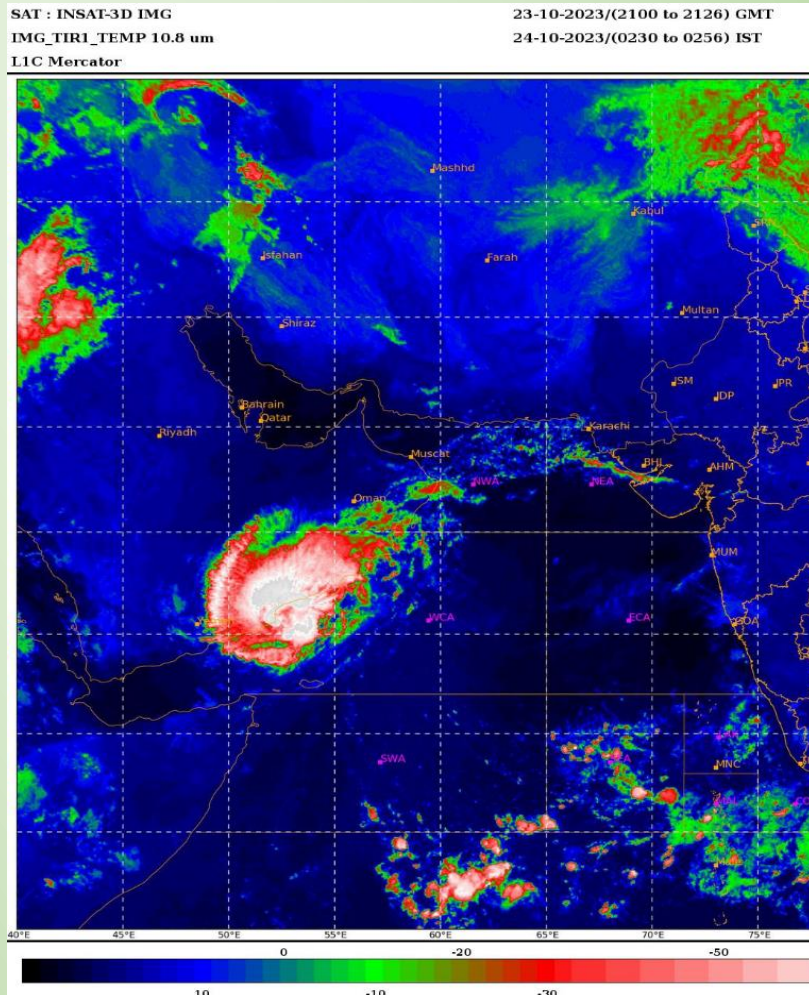




Extremely Severe Cyclonic Storm “TEJ” over the Arabian Sea (20th-24th October, 2023): A Report



Typical satellite imagery during landfall of extremely severe cyclonic storm “TEJ” at 2100 UTC of 23rd October (0230 IST of 24th October 2023)

Cyclone Warning Division
India Meteorological Department
New Delhi

Extremely Severe Cyclonic Storm “TEJ” over the Arabian Sea (20th-24th October, 2023): A Report

1. Life History of “TEJ”:

- An upper air **Cyclonic Circulation** formed over the Lakshadweep and adjoining southeast Arabian Sea (AS) on 15th October. It gradually moved west-northwestwards and lay over southeast AS and adjoining Lakshadweep on 17th October.
- Under its influence a **Low Pressure Area** formed over southeast and adjoining eastcentral AS in the early morning (0530 hrs IST/0000 UTC) of 18th October, 2023.
- It lay as a **Well Marked Low pressure Area (WML)** over southwest Arabian Sea in the midnight (2330 hours IST) of 19th Oct over the same region.
- It concentrated into a **Depression (D)** over southwest AS in the morning (0530 hrs IST/0000 UTC) of 20th October and lay centered about 1280 km east-southeast of Al Ghaidah.
- It moved west-northwestwards and intensified into a **Deep Depression (DD)** in the evening (1730 hrs IST/1200 UTC) of 20th October 2023 over southwest AS and lay centred about about 1240 km east-southeast of Al Ghaidah.
- Continuing to move further west-northwestwards, it intensified into the **Cyclonic Storm (CS)** “TEJ” pronounced as “TEJ” in the early morning (0530 hrs IST/0000 UTC) of 21st October 2023 over southwest AS and into a severe cyclonic storm (SCS) in the same afternoon (1130 hrs IST/0600 UTC) over the same region.
- From 21st afternoon (1430 hrs IST/0900 UTC), it started moving northwestwards and intensified into a **Very Severe Cyclonic Storm (VSCS)** in the night (2030 hrs IST/ 1500 UTC) of 21st October over the same region.
- Moving further northwestwards, it intensified rapidly into an **Extremely Severe Cyclonic Storm (ESCS)** in the morning (0830 hrs IST/ 0300 UTC) of 22nd Oct over westcentral and adjoining southwest AS.
- “TEJ” exhibited rapid intensification during midnight (2330 hours IST/1800 UTC) of 21st to noon (1130 hours IST/0600 UTC) of 22nd October, reaching its peak intensity of 95 knots in the morning (0830 hours IST/0300 UTC) of 22nd October. It then maintained its intensity till early hours (0230 hours IST) of 24th Oct / 2100 UTC of 23rd Oct.
- Thereafter, it entered into an area with less ocean thermal energy and high vertical wind shear. It also experienced cold/dry air incursion from Arabian Peninsula. Under these unfavourable conditions, it gradually started weakening.
- Continuing to move northwestwards, it weakened into a **VSCS** in the morning (0830 hours IST/0300 UTC) of 23rd October over westcentral AS. Weakening trend further continued with land interactions and “TEJ” crossed Yemen coast close to South of Al Ghaidah in the early hours (between 0230 and 0330 hours IST) of 24th October (between 2100 and 2200 UTC of 23rd October) as a **VSCS** with intensity of 65 knots gusting to 75 knots (120-130 kmph gusting to 140 kmph).
- Thereafter, it moved nearly westwards and weakened rapidly into an **SCS** over coastal Yemen in the early morning (0530 hours IST/0000 UTC), into a CS over Yemen in the noon (1130 hours IST/0600 UTC), into a DD in the afternoon (1430 hours IST/0900 UTC), into a D in the evening (1730 hours IST/1200 UTC) and into a WML over Yemen in the night (2030 hours IST/1500 UTC) of 24th

- The observed track of the system is presented in **Fig. 1**. The best track parameters associated with the system are presented in Table 1.

Table1: Best track positions and other parameters of the Extremely Severe Cyclonic Storm TEJ over AS during 20th – 24th October, 2023

Date	Time (UTC)	Latitude	Longitude	CI No	ECP	MSW (kt)	ΔP	Category
20.10.23	0300	9.3	61.7	1.5	1004	25	4	D
	0600	9.3	61.5	1.5	1004	25	4	D
	1200	9.4	61.3	2.0	1003	30	5	DD
	1800	9.5	60.7	2.0	1002	30	6	DD
21.10.23	0000	9.9	59.4	2.5	1001	35	7	CS
	0300	10.1	58.8	3.0	998	45	10	CS
	0600	10.3	58.4	3.0	996	50	12	SCS
	0900	10.2	57.9	3.5	995	55	13	SCS
	1200	10.6	57.4	3.5	992	55	16	SCS
	1500	11.1	57.0	4.0	988	65	20	VSCS
	1800	11.3	56.6	4.5	980	75	28	VSCS
	2100	11.7	56.1	4.5	976	80	32	VSCS
22.10.23	0000	12.0	56.0	4.5	972	85	36	VSCS
	0300	12.3	55.4	5.0	964	95	44	ESCS
	0600	12.6	55.1	5.0	964	95	44	ESCS
	0900	12.9	54.7	5.0	964	95	44	ESCS
	1200	13.3	54.4	5.0	964	95	44	ESCS
	1500	13.6	54.1	5.0	964	95	44	ESCS
	1800	13.8	53.9	5.0	964	95	44	ESCS
	2100	14.1	53.6	5.0	966	95	42	ESCS
23.10.23	0000	14.4	53.5	5.0	968	90	40	ESCS
	0300	14.7	53.2	4.5	972	85	36	VSCS
	0600	15.0	52.9	4.5	976	80	32	VSCS
	0900	15.1	52.8	4.5	978	80	30	VSCS
	1200	15.4	52.7	4.0	981	75	27	VSCS
	1500	15.6	52.5	4.0	984	70	24	VSCS
	1800	15.8	52.3	4.0	986	70	22	VSCS
	2100	15.9	52.2	4.0	988	65	20	VSCS
24.10.23		Crossed Yemen coast close to south of Al Ghaidah between 2100 UTC and 2200 UTC near (15.90N/52.15E)						
	0000	15.9	52.1	-	990	60	18	SCS
	0300	16.0	51.8	-	996	50	12	SCS
	0600	16.1	51.5	-	1000	40	8	CS
	0900	16.1	51.3	-	1002	30	6	DD
	1200	16.2	51.0	-	1004	25	4	D
	1500	Weakened in a WML area over Yemen						

