached the northeastern states and caused squally wind and heavy to extremely heavy rainfall activity over Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura on 27th and 28th May. Some of the states like Assam, Meghalaya, Mizoram and Tripura reported extremely heavy rainfall leading to floods and landslides, especially over Mizoram, Tripura and South Assam and also in Bangladesh. Extremely heavy rainfall of 66 cm was reported at Mawsynram & Cherrapunji in 24 hours ending at 0830 hrs IST of 30th May & 59 cm was reported at Sohra (Meghalaya) in 24 hours ending at 0830 hrs IST 28th May and 30 cm over West Bengal in 24 hours ending at 0830 IST of 27th May. Maximum storm surge of 3.8 meters over Bangladesh and about one metre over south and north 24 Pargana districts of West Bengal was reported at the time of landfall.

Table1: Best track positions and other parameters of the SCS “REMAL” over BoB during 24th -28th May, 2024

Date	Time (UTC)	Lat.	Long.	C.I. NO.	Estimated Central Pressure (hPa)	Estimated Maximum Sustained Surface Wind (kt)	Estimated Pressure drop at the Centre (hPa)	Grade
24.05.24	0000	15.0	88.4	1.5	996	25	3	D
	0300	15.5	88.7	1.5	996	25	3	D
	0600	15.8	88.9	1.5	996	25	3	D
	1200	16.2	89.1	1.5	995	25	3	D
	1800	16.8	89.4	1.5	995	25	3	D
25.05.24	0000	17.6	89.7	2.0	993	30	4	DD
	0300	18.0	89.7	2.0	992	30	5	DD
	0600	18.2	89.7	2.0	991	30	5	DD
	1200	18.8	89.5	2.5	990	35	6	CS
	1500	19.1	89.5	2.5	989	35	7	CS
	1800	19.3	89.4	2.5	988	40	8	CS
	2100	19.4	89.4	2.5	986	45	10	CS
26.05.24	0000	19.5	89.4	3.0	984	50	12	SCS
	0300	19.8	89.3	3.0	984	50	12	SCS
	0600	20.2	89.2	3.5	983	50	13	SCS
	0900	20.6	89.2	3.5	981	55	15	SCS
	1200	21.1	89.2	3.5	978	60	18	SCS
	1500	21.4	89.2	3.5	978	60	18	SCS
		Crossed the Bangladesh & adjoining West Bengal coasts between Sagar islands and Khepupara close to southwest of Mongla near latitude 21.75°N and longitude 89.20°E between 2230 hours IST of 26 th and 0030 hours IST						

		of 27 th May (1700 – 1900 UTC of 26 th May)						
1800		21.7	89.2	3.5	978	60	18	SCS
2100		22.0	89.2	-	980	55	16	SCS
27.05.24	0000	22.5	89.2	-	982	45	14	CS
	0300	22.8	89.2	-	984	40	12	CS
	0600	23.0	89.2	-	985	35	11	CS
	0900	23.3	89.3	-	986	35	10	CS
	1200	23.6	89.7	-	987	35	9	CS
	1500	23.8	90.2	-	988	30	8	DD
	1800	24.0	90.5	-	990	30	6	DD
28.05.24	0000	24.4	91.1	-	991	20	5	D
	0300	24.7	91.5	-	992	20	4	D
	0600	25.1	91.8	-	993	20	3	D
	1200	Weakened into a well-marked low pressure area (WML) over Northeast Assam and neighbourhood						

Maximum sustained surface wind speed (MSW) in knots (kt), 1 kt = 1.86 kmph,
D: Depression, DD: Deep depression, CS: Cyclonic storm, SCS: Severe Cyclonic Storm,
ECP: Estimated Central Pressure, C.I. No.: Current Intensity No., ΔP : Pressure drop at
centre,

3. Monitoring of SCS, “REMAL”

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored since 9th May, about 15 days prior to formation of depression on 24th May and 18 days prior to the landfall of system over Bangladesh-West Bengal coasts. The information about the system was first released in the weekly extended range outlook issued by IMD on 9th May, indicating formation of depression over central parts of south BoB around 23rd May during the week 2 (17-23 May). Further, the extended range outlook issued on 16th May, indicated formation of a depression over central BoB during the beginning of the week (24-30 November) with moderate confidence (34-67%) (about 8 days ahead of formation of depression on 24th May). Further, the extended range outlook issued on 23rd May indicated with high confidence

The cyclone was monitored with the help of available satellite observations from INSAT 3D and 3DR, SCAT SAT, ASCAT, microwave imageries and available ships, buoy observations, Doppler Weather Radar Kolkata & Agartala (India) & Khepupara (Bangladesh) and coastal observations in the region. Various global models and dynamical-statistical models run by Ministry of Earth Sciences (MoES) institutions including IMD, NCMRWF, IITM & INCOIS and guidance from models from various international agencies under bilateral arrangement and cyclone specific Hurricane Weather Research Forecast (HWRF) model were utilized to predict the genesis, track, landfall and intensity of the cyclone as well as associated severe weather. The forecasts were mainly based on multi-model ensemble technique developed by IMD further modulated by observations and experience, expertise & analysis by the forecasters at IMD. An indigenously developed digitized forecasting system of IMD was utilized for analysis and comparison of various observations and numerical weather prediction models guidance, decision making process and warning products generation. Typical imageries from INSAT 3D (R) and DWR Kolkata are presented in **Fig. 5**.

4. Operational Forecast Performance:

i) Pre-Genesis Forecast performance

- ❖ First information about likely cyclogenesis (formation of depression) over Bay of Bengal (BoB) during end of the week (17th-23rd May) was issued in the extended range outlook issued on 9th May (about 15 days ahead of formation of depression on 24th May) (**Fig. 6a**).
- ❖ The extended range outlook was further updated on 16th May. It indicated likely formation of depression over central BoB with moderate confidence (34-67%) (about 8 days ahead of formation of depression and 11 days ahead of landfall over Bangladesh) (**Fig. 6b**).
- ❖ Daily tropical weather outlook issued since 19th May indicated moderate probability of formation of depression during 24th – 25th (about 5 days ahead). The graphical tropical weather outlooks issued during 19th-22nd May indicated area of genesis from 5 days ahead of cyclogenesis (**Fig. 7**).
- ❖ The Pre-genesis track, intensity and structure forecast issued on 23rd May on formation of well-marked low pressure area over westcentral BoB indicated the genesis over central BoB on 24th, initial north-northeastwards movement followed by nearly northwards movement towards north BoB and intensification upto severe cyclonic storm stage(**Fig. 8**).
- ❖ It was followed by the extended range outlook issued in the evening of 23rd May (**Fig. 6c**) indicating high confidence of genesis with the area of genesis over central BoB and movement towards Bangladesh-West Bengal coasts.

ii) Operational track, intensity and landfall forecast performance

- (a) On formation of depression in the early morning of 24th May, the track and intensity forecast issued at 0915 hours IST of 24th May (about 2 days and 15 hours ahead of landfall on 26th May), indicated the system to move initially north-northeastwards, followed by nearly northwards movement and crossing over Bangladesh and adjoining West Bengal coast around midnight (1800 UTC) of 26th May with MSW of 60 knots (110-120 gusting to 135 kmph).
- (b) Subsequently, all forecasts were continued consistently without any significant change. The observed and first forecast track along with Cone of Uncertainty (CoU) and wind distribution forecast issued on 24th May on formation of depression and 26th May on the day of landfall are presented in **Fig. 9 (i & ii)**.

Thus, genesis, track, intensity and landfall point and time of cyclone REMAL were predicted correctly well in advance.

- (c) The track forecast errors for 24, 48 and 72 hrs lead period were 71, 48 and 80 km respectively against the long period average (LPA) errors of 72, 112 and 156 km respectively based on data of 2019-23 (**Fig. 10a**). The track forecast skills calculated against Climatology & Persistence (CLIPER) forecast for 24, 48 and 72 hrs lead period were 51, 86 and 87 km respectively against the long period average (LPA) skill of 66, 75 and 76% respectively based on data of 2019-23 (**Fig. 10b**). The operational track forecast errors were less than the LPA errors for all lead periods.
- (d) The absolute errors (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 5.7, 2.2 and 6.7 knots against the LPA errors of 7.1, 10.3 and 13.8 knots based on data of 2019-23 respectively (**Fig.11a**). The skills in intensity forecast based on AE calculated against persistence based forecast for 24, 48 and 72 hrs lead period were 73, 93 and 78% against the LPA skills of 57, 71 and 77% based on data of 2019-23 respectively (**Fig.11b**).

For all lead periods, the operational intensity forecast errors were less and skills were more than the LPA.

- (e) The root mean square errors (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 7.6, 3.3 and 8.2 knots against the LPA errors of 9.2, 12.8 and 16.5 knots based on data of 2019-23 respectively (**Fig.12a**). The skills in intensity forecast based on RMSE calculated against persistence based forecast for 24, 48 and 72 hrs lead period were 71, 92 and 77% against the LPA skills of 63, 73 and 76% based on data of 2019-23 respectively (**Fig.12b**). For all lead periods, the operational intensity forecast errors were less and skills were more than the LPA.
- (f) The landfall point forecast errors for 12, 24, 48 and 60 hrs lead period were Zero, 20, 36 and 25 km respectively against the LPA errors of 11, 18, 42 and 56 km based on data of 2019-23 respectively (**Fig.13a**). Considering the average eye diameter as 50 km, there was almost **zero landfall point forecast errors for all lead periods**.
- (g) The landfall time forecast errors for 12, 24, 48 and 60 hrs lead period were **Zero, 1.0, Zero** and 2.0 hours respectively against the LPA errors (2018-22) of 2, 2.8, 4.6 and 7.7 hours based on data of 2019-23 respectively (**Fig.13b**). **For all lead periods, the landfall time errors were appreciably less than LPA errors.**

Thus, the genesis, track, intensity, landfall point and landfall time of cyclone REMAL were correctly predicted with reasonable lead period (about 3-4 days in advance), which helped the disaster managers to take appropriate response actions for minimising loss of lives and properties.

7. Warnings and advisories issued

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...+72 hours and upto +96 hrs lead period commencing from 23rd May till the system weakened into a low pressure area. The above forecasts were issued from the stage of low pressure area along with the cone of uncertainty in the track forecast once daily during pregenesis stage, five times a day during depression stage and every three hour during the cyclone period.
- **Cyclone structure forecast for shipping and coastal hazard management:** The radius of maximum wind and radii of MSW ≥ 28 , ≥ 34 and ≥ 50 knots wind in four geographical quadrants of cyclone were issued along with graphics, commencing from 23rd May.
- **Colour coded 4 stage warnings:**

Pre-cyclone Watch (Yellow message):

Pre-cyclone Watch for West Bengal coast was issued at 1400 hrs IST (0830 UTC) of 23rd May at the stage of well-marked low pressure area (about 82 hours ahead of landfall)

Cyclone Alert (Orange message):

Cyclone Alert for West Bengal coast was issued at 0915 hours IST (0345 UTC) of 25th May at the stage of deep depression (about 39 hours prior to landfall)

Cyclone Warning (Red message):

Cyclone warning for West Bengal coast was issued at 2100 hours IST (1530 UTC) of 25th May at cyclonic storm stage (about 26 hours prior to landfall).

- **Adverse weather warning bulletins:** The tropical cyclone forecasts along with expected adverse weather like heavy rainfall, flash flood, gale wind, state of sea and storm surge for Bay of Bengal, Bangladesh, West Bengal, Odisha, Andaman & Nicobar Islands and Northeastern states including Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Mizoram and Tripura were issued with every six/three hourly update to central, state and district level disaster management agencies including Ministry of Home Affairs (MHA), National Disaster Response Force (NDRF), National Disaster Management Authority (NDMA) and state disaster management agencies. The bulletins also contained the suggested action for disaster managers and general public in particular for fishermen, ports, offshore & onshore industries and installations and people. These bulletins were also issued to Defence including Indian Navy & Indian Air Force, NDRF, Indian Coast Guard, Ports, Shipping, Mines, Fishery, Railways, Surface transport and aviation authorities etc. For cyclone "REMAL" the advisories for winds & sea condition for fishermen over Bay of Bengal were also provided to WMO and WMO/ESCAP Panel countries including Bangladesh and Myanmar.

✓ **Wind warning**

The wind warning for different states like West Bengal, Odisha, Andaman Islands and Northeastern states including Assam, Meghalaya, Arunachal Pradesh, Nagaland, Manipur, Mizoram and Tripura were issued at district level also about 5 days in advance. Typical example of district-wise wind warnings issued for West Bengal and Northeastern states of India is presented in **Fig. 14.** and verification of wind warning is given in Annexure 1.

✓ **Storm surge and coastal inundation warning:**

Storm surge of height about 1.0-1.5 m and 3.0-4.0 m was predicted by IMD to inundate low lying areas of coastal West Bengal and Bangladesh respectively at the time of landfall. This information was provided in all warning and advisory bulletins since 1230 hours IST (0700 UTC) of 24th May (about 60 hours ahead of landfall). Typical example is presented in **Fig. 15 a** and verification of storm surge warning is given in Annexure 1. During cyclone REMAL, probabilistic storm surge (P-surge) guidance was also issued indicating 80% probability of storm surge height exceeding 3 m along & off Bangladesh coast between 90E & 90.80E and probability of coastal inundation along the rivers and creeks. Typical P-surge is presented in **Fig. 15 b.**

✓ **Heavy rainfall warning**

Heavy to extremely heavy rainfall over West Bengal, and Northeastern states during 26th - 29th May were well predicted in advance and warnings were issued at district level to public and state/central level disaster managers since 23rd May (about 4 days in advance). Typical example is presented in **Fig. 16.** Verification of Heavy Rainfall warning issued by IMD is presented in Annexure 1.

✓ **Quantitative precipitation forecast (QPF) for river catchments:**

The Flood Meteorological Office, Guwahati issued quantitative precipitation forecast (QPF) for next 7 days from 24th -28th May for river catchments of Brahmaputra and Barak

in Assam (Badarpurghat, Silchar, Neamatighat, Dhubri, Dibrugarh, Goalpara, Tezpur, Guwahati, Khowang, Dhansiri, Golaghat, Jiabharali, Kampili, Lohit at Dholla, Manas Beki, Sankosh), Arunachal Pradesh (Passighat, Subansiri) and Tripura (Gumti, Manu).

✓ **Flash Flood Guidance:**

IMD, New Delhi acts as WMO's Regional Centre for Flash Flood Guidance at watershed level over South Asian region (Nepal, Bhutan, Bangladesh, Sri Lanka and India). It covers about 1 lakh watersheds in the region. During cyclone "REMAL" flash flood guidance for Bangladesh, West Bengal and Northeastern states of India were issued three times a day since 25th May with validity upto next 24 hours. A sample flash flood guidance issued for West Bengal, Bangladesh and Northeastern States is placed at **Fig. 17**.

✓ **Impact Based Forecast:**

Web based Dynamic Composite Risk Atlas was utilized to provide dynamic impact based forecast of wind and flood hazards associated with cyclone "REMAL" from 25th May onwards for West Bengal, every six hour. Typical graphical product depicting wind and flood hazards based on 1130 hours IST forecast of 25th May is presented in **Fig. 18**.

- **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 fishermen were also presented in graphics along with colour codes in the website.
- **Warnings and advisories through social media:** Daily updates (every three hour 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.
- **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 and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services Division at New Delhi and bulletins for maritime interest were issued by Area Cyclone Warning Centres of IMD at Chennai & Kolkata, Cyclone Warning Centres at Bhubaneswar and Visakhapatnam for coastal and high sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen in Bay of Bengal and Andaman Sea were issued since 18th May by IMD HQ and Cyclones Warning Centres of IMD. Typical example of fishermen warning graphics issued on 24th May is presented in **Fig. 19**.
- **Customised location specific bulletins:** Three/six hourly customised location specific bulletins were issued for offshore/onshore industries, ports, locations of Indian Oil Corporation, Indian Air Force with information about the location of cyclone from the concerned industry/port/installation etc, nearest time of arrival and corresponding distance & intensity of cyclone, likely wind speed. A sample bulletin for West Bengal and Odisha Ports is presented in **Fig. 20**.
- **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) by

Meteorological Watch Offices. It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong since 2100 hrs IST (1530 UTC) of 24th May.

