Government of India
Ministry of Earth Sciences

India Meteorological Department

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Sub: Salient features of the cyclonic disturbances over the North Indian Ocean during 2022

The salient features of the cyclonic disturbances (CDs) over the north Indian Ocean (NIO) during the year 2022, the operational forecast performance of India Meteorological Department (IMD) and new initiatives during the year are presented below:

1. Salient features of CDs over the NIO

Following CDs developed over the NIO during 2022:

(i) Deep depression over Bay of Bengal during 03-06 March, 2022
(ii) Deep depression over North Andaman Sea during 20-23 March, 2022
(iii) Severe cyclonic storm Asani over Bay of Bengal during 07-12 May, 2022
(iv) Depression over Bay of Bengal during 20-21 May, 2022
(v) Depression over Arabian Sea during 16-18 July, 2022
(vi) Depression over coastal Odisha during 09-10 August, 2022
(vii) Depression over Arabian Sea during 12-13 August, 2022
(viii) Depression over Bay of Bengal during 14-16 August, 2022
(ix) Deep depression over Bay of Bengal during 19-23 August, 2022
(x) Depression over South Odisha during 11-12 September, 2022
(xi) Cyclonic Storm Sitrang over Bay of Bengal during 22-25 October, 2022
(xii) Depression over Bay of Bengal during 20-22 November, 2022
(xiii) Severe Cyclonic Storm Mandous over Bay of Bengal during 06-10 December, 2022
(xiv) Deep Depression over Arabian Sea during 14-17 December, 2022
(xv) Depression over Bay of Bengal during 22-25 December, 2022

Observed tracks of the CDs during 2022 are presented in **Fig. 1.**

- **Annual Frequency of CDs**: During 2022, 15 CDs (maximum sustained wind speed (MSW) ≥ 17 knots) developed over the NIO against **normal (during 1965-2021)** of 11.2 per year. Thus, **annual activity of formation of CD was above normal during the year 2022.**
- **Frequency of different categories of CDs**: There were 12 depressions and deep depressions (MSW: 17-33 knots) (Normal: 6.5 per year), 1 cyclonic storm (MSW: 34-47 knots) (Normal: 1.8 per year) and 2 severe cyclonic storms (MSW: 48-63 knots) (Normal: 2.9 per year) during the year 2022. A total of 3 cyclones (MSW≥ 34 knots) developed over the NIO during 2022 against normal of 4.7 per year. **Overall, the frequency of formation of depressions over the region was above normal and that of cyclones was below normal during 2022.**
- **Frequency of CDs over Bay of Bengal and Arabian Sea**: There were 3 CDs over Arabian Sea (Normal: 2.3 per year), 10 over Bay of Bengal (Normal: 7.8 per year) and 2 over land (Normal: 1.1 per year) during 2022. **Basin-wise activity wrt formation of CDs was above normal over Bay of Bengal, Arabian Sea and Land.**

- **Frequency of cyclones over Bay of Bengal(BoB) and Arabian Sea(AS)**: 3 cyclones developed over the BoB and zero over the AS against normal of 3.5 per year and 1.2 per year over the BoB and AS respectively. Thus, frequency of formation of CS over both the basins was below average.
- **Unique features wrt frequency of cyclones:** During 2022, no cyclone developed over the AS against normal (1965-2020) of 1.2 per year. In past, no cyclone over the AS was observed in 1990, 1991, 1997, 2000, 2005, 2008, 2013, 2016, 2017.
- **Unique feature wrt intensity of cyclones:** There was no very severe cyclonic storm during 2022. Last such activity was observed 10 years ago in 2012 followed by 2009, 2005, 2002, 1986 (during the period 1982-2021).
- **Frequency of CDs in different seasons**: There were 4 CDs during pre-monsoon season (March-May) (Normal: 1.4 per year), 6 CDs during monsoon season (June-September) (Normal: 4.9 per year) and 5 during post-monsoon season (October-December) (Normal: 4.8 per year). S**eason-wise activity was above normal during pre-monsoon season.**
- **Movement:** Asani exhibited multiple recurvatures (significant change in direction of movement), very slow movement and weakening before landfall. Sitrang followed recurving track, very fast movement prior to landfall and very short life period. Mandous also followed recurving path and slow movement. Thus, all the 3 TCs during 2022 had recurving tracks and either slow or fast movement before and during landfall and two out of three cyclones had weakening trend before landfall.
- **Landfall:** All the 3 cyclones were landfalling systems (Normal: 3.2 per year). However, hile Asani crossed coast a deep depression, Sitrang and Mandous crossed coast as cyclonic storms.
- **Annual Accumulated Cyclone Energy:** The Annual Accumulated Cyclone Energy (a measure of damage potential) in association with cyclones during 2022 was 6.37X 10^4 $knots^2$ against the long period average (LPA) based on data of (1982-2020) of (a) 14.41 X 10^4 $knots^2$ for cyclones over the BoB, (b) 6.77 X 10^4 $knots^2$ over the AS and (c) 21.18 X 10^4 $knots^2$ over the NIO. Thus, the damage potential of cyclones during 2022 was less as compared to annual average over the BoB, AS and NIO.
- **Power Dissipation Index**: The Annual Power Dissipation Index (a measure of loss) in association with cyclones during 2022 was 3.04 X 10^6 $knots^3$ against the LPA based on data of (1982-2020) of (a) 9.51 X 10^6 $knots^3$ for cyclones over the BoB, (b) 4.57 X 10^6 $knots^3$ over the AS and (c) 14.08 X 10^6 $knots^3$ over the NIO. Thus, the measure of loss due tocyclones during 2022 was less as compared to annual average over the BoB, AS and NIO.
- **Total life period:** Total number of CD days over the NIO during 2022 was 39 days and 9 hours during 2022 against the LPA (based on data during 1990-2020) of 29 days and 20 hours. It was mainly due to increased frequency of depressions/ deep depressions instead of longer life period of any CDs.
- **Average translational speed:** Six hourly average translational speed of cyclones during 2022 was 15.5 kmph against LPA (based on data during 1990-2020) translational speed of 13.9 kmph for cyclones over BoB. This it was near normal.
- In spite of the recurving tracks and increased difficulty level in forecasting, all the parameters including genesis, track, landfall point, landfall time & intensity and associated adverse weather including heavy rainfall, wind and storm surge were predicted accurately with sufficient lead period. It enabled disaster managers, stakeholders and general public to take response actions which resulted in significant reduction in death toll and management of cyclonic disturbances over the region.
- **Operational Forecast Performance:** The average track forecast errors during 2018-22 have been 75 km, 113 km and 154 km respectively for 24, 48 and 72 hrs against the average errors of 93, 144 and