ECP: Estimated Central Pressure, C.I. No.: Current Intensity No., ΔP : Pressure drop at centre,

Kt: Knots, 1 kt= 1.85 kmph, MSW: Maximum Sustained surface Wind

2. Salient Features

- (i) It was the first cyclone of the post-monsoon season 2023 and second cyclone of the year over AS.
- (ii) It was the third cyclone to make landfall in Yemen after VSCS Luban in 2018 and CS Sagar in 2018 since 1965.
- (iii) **Twin cyclones** “TEJ” during 20th -24th October and “HAMOON” during the 21st - 25th October, 2023 developed over the AS and Bay of Bengal (BoB) simultaneously. Such simultaneous occurrence of cyclones over both the basins is one of the rare events. In past last such activity was observed in 2019, with development of Super Cyclonic Storm Kyarr (30th October-2nd November) & Maha (30th October-7th November) over AS and Bulbul (5th-7th November) over the Bay of Bengal. Kyarr & Maha weakened over sea and Bulbul crossed West Bengal coast. Similar activity was also observed in 2018 with formation of VSCS Luban (6-15 October, 2018) that crossed Yemen and adjoining Oman coasts and VSCS Titli (8-13 October) that crossed north Andhra Pradesh and south Odisha coasts on 11th October, 2018. Prior to 2018, this activity was observed in 1977 with simultaneous formation of two VSCSs in November, 1977, viz. (i) Bay of Bengal Super Cyclonic Storm (14-20 Nov., 1977) which crossed Andhra Pradesh coast near Chirala on 19th Nov. and (ii) Bay of Bengal VSCS (09th -23rd Nov., 1977) which crossed Tamil Nadu coast close to south of Nagapattinam on 12th Nov. and then emerged into Arabian Sea, made a looping track, intensified into an SCS, weakened thereafter and crossed Karnataka coast to the north of Mangalore on 29th Nov. as a depression. The tracks of these twin cyclones are shown in **Fig 2**.
- (iv) Climatologically, about 66 cyclones (MSW \geq 62 kmph) developed over the AS (**Fig. 3a**) during 1965-2022. Out of these 13 crossed Arabia-Africa coasts during the period with 3 crossing Yemen, 2 Somalia, 6 Oman, 1 Iran and 1 Pakistan (**Fig. 3b**).
- (v) **Movement:** “TEJ” initially moved west-northwestwards till afternoon (1430 hours IST/0900 UTC) of 21st. Thereafter, it moved northwestwards till 0000 UTC of 23rd, north-northwestwards till landfall (2100 UTC of 23rd) and thereafter, nearly westwards (**Fig.1 and Fig.4a**). “TEJ” moved along the periphery of ridge near 14°N in association with anticyclone over central Arabian Sea and thus exhibited initial west-northwestwards movement, followed by northwestwards and then north-northwestwards movement prior to landfall. As it moved away from the anticyclone, it moved nearly westwards after landfall. It moved with a 6-hourly average translational speed of 14.4 kmph.
- (vi) **Rapid intensification and rapid weakening:**
This system exhibited unique feature in terms of its intensification. It exhibited Rapid Intensification (RI) process during midnight (1800 UTC/ 2330 hours IST) of 21st October and evening (1200 UTC/1730 hours IST) of 22nd October. The maximum sustained wind speed (MSW) increased from 35 kts at 0530 hrs IST/0000 UTC of 21st to 85 kts at 0530 hrs IST/0000 UTC of 22nd and further to 95 kts at 0830 hrs IST/0300 UTC of 22nd October. Thus, **MSW increased by 50 knots in 24 hours** ending at 0530 hrs IST of 22nd October (**Fig. 4b**). The process continued till 1200 UTC of 22nd October. Rapid intensification was observed mainly because “TEJ” traversed in a region with low vertical wind shear, higher sea surface temperature and higher ocean heat content. Also, there was increased warm moist air incursion in the core of the system and strong outflow in upper levels over southwest AS that supporting rapid intensification of the system. Thereafter, from 2100 UTC of 22nd, it entered into an unfavourable environment with colder sea conditions, higher vertical wind shear, gradually increasing cold dry entrainment into the core from Arabian Peninsular region. All these features led to weakening of the system and the system crossed Yemen coast as a VSCS with MSW of 65 knots gusting to 75 knots (120-130 kmph gusting to 145 kmph) during 2100 – 2200 UTC of 23rd October. Thereafter, the system weakened rapidly over land

registering a fall in MSW to 25 knots at 1200 UTC of 24th from 75 knots at 1200 UTC of 23rd, a fall in MSW by 50 knots in 24 hours. Over the sea, there was rapid weakening during 2100 UTC of 22nd to 2100 UTC of 23rd with decrease in intensity from 95 kt to 65 kt (by 30kt).

In recent years, similar kind of rapid intensification was observed in Super Cyclonic Storm Amphan over Bay of Bengal in May, 2020 (registering an increase of about 65 knots in 24 hours). Other recent cyclones over AS region like Kyarr in 2019 and Tauktae in 2021 registered an increase of 35 knots in 24 hours.

(vii) Double Eyewall Formation and Eyewall Replacement Cycle:

During the period 0300 UTC to 1200 UTC of 22nd October, the system exhibited double eyewall formation followed by eyewall replacement **cycle**. Eyewall replacement cycle was completed at 1200 UTC of 22nd October (**Fig.5**).

(viii) Maximum sustained wind speed and estimated central pressure:

The system reached its peak intensity of 95 knots at 0300 UTC of 22nd October and maintained its peak intensity till 2100 UTC of 22nd October. The lowest estimated central pressure of 964 hPa with pressure drop of about 44 hPa was observed during the period of 0300 UTC to 1800 UTC of 22nd October.

(ix) Track length:

The track length of "TEJ" was 1435 km against the normal of 1460 km during post-monsoon season over Arabian Sea based on data of 1990-2020, thus near normal.

(x) Average Life Period:

The average life period (D to D) of "TEJ" was 4 & 12 hours against the normal of 4 days & 11 hours for VSCS category over the AS during post monsoon season.

(xi) 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 10.0×10^2 knots, 7.69×10^4 knots² and 6.23×10^6 knots³ respectively against normal of 15.73×10^2 knots, 12.13×10^4 knots² and 10.22×10^6 knots³ for ESCS category over AS for post monsoon season during the period 1990-2020. Thus, its damage potential and loss were less than normal due to an ESCS over the AS during post-monsoon season.

3. Monitoring of ESCS, "TEJ"

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored since 12th October, about 8 days prior to formation of depression on 20th October and 11 days prior to the landfall of system over Yemen coast. The information about the system was first released in the weekly extended range outlook issued by IMD on 12th October (**Fig. 6a**), indicating formation of depression over southeast AS during the week 2 (20-26 October, around 20th October with low probability (1-33%). Further, the extended range outlook issued on 19th October (**Fig. 6b**), indicated formation of depression around 20th October with high probability (68-100%) about 1 day ahead of formation over southwest AS and 5 days in advance of landfall over Yemen.

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 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. which was further value added to arrive at consensus forecast by considering various prognostic & diagnostic features, observational features, initial conditions and consistency of individual models etc. A 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) are presented in **Fig.7**. The INSAT 3D imageries during entire life cycle of the system, ASCAT and microwave imageries are placed in Annexure to this report.

4. Operational Forecast Performance:

i) Pre-Genesis Forecast performance

- ❖ First information about likely cyclogenesis over south AS during the week (20th -26th Oct), around 20th was issued in the extended range outlook issued on 12th Oct. about 8 days prior to formation of depression on 20th Oct. (**Fig. 6a**)
- ❖ The tropical Weather Outlook issued on 14th Oct. indicated likely formation of an upper air cyclonic circulation around 15th, low pressure area around 17th and depression around 20th. Since then the Daily Tropical Weather Outlooks issued indicated formation of depression over AS around 20th (**Fig. 8**)
- ❖ Actually, a cyclonic circulation formed over Lakshadweep & adjoining southeast AS on 15th Oct., low pressure area formed over southeast & adjoining southwest AS on 18th and depression over southwest AS on 20th October. The cyclogenesis (formation of depression) was predicted 8 days ahead.
- ❖ The daily report under Tropical Cyclone Forecasting Programme (TCFP) for North Indian Ocean issued on 15th Oct., gave detailed discussion of environmental features prevailing over the AS and BoB and guidance from various models. Since 15th Oct., onwards, the system was continuously monitored and discussed in TCFP report.