- **Diagnostic and prognostic features of cyclone:** The prognostic and diagnostic features of the cyclone based on all meteorological observations and numerical model guidance were described in each RSMC bulletin since 22nd May during the period.
- **Director General of Meteorology** and other experts in Cyclone Warning Centres addressed media regularly. Regular online discussions were also held with the Director, Bangladesh Meteorological Department.
- **Briefings by Director General of Meteorology to Senior Government Officials:**
 - ❖ National Crisis Management Committee (NCMC) meeting was held under the chairmanship of Cabinet Secretary on 24th May based on the cyclone warnings issued by IMD to review the preparedness and follow up actions. DG, IMD made the presentation on current status and forecast/Warnings issued as well as damage expected and suggested actions for West Bengal, Odisha and Northeastern states.
 - ❖ Hon'ble Prime Minister Shri Narendra Modi reviewed the response and preparedness on 26th May. DG IMD presented the current status and forecast/Warnings issued as well as damage expected and suggested actions for West Bengal, Odisha and Northeastern states.

Statistics of bulletins issued by Cyclone Warning Division, RSMC New Delhi and different offices are given in Table 2-3.

Table 2: Bulletins issued by Cyclone Warning Division, New Delhi

S. No.	Bulletin type	No. Of Bulletins	Issued to
1	National Bulletin	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, Secretary MOES, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, PIB MOES, DG National Disaster Response Force, Director Punctuality, Indian Railways, Secretaries to Govt of India for Surface Transport, Mines, Agriculture, Ports, Shipping & Waterways, Fishery, Aviation, Power, Telecommunication, Petroleum & Natural Gas etc. and Chief Secretary to Government of Odisha, West Bengal, Andhra Pradesh, Tamil Nadu, Andaman & Nicobar Islands, Puducherry, Tripura, Mizoram, Manipur and Nagaland, Andaman & Nicobar Islands.
2	RSMC Bulletin	34	1. IMD's website 2. WMO/ESCAP member countries through GTS and E-mail
3	Flash Flood Guidance Bulletin	12	Email to National level disaster managers, Central Water Commission, Ministry of Home Affairs, Ministry of Water Resources, South Asian countries including Bangladesh Meteorological Department, Flood Met Offices, social media, RSMC & Mausam website
4	QPF Forecast for river catchments	5	Email to Central Water Commission, Flood Met Offices, IMD forecasters and websites
5	GMDSS	13	1. IMD website, RSMC New Delhi website

	Bulletins		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	14	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 Bulletin	13	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	Customised Location specific forecast	15 each	Issued to Port Authorities, offshore/onshore industries, Indian Oil Corporation, Indian Air Force and Indian Coast Guard by email to concerned stake holders
9	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) 1,84,598 to General Public by IMD Headquarters
10	Warnings through Social Media	35 times	Cyclone Warnings were uploaded on Social networking sites (Facebook and Tweeter) since inception to weakening of system (every time when there was change in track, intensity and landfall characteristics).
11	Warnings through whatsapp	35 times	Warnings and bulletins were shared through WhatsApp with Disaster managers, media, WMO/ESCAP Panel member countries, offshore & onshore industries
12.	Press Release	7	Disaster Managers, Media persons by email and uploaded on website
13	DGM Bulletins	7	High level disaster managers by email and FAX including Principal secretary to Prime Minister, Home Secretary, NDMA, NDRF, Secretaries of various Ministries & concerned states and disaster management agencies mentioned in SN1.
14	Press Briefings	Daily	Regular briefing frequently
15	Hourly Bulletin	7	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, Secretary MOES, Headquarter Integrated Defence Staff, Director General Doodarshan, All India Radio, PIB MOES, DG National Disaster Response Force, Director Punctuality, Indian Railways, Secretaries to Govt of India for Surface Transport, Mines, Agriculture, Ports, Shipping & Waterways, Fishery, Aviation, Power, Telecommunication, Petroleum & Natural Gas etc. and Chief Secretary to Government of Odisha, West Bengal, Andhra Pradesh, Tamil Nadu, Andaman & Nicobar Islands, Puducherry, Tripura, Mizoram, Manipur and Nagaland, Andaman & Nicobar Islands. 3. WMO/ESCAP Panel member countries

Table 3: Statistics of bulletins issued by Area Cyclone Warning Centre (ACWC) Kolkata (Kol), Cyclone Warning Centre (CWC) Bhubaneswar (BBN), Visakhapatnam (VSK), Regional Meteorological Centre Guwahati, Meteorological Centre Imphal (IMP)/ Kohima (KM)/ Itanagar (ITN), Shillong (SH)/ Aizawl (AZL)

S.N.	Type of Bulletin Number	Statistics of bulletins								
		ACWC KOL	CWC BBN	CWC VZK	RMC GHT	MC IMP	MC KM	MC ITN	MC SH	MC AZL
1.	Sea Area Bulletins	17	-	-	-	-	-	-	-	-
2.	Coastal Weather Bulletins	17	13	13	-	-	-	-	-	-
3.	Fishermen Warnings issued	26	21	21	-	-	-	-	-	-
4.	Port Warnings	17	09	09	-	-	-	-	-	-
5.	Heavy Rainfall Warning	27		03	59	07	07	07	07	05
6.	Gale Wind Warning	21		-	-	-	-	-	-	-
7.	Storm surge Warning	14	-	-	-	-	-	-	-	-
8.	Information & Warning issued to State Government and other Agencies	28 (Spl) 13 (Hrly)		-	94	07	07	14	27	14
9.	SMS	22.30 Crore		-	96	05	09	11	08	02
10.	No. of Press releases	5+3 regional language		7	49	07	04	07	07	11
11.	No. of impact-based warnings for District/City	28/4		40	32/12	02	02	03/02	5	03
12.	No. of whatsapp messages	41 times		105	2233	362	56	612	415	212
13.	No. of updates on facebook	41 times		06	116	-	-	12	22	12
14.	No. of updates on tweeter/Instagram	41		7/4	106	-	-	06	32	-
15.	No. of Forecast/warning video released	--		5	17	-	-	03	-	02
16.	No. of Audio bites released	Frequent			-	-	-	-	-	-

8. Realized Weather

8.1. Realised rainfall

The system caused heavy to extremely heavy rainfall activity over West Bengal, Bangladesh and Northeastern states of India including Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura. NCMRWF IMD satellite gauge merged data plot showing 24 hours accumulated rainfall ending at 0300 UTC of dates during 23rd – 29th May is presented in **Fig. 21**.

24 hours accumulated realized heavy rainfall (≥ 7 cm) ending at 0830 hours IST of date are given below:

25th May, 2024

Andaman & Nicobar Islands:

Port Blair-7

26th May 2024:

Light to moderate rainfall at many places with heavy rainfall at isolated places over Tripura. Light to moderate rainfall at many places with heavy rainfall at isolated places over Andaman & Nicobar Islands.

Tripura:

Manughat (Dholai) 8, Secretariat (West Tripura) 7

Andaman & Nicobar Islands:

Maya Bandar-13

27th May 2024

Bangladesh: Light to moderate rainfall at most places with heavy to very heavy falls (up to 16 cm) at a few places over coastal Bangladesh.

Indian States:

Light to moderate rainfall at most places with heavy falls at isolated places over Mizoram, Manipur, Assam, Arunachal Pradesh, Odisha and heavy to very heavy falls at isolated places over Meghalaya and extremely heavy rainfall at isolated places over Gangetic West Bengal.

Arunachal Pradesh : Hollongi (Papumpara) 7

Assam: Beki Mathungari (Barpeta), N.lakhimpur/Lilabari (Lakhimpur) 10 each, Majuli (Jorhat), Tezpur (Shonitpur) 7 each

Meghalaya: Shella (East Khasi Hills) 17, Mynram (East Khasi Hills) 8, Cherrapunji (East Khasi Hills), Cherrapunji (East Khasi Hills) & Sohra (East Khasi Hills) 7 each.

Manipur: Ukhurul (Ukhurul) & Chandel (Chandel) 7 each

Mizoram: Mizoram University (Aizawal), Kolasib (Kolasib), Kolasib (Kolasib), Aizwal (Aizawl) & 8 each.

Odisha: Ranpur 9, Rajnagar 8, Bhapur, Aul & Nawana 7 each

Gangetic West Bengal: Tarakeshwar 30, Sagar Island 18, Alipore 15, Durgachack 14, Contai & Uluberia 13 each, Diamond Harbour 12, Amta 11, Saltlake & Canning 10 each, Dum Dum, Kakdwip & Kalyani S 9 each, Rajnagar, Barrackpur & Basirhat 8 each, Champasari, Barobhisha, Bagati & Digha 7 each.

28th May 2024

Bangladesh: Light to moderate rainfall at most places with heavy to very heavy falls (upto 16 cm) at a few places over coastal Bangladesh and very heavy to extremely heavy rainfall at isolated places (upto 32 cm) over southeast Bangladesh.

Indian States:

Light to moderate rainfall at most places with heavy to very heavy rainfall at isolated places over Arunachal Pradesh, Manipur, Mizoram, Tripura, Sub-Himalayan West Bengal (SHWB), Sikkim and heavy to very heavy rainfall at a few places with extremely heavy falls at isolated places over Assam, Meghalaya, Tripura.

Arunachal Pradesh: Nari (Lower Siang) 13, Basar (West Siang) & Basar (West Siang) 8 each, Huri (KurungKumey) 7.

Assam: Umrangso (Dima Hasao) 24, Karimganj (Karimganj) 22, Silchar (Cachar) 17, Karimganj (Karimganj), Matijuri (Hailakandi), B P Ghat (Karimganj) & Lala (Hailakandi) 16 each, Hailakandi (Hailakandi), Silchar (Cachar), Udalguri (Udalguri) & Badarpur (Karimganj) 15 each, Lkhep (KarbiAnglong) & A P Ghat (Cachar) 14 each, Gharmura (Hailakandi) 13, Halflong (Dima Hasao) 11, Lakhipur (Cachar) & Dholai (Cachar) 9 each, Kheronighat (KarbiAnglong), Lakhipur (Cachar), Amraghat (Cachar) & Amraghat (Cachar) 8 each, Harinagar (Karimganj) & Cachar (Cachar) 7 each

Meghalaya: Cherrapunji (East Khasi Hills) 59, Mawphlang (East Khasi Hills) & Cherrapunji (East Khasi Hills) 39 each, Mynram (East Khasi Hills) 36, Jowai (West Jaintia Hills) 27, Rattacherra (East Jaintia Hills) 26, Shillong C.S.O. (East Khasi Hills) & Shillong (East Khasi Hills) 24 each, Mawkyrwat (South West Khasi Hills) & Williamnagar (East Garo Hills) 23 each, Mawkyrwat (South West Khasi Hills) 22, Khliehriat (East Jaintia Hills) 18, Barapani (RiBhoi) 17, Nongpuh (RiBhoi) 7

Manipur: Ukhrul (Ukhrul) & Jiribam (Imphal East) 9 each, Bishnupur (Bishnupur), Chandel (Chandel) & Thoubal (Thoubal) 7 each.

Mizoram: Mizoram University (Aizawl) 20, Thingsulthiah (Aizawl) 17, Vairengte (Kolasib) 12, Kolasib (Kolasib) & Mamit (Mamit) 10 each, Lunglei (Lunglei) & Kolasib (Kolasib) 9 each.

Tripura: Kailashashar (Unakoti), Kumhat (Unakoti) & Kumhat (Unakoti) 25 each, Nutanbazar (North Tripura) & Dhalai (Dhalai) 24 each, DM Office (West Tripura) 23, Kailashahar (Unakoti) & Secretariat (West Tripura) 22 each, Agartala (West Tripura), Budhjongnagar (West Tripura), Kadamtala (North Tripura) & Manughat (Dhalai) 21 each, Amarpur (Gomati) & Khowai (Khowai) 20 each, Nagicherra (West Tripura), Khowai (Khowai), Lembuchhera (West Tripura), Gajaria (Sipahijhala) & Arundhutinagar (West Tripura) 19 each, Ashapara (North Tripura) & Dharmanagar/ Panisagar (North Tripura) 18 each, Gandachara (Dhalai), Houra (West Tripura), Kadamtala (North Tripura), Sabroom (South Tripura) & Amarpur (Gomati) 17 each, Sipahijhala (Sipahijhala) & Kamalpur (Dhalai) 16 each, Udaipur (Gomati) & Sonamurahanbhog (Sipahijhala) 15 each, South (South Tripura), Lengpui (Aizawl) & Amarpur (Gomati) 14 each, Kanchanpur (North Tripura) 13, Kamalpur (Dhalai) 12, Cti (Sipahijhala), Belonia (South Tripura), Sabroom (South Tripura), Gokulpur (Gomati), Gandacherra (Dhalai) & Bishalgarh (Sipahijhala) 11 each, Belonia (South Tripura) & Karbook (Gomati) 10 each, Chhanu (Dhalai) 9, Bagafa (South Tripura) 8, Eden Lounge (North Tripura) 7.

29 May 2024

Light to moderate rainfall at most places with heavy rainfall at isolated places over Nagaland, Manipur, Tripura, Sub Himalayan West Bengal & Sikkim and heavy to very heavy falls at isolated places over Arunachal Pradesh & Mizoram. Light to moderate rainfall at most places with heavy to very heavy falls at a few places over Assam and extremely heavy rainfall at isolated places over Meghalaya.

Arunachal Pradesh: Bomdila (West Kameng) 19, Miao (Changlang) 12, Miao (Changlang) 11, Namsai (Lohit) & Kalaktang (West Kameng) 7 each.

Assam: Cachar (Cachar) & Lala (Hailakandi) 18 each, Lakhimpur (cachar) 17, Hailakandi (Hailakandi), Amraghat (Cachar) & Haflong (Dima Hasao) 15 each, Dholai (Cachar) & Silchar (Cachar) 14 each, Amraghat (Cachar) 13, A.P.Ghat (Cachar) & Kokrajhar (Kokrajhar) 11 each, Silchar (Cachar) & Harinagar (Karimganj) 10 each, Gossaigaon (Kokrajhar), Fakiragram (Kokrajhar), Lakhimpur (cachar), Goalpara (Goalpara) & Karimganj (Karimganj) 9 each, Karimganj (Karimganj), Karimganj (Karimganj), Badarpur (Karimganj) & Bilasipara (Dhubri) 8 each, Baithlghanso (KarbiAnglong), Hazuwa (Barpeta), Dhemaji (Dhemaji), B.P.Ghat (Karimganj) & Beki Mathanguri (Barpeta) 7 each.

Meghalaya: Pynursula (East Khasi Hills) 31, Cherrapunji (East Khasi Hills) 28, Khliehriat (East Jaintia Hills) & Cherrapunji (East Khasi Hills) 18 each, Secretariat Hills (East Khasi Hills) 7.

Nagaland: Tening (Peren) 10

Manipur: Ukhrul (Ukhrul) 11, Imphal (ImphalEast) 9, Jiribam (Imphal East) 7,

Mizoram: Lawngtlai (Lawngtlai) 15, Chawnhu (Lawngtlai) 13, Lawngtlai (Lawngtlai) 12, Vairengte (Kolasib) 10, Saiha (Saiha) 9 .

Tripura: Kadamtala (North Tripura) 11, Nutan Bazar (North Tripura) 8.

Sub-Himalayan West Bengal: Kumargram & Hasimara 19 each, Buxaduar 16, Barobhisha & Champasari 11 each, Chengmari/Diana 10

Sikkim: Chepan 12

30th May:

Light to moderate rainfall at many places with heavy rainfall at isolated places over Nagaland, Manipur, Arunachal Pradesh and heavy to very heavy rainfall at a few places over Assam & Meghalaya and extremely rainfall at isolated places over Meghalaya.

Assam: Halflong (N. C. Hills) 13, Fakiragram (Kokrajhar) 12, Aie Nh Xing (Bongaigaon) 12, Lakhimpur (Cachar) 11, Lakhimpur (Cachar) 10, Silchar (Cachar), Silchar (Cachar) & Manash Nh Xing (Barpeta) 9 each, A P Ghat (Cachar), Gossaigaon (Kokrajhar) & Karimganj (Karimganj) 8 each, B P Ghat (Karimganj), Beky Rly.bridge (Barpeta), Dudhnoi (Goalpara), Harinagar (Karimganj) & Kokrajhar (Kokrajhar) 7 each

Meghalaya: Mawsynram (East Khasi Hills) & Cherrapunji (East Khasi Hills) 66 each, Cherrapunji (East Khasi Hills) 63, Khliehriat (East Jaintia Hills) 33, Jowai (West Jaintia Hills) 31, Mawphlang (East Khasi Hills) 21, Mawkyrwat (South West Khasi Hills) 20, Mawkyrwat (South West Khasi Hills) 19

Nagaland: Tening (Peren) 10,

Manipur: Jiribam (Imphal East) 11, Tamenglong (Tamenglong) 7

8.2. Realised wind

Khepupara and Patuakhali stations in Bangladesh reported 111 kmph during landfall. In West Bengal highest wind speed of 91 kmph was reported at Dum Dum followed by 78 kmph at Canning. Realised wind reported at different stations of Bangladesh and West Bengal is presented in **Table 4 and 5 respectively**. It is observed that maximum wind

over Bangladesh was observed after landfall during the passage of rear sector of cyclone over land. Estimated maximum sustained wind speed realised during cyclone “REMAL” is presented in **Fig. 22**.