201 km during 2012-21. The average errors in intensity forecast during 2018-22 have been 7.4 knots, 10.5 knots and 14.0 knots respectively for 24, 48 and 72 hrs lead period of forecast against the average errors of 10.4, 15.5 and 15.7 knots during 2012-21. The annual average landfall point forecast errors for the year 2022 have been 14.8 km, 24.5 km and 4.5 km for 24, 48 and 72 hrs lead period against the past five years average errors of 30.7 km, 43.9 km and 85.7 km during 2012-2021.

- The accuracy in both track and intensity prediction registered an overall improvement of 20-30% upto 72 hours lead period during 2018-22 as compared to that of 2013-17. The accuracy in landfall point prediction registered an overall improvement of 40-70% upto 72 hours lead period during 2018-22 as compared to that of 2013-17.
- **Death toll:** The cyclones during 2022 caused total number of 5 deaths in India and 38 deaths in WMO/ESCAP panel member countries (viz. Bangladesh and Sri Lanka).

2. Monitoring and forecasting:

IMD utilized all it's resources for monitoring and prediction of CDs during 2022. We are happy to inform you that all the cyclonic disturbances were monitored and predicted with sufficient lead time and great accuracy. IMD maintained continuous watch over the NIO and monitored all the disturbances with issue of extended range outlook (valid for next 15 days), daily tropical weather outlook (valid for next 5 days), daily detailed prognostic and diagnostic report during October-December (valid for next 7 days) and 6hourly/3hourly/hourly structured bulletins on formation of cyclonic disturbance period. The CDs were monitored with the help of available satellite observations from INSAT 3D and 3DR, polar orbiting satellites, available ships & buoy observations in the region, Doppler Weather Radars (DWR) and observations from coastal observatories. Various global models and dynamical-statistical models run by Ministry of Earth Sciences (MoES) institutions including IMD, NCMRWF, IITM and INCOIS were utilized to predict the genesis, track, landfall and intensity of the CDs as well as associated severe weather including heavy rainfall, strong winds and storm surge. 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. The forecasts were mainly based on multi-model ensemble techniques developed indigenously by IMD.

3. Forecast performance of RSMC New Delhi

3.1. Annual Performance during 2022

a. Genesis Forecast performance: All the CDs developed over the region were predicted in the extended range outlook (ERO) issued every Thursday. Cyclone Asani was predicted in the ERO guidance issued on 28th April, about 9 days ahead of formation of depression over BoB on 7th May. Sitrang was predicted in the ERO guidance issued on 6th October, about 16 days ahead of formation of depression over BoB on 16th October. Mandous was predicted in the ERO guidance issued on 24th November, about 12 days ahead of formation of depression over BoB on 6th December.

b. Pregenesis track and intensity forecast performance: IMD issued pre-genesis forecast of track, intensity and landfall iro the cyclones from low pressure area stage with reasonable accuracy. The pre-genesis track forecast of cyclone, Mandous had almost zero landfall point & time as well as landall intensity forecast errors.

c. Track forecast performance: Annual average track forecast errors in 2022 have been 42.3 km, 77.5 km and 108.0 km, respectively for 12, 24 and 36 hrs against the long period average (LPA) errors of 51.7, 82.4 and 100.3 km based on data of 2012-2021. The forecast accuracy since 2003 indicates an improvement at the rate of 5.8 km/year (58 km in 10 years) for 24 hrs lead period.

d. Intensity forecast performance: The annual average absolute error (AE) in intensity forecast error has been 3.8 knots, 4.0 knots and 5.0 knots against the LPA (2012-21) errors of 8.9, 13.0 and 14.9 knots for 24, 48 and 72 hrs lead period respectively. The intensity forecast accuracy since 2005 indicates an improvement at the rate of 0.52 knots/year (5.2 knots in 10 years) for 24 hrs lead period.

e. Landfall point forecast performance: The annual average landfall point forecast errors for the year 2022 have been 14.8 km, 24.5 km and 4.5 km against the LPA (2012-21) errors of 32.5 km, 62.9 km and 103.9 km for 24, 48 and 72 hrs lead period respectively. The landfall point forecast accuracy since 2003 indicates an improvement at the rate of 14.4 km/year (144 km in 10 years) for 24 hrs lead period since 2003.

f. Landfall time forecast performance: The landfall time forecast errors for the year have been 5.0, 7.5 and zero hrs against the LPA (2012-21) errors of 3.1, 4.9 and 6.6 hrs for 24, 48 and 72 hrs lead period respectively. The landfall time forecast accuracy since 2003 indicates an improvement at the rate of 0.18 hours/year (1.8 hours in 10 years) for 24 hrs lead period since 2003.

The annual average track, intensity, landfall point and landfall time forecast accuracy during 2022 compared to LPA (2012-2021) accuracy are presented in **Fig. 2**. Typical observed and forecast tracks with cones of uncertainty and quadrant wind distributions during cyclone Sitrang and Mandous are presented in **Fig. 3** and **Fig.4** respectively.