ii) Operational track, intensity and landfall forecast performance

- ❖ The first advisory issued on formation of depression on 20th October indicated landfall over Oman & adjoining Yemen coasts around 2100 UTC of 24th (0230 IST of 25th) October with intensity of 40 knots. Peak intensification was indicated as 55 knots.
- ❖ Regular 6/3 hourly warnings were provided since then till the weakening of system into a well-marked low pressure area.
- ❖ The subsequent advisory based on 0000 UTC (0530 IST) of 22nd Oct. indicated shifting of track slightly southwards and cyclone crossing Yemen-Oman coasts with intensity of 70 knots.
- ❖ The forecast based on 0600 UTC (1130 IST) of 22nd indicated, crossing of cyclone over Yemen close to Al Ghaidah with MSW of 70 knots gusting to 80 knots around midnight (1800-2100 UTC) of 23rd October (about 2 days and 15 hours ahead of landfall). Observed and forecast track & intensity issued based on 0600 UTC (1130 IST) observations of 22nd October about 2 days and 15 hours ahead of landfall are presented in **Fig.9**.
- ❖ The track forecast errors for 12, 24, 48 and 72 hrs lead period were 43, 68, 127 and 206 km respectively against the long period average (LPA) errors (2018-22) of 46, 74, 112, and 153 km respectively (**Fig. 10a**). For all lead periods upto 48 hours, the operational track forecast errors were comparable to LPA errors. The skill in track forecast (**Fig. 10b**) was comparable to LPA skill upto 48 hours lead period. The track forecast skill for 12, 24, 48 and 72 hrs lead

period was 57, 65, 70 and 66% respectively against the long period average (LPA) errors (2018-22) of 61, 65, 77, and 78% respectively. The operational 48 hrs track forecast error was higher, as “TEJ” had a multiple recurvatures and rapid intensification. Both the situations adversely affect the forecast. Studies show that track & intensity are correlated. Increased error in track lead to increased error in intensity prediction and vice-versa. Similarly recurving tracks are difficult to predict compared to straight moving cyclones.

- ❖ The absolute error (AE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 12.1, 19.5 and 22.5 knots against the LPA errors of 7.4, 10.5 and 14.0 knots during 2018-22 respectively (**Fig.11a**). The skill in intensity forecast based on AE for 24, 48 and 72 hrs lead period was 47, 72 and 65% against the LPA skill of 55, 74 and 77% during 2018-22 respectively (**Fig.11b**). The intensity forecast errors were higher than LPA as the impact of approaching trough in westerly that provided favourable environment for rapid intensification of the system could not be captured by the models. However, the errors for longer lead period (96 and 120 hrs) are comparable, as the weakening of the system prior to landfall was well captured based on environmental conditions and also by the models.
- ❖ The root mean square error (RMSE) of intensity (wind) forecast for 24, 48 and 72 hrs lead period were 14.9, 25.9 and 24.6 knots against the LPA errors of 9.3, 13.1 and 16.8 knots during 2018-22 respectively (**Fig.12a**). The skill in intensity forecast based on RMSE for 24, 48 and 72 hrs lead period was 51, 70 and 71% against the LPA skill of 42, 61 and 73% during 2018-22 respectively (**Fig.12b**).
- ❖ The landfall point forecast errors for 24, 48 and 72 hrs lead period were 23.1, 45.6, 109.7 km respectively against the LPA errors (2018-22) of 26.2, 39.9 and 75.7 km during 2018-22 respectively (**Fig.13a**). **The landfall point forecast errors were less than the LPA upto a lead period of 36 hours, comparable for 48 hrs and higher than LPA error for 72 hrs lead period.**
- ❖ The landfall time forecast errors for 24, 36, 48 and 72 hrs lead period were 1.0, **zero, 8** and 27 hours respectively against the LPA errors (2018-22) of 2.8, 4.3, 4.5 and 8.0 hours during 2018-22 respectively (**Fig.13b**). For all lead periods less than 36 hours, the landfall time errors were appreciably less than LPA errors. For 36 hours lead period, there was zero error in landfall time prediction and error was higher for 72 hrs lead period.

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... +96 hrs lead period commencing from 20th October till the system weakened into an LPA. The above forecasts were issued from the stage of depression along with the cone of uncertainty in the track forecast once daily, five times a day during depression and every three hours during the cyclone period.
- **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 alongwith cone graphics, commencing from 20th October.
- **Adverse weather warning bulletins:** The tropical cyclone forecasts alongwith expected adverse weather like gale wind, state of sea for Arabian Sea (south & central) 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 Agency (NDMA) for all concerned states along the west coast of India including Lakshadweep Islands, Kerala, Karnataka, Maharashtra, Goa & Gujarat. The bulletins also contained the suggested action for disaster managers and general public in particular for fishermen, ports and off & along shore activities. These bulletins were also issued to Defence including Indian Navy & Indian Air Force, NDRF, Indian Coast Guard, ports, Shipping, fishery, Railways, surface transport and aviation authorities. From cyclone "TEJ" the advisories for winds & sea condition over south & central AS were also provided to WMO and WMO/ESCAP PTC member countries including Oman and Yemen.

- **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 alongwith colour codes in the website.
- **Warnings and advisories 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.
- **Press Conference, Press release and Media briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website, video capsule by DGM and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services Division at New Delhi and bulletins for maritime interest were issued by Area cyclone warning centres of IMD at Mumbai, Cyclone warning centres at Thiruvananthapuram & Ahmedabad, Meteorological Centra Goa & Karnataka to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen for deep Sea of Arabian Sea were issued since 16th October.
- **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.
- **Diagnostic and prognostic features of cyclone:** The prognostics and diagnostics of the systems were described in the RSMC bulletins since 20th Oct and in daily cyclone forecasting programme report commencing from 15th Oct.
- **Director General of Meteorology** addressed media through press conference. Short video capsule on the status of TEJ was also issued by DG IMD for all stakeholders. It was also sent to Yemen and Oman.

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	(A) National Bulletin (B) Special Message	34 2	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, Ministry of Science & Technology, Secretary MOES, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, PIB MOES, UNI, DG National Disaster Response Force, Director, Punctuality, Indian Railways, Chief Secretary: Government of Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman & Diu, Dadra and Nagar Haveli
2	RSMC Bulletin	37	1. IMD's website 2. WMO/ESCAP member countries through GTS and E-mail.
3	GMDSS Bulletins	16	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	17	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	17	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.
6	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) 4,19,581 to General Public and disaster managers along the west coast of India by IMD Headquarters
7	Warnings through Social Media	Daily	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).
8	Press Release	7	Disaster Managers, Media persons by email and uploaded on website
9	Press Briefings	Daily	Regular briefing daily
10	Hourly Bulletin	-	-

8. Realized Weather

As estimated the MSW of 120-130 kmph gusting to 145 kmph (65 knots gusting to 75 knots) were observed during landfall. The estimated MSW and wind distribution in different quadrants during the life cycle of ESCS TEJ is presented in **Fig. 14**.

IMD predicted storm surge of height 2.0-2.5 m to inundate the low lying areas of Yemen between Al Ghaydah and Faydami. The estimated surge is presented in **Fig.15**. The estimated peak surge was about 1.5 m.

9. Damage report

As per media reports from Yemen, ESCS TEJ caused 2 deaths in Yemen. It caused widespread floods and power outages, extensive damage to buildings, cell phone towers, trees etc. in Yemen. Some damage photographs are presented at **Fig. 16**.

10. Acknowledgements:

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. India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge contribution from WMO and WMO/ESCAP member countries including Yemen and Oman. All the stake holders and disaster management agencies who contributed to the successful monitoring, prediction and early warning service of ESCS TEJ are also duly acknowledged. The support from various Divisions/Sections of IMD including Area Cyclone Warning Centre (ACWC) Mumbai, Cyclone Warning Centre Thiruvananthapuram, Ahmedabad, and Meteorological centres Bengaluru & Goa. Numerical Weather Prediction Division, Satellite and Radar Division, Surface & Upper air instruments Divisions, and Information System and Services Division of IMD are also duly acknowledged.