Table 4: Realised wind (kmph) in Bangladesh

Name	Date	TIME	Wind (Kmph)
Khepupara	27-05-2024	01:30-02:00 AM	111
Khepupara	26-05-2024	11:30-11:59 PM	91
Patuakhali	27-05-2024	01:30-02:00 AM	111
Patuakhali	26-05-2024	11:30-11:59 PM	102
Patuakhali	26-05-2024	2:30 PM	89
Satkhira	26-05-2024	11:30-11:59 PM	70
Mongla	27-05-2024	12:30 PM	80
Mongla	27-05-2024	3:00 AM	79
Khulna	27-05-2024	11:30-11:59 PM	72
Dhaka	27-05-2024	6:20 AM	59
Chandpur	27-05-2024	3:30 AM	65
Patenga	27-05-2024	6:05 AM	74
Patenga	27-05-2024	11:45 AM	92

Table 5: Realised wind over West Bengal during landfall

Station	Highest Wind Speed (kmph)
Dum Dum	91
Canning	78
RKM College	78
Kolkata	74
Uluberia	73
Diamond Harbour	69
Baruipur	69
Ramsaday College	67
Kzi Airport	65
Kalyani	65
Howrah	65
Sagar Deep	63

Realised strong winds (kmph) till 0830 hours IST of date over Northeastern States of India:

27th May 2024

Assam: Guwahati University (Kamrup (M)) 65, Dudhnoi (Goalpara) & Karimganj (Karimganj) 56 each, Bongaigaon (Bongaigaon), Kokraghar (Kokrajhar) & Nalbari (Nalbari) 52 each, Mushalpur (Baksa) & Barpeta (Barpeta) 46 each, Kajalgaon (Chirang) 44.

Meghalaya: Mawkyrwat (South West Khasi Hills) 76, Tura (West Garo Hills) 67, Jowai (Jointia Hills) 65, Shillong (East Khasi Hill) 61, Umiam (Ri Bhoi) 48.

Mizoram: Mizoram_University (Aizawl) 57, Kolasib (Kolasib) 54.

Tripura: A D Nagar (West Tripura) 63, Kailasahar (Unakoti) 56, Gandachara (Dhalai) 52, Sabroom (South Tripura) 48, Gokulpur (South Tripura) 46, Sipahijala (Sipahijala) 44, Khowai (Khowai) 37.

28th May 2024

Assam: Guwahati Observatory (Kamrup (M)) 70, Morigaon (Morigano) 63, Nagaon (Nagaon) 54, Guwahati city (Kamrup (M)) 50, Silchar (Cachar) 46, Mangaldoi (Darrang) 44, Hailakandi (Hailakandi) 41.

Meghalaya: Nongstonin (West Khasi Hill) 48.

Mizoram: Champai (Champai) 81, Hnathial (Hnathial) 46.

Tripura: Ashapara (North_Tripura) 59

8.3. Realised storm surge

Storm surge of about 3.8 m height inside the creeks of Balaswar river close to Sapleja, Bangladesh occurred during landfall (**Fig. 23**). The inundation details are given below:

- ❖ Inland inundation of about 1 - 2 km along the banks of Balaswar river between 'Gabbaria' & 'Haringhata' of Bangladesh.
- ❖ Inland inundation of about 1.5 to 2 km along the banks of Tetula river close to Rangabali & about 3.5 km around Burirchar, Bangladesh.
- ❖ Inland inundation of about 4 km near Aicha, Bangladesh.
- ❖ Inland inundation of about 2 - 5 km along the parts of Meghana river banks.

Storm surge of about one metre height above astronomical tide was realised over south and north 24 Pargana districts of West Bengal during the landfall.

9. Damage report

As per media reports, in West Bengal, the cyclone caused significant structural damages and loss of lives. 7 fatalities were recorded, including deaths from collapsing roofs, electrocution, and accidents caused by falling electric wires. Bangladesh faced a similar fate, with Cyclone Remal claiming at least 10 lives and destroying over 30,000 homes. In Northeast India, Mizoram bore the brunt of the cyclone's wrath, with 30 fatalities reported mainly due to landslides. Landslides, collapsed quarries, and disrupted connectivity caused widespread destruction. Assam, Nagaland, Meghalaya, Tripura, and Manipur also suffered casualties, injuries, and infrastructure damage. Floods, landslides, and road blockages hampered rescue and relief efforts, displacing thousands and damaging homes, bridges, and roads. The cyclone disrupted normal life, with power outages, disrupted communication networks, and extensive agricultural losses. The damage photographs received from different sources are presented in **Fig. 24-26**.

10. New Initiatives:

- ❖ Introduction of graphical Tropical Weather Outlook indicating probable area of genesis (**Fig. 7**)
- ❖ Introduction of Probabilistic Storm Surge forecast (**Fig. 15 b**).
- ❖ Introduction of customised location specific forecast for Ports along the east coast of India (**Fig. 20**)

All graphics are available in Annexure 2.

11. Acknowledgements:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge contribution from WMO and WMO/ESCAP member countries including Sri Lanka, Bangladesh, Myanmar and Thailand for observational data. The contribution from all the stakeholders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of SCS REMAL is also duly acknowledged. 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. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Chennai & Kolkata, Cyclone Warning Centres Bhubaneswar, Visakhapatnam, Regional Meteorological Centre Guwahati, Meteorological Centres Port Blair, Imphal, Kohima, Itanagar, Shillong & Aizawl and Doppler Weather Radar Station at Kolkata & Agartala and all coastal observatories of Odisha and West Bengal is acknowledged. The contribution from Numerical Weather Prediction Division, Satellite and Radar Divisions, Surface & Upper Air Instruments Divisions, Agromet Advisory Services Division, Information System and Services Division, National Weather Forecasting Centre and Cyclone Warning Division at IMD is also duly acknowledged.

Verification of Heavy rainfall warning issued by IMD

Date	Forecast of Heavy Rainfall based on 0300 UTC of date H: Heavy, VH: Very Heavy, EH: Extremely Heavy	Realized Rainfall at 0300 UTC of date
23 rd May, 2024	<ul style="list-style-type: none"> ➤ H-VH rainfall at isolated places over coastal districts of West Bengal and adjoining districts of North Odisha on 26th and 27th May. ➤ H-VH rainfall at isolated places over Mizoram, Tripura and South Manipur on 26th and 27th May. 	<p><u>25th May:</u></p> <p>H rainfall at isolated places over Andaman Islands</p>
24 th May, 2024	<ul style="list-style-type: none"> ➤ H-VH rainfall at isolated places over coastal districts of West Bengal on 26th & 27th and isolated heavy rainfall over North Coastal Odisha on 25th & 26th May and isolated EH rainfall over coastal districts of West Bengal on 26th May. H-VH rainfall at isolated places over eastern districts of Sub-Himalayan West Bengal on 27th and 28th May. ➤ H-VH rainfall at isolated places over Mizoram, Tripura & South Manipur on 26th and over Assam & Meghalaya, Arunachal Pradesh, Nagaland, Mizoram, Manipur & Tripura on 27th & 28th May. ➤ Isolated EH rainfall over Assam & Meghalaya on 27th & 28th May, Arunachal Pradesh on 28th May and Mizoram & Tripura on 27th May. ➤ H-VH rainfall at isolated places over Andaman Islands on 24th May and heavy rainfall at isolated places over north Andaman Islands on 25th May. 	<p><u>26th May, 2024:</u></p> <p>H rainfall at isolated places over Tripura and Andaman Islands.</p> <p><u>27th May 2024</u></p> <p>H falls at isolated places over Mizoram & Manipur, Assam, Arunachal Pradesh, Odisha, H-VH falls at isolated places over Meghalaya and extremely H rainfall at isolated places over Gangetic West Bengal.</p>
25 th May, 2024	<ul style="list-style-type: none"> ➤ West Bengal: H-VH rainfall at a few places over coastal districts of West Bengal and eastern districts of Gangetic West Bengal adjacent to Bangladesh on 26th & 27th with isolated EH rainfall over these districts on 26th May. H-VH rainfall at isolated places over eastern districts of Sub-Himalayan West Bengal on 27th and 28th May. ➤ Odisha: Isolated heavy rainfall over North Coastal Odisha on 25th & 26th May. ➤ Northeastern States: H-VH rainfall at isolated places over Mizoram, Tripura and South Manipur on 26th and over Assam, Meghalaya, Arunachal Pradesh, Nagaland, Mizoram, Manipur & Tripura on 27th & 28th May. Isolated EH rainfall over Assam, Meghalaya on 27th & 28th May, Arunachal Pradesh on 28th May and Mizoram & Tripura on 27th May. ➤ Andaman Islands: Isolated H rainfall over north Andaman Islands on 25th May. 	<p><u>28th May 2024</u></p> <p>H-VH rainfall over Arunachal Pradesh, Manipur, Mizoram, Tripura, Sub-Himalayan West Bengal (SHWB) & Sikkim at isolated places and H-VH rainfall at few places with EH falls at isolated places over Assam, Meghalaya & Tripura.</p>
26 th May, 2024	<ul style="list-style-type: none"> ➤ West Bengal: H-VH rainfall at a few places over coastal districts of West Bengal and eastern districts of Gangetic West Bengal adjacent to Bangladesh on 26th & 27th with isolated EH rainfall (≥ 20 cm) over these districts on 26th May. The peak rainfall activity during noon of 26th to noon of 27th May. H-VH rainfall at isolated places over eastern districts of Sub-Himalayan West Bengal on 27th and 28th May. ➤ Odisha: Isolated H rainfall over North Coastal Odisha on 26th May. ➤ Northeastern States: H-VH rainfall at isolated places over Mizoram, Tripura and South Manipur on 26th and over Assam, Meghalaya, Arunachal Pradesh, Nagaland, Mizoram, Manipur & Tripura on 27th & 28th May. Isolated EH rainfall (≥ 20 cm) over Assam, Meghalaya on 27th & 28th May, Arunachal Pradesh on 28th May and Mizoram & Tripura on 27th May. 	<p><u>29th May 2024</u></p> <p>H rainfall at isolated places over Nagaland, Manipur,</p>

27 th May, 2024	<p>➤ West Bengal: H-VH rainfall at a few places over coastal and eastern districts of Gangetic West Bengal adjacent to Bangladesh on 27th May. H-VH rainfall at a few places likely over eastern districts of Sub-Himalayan West Bengal on 27th and 28th May.</p> <p>➤ Northeastern States: H-VH rainfall at a few places over Assam, Meghalaya, Arunachal Pradesh, Nagaland, Mizoram, Manipur & Tripura on 27th & 28th May. Isolated EH rainfall (≥ 20 cm) over Assam, Meghalaya, Mizoram & Tripura on 27th and Arunachal Pradesh on 28th May.</p>	Tripura, SHWB & Sikkim and H-VH falls at isolated places over Arunachal Pradesh & Mizoram. H-VH falls at few places over Assam and extremely H rainfall at isolated places over Meghalaya.
28 th May, 2024	<p>➤ Northeastern States: H-VH rainfall at a few places is very likely over Eastern Assam, Meghalaya, Mizoram & Tripura and at isolated places over Arunachal Pradesh, Nagaland, Manipur on 28th May. Isolated EH rainfall (≥ 20 cm) over south & East Assam, Meghalaya & Tripura on 28th May.</p>	30th May H rainfall at isolated places over Nagaland, Manipur, Arunachal Pradesh and H-VH rainfall at a few places over Assam & Meghalaya. EH rainfall at isolated places over Meghalaya.
29 th May, 2024	<p>➤ Northeastern States: Isolated H-VH rainfall over Arunachal Pradesh, Assam & Meghalaya and isolated heavy rainfall over Nagaland, Manipur, Mizoram & Tripura on 29th and 30th May, 2024. Isolated EH falls over Meghalaya on 29th May, 2024.</p>	

Verification of wind warning issued for West Bengal and Bangladesh

Date/ Base Time of observation	Gale/ Squally wind Forecast	Realised 24- hour Gale/ Squally wind Forecast till 0830 hours IST of date
24.05.2024 /0300UTC	40-50 gusting to 60 kmph along & off Bangladesh, West Bengal and adjoining north Odisha coasts from 12 UTC of 25 th May. To increase becoming 60-70 gusting to 80 kmph from 00 UTC of 26 th May and 100-120 gusting to 135 kmph along & off Bangladesh and adjoining west Bengal coasts from evening of 26 th for subsequent 12 hours.	Bangladesh: Khepupara and Patuakhali stations in Bangladesh reported highest wind speed of 111 kmph during landfall on 26 th midnight.
25.05.2024 /0300UTC	(A) along & off Bangladesh and west Bengal coasts: <ul style="list-style-type: none"> • 100-120 gusting to 135 kmph along & off Bangladesh and adjoining West Bengal coasts from 1200 UTC of 26th May for subsequent 6 hours. (B) North-eastern states: <ul style="list-style-type: none"> • 50-60 gusting to 70 kmph over Mizoram Tripura & south Manipur on 26th & 27th May and 40-50 gusting to 60 kmph over south Assam and Meghalaya on 27th May 	West Bengal: Highest wind speed of 91 kmph was reported at Dum Dum followed by 78 kmph at Canning during landfall on 26 th midnight. Northeastern states of India:
26.05.2024 /0300UTC	(A) along & off Bangladesh and West Bengal coasts: <ul style="list-style-type: none"> • 100-120 gusting to 135 kmph along & off Bangladesh and adjoining west Bengal coasts from 1200 UTC of 26th May till 0000 UTC of 27th May. (B) Northeastern states: <ul style="list-style-type: none"> • 50-60 gusting to 70 kmph over Mizoram Tripura south Manipur on 26th & 27th May and 40-50 gusting to 60 kmph over south Assam and Meghalaya on 27th May. 	Assam (Guwahati University) reported maximum of 65 kmph, Meghalaya (Mawkyrwat) reported 76 kmph, Mizoram (Mizoram University) 57 kmph, Tripura (A D Nagar) 63
27.05.2024	(A) Along & off Bangladesh and west Bengal coasts	

/0300UTC	<ul style="list-style-type: none"> • 80-90 gusting to 100 kmph along & off Bangladesh and adjoining west Bengal coasts during next 3 hours. <p>(B) Northeastern states:</p> <ul style="list-style-type: none"> • 50-60 gusting to 70 kmph over Mizoram Tripura & south Manipur on 27th May and 40-50 gusting to 60 kmph over & Mizoram, Manipur and remaining parts of Assam on 27th May. To reduce to 40-50 gusting to 60 kmph over Assam & Meghalaya till noon of 28th May. 	<p>kmph in 24 hours till 0830 hours IST of 27th May.</p> <p>Assam (Guwahati Observatory) reported 70 kmph, Meghalaya (Nongstonin) 48 kmph, Mizoram (Champai) 81 kmph and Tripura (Ashapara) 59 kmph in 24 hours till 0830 hours IST of 28th May.</p>
28.05.2024 /0300UTC	<p>(A)Northeastern States:</p> <ul style="list-style-type: none"> • 40-50 gusting to 60 kmph over Eastern Assam and Meghalaya, Mizoram, Tripura and 35-45 gusting to 55 kmph over Nagaland, Manipur and remaining parts of Assam till evening of 28th May. 	

