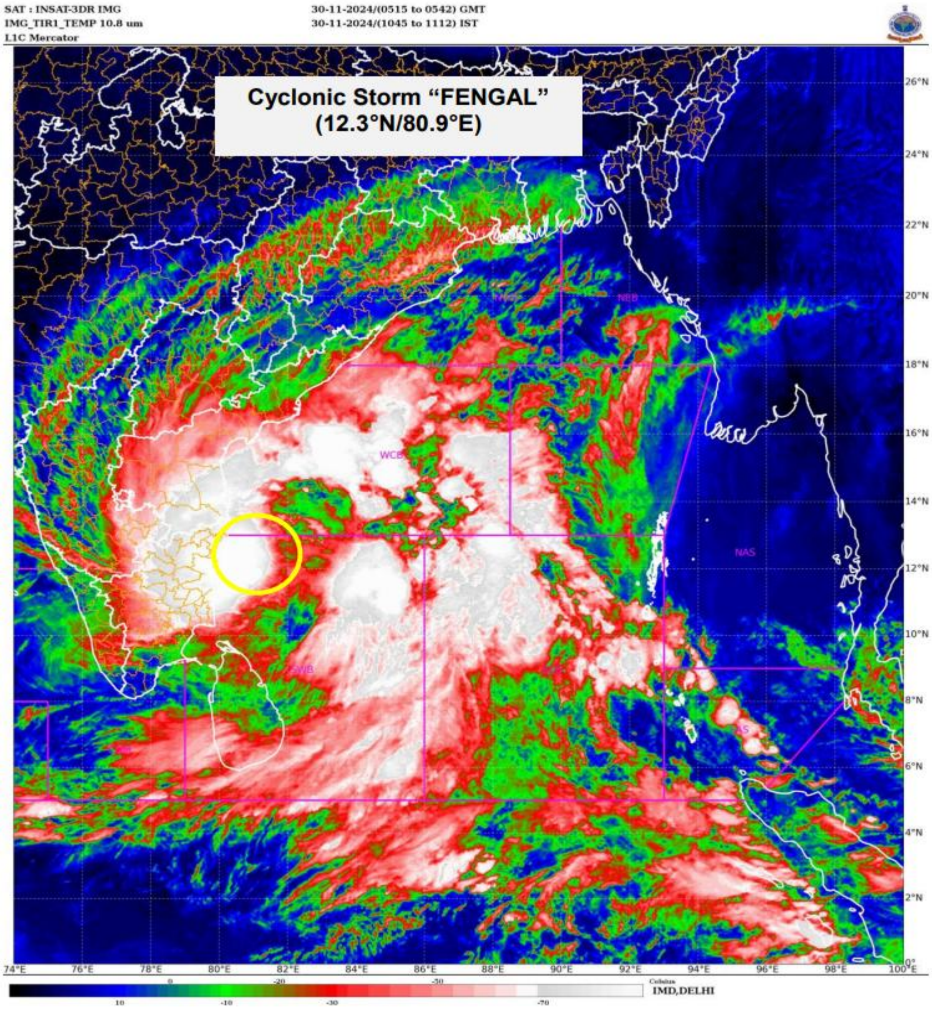
WMO/ESCAP
PANEL ON TROPICAL CYCLONES
ANNUAL REVIEW 2024



SATELLITE IMAGERY OF EXTREMELY SEVERE CYCLONIC STORM, FENGAL OVER BAY OF BENGAL

WMO

WORLD METEOROLOGICAL ORGANISATIONAND ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

ESCAP

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PREFACE

First commenced in 1997, the publication of ***WMO/ESCAP Panel*** - *Annual Review* has entered **twenty-eighth** year of issue for the year 2024. Considerable efforts have gone into producing this document in order to make it useful scientifically and informative for the members of panel. Panel Members are encouraged to make more contributions for further improvement of this publication.

WMO and ***ESCAP*** have played a commendable role in disaster mitigation efforts in the Panel region through continued interaction with the governments of the member countries. There is increasing realization that disaster mitigation effort must encompass all spheres including scientific research on natural hazards, establishment of integrated-all-hazard early warning system and most importantly, empowering communities to be self-reliant for timely and proper response to warnings. Despite rapid technological advances made in the recent past, the problem of generating accurate weather forecasts and associated warnings/ advisories and their timely dissemination to the communities at highest risk continues to be a great challenge. In order to make the early warning system more effective, it is essential that the Panel Members take new initiatives. The basic aim of the panel is to improve the quality and content of cyclone warnings, devise methods for quick dissemination of warnings and flood advisories and ensure proper response by concerned agencies and the community.

This review highlights the achievements made during the year, 2024 in the region in pursuance of the goals set out by the ***WMO / ESCAP*** *Panel* and the activities of other international and national organizations in support of the above tasks, within the overall objective of mitigating the impact of natural hazards. I would like to express my sincere thanks to all the Panel Members for their valuable input and contributions and hope for thesame in the future.

Chief Editor

WMO AND THE WMO / ESCAP PANEL ON TROPICAL CYCLONES

WORLD METEOROLOGICAL ORGANIZATION (WMO)

The World Meteorological Organisation (WMO), of which 193 States and Territories are Members, is a specialised agency of the United Nations. The objectives of the organisation are:

- To facilitate international co-operation in the establishment of networks of Stations and Centres to provide Meteorological and Hydrological services and observations;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote standardisation of meteorological and related observations and ensure the uniform publication/circulation of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services and
- To encourage research and training in meteorology and, as appropriate, in related fields and to assist in co-ordinating the international aspects of such research and training.

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (ESCAP)

The Economic and Social Commission for Asia and the Pacific (ESCAP) aims to initiate and participate in measures for concerted action towards the development of Asia and the Pacific, including the social aspects of such development, with a view to raising the level of economic activity and standards of living and maintaining and strengthening the economic relations of countries and territories in the region, both among themselves and with other countries in the world. The commission also:

- Provides substantive services, secretariats and documentation for the Commission and its subsidiary bodies;
- Undertakes studies, investigations and other activities within the commission’s terms of reference;
- Provides advisory services to Governments;
- Contributes to the planning and organisation of programmes of technical co-operations and acts as executing agency for those regional projects decentralised to it.

WMO / ESCAP PANEL ON TROPICAL CYCLONES

Huge loss of human life, damage to property and unbearable sufferings of human beings caused by tropical cyclones in coastal areas in various parts of the globe likeAtlantic, Pacific, China Sea and North Indian Ocean (NIO) coast are regular features.

The disaster potential due to cyclones is particularly high in the NIO comprising of the Bay of Bengal & the Arabian Sea region, which is being associated with high storm surge, which is the greatest killer in a cyclone. This region has the distinction of having experienced the world’s highest recorded storm tide of 41 feet (1876 Bakherganj cyclone near