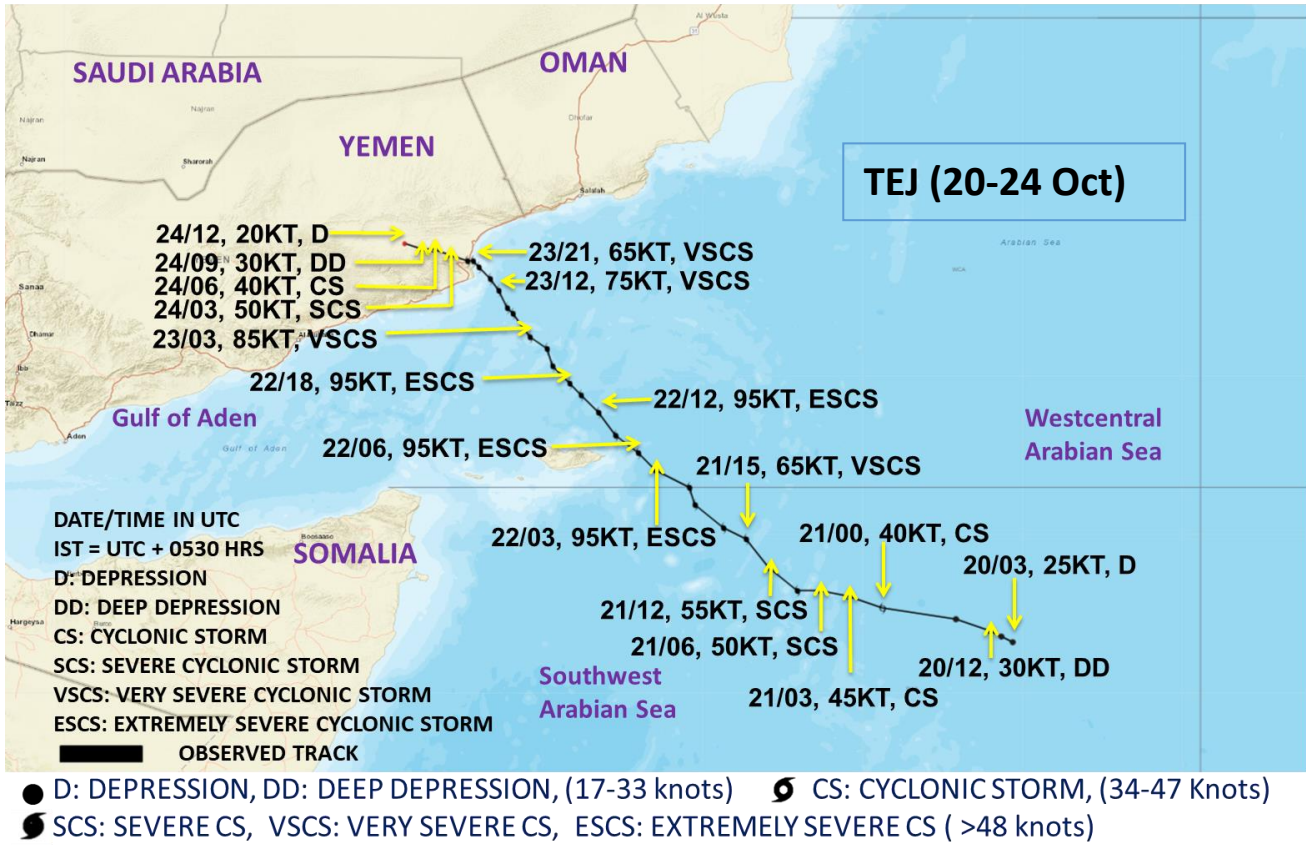


Fig. 1: Observed track of extremely severe cyclonic storm “TEJ” during 20-24 October, 2023

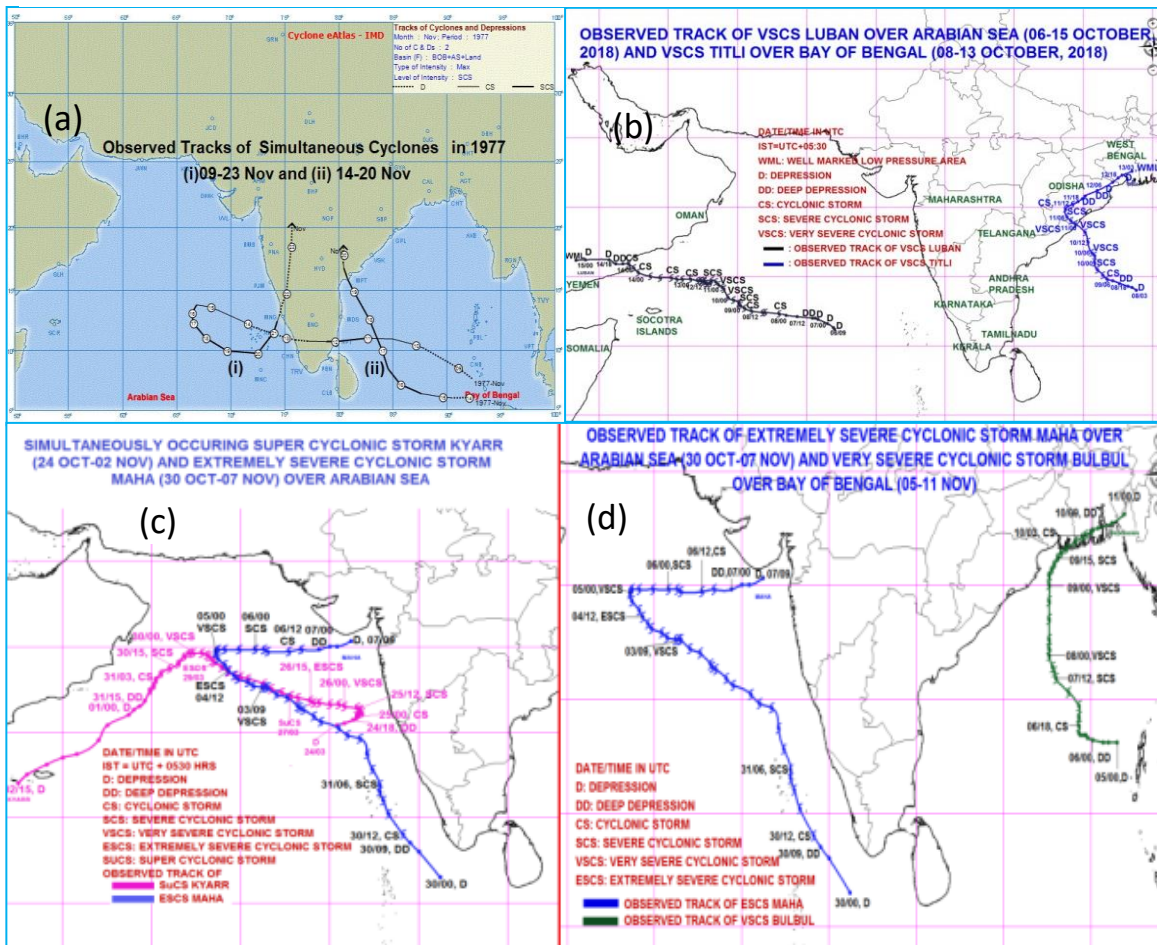


Fig. 2: Tracks of twin cyclones over the Arabian Sea and Bay of Bengal during (a) 1977, (b) 2018 and (c) 2019

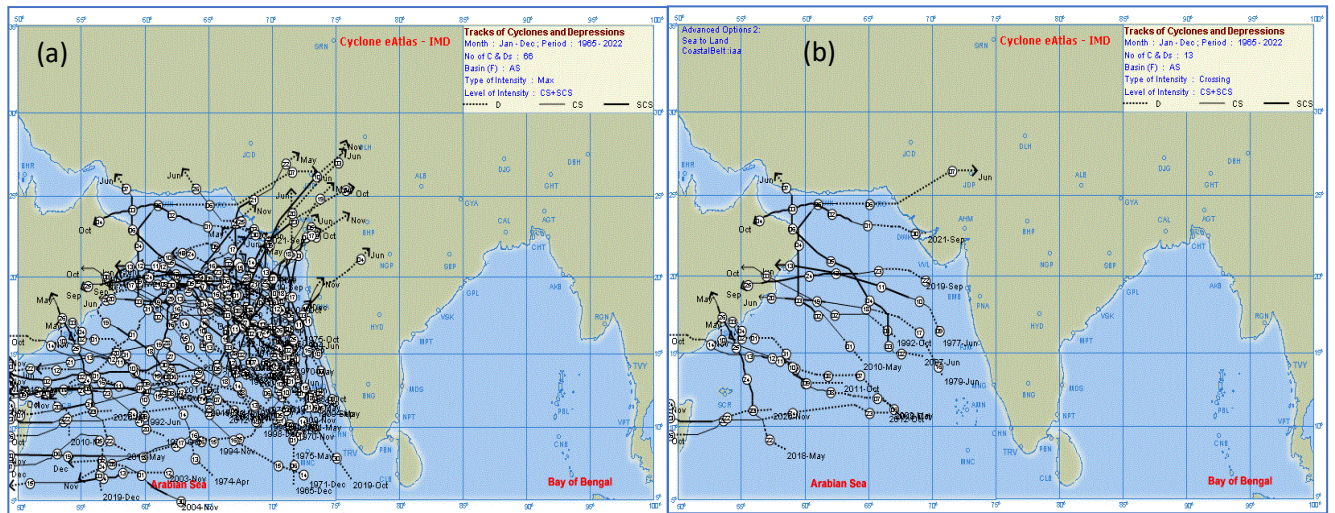


Fig. 3: (a) Tracks of cyclones (maximum sustained wind speed (MSW) \geq 34 knots) and (b) tracks of cyclones crossing Iran-Arabia-Africa region during the period 1965-2022