Verification of storm surge warning issued for West Bengal and Bangladesh

Date/ Base Time of observation	Storm Surge Forecast at 0300 UTC of date	Realised Storm Surge at the time of landfall
24.05.2024 /0300UTC	Storm surge of about 1 meter height above astronomical tide is likely to inundate low lying areas of coastal West Bengal and 3-4 m height above astronomical tide likely to inundate low lying areas of coastal Bangladesh around the time of landfall.	<ul style="list-style-type: none"> ➤ Storm surge of about 1.0 m height above astronomical tide was observed over North & South 24 Parganas districts of West Bengal during landfall ➤ Storm surge of about 3.8 m height inside the creeks of Balaswar river close to Sapleja, Bangladesh occurred during landfall.
25.05.2024 /0300UTC	-do-	
26.05.2024 /0300UTC	-do-	

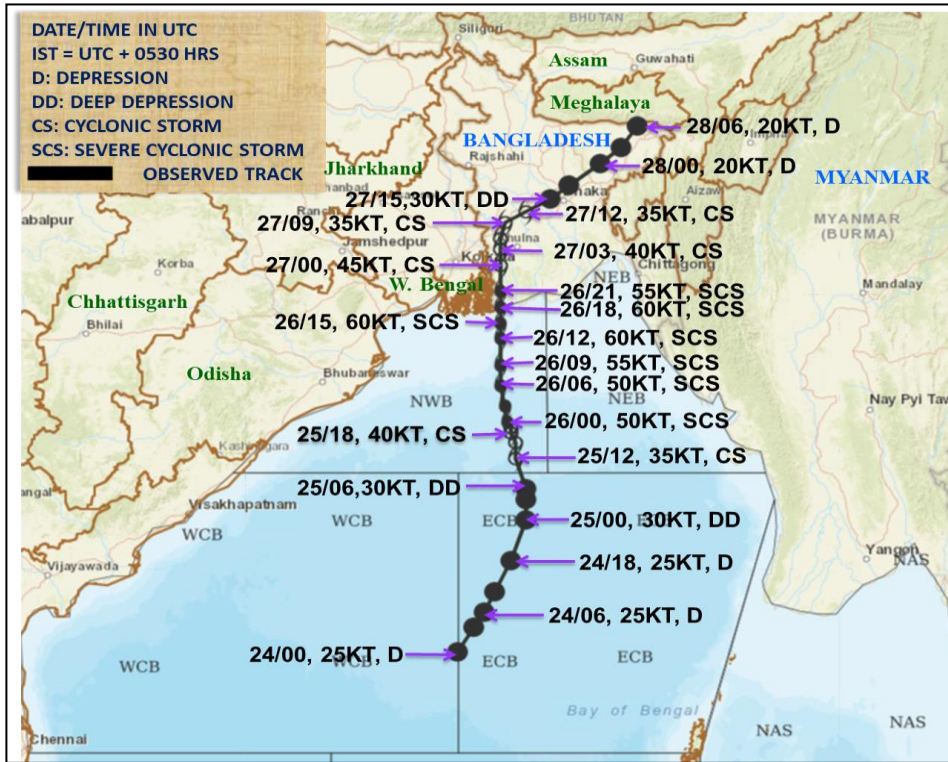


Fig. 1: Observed track of severe cyclonic storm “REMAL” over the Bay of Bengal during 24th – 28th May, 2024

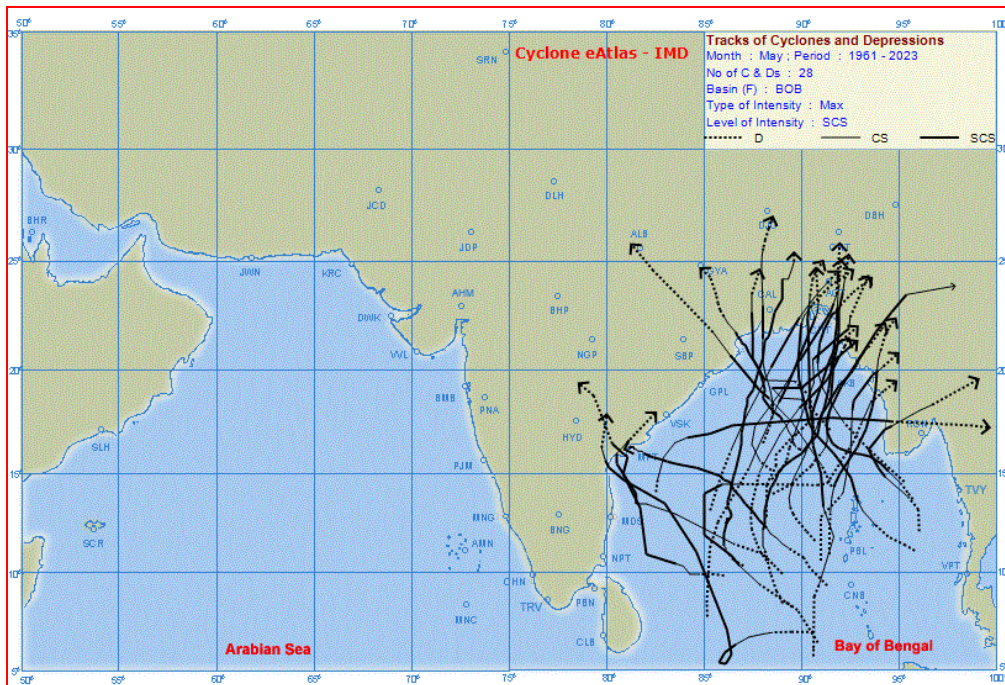


Fig. 2: Tracks of SCS developing over the BoB in the month of May during 1961-2023

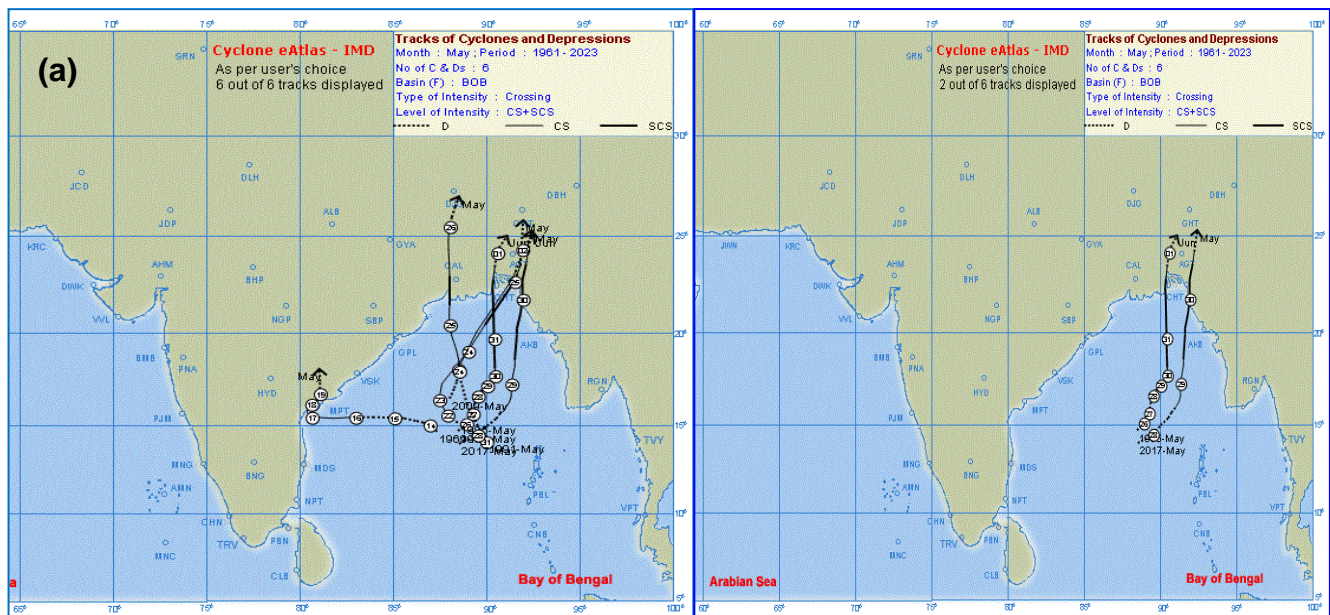


Fig. 3: Tracks of cyclones developing in the grid box (13-18N/86-90E) within $\pm 2.5^\circ$ of point of genesis and (b) analogous tracks in the month of May during 1961-2023

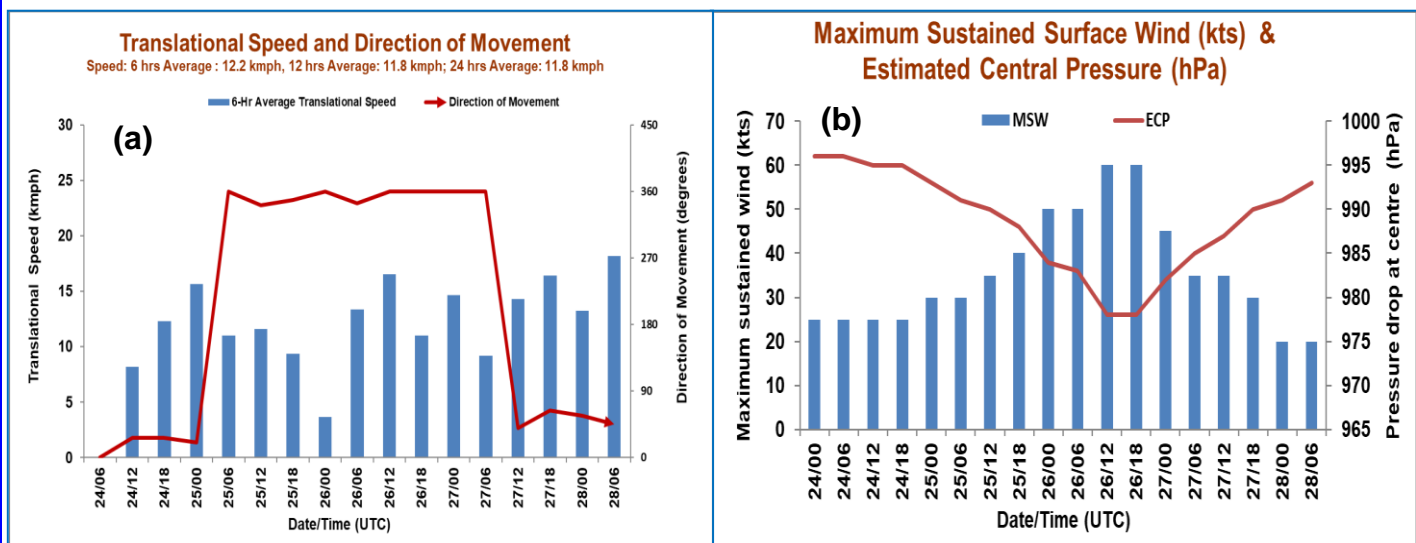


Fig. 4: (a) 6 hourly average translational speed and (b) maximum sustained wind speed & estimated central pressure during life cycle of REMAL

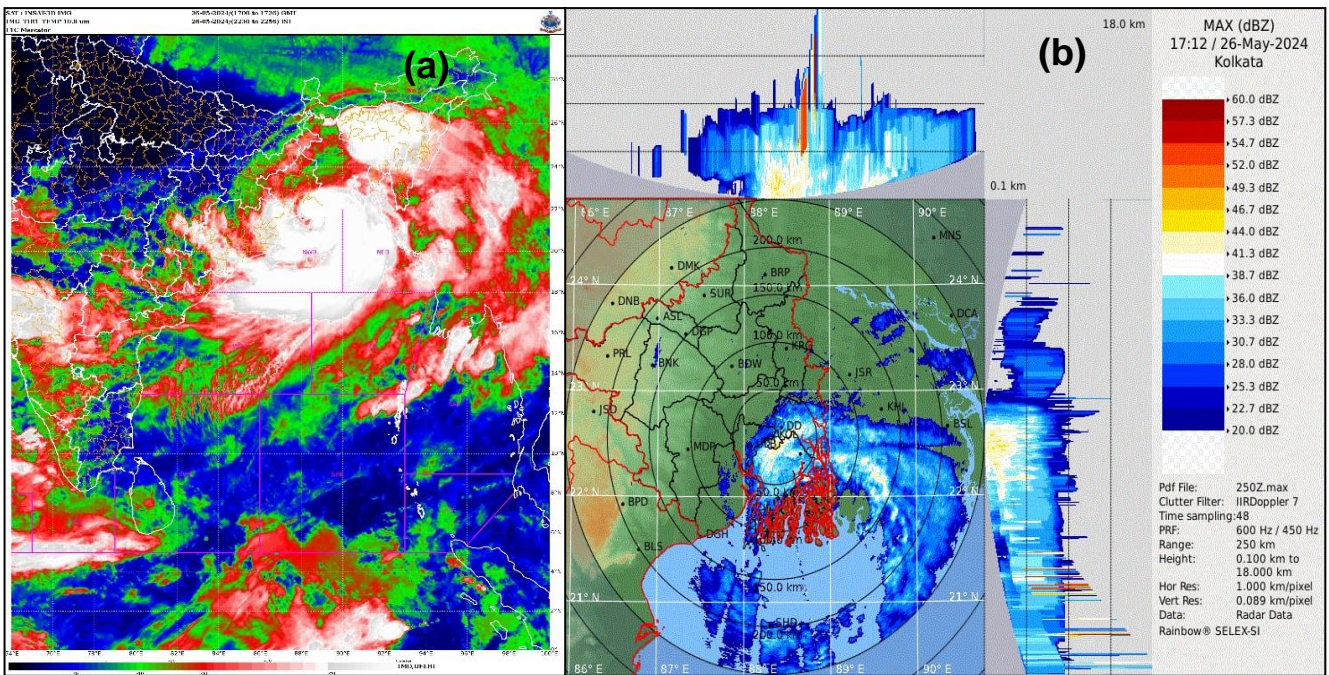


Fig. 5: Typical (a) enhanced color imagery from INSAT 3D(R) at 2230 hrs IST/ 1700 UTC and (b) reflectivity imagery from Doppler Weather Radar, Kolkata at 1840 hrs IST/1712 UTC of 26th May, 2024 in connection with Severe cyclonic storm “REMAL”

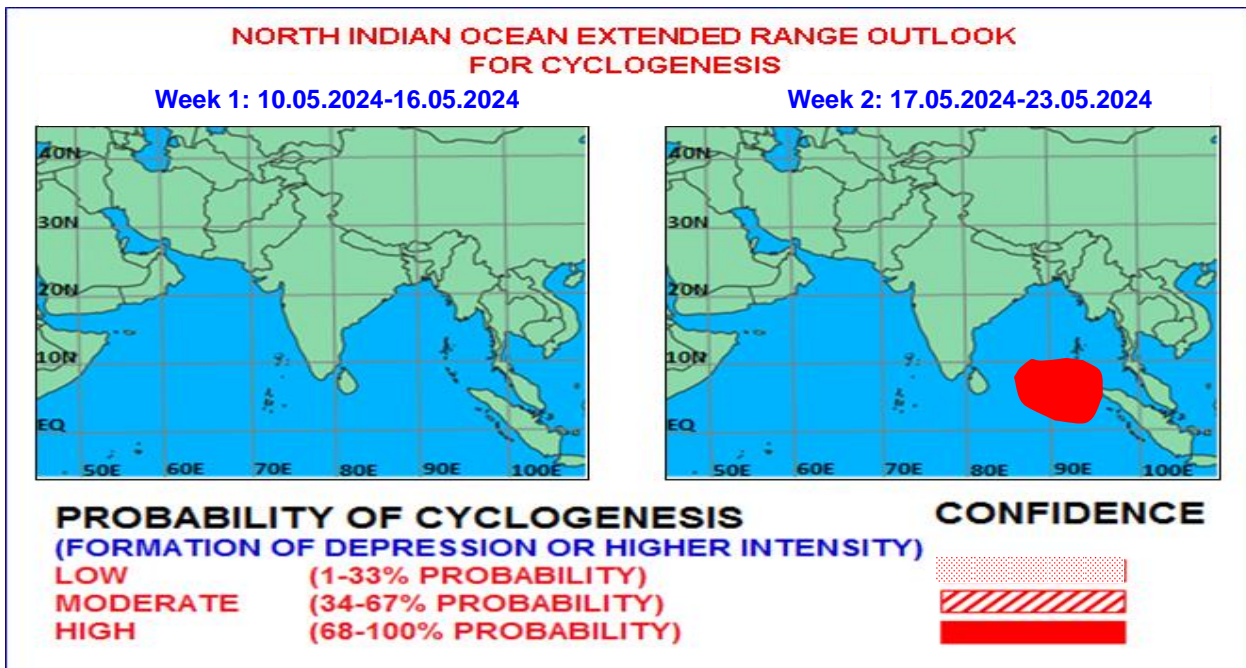


Fig. 6 (a): Weekly extended range outlook issued by IMD on 9th May, 2024, (15 days prior to formation of depression on 24th May) indicating area of cyclogenesis over southeast & adjoining southwest BoB during the week 2 (actually on 23rd the system lay as a well-marked low pressure area over eastcentral BoB)