3.2. Forecast Performance during 2018-22 vis-a-vis 2013-17

a. The average track forecast errors during 2018-22 have been 74 km, 112 km and 153 km respectively for 24, 48 and 72 hrs against the average errors of 93, 144 and 201 km during 2013-17. **The accuracy in track prediction registered an overall improvement of 20-25% upto 120 hours lead period during 2018-22.**

b. The average errors in intensity forecast during 2018-22 have been 7.4 knots, 10.5 knots and 14.0 knots respectively for 24, 48 and 72 hrs lead period of forecast against the average errors of 10.4, 15.5 and 15.7 knots during 2013-17. **The accuracy in intensity prediction registered an overall improvement of 20-30% upto 72 hours lead period during 2018-22.**

c. The annual average landfall point forecast errors during 2018-22 have been 26.2 km, 39.9 km & 75.6 km for 24, 48 & 72 hrs lead period against the average errors of 42.3 km, 94.8 & 122.1 km during 2013-17. **Thus, the accuracy in landfall point prediction registered an overall improvement of 40-70% upto 72 hours lead period during 2018-22.**

d. The landfall time forecast errors during 2018-22 have been 2.8, 4.5 & 3.8 hrs for 24, 48 & 72 hrs lead period against the average errors of 3.6, 5.4 & 8.0 hrs respectively during 2013-17. **Thus, the accuracy in landfall time prediction registered an overall improvement of 15-25% upto 48 hours lead period during 2018-22.**

The comparative analysis of track, landfall and intensity errors during 2018-22 vis-à-vis the errors during 2013-17 are presented in **Fig. 5.**

3.3. Five year moving average errors

Considering the fact that NIO region experiences, an average of about 5 cyclones in a year, the forecast performance in track, landfall and intensity prediction has been presented as 5 year moving average errors in **Fig. 6.** Despite the fact that NIO region is a data sparse region with poor socio-economic conditions, it is clearly seen that over the years there has been significant improvement in track, intensity and landfall point & time prediction over the region.

4. **Death toll due to cyclones:** The cyclones during 2022 caused 5 deaths in India and 38 deaths in WMO/ESCAP panel member countries (viz.Bangladesh and Sri Lanka). The comparative figures indicating death toll over the Indian region and WMO/ESCAP panel member countries since 2010 is presented in **Fig.7**. It indicates that there has been significant reduction in loss of human lives due to cyclones hitting India as well as WMO/ESCAP Panel countries in North Indian Ocean region.

5. **Bulletins issued by IMD during 2022:**

(a) IMD maintained round the clock watch over the NIO region and issued extended range outlooks (ERO) every Thursday with probabilistic cyclogenesis forecast valid for next 2 weeks.
(b) It was followed by daily tropical weather outlook (TWO) with probabilistic cyclogenesis forecast for next 5 days.
(c) On the likely formation of depression, IMD issued pre-genesis track and intensity forecast once in a day at the stage of low pressure area.
(d) On the formation of depression, IMD issued regular bulletins 6hrly followed by 3 hrly bulletins from the stage of cyclonic storm and hrly bulletin in case of a landfalling cyclone, about 12 hrs prior to landfall
(e) Special daily prognostic and diagnostic bulletin under Tropical Cyclone Forecasting Programme (TCFP) was issued during October-December.
(f) Statistics of bulletins issued during the year is given below:

Extended Range Outlook: 52
Tropical Weather Outlook: 326
RSMC Bulletin: 163
National Bulletin: 188
Hourly Bulletins: 20
Bulletins for International Civil Aviation: 37
Press Release: 42

6. **Major initiatives in various components of early warning system of TCs during 2022 included:**

a. Observations: i) Augmentation of high wind speed recorders along the east and west coast of India with current no. across country reaching 36 HWSRs, ii) augmentation of radar network to 36countrywide, iii) New Rapid tool (Version-2)(available at **https://rapid.imd.gov.in/rapid/**) for better analysis of satellite, radar and model products, iv) availability of **Meteosat-9 products at the link: http://foreignsat.imd.gov.in/, (web GIS based decision support system to compare, comprehend and analyse the observation and models products and arrive at the decision on current status and forecast, v) During cyclone Mandous,** Doppler Weather Chennai released 3D analysis of precipitation during landfall of SCS Mandous (https://youtu.be/1S2BeFLVVfE).

b. Modeling: i) Introduction of High Resolution Rapid Refresh Model (**https://nwp.imd.gov.in/wrf_HRRR_nwp_sp.php)** with continuous assimilation of radar data alongwith other conventional observations. ii) Introduction of new multi model ensemble technique for cyclone track, intensity and landfall prediction , iii) Generation of single panel plots of IMD GFS, NCEP GFS, JMA, NEPS, GEFS, NCUM, WRF, NCUM-R, ECMWF, iv) All in one Meteograms for better visualization and decision making (IMD WRF, IMDGFS, GEFS, NEPS), (v) EWRF model for cloud to ground lightning provides forecast for lightning density, reflectivity and hourly rainfall for next 12 hours.