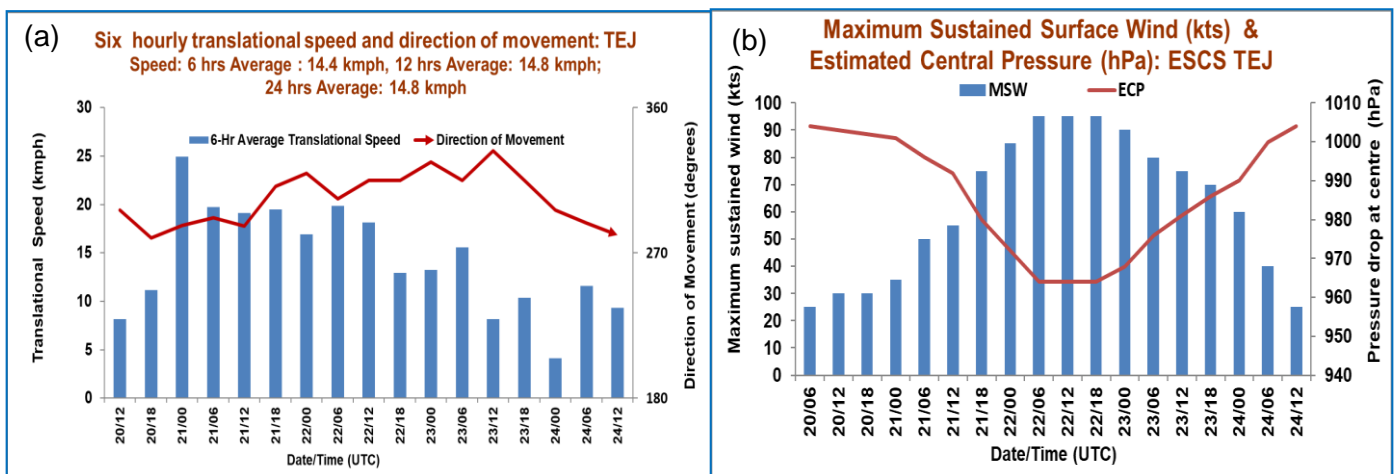


Fig. 4: (a) 6-hourly translational speed & direction of movement and (b) maximum sustained wind speed & estimated central pressure during life cycle of ESCS "TEJ"

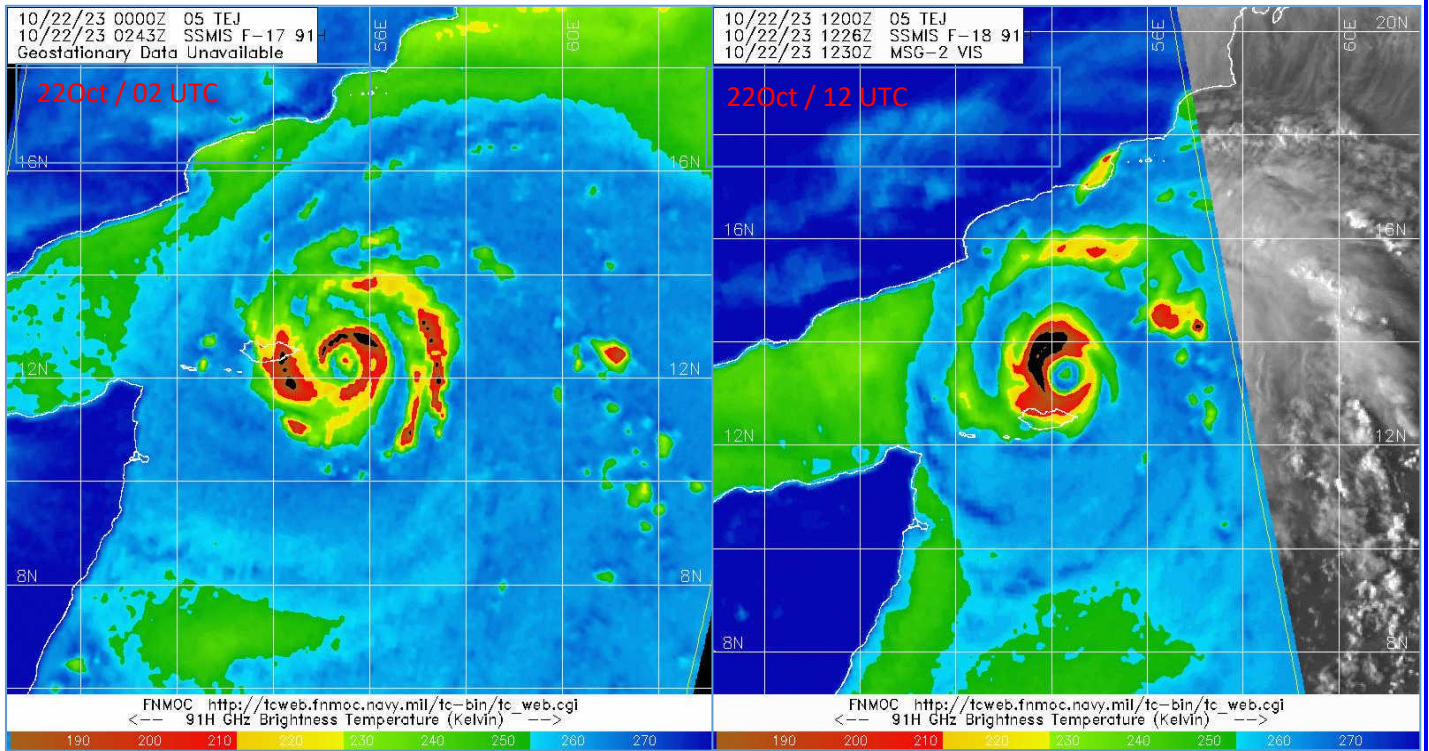


Fig. 5: Satellite imagery showing double eye-wall pattern during life cycle of ESCS “TEJ”

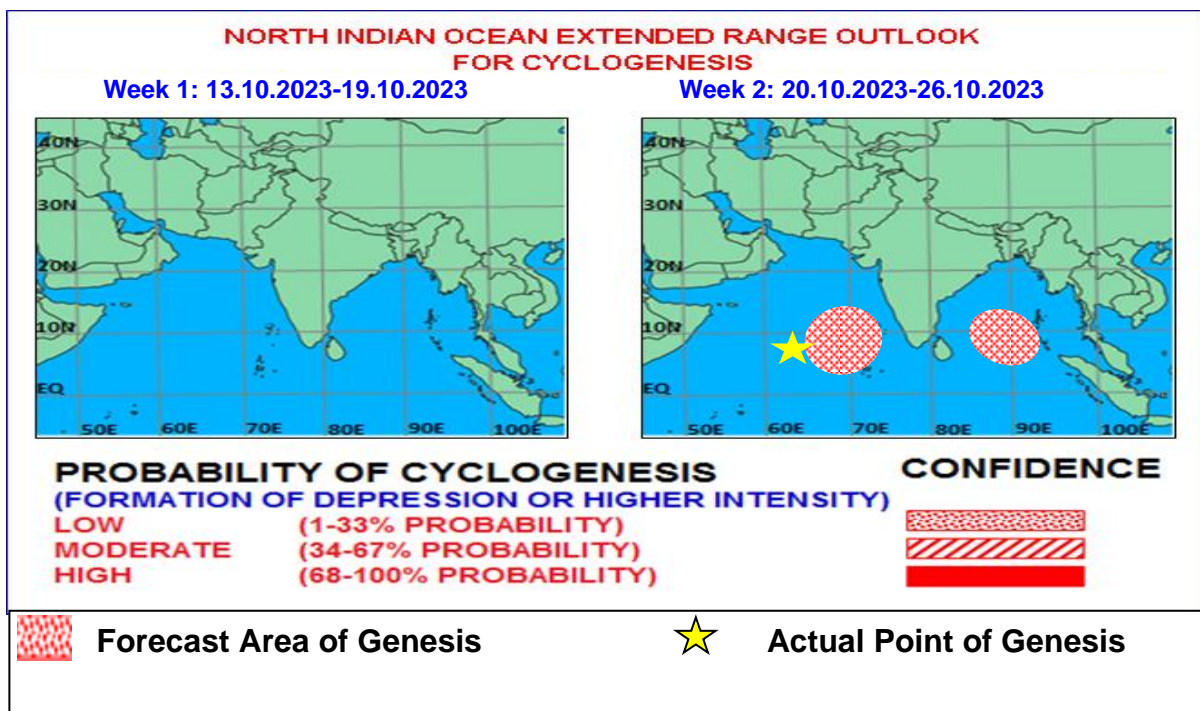


Fig. 6(a): Weekly extended range outlook issued by IMD on 12th October about 8 days prior to formation of depression on 20th October and 11 days prior to the landfall of system over Yemen coast indicating formation of depression over southeast AS during the week 2 (20-26 October, around 20th October)