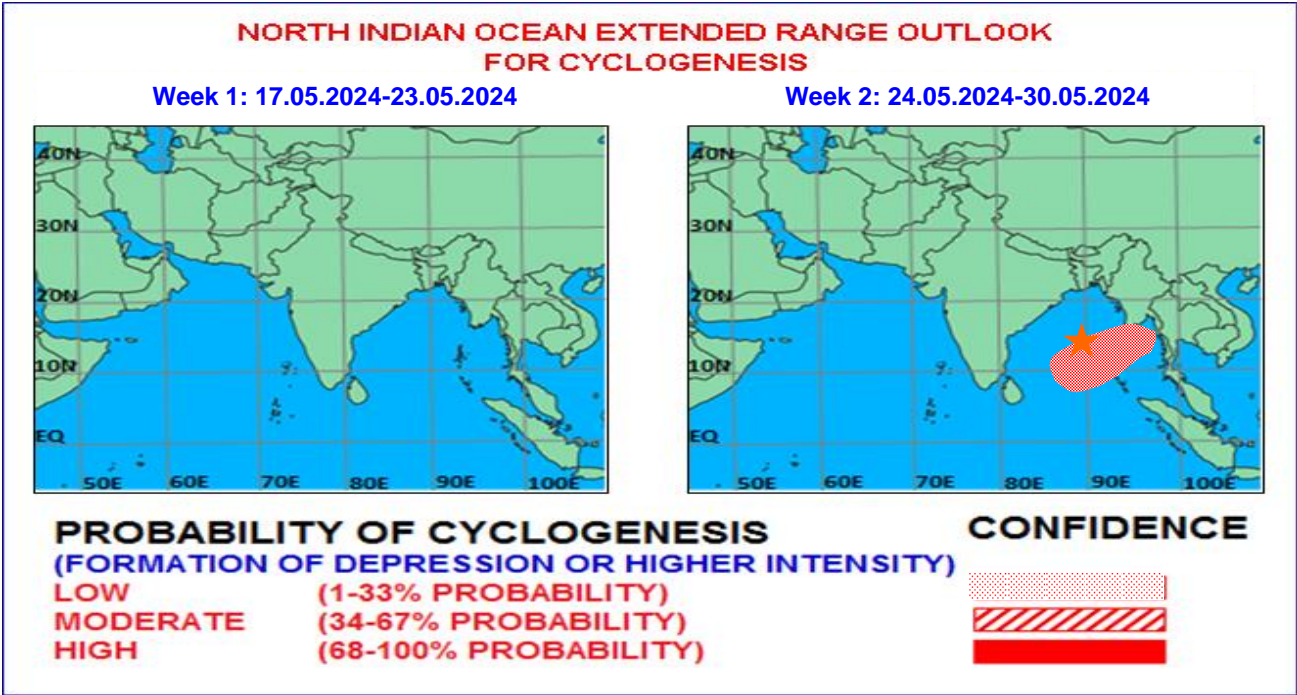


Fig. 6 (b): Weekly extended range outlook issued by IMD on 16th May, 2024, (8 days prior to formation of depression on 24th May) indicating area of cyclogenesis over central BoB during the week 2 (actually on 24th the system lay as a depression over central BoB)

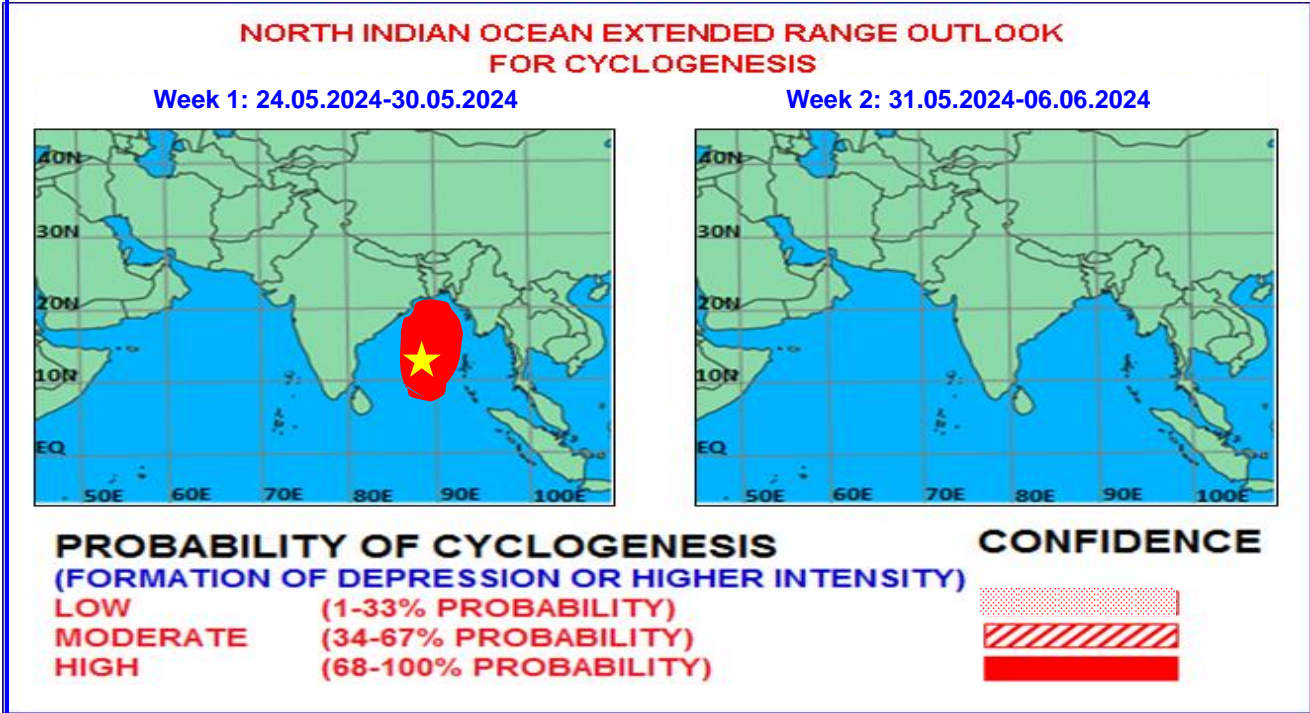
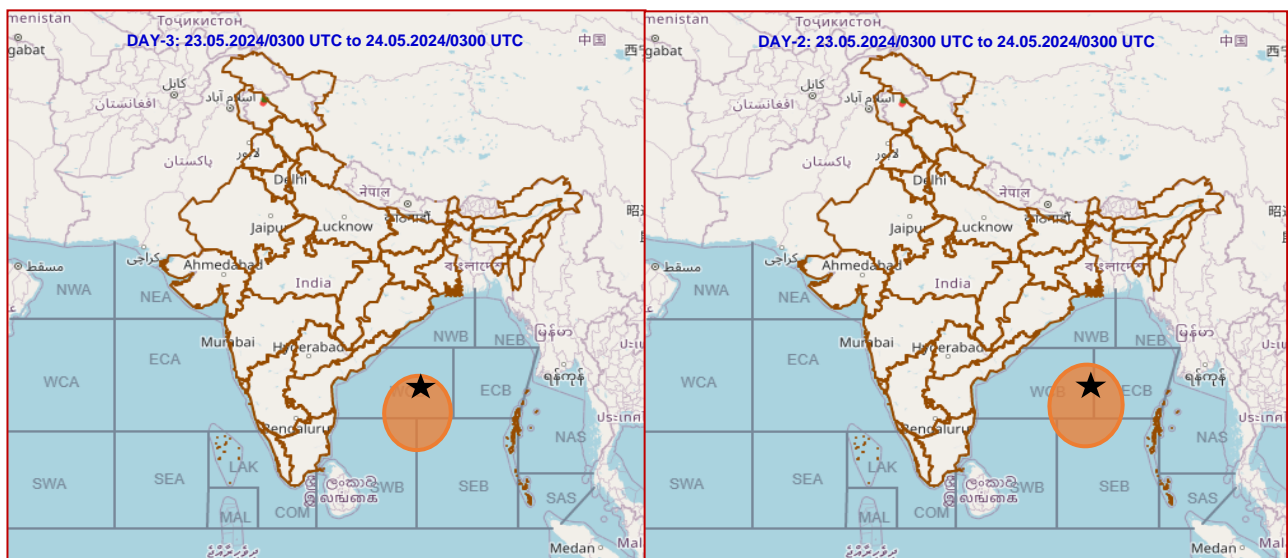
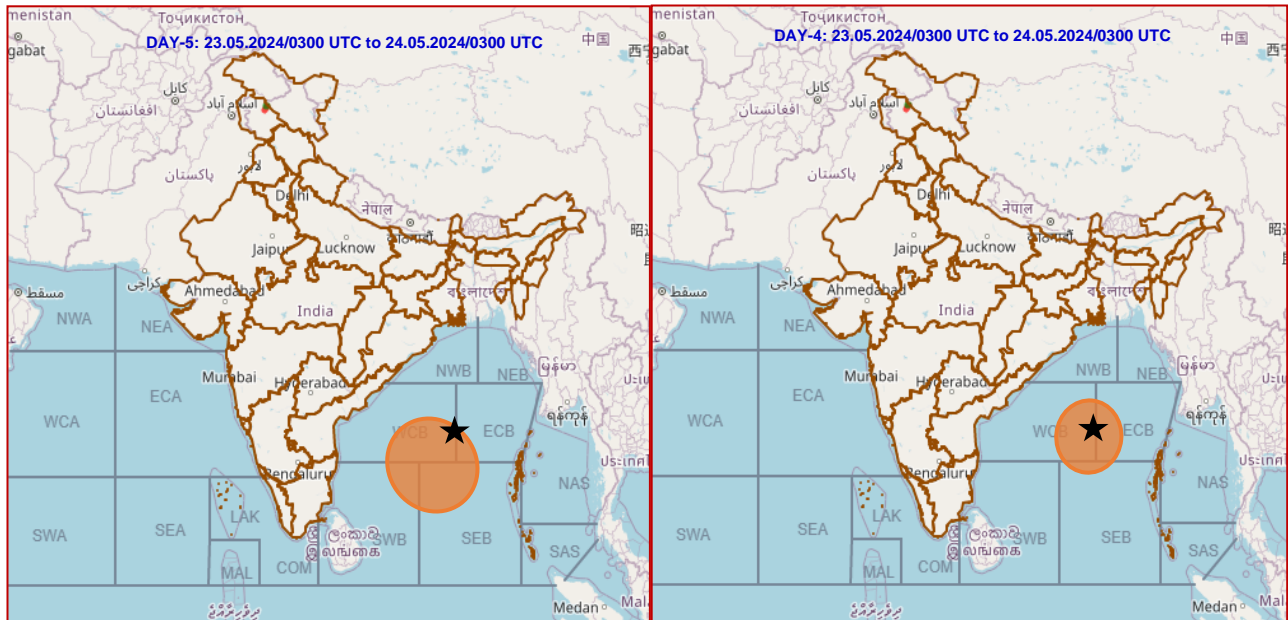


Fig. 6 (c): Weekly extended range outlook issued by IMD on 23rd May, 2024 indicating area of genesis and movement towards Bangladesh coast with high confidence.



Probability of Cyclogenesis (formation of depression)	Color Code
Low (1-33%)	
Moderate (34-67%)	
High (68-100%)	

Fig. 7: Graphical Tropical Weather Outlook issued on (a) 19th May, (b) 20th May, (c) 21st May and (d) 22nd May for 24th May indicating probable area of genesis and actual position of genesis about 3 days and 2 days ahead of formation of depression

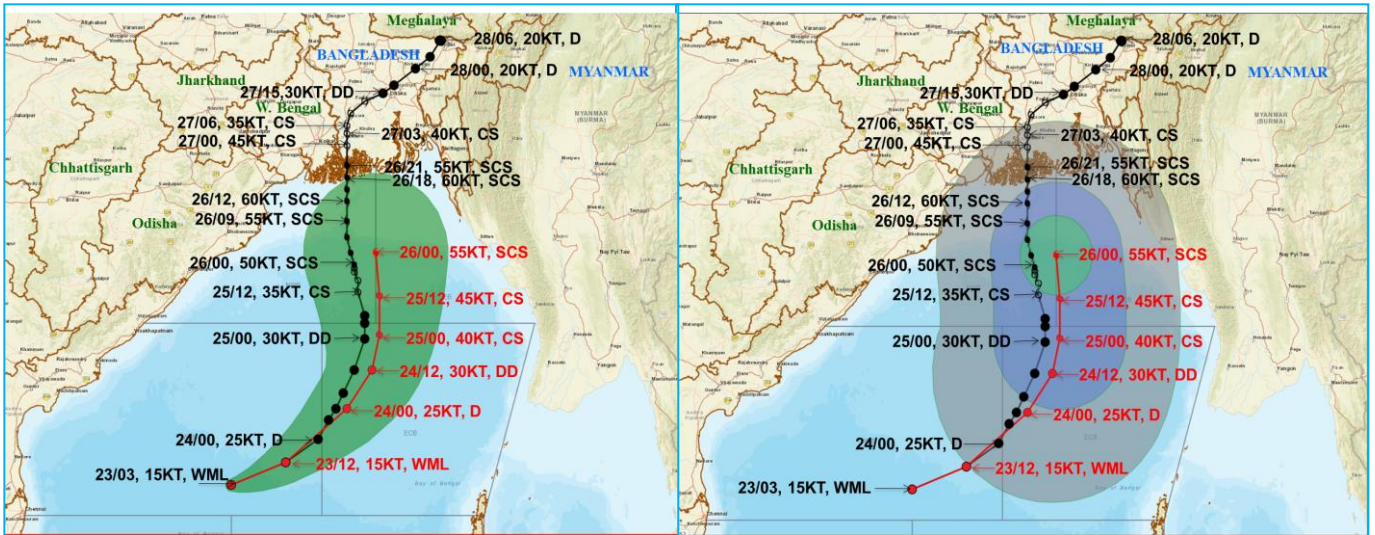


Fig. 8: Observed track & intensity along with predicted Pre-genesis track and intensity forecast issued at the stage of well-marked low pressure area on 23rd May 2024 about 3 days and 12 hours ahead of landfall on 26th May demonstrating accuracy in track and intensity forecast

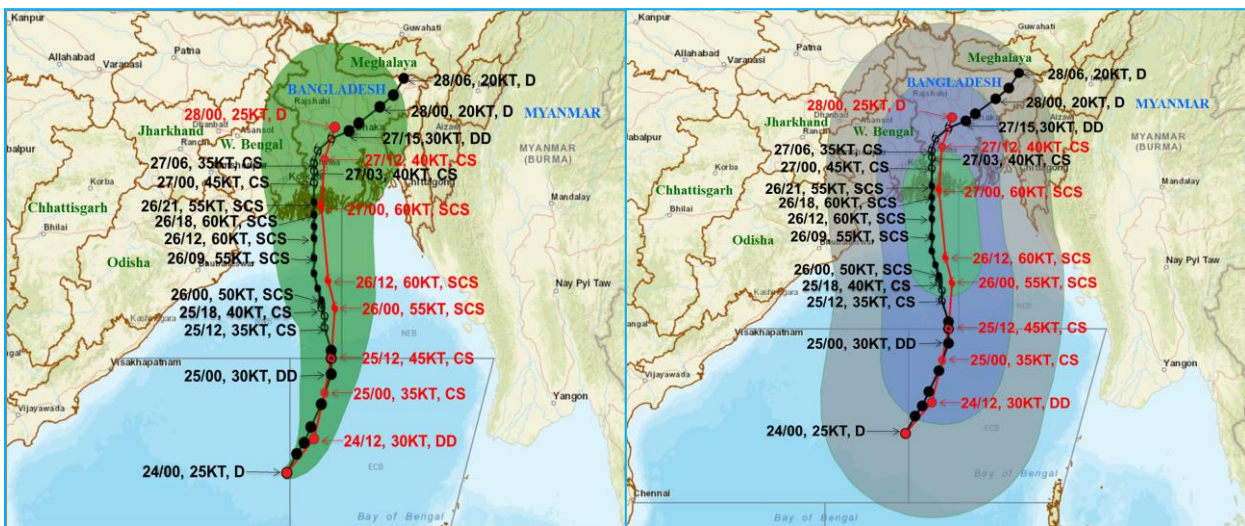



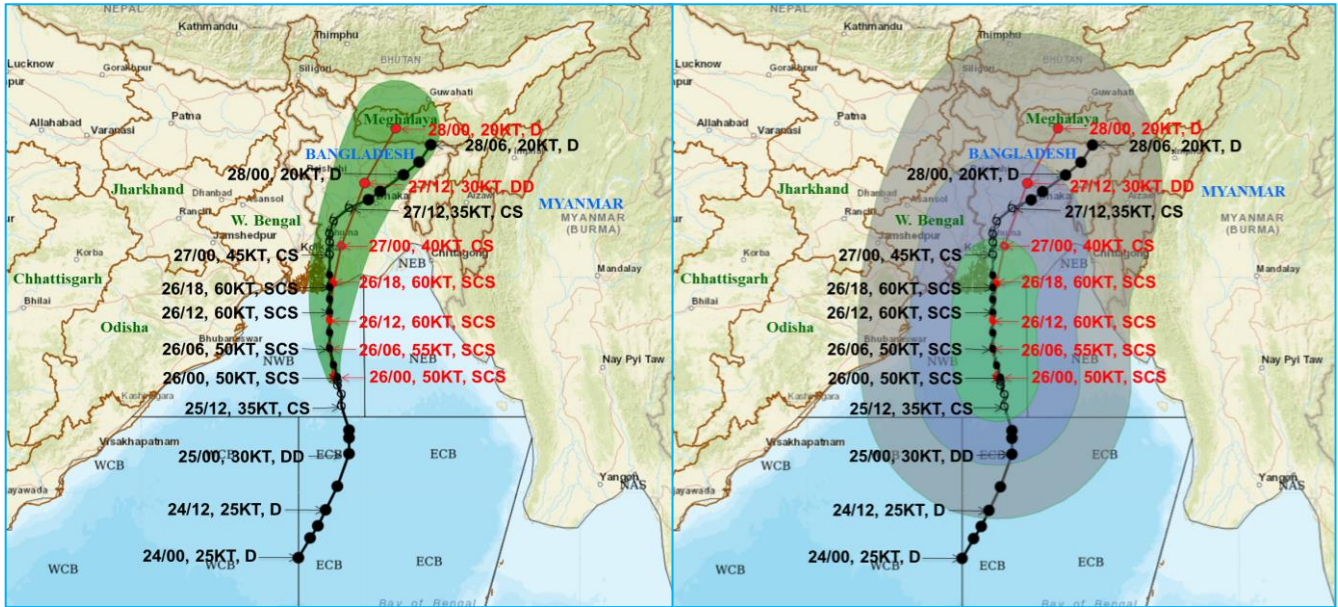


Fig.9(i): Observed and Forecast track issued at 0915 hrs IST/0345 UTC of 24th May demonstrating accuracy in track and intensity forecast about 62 hours ahead of landfall