c. Forecasting Services: (i) Web based Dynamic Composite Risk Atlas (Web-DCRA) Tool for generating dynamic impact based forecast, (ii) development of decision support system for rainfall & winds on GIS platform indigenously for forecasters, (iii) development of fishermen warning graphics based on multi model guidance, (iv) introduction of probabilistic guidance for area of maximum sustained wind speed exceeding 20 knots and 35 knots, (v) introduction of pre-genesis forecast of track, intensity & structure, (vi) introduction of distance from forecast track and nearest time of arrival since March, 2022, (vii) introduction of customized location specific bulletins for offshore industries, (viii) availability of marine bulletins in textual, graphical and interactive GIS platform for users for easy decision making

d. Warning Dissemination: RSMC utilises all means of communication for transmission including email, FAX, websites, social networking platforms (facebook, tweeter, whatsapp), SMS etc. During 2022, new initiatives included (i) development of Application Programming Interface being utilised by Global Multi-hazard Alert System (GMAS) of WMO, Google, Apple, Windy and various central and state governments agencies, press & electronic media including DD News etc., (iii) crowd sourcing, (iv) common alert protocol (CAP) implementation and (v) dissemination of cyclone bulletins to WMO/ESCAP member countries through whatsapp.

e. Forecast Verification: Introduction of verification of forecast to determine accuracy of (i) genesis forecast in extended and medium range and (ii) pre-genesis track & intensity forecast apart from earlier introduced forecast verification methods for track, intensity, landfall of cyclonic disturbances and associated adverse weather forecasts.

5. Capacity Building Measures:

- IMD conducted pre-cyclone exercise meetings with national and state level disaster managers in first week of April & October, 2022
- Two weeks Cyclone forecasters training for 13 member countries of WMO/ESCAP Panel in April,
- Training about basics of cyclones for off-shore operators, coast guards, Directorate General of Hydrocarbons and related Ministries officials in May, 2022

6. Major publications

During 2022 IMD released following publications wrt cyclones

(i) Report on cyclonic disturbances over North Indian Ocean during 2021,

(ii) Tropical Cyclone Operation Plan (TCP-21) including explicit formulation of the procedures adopted in the Bay of Bengal and Arabian Sea region for the preparation, distribution and exchange of information and warnings pertaining to tropical cyclones by 13 member countries and their respective contact details. The report is prepared by IMD and published by WMO.

(iii) Forecast Demonstration Project during 2021: A Report,

(iv) Preliminary Reports on cyclonic disturbances during 2022,

(v) Best track data of all cyclonic disturbances during 2022,

(vi) Updation of various datasets on climatology of cyclones on RSMC website,

(vii) Archival of all bulletins on RSMC website since 2011

All these measures enabled the disaster managers and general public in reducing the loss of human life to double digit during the year. It also helped in building confidence among disaster managers, stakeholders, media & general public for successful management of cyclonic disturbances and hence minimisation of losses.

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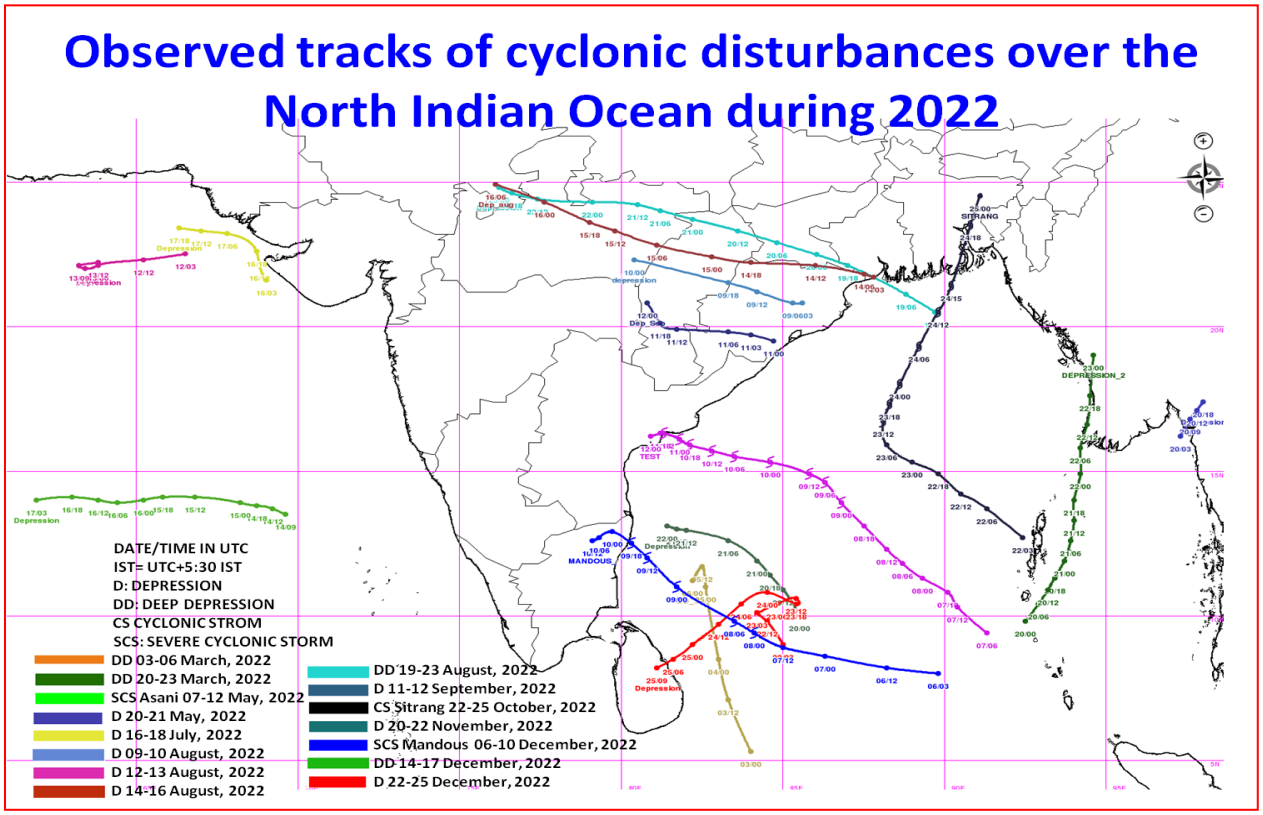