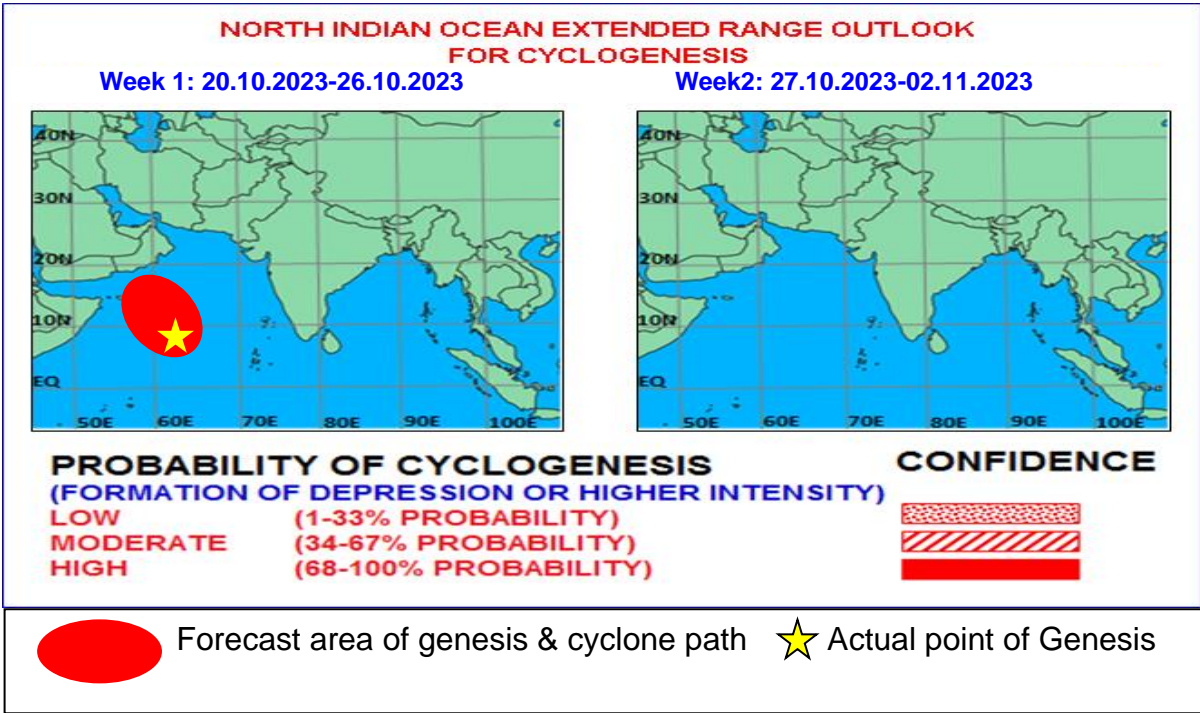


Fig. 6(b): Weekly extended range outlook issued by IMD on 19th October indicating formation of depression around 20th October with high probability (68-100%) about 1 day ahead of formation over southwest AS and 5 days in advance of landfall over Yemen.

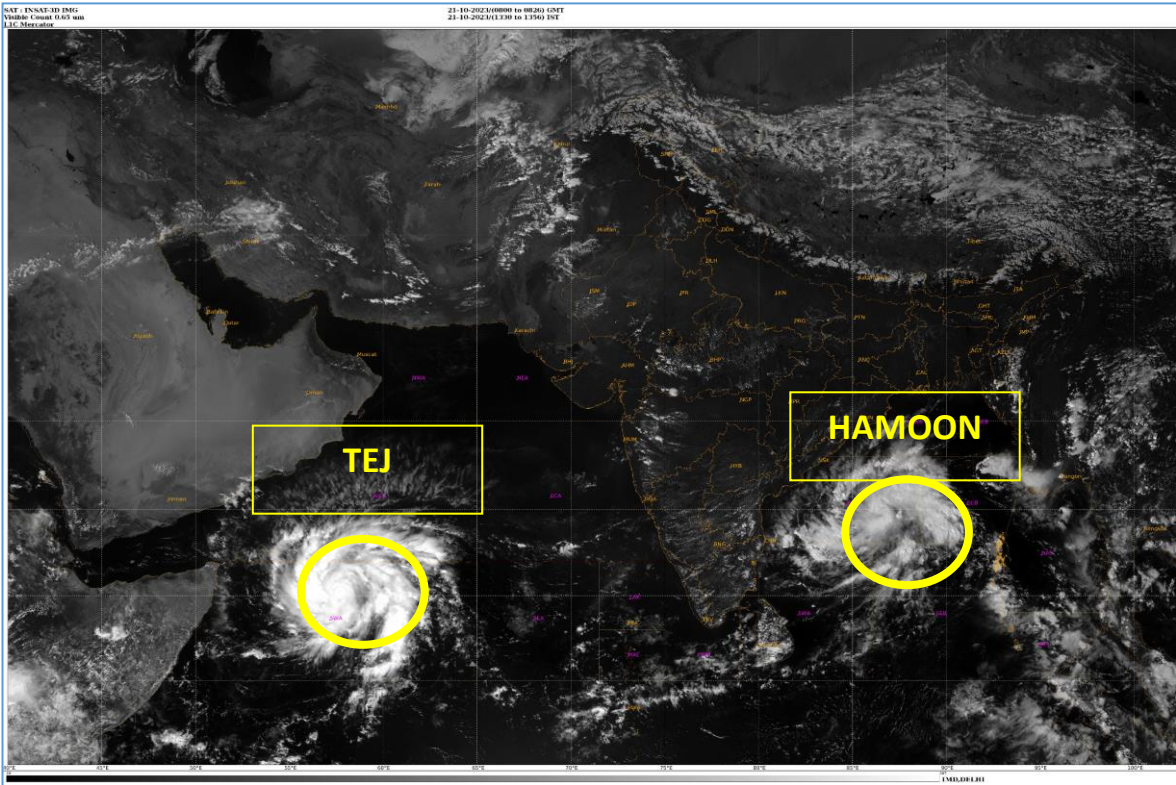


Fig.7: Typical INSAT 3D (R) imagery showing twin Cyclones

AN UPPER AIR CYCLONIC CIRCULATION IS LIKELY TO FORM OVER SOUTHEAST & ADJOINING EASTCENTRAL ARABIAN SEA DURING NEXT 24 HOURS. UNDER ITS INFLUENCE, A LOW PRESSURE IS LIKELY TO DEVELOP OVER THE SAME REGION AROUND 17TH OCTOBER, 2023. IT IS LIKELY TO MOVE WEST-NORTHWESTWARDS AND INTENSIFY FURTHER DURING SUBSEQUENT 48 HOURS.

SCATTERED LOW AND MEDIUM CLOUDS WITH EMBEDDED MODERATE TO INTENSE CONVECTION LAY OVER SOUTH ARABIAN SEA & COMORIN AREA.

PROBABILITY OF CYCLOGENESIS (FORMATION OF DEPRESSION) DURING NEXT 168 HRS:

24 HOURS	24-48 HOURS	48-72 HOURS	72-96 HOURS	96-120 HOURS	120-144 HOURS	144-168 HOURS
NIL	NIL	NIL	NIL	NIL	LOW	MOD

PROBABILITY OF CYCLOGENESIS (FORMATION OF DEPRESSION):
 NIL: 0%, LOW: 1-33%, MODERATE: 34-66% AND HIGH: 67-100%

Fig. 8: Tropical Weather Outlook dated 14th October indicating likely formation of an upper air cyclonic circulation around 15th, low pressure area around 17th and depression around 20th with moderate probability (34-66%).

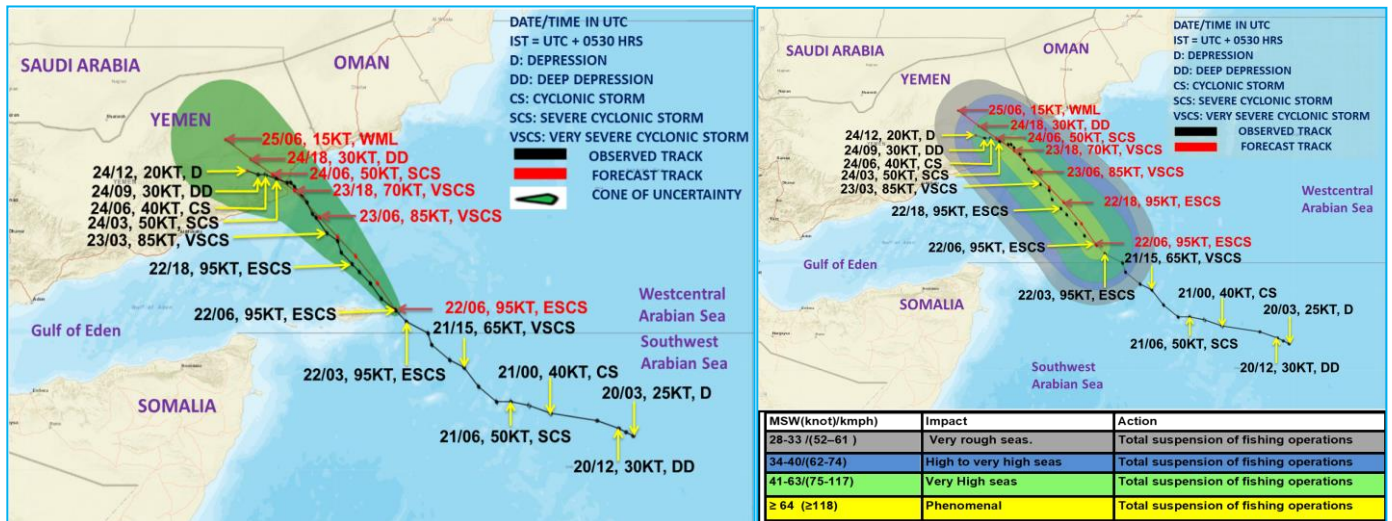


Fig. 9: Observed track and forecast track & intensity issued based on 0600 UTC observation of 22nd October about 2 days and 15 hours ahead of landfall.