WML: WELL MARKED LOW
 D: DEPRESSION,
 DD: DEEP DEPRESSION,
 CS: CYCLONIC STORM,
 SCS: SEVERE CS,

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

 OBSERVED TRACK
 FORECAST TRACK
 CONE OF UNCERTAINTY



WML: WELL MARKED LOW
D: DEPRESSION,
DD: DEEP DEPRESSION,
CS: CYCLONIC STORM,
SCS: SEVERE CS,

	MSW(knot/kmph)	Impact	Action
OBSERVED TRACK	28-33 ((52-61)	Very rough seas.	Total suspension of fishing operations
FORECAST TRACK	34-40((62-74)	High to very high seas	Total suspension of fishing operations
CONE OF UNCERTAINTY	41-63((75-117)	Very High seas	Total suspension of fishing operations

Fig.9(ii): Observed and Forecast track issued at 0930 hrs IST/0400 UTC of 26th May demonstrating accuracy in track and intensity forecast about 15 hours ahead of landfall

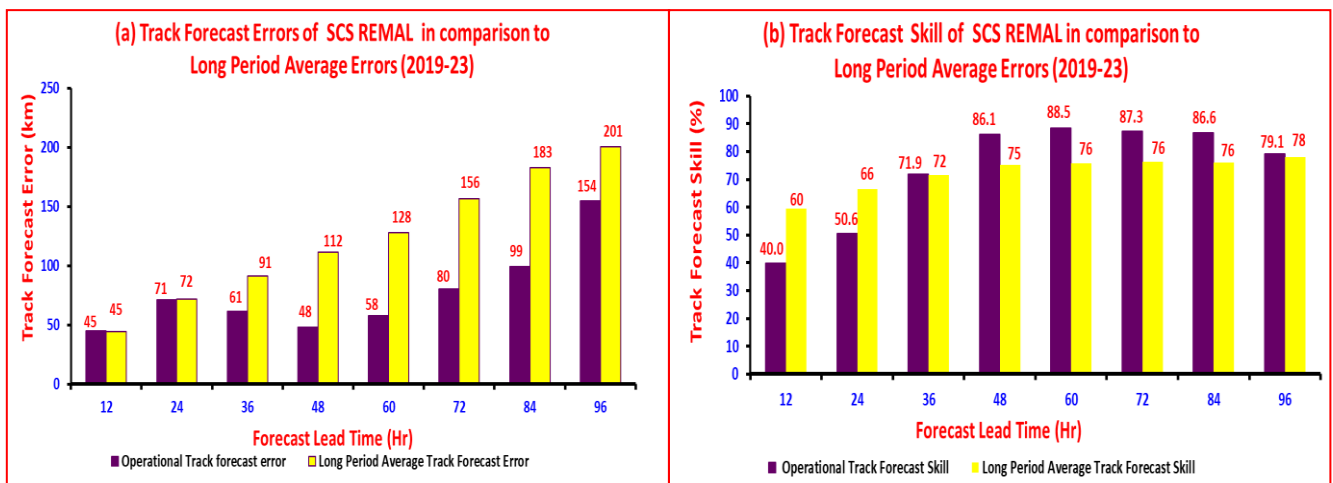


Fig. 10: (a) Track forecast errors and (b) skills against Climatology & Persistence (CLIPER) compared to long period average (LPA of 2019-2023) errors & skills respectively

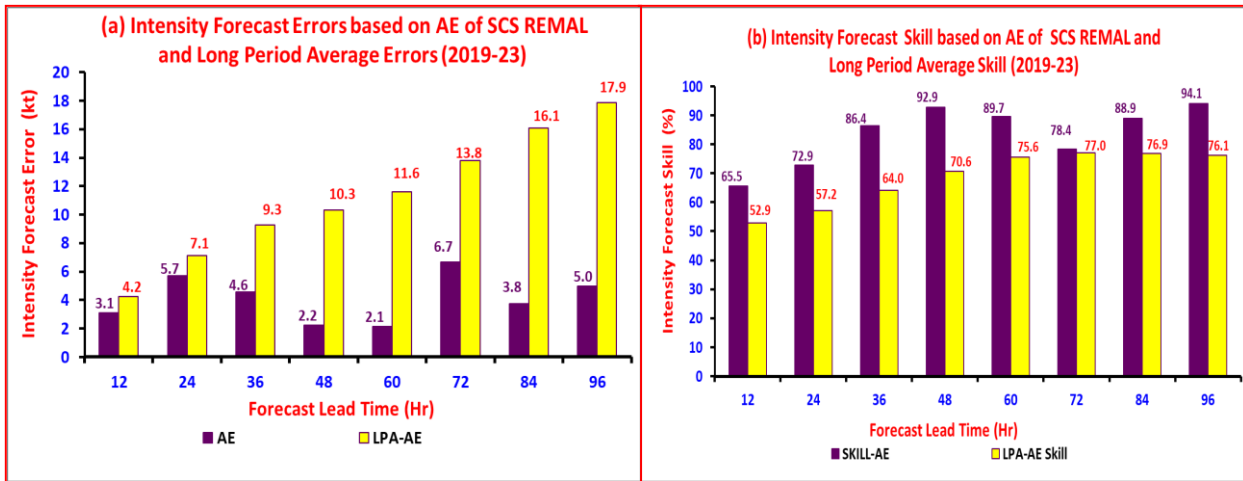


Fig. 11(a): Intensity forecast errors (AE) and (b) skills against Persistence compared to long period average (LPA of 2019-23) errors & skills respectively based on absolute error (AE).

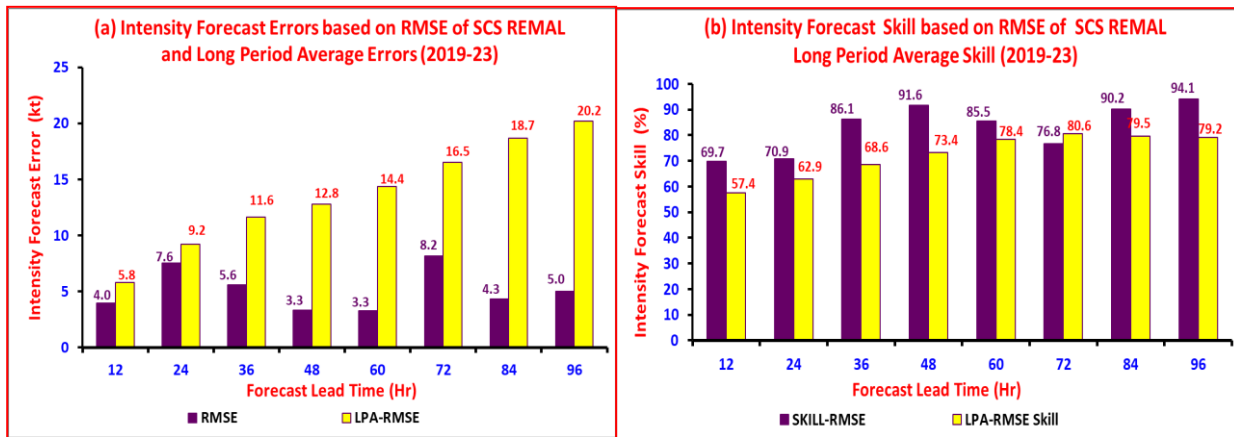


Fig. 12 (a): Intensity forecast errors (RMSE) and (b) skills against Persistence forecast compared to long period average (LPA: 2019-2023) errors & skills respectively

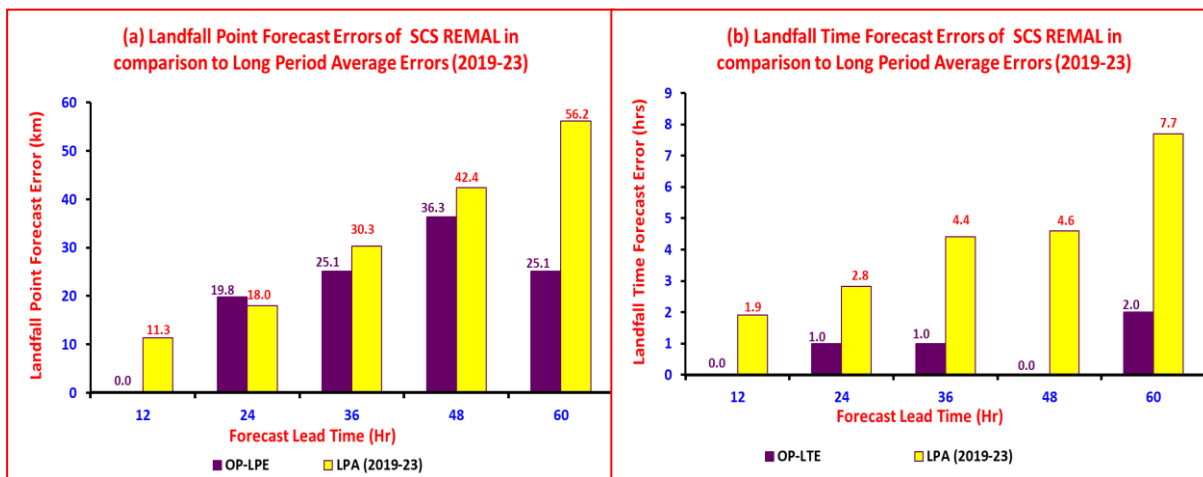


Fig. 13: (a) Landfall point and (b) time errors against the long period average (LPA: 2019-2023) errors

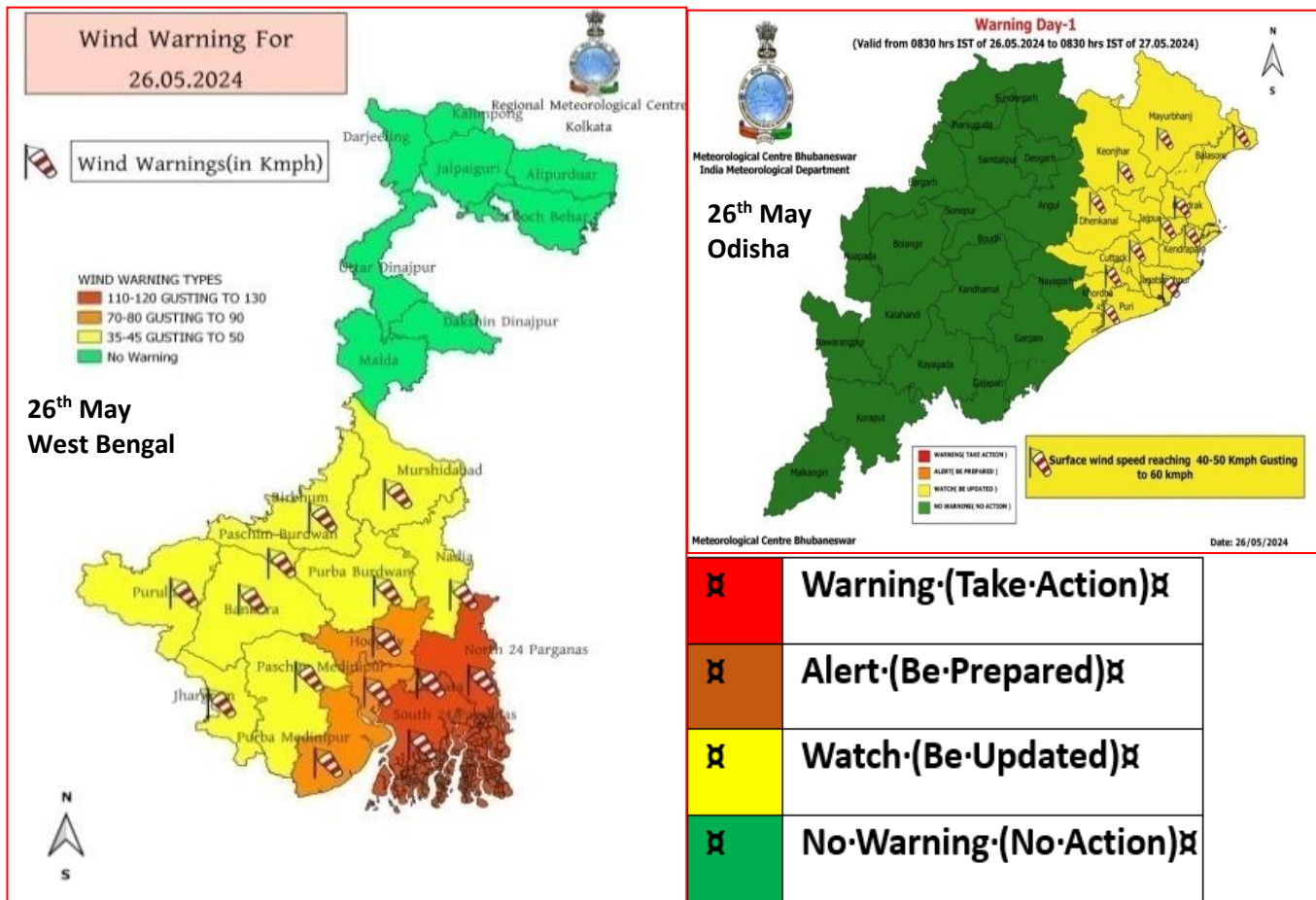


Fig. 14: Typical district-wise wind warnings for West Bengal & Odisha for 26th May

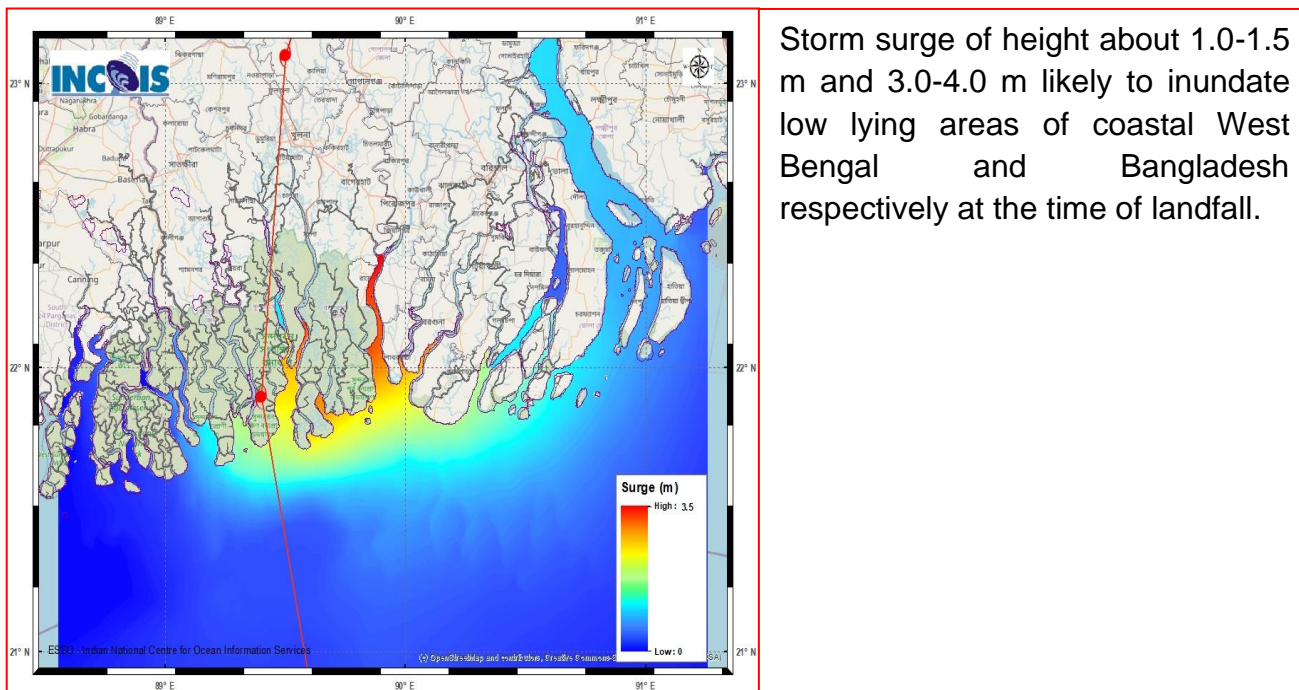


Fig. 15 a: Typical storm surge guidance issued on 24th May for West Bengal and Bangladesh coasts