Fig. 1: Tracks of cyclonic disturbances over the North Indian Ocean during 2022

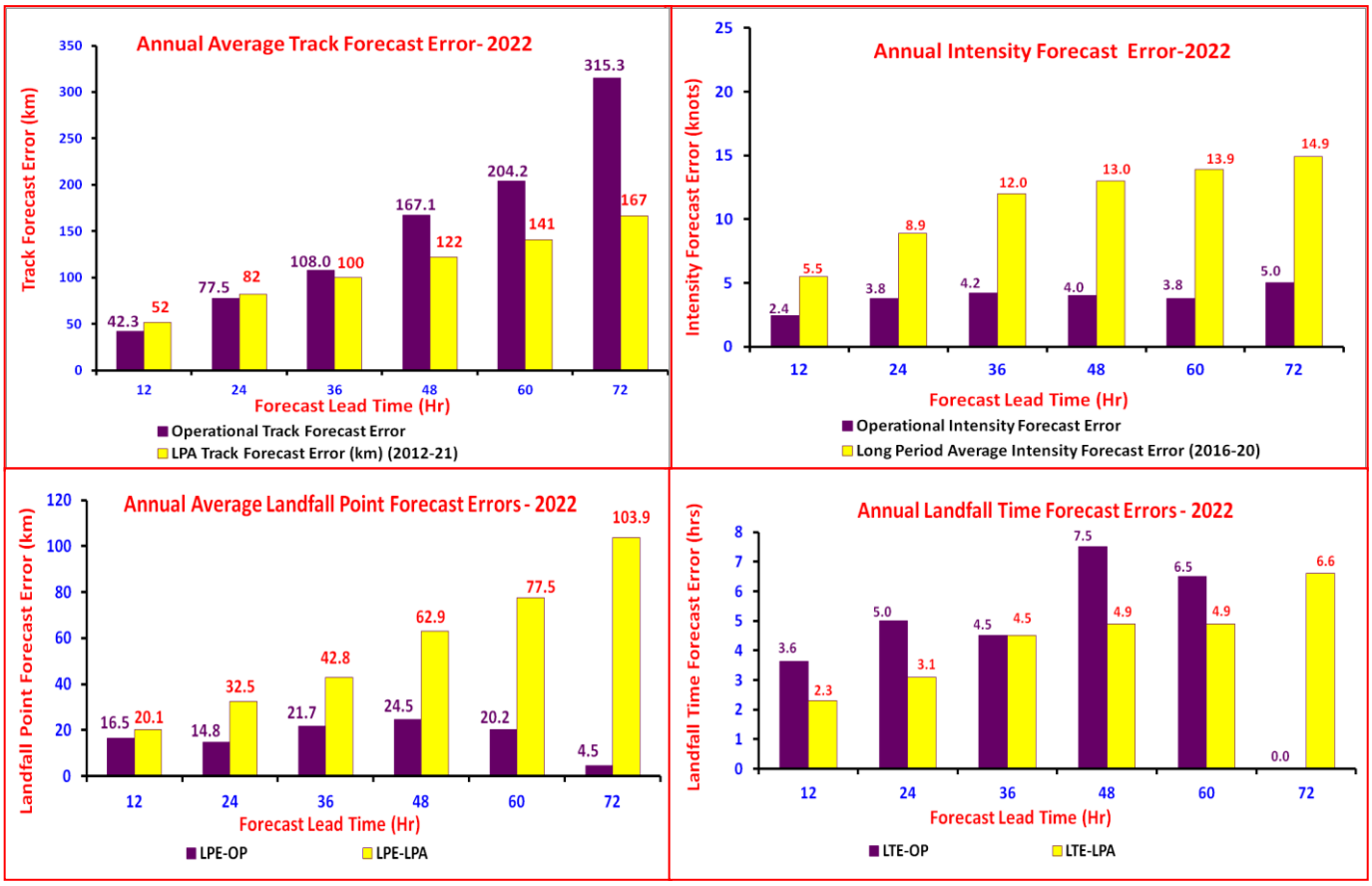