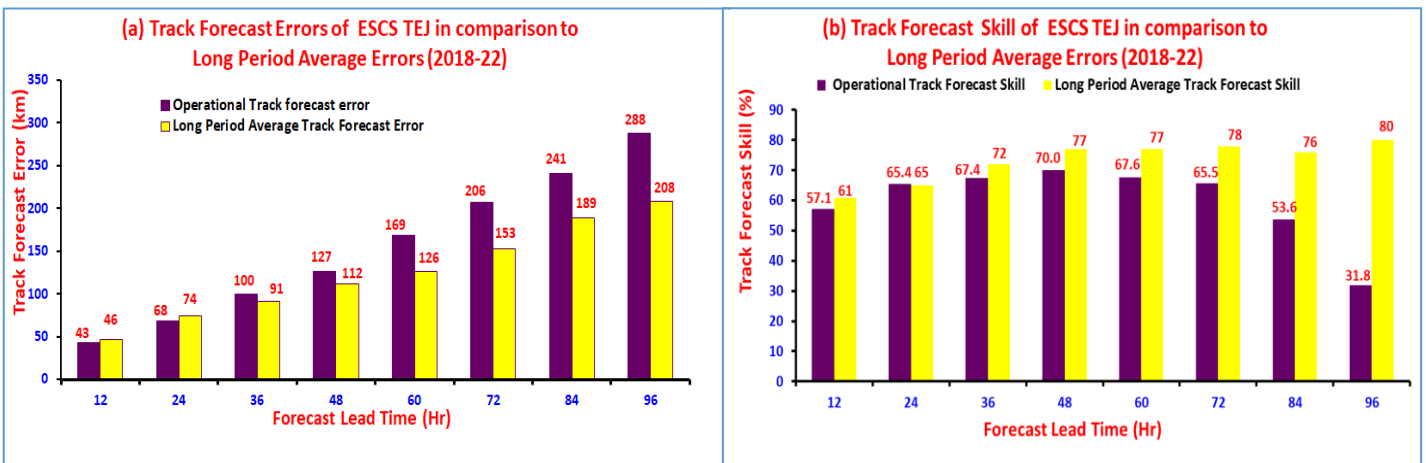


Fig. 10: (a) Track forecast errors and (b) track forecast skill against the long period average (LPA) errors (2018-22).

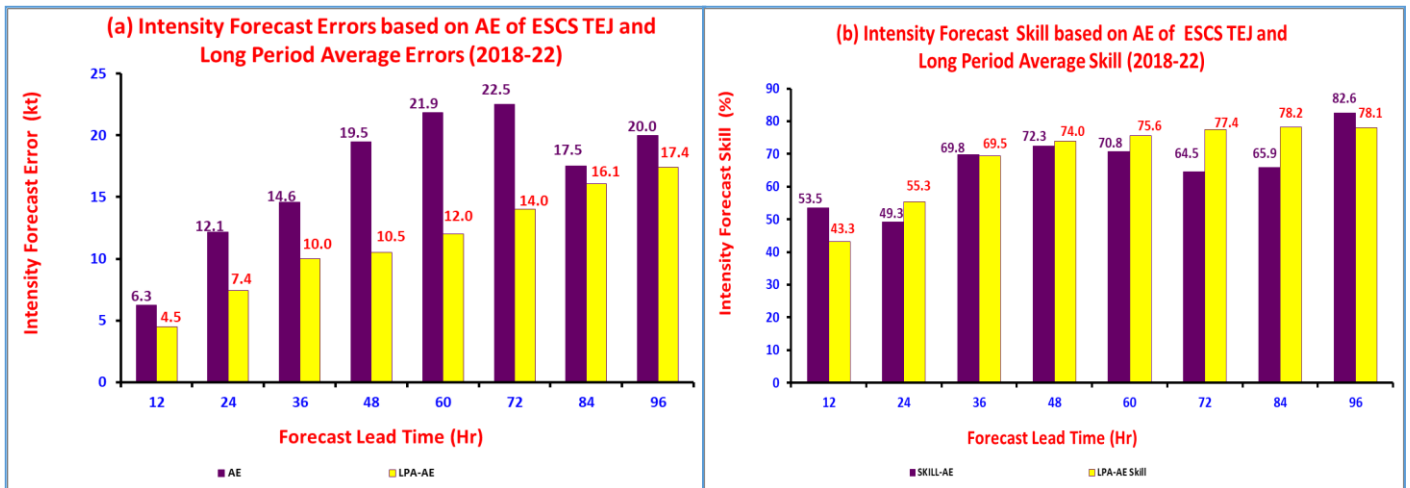


Fig. 11: (a) Absolute error (AE) in intensity forecast (b) intensity forecast skill based on AE against the long period average (LPA) errors (2018-22).

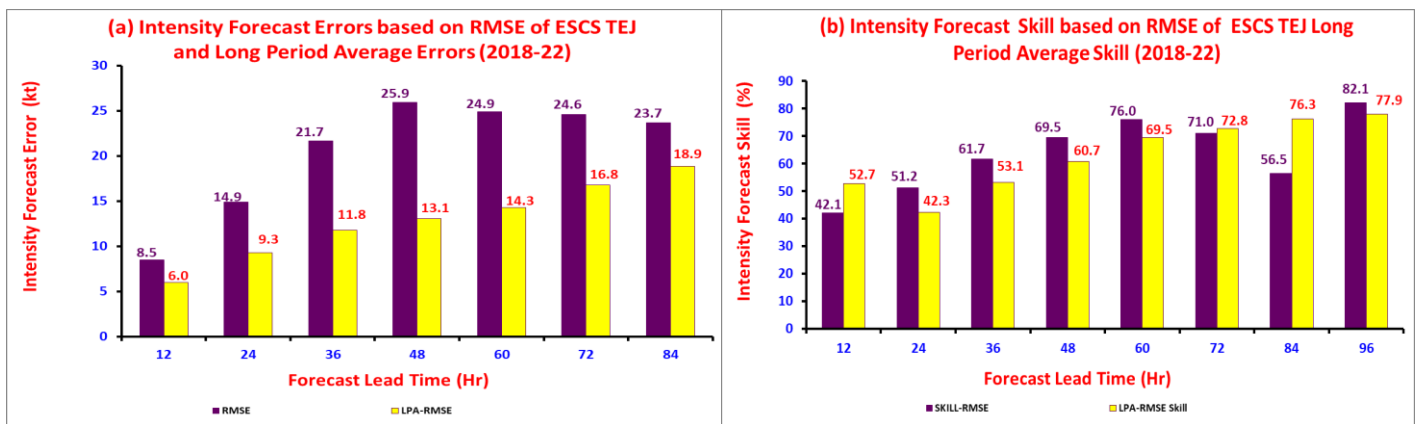


Fig. 12: (a) Root Mean Square Error (RMSE) in intensity forecast and (b) Intensity forecast skill against the long period average (LPA) errors (2018-22)