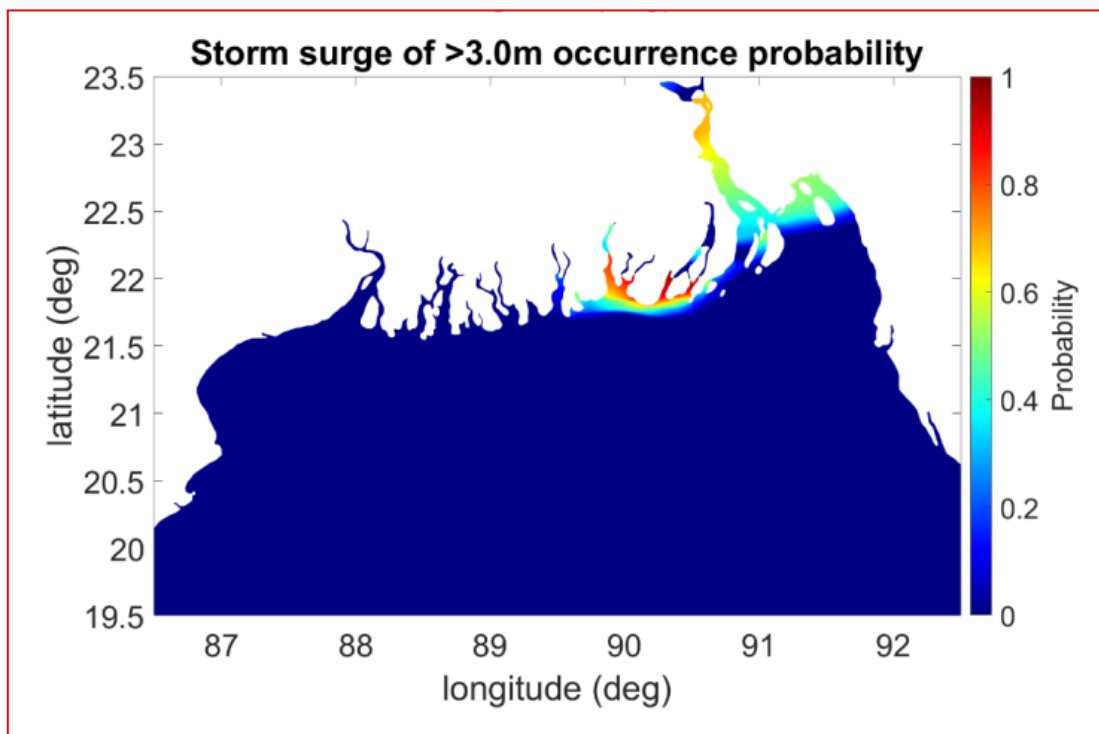


Fig. 15 b: Probabilistic Storm Surge during SCS REMAL

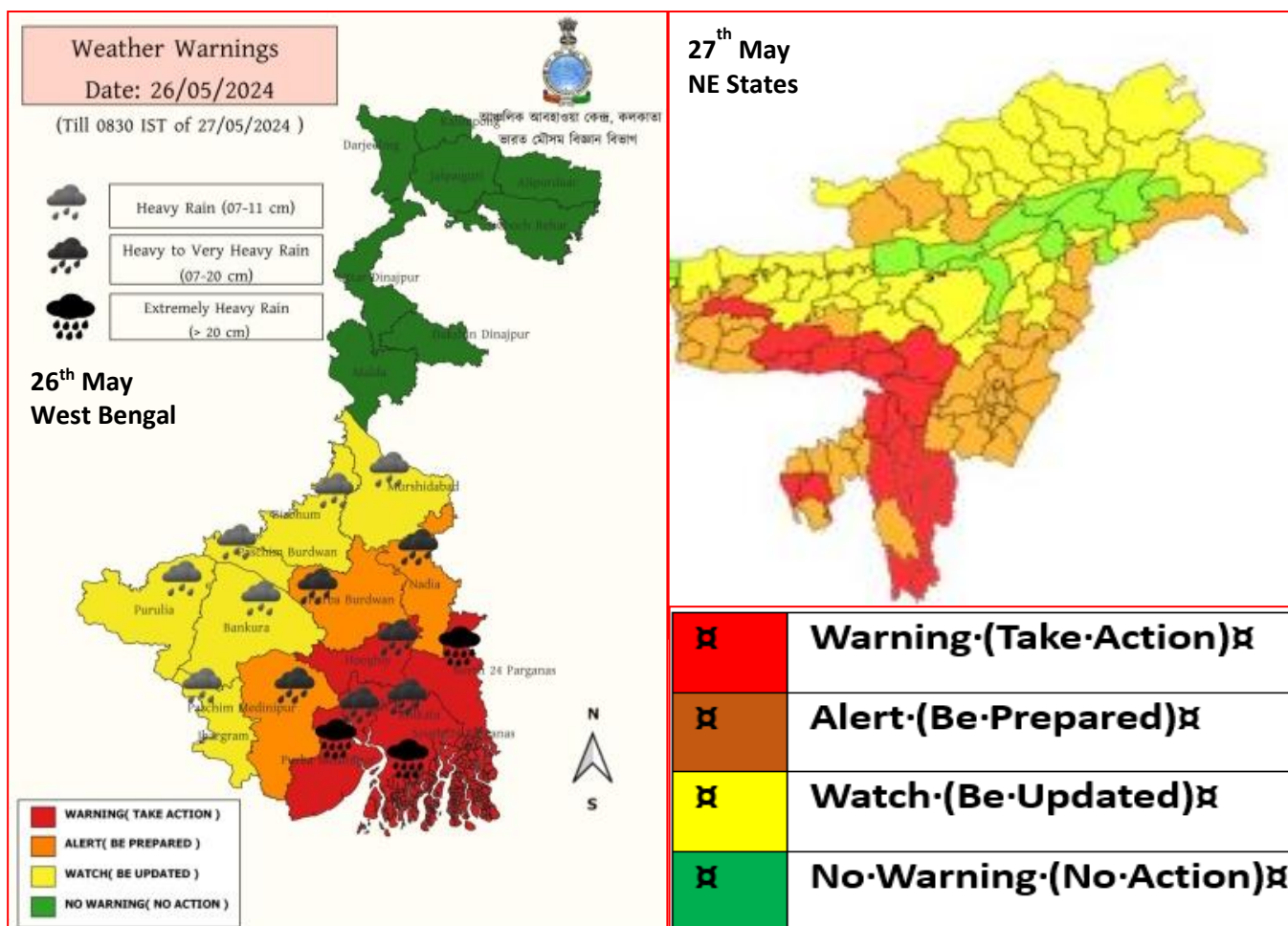
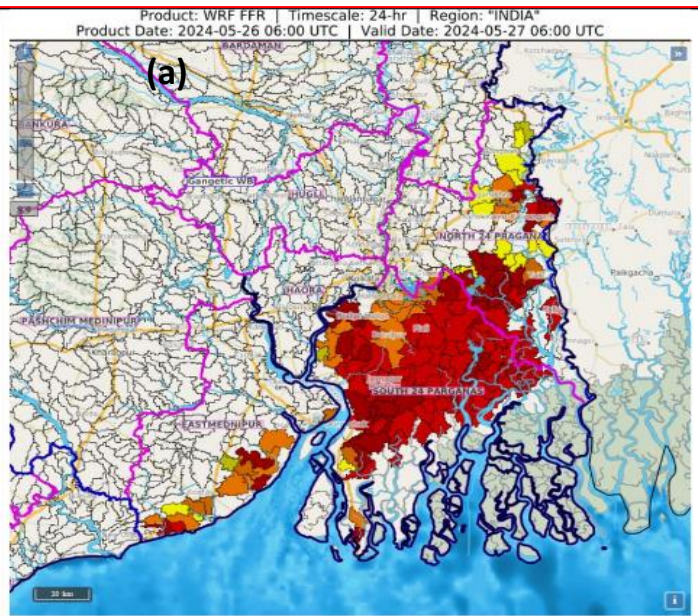


Fig. 16: Typical district-wise rainfall warnings for West Bengal and Northeastern states for 26th and 27th May respectively.

24 hours Outlook for the Flash Flood Risk (FFR) till 1130 IST of 27-05-2024 :

Low to Moderate flash flood risk likely over few watersheds & neighbourhoods of **extreme southern parts of Gangetic West Bengal** Met Sub-divisions during next 24 hours.

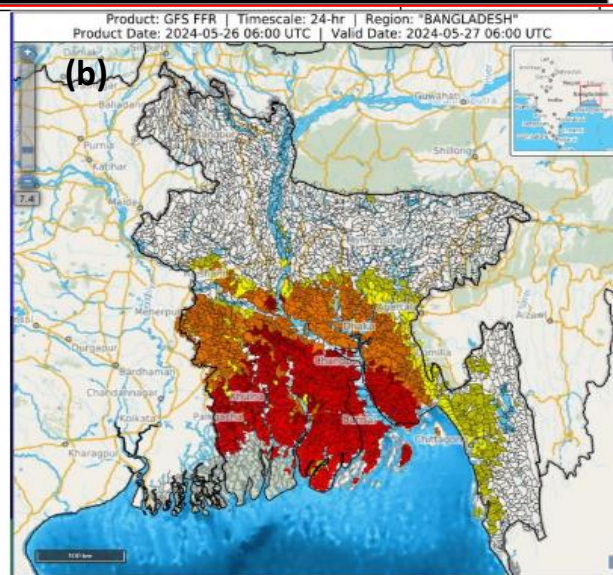
Surface runoff/ Inundation may occur at some fully saturated soils & low-lying areas over AoC as shown in map due to SCS Remal occurrence in next 24 hours.



24 hours Flash Flood Risk Outlook till 0600 UTC of 27.05.2024:

Moderate to High flash flood risk likely over few watersheds & neighbourhoods of **coastal region and adjoining southern parts of Bangladesh** (as indicated in adjacent map) during next 24 hours.

Surface runoff/ Inundation may occur at some fully saturated soils & low-lying areas over AoC as shown in map due to SCS Remal occurrence in next 24 hours.



24 hours Outlook for the Flash Flood Risk (FFR) till 0530 IST of 28-05-2024 :

Low to Moderate flash flood risk likely over few watersheds & neighbourhoods of **Assam & Meghalaya** and NMMT Met Sub-divisions during next 24 hours.

Surface runoff/ Inundation may occur on low lying areas due to persistent rainfall under the influence of impending Cyclonic Storm "Remal" in next 24 hours.

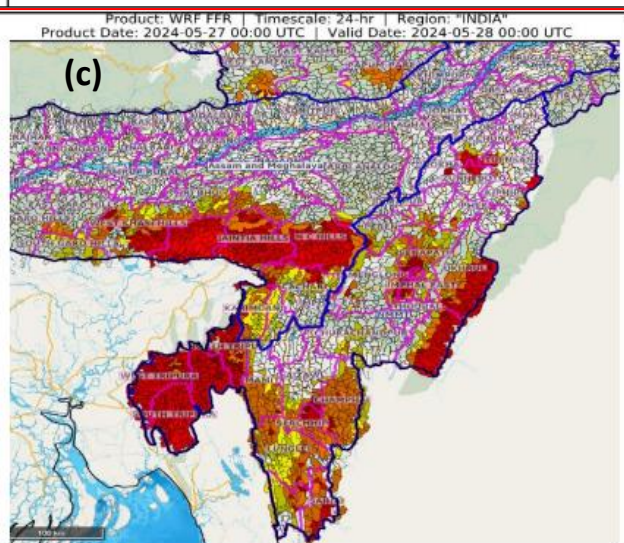


Fig. 17: Typical Flash Flood Guidance issued for (a) West Bengal & (b) Bangladesh issued on 0700 UTC of 25th May and (c) Northeastern States of India based at 0100 UTC of 27th May, 2024 valid for next 24 hours

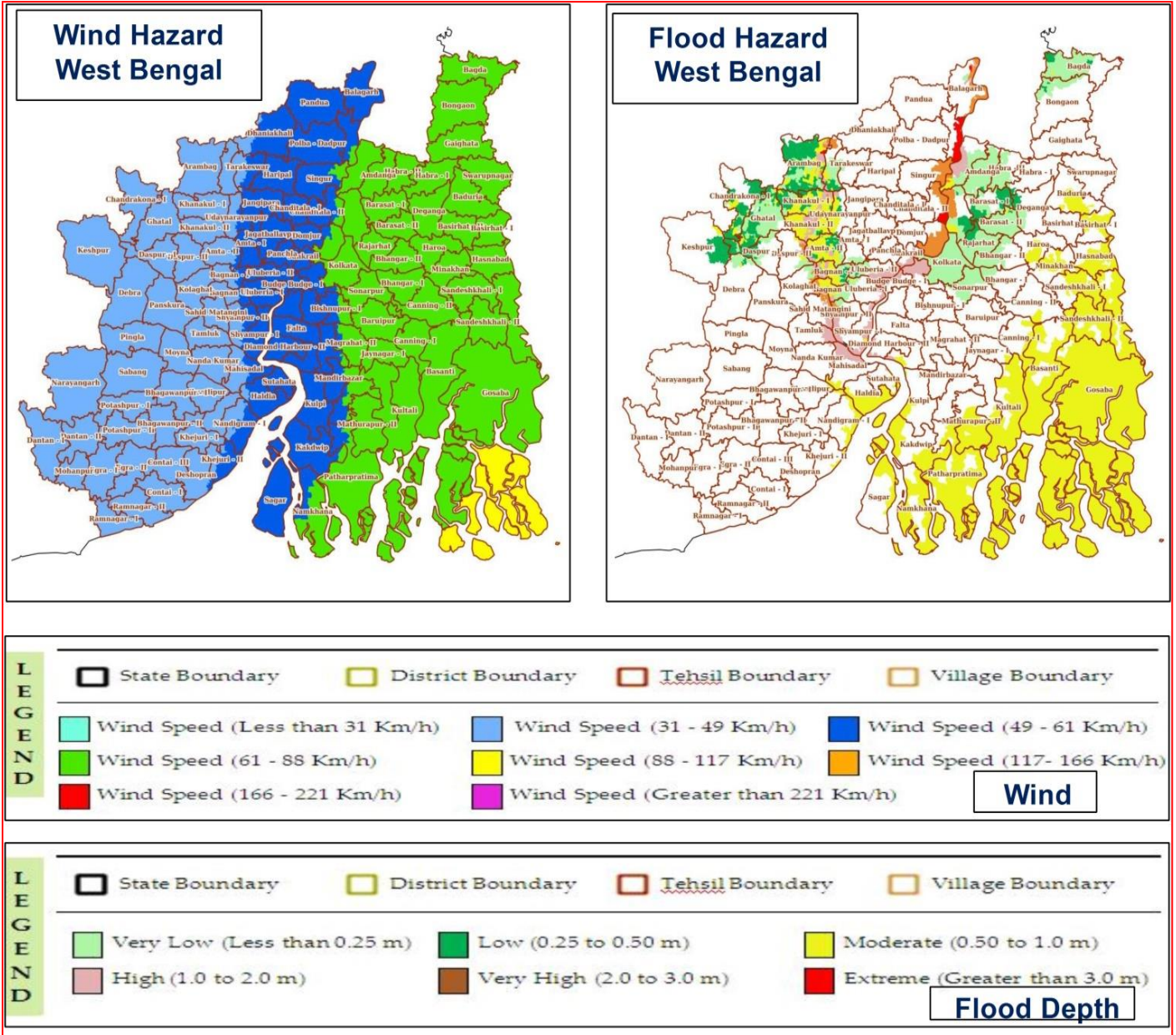


Fig. 18: Wind and Flood hazard maps at village level from Web based Dynamic Composite Risk Atlas based on 0600 UTC of 25th May track & intensity forecast by IMD