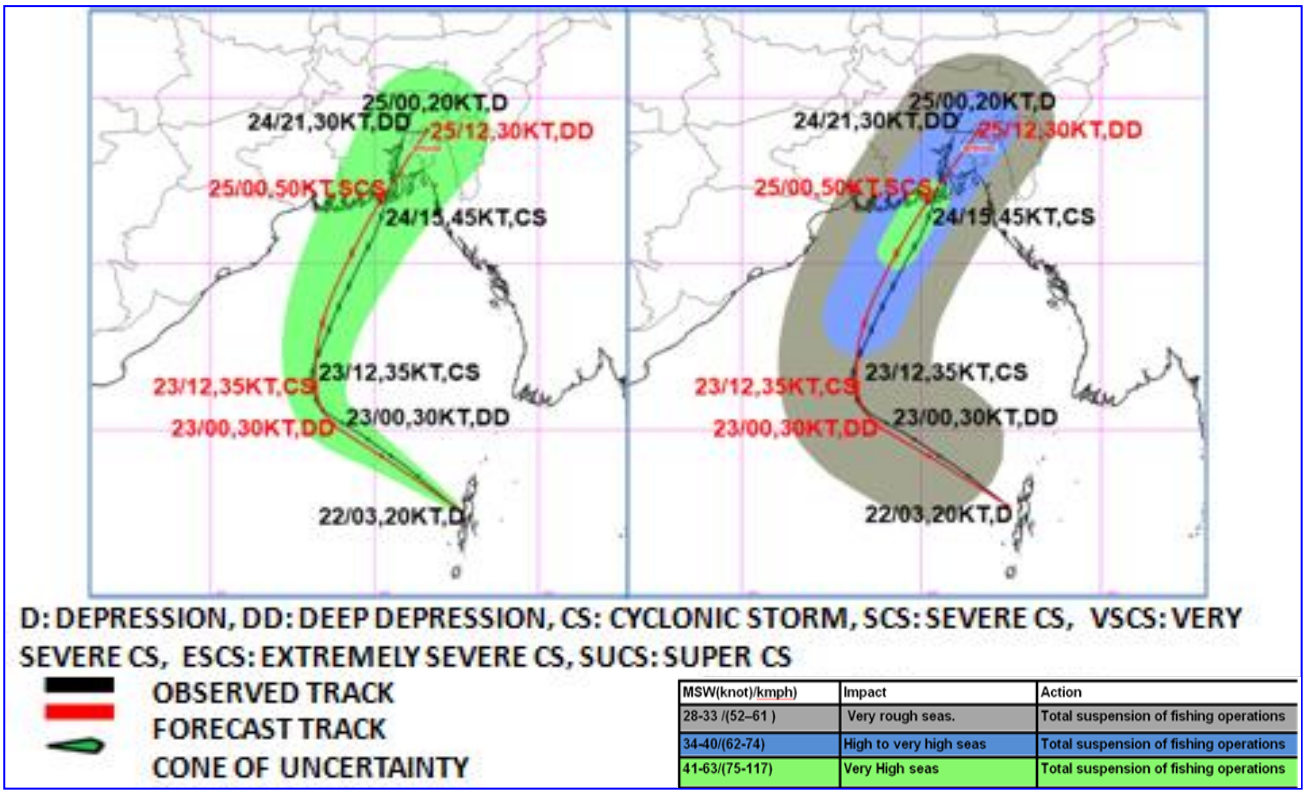
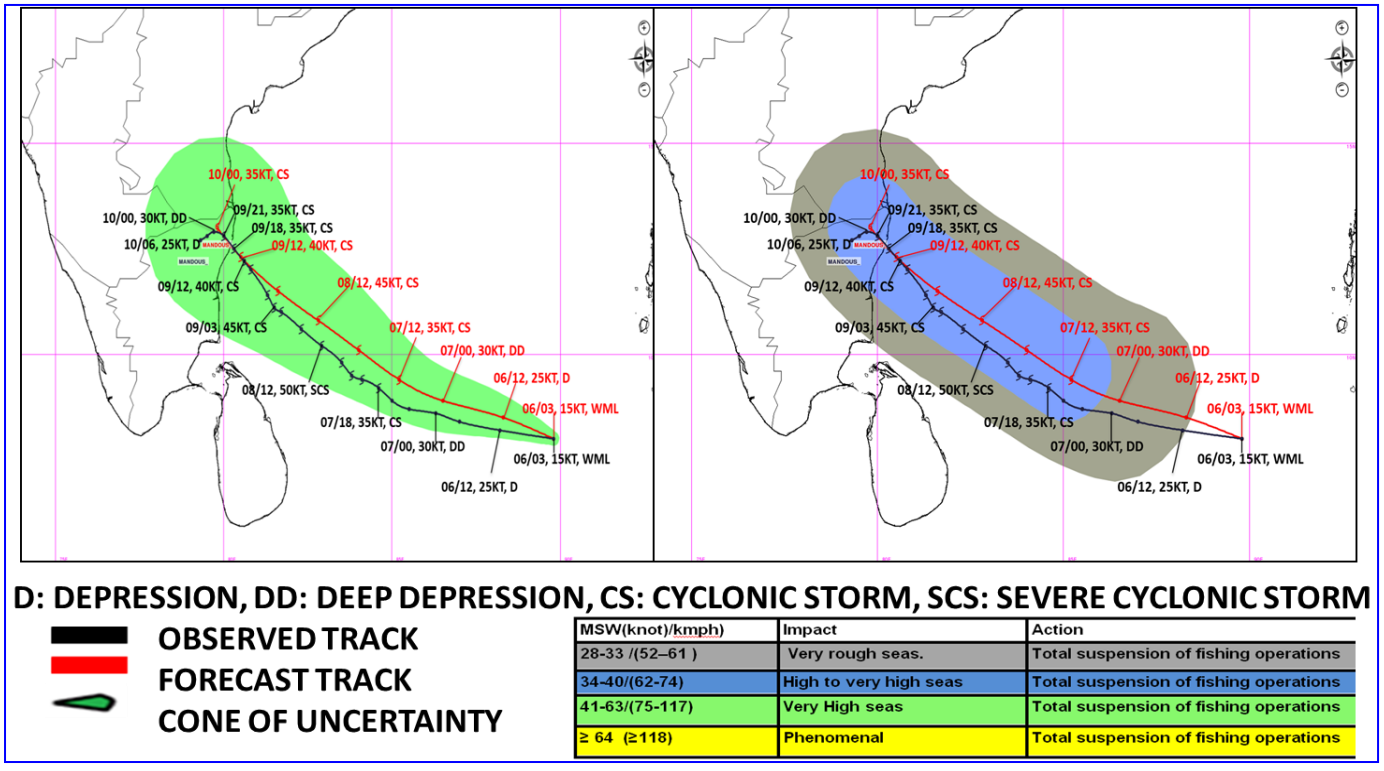