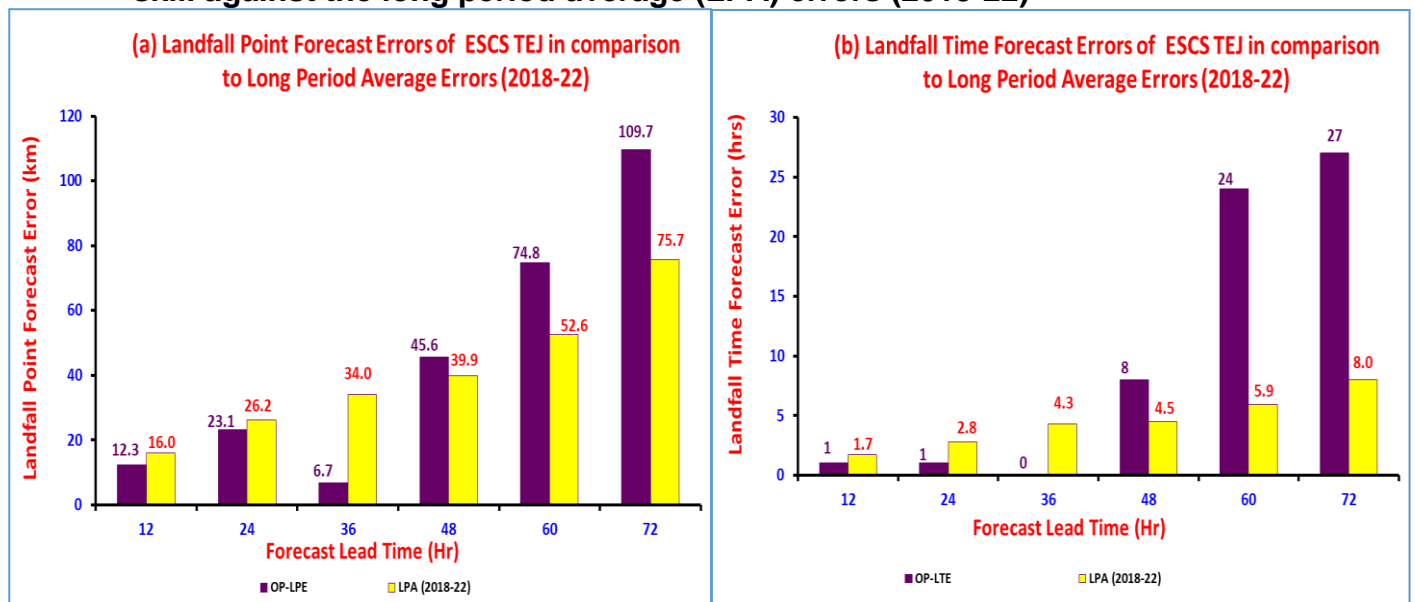
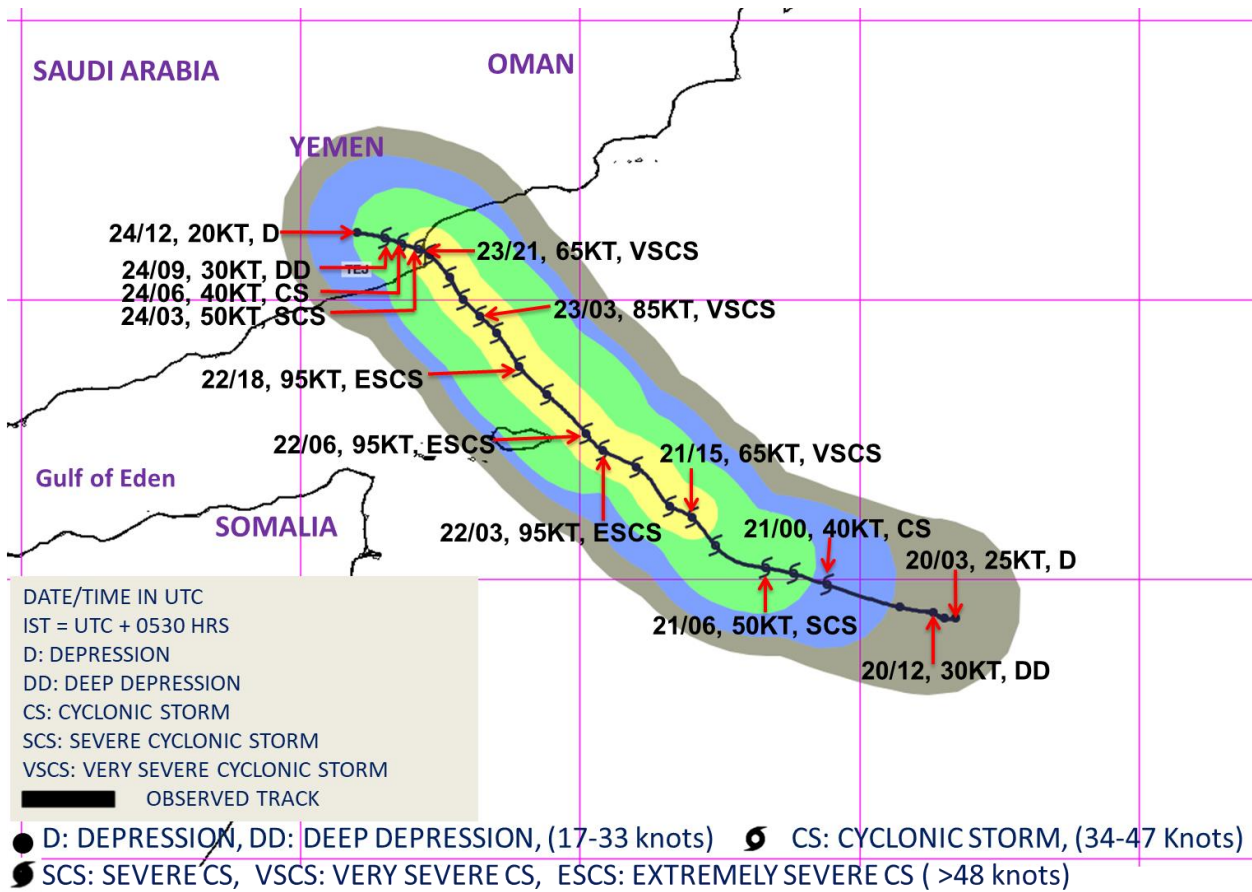


Fig. 13: (a) Landfall point and (b) time error against the long period average (LPA) errors (2018-22)



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

Fig. 14: Estimated MSW during the life cycle of ESCS TEJ

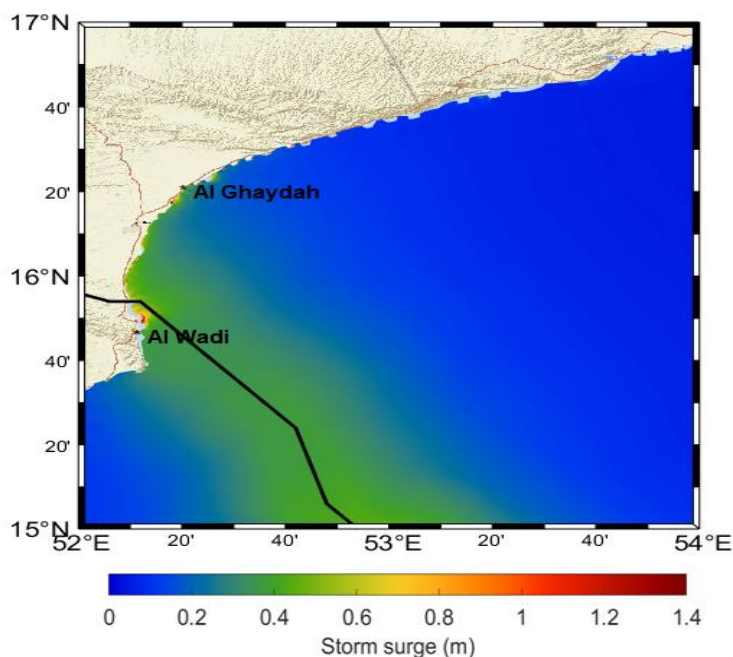
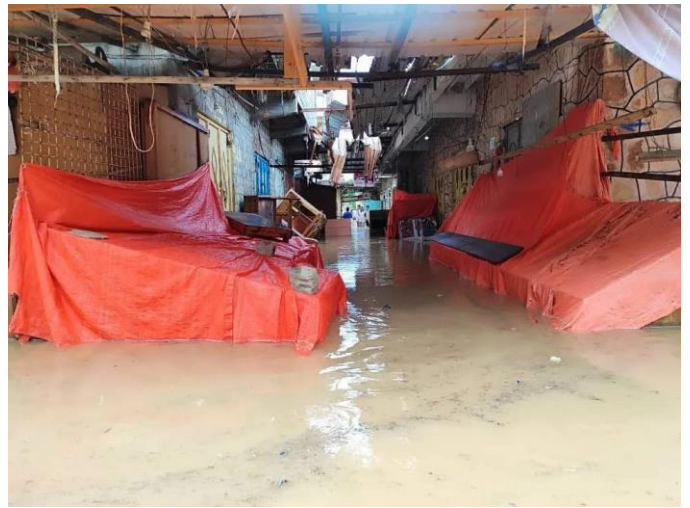


Fig. 15: The estimated Storm Surge at the time of landfall ESCS TEJ



Fig. 16(a): Extensive damage to residential areas and fishing ports of Yemen due to Cyclone TEJ



16(b): Flooding in YEMEN due to heavy to very heavy rainfall in association with cyclone TEJ

X

X

X