Fishermen Warning Graphics

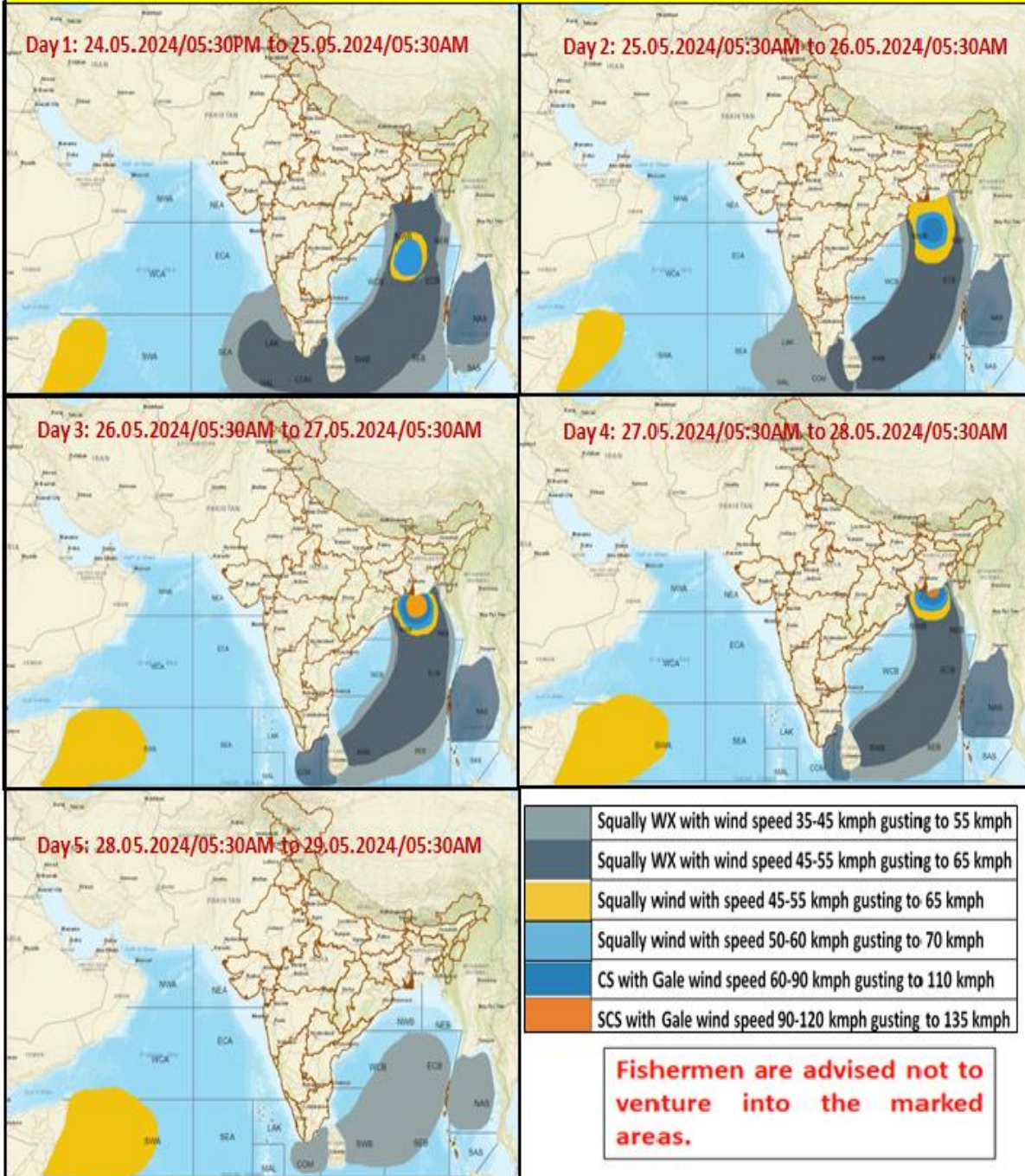


Fig. 19: Fishermen Warning graphics issued on 24th May, 2024 on formation of depression indicating the forbidden area for fishermen and expected wind speed over different regions of BoB

TABLE 4: CYCLONIC DISTURBANCE FORECAST FOR PORTS BASED ON 2330 hrs IST of 25th May,2024

SI	DESCRIPTION OF PORT NAME(LAT ^o N /LON ^o E)	LOCATION		CURRENT LOCATION FROM CENTRE OF CYCLONIC DISTURBANCE		FORECAST PARAMETERS WHEN THE CYCLONIC DISTURBANCE WOULD BE NEAREST TO THE PORT							
						DATE/TIME(IST) OF OCCURRENCE	DISTANCE OF CD FROM PORT	DIRECTION OF CD FROM PORT	MSW OVER PORT(KTS)	UNCERTAINTY IN		STORM SURGE	SIGNIFICANT WAVE HEIGHT (M)
		DISTANCE (KM)	DIRECTION	DISTANCE (KM)	MSW (KTS)								
ACWC Kolkata													
12.	Port Blair (11.67,92.5)	19.3	89.4	912	NNW	25.05.24/2330	912	SSE	<27	5	5	<4	Rough
13.	Sagar Island (21.72,88.1)	19.3	89.4	302	SSE	26.05.24/2030	124	W	49	20	10	6-10	High
14.	Haldia (22.02,88.06)	19.3	89.4	333	SSE	26.05.24/2330	128	W	49	25	10	6-10	High
15.	Kolkata Port (22.32,88.18)	19.3	89.4	359	SSE	26.05.24/2330	121	WNW	49	25	10	6-10	High
CWC Bhubaneswar													
16.	Checked out Gopalpur (19.27,84.92)	19.3	89.4	471	E	25.05.24/2330	471	W	<27	5	5	<4	Rough
17.	Puri (19.81,85.83)	19.3	89.4	379	E	26.05.24/0830	373	W	<27	10	5	<4	Rough
18.	Paradip (20.27,86.67)	19.3	89.4	306	ESE	26.05.24/1130	278	W	33	15	5	4-6	Very Rough
19.	Dhamra (20.78,86.97)	19.3	89.4	303	ESE	26.05.24/1130	243	W	33	15	5	4-6	Very Rough

Fig.20: Customised Location specific bulletin for Ports

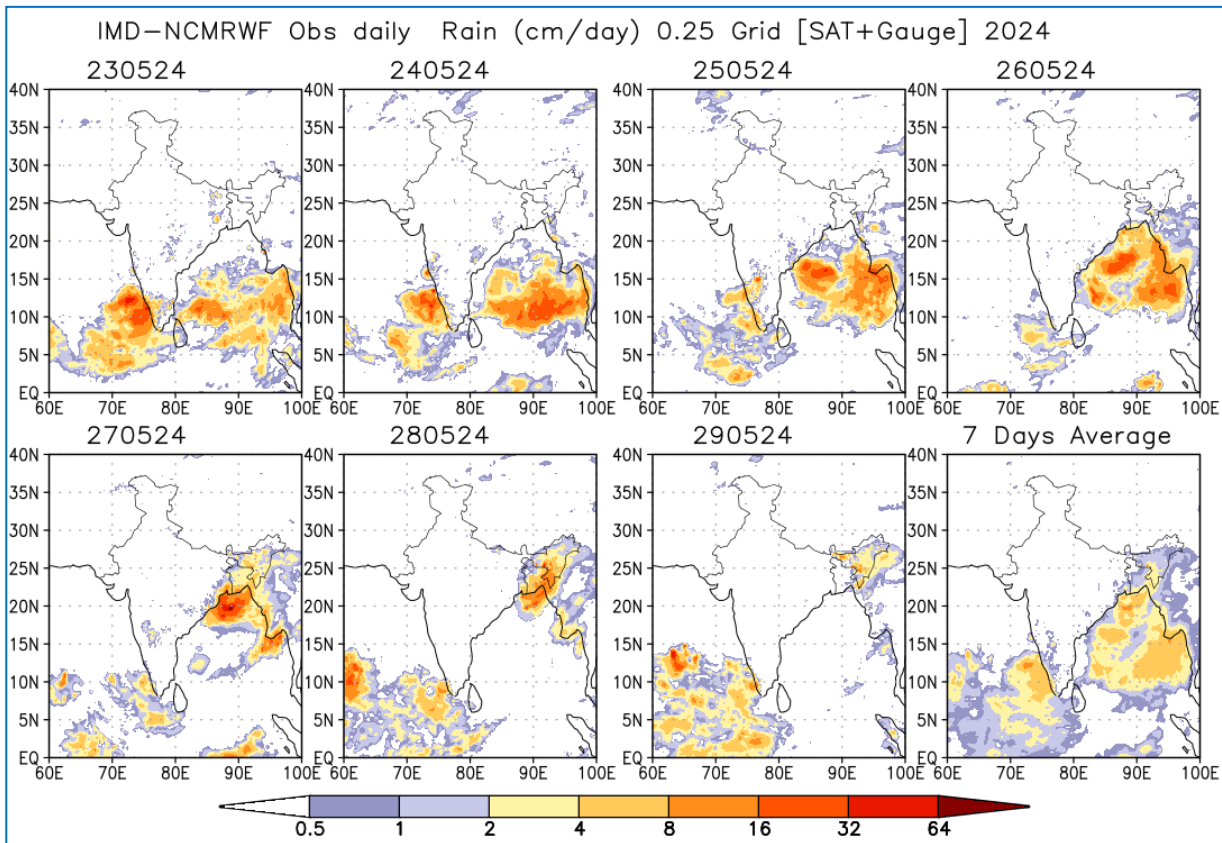


Fig. 21: NCMRWF-IMD satellite gauge merged data plots of 24 hours accumulated realized rainfall ending at 0830 IST of 23rd May to 29th May, 2024

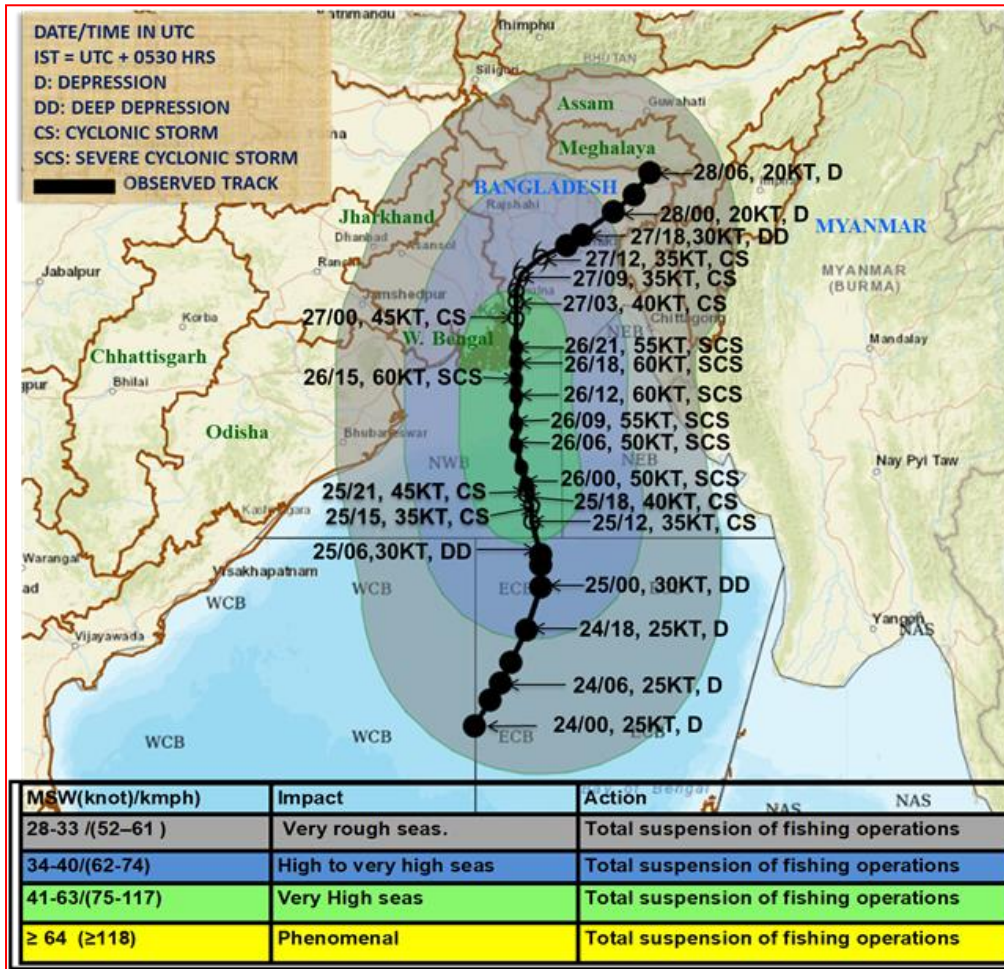


Fig. 22: Estimated maximum sustained wind during the life cycle of SCS REMAL

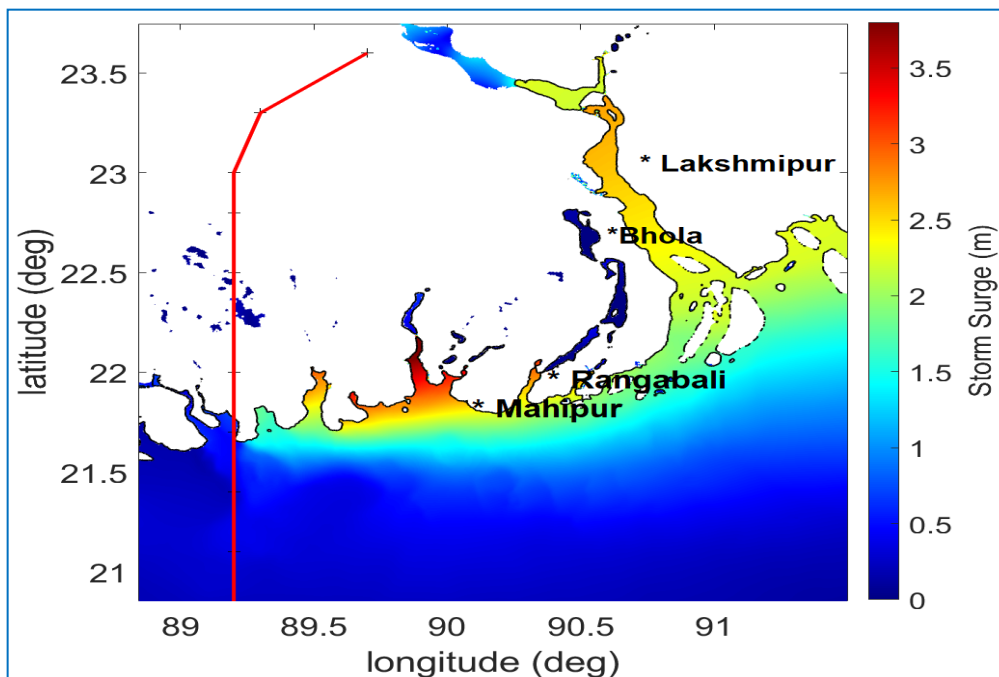


Fig.23: Estimated storm surge based on best track parameters of SCS REMAL



Fig. 24(a) Cyclone Remal leaves trails of destruction in coastal Bangladesh (ddindia.co.in, 27th May, 2024), (b) Cyclone Remal made landfall in Bangladesh on May 26, 2024 (edition.cnn.com, 26th May, 2024), (c) Bangladesh's coastal districts devastated by SCS Remal (asinews.it, 28th May, 2024), (d) West Bengal damaged by Cyclone Remal (economictimes.indiatimes.com, 27th May, 2024), (e) Remal flattened fragile structure in West Bengal (ET 28 May, 2024) and (f) Rescue team clearing fallen tress in West Bengal (Air News Alerts, 28 May 2024)



Fig. 25: (a) A tree falls on a school bus in Sonitpur (indiatvnews.com, 28th May, 2024), (b) Landslides unearth hundreds of graves in Mizoram (eastmojo.com, 28th May, 2024), (c) A car damaged after a shed fell on it after the landfall of Cyclone Remal in Guwahati on Tuesday (indianexpress.com, 28th May, 2024), (d) A house damaged by the severe cyclonic storm, Remal (indiatvnews.com, 27th May, 2024)



Fig. 26: Damage over Northeastern states of India (a) Tree fell on a school bus killing students (Source: All India Media Association, 28 May) (b) Landslide due to SCS Remal (Source: East Mojo dated 28 May) (c) Uprooting of electric pole due to SCS Remal (d) Uprooting of tree and falling on bus due to SCS Remal (Source: All India Media Association, 28 May)