Fig. 2: Annual average track, intensity, landfall point and landfall time forecast accuracy during 2022



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

Fig.3: Observed and forecast track issued at 0830 hours IST of 22nd October (63 hours prior to landfall) indicating accuracy in track, landfall and intensity



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.4: Observed and forecast track issued at 0830 hours IST of 6th December (90 hours prior to landfall) indicating accuracy in track, landfall and intensity

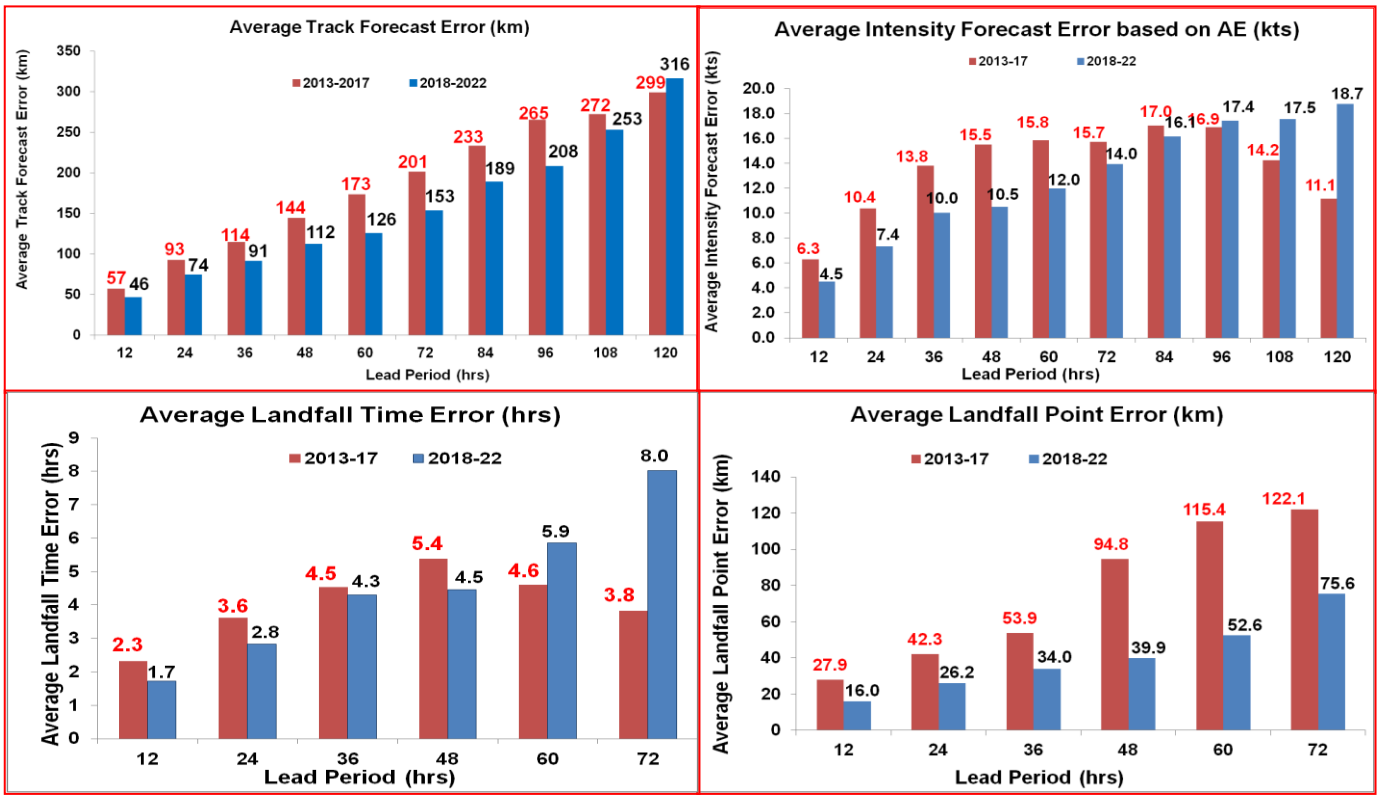


Fig. 5: Comparative analysis of track, intensity, landfall point and landfall time errors during 2018-22 vis-à-vis the errors during 2013-17

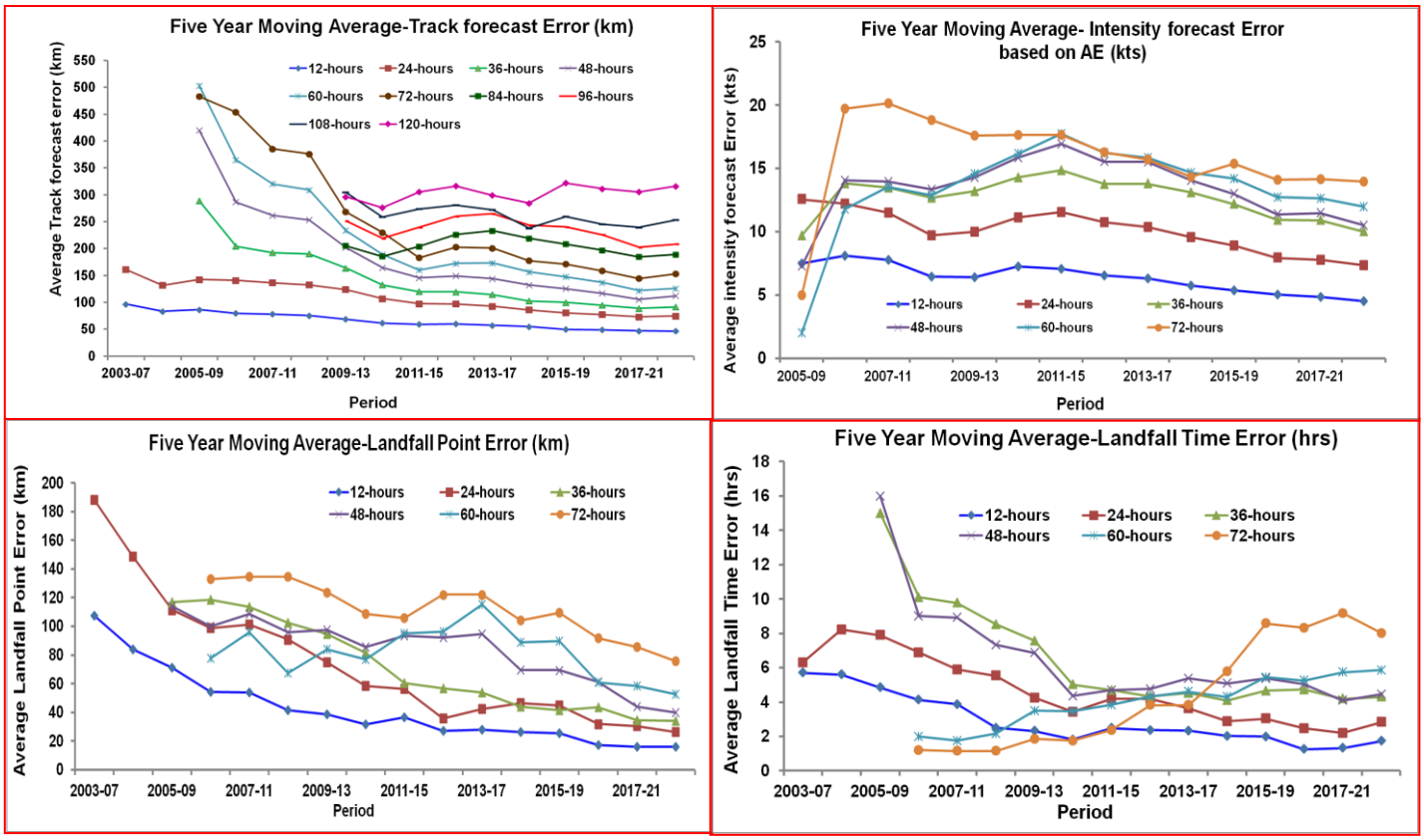


Fig. 6: Five year moving average track, intensity, landfall point and landfall time errors

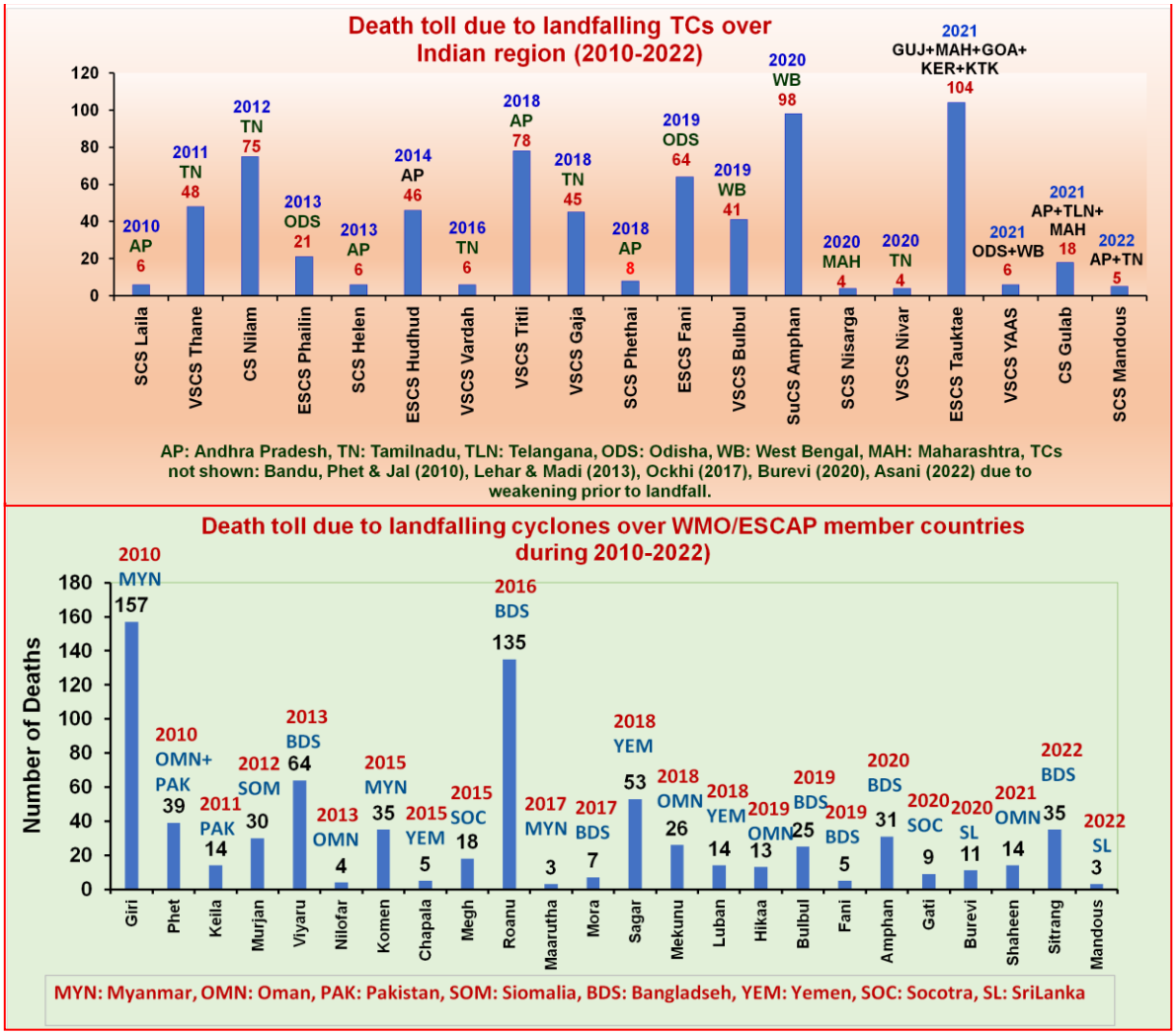


Fig. 7: Death toll due to cyclones during 2022 over Indian region and WMO/ESCAP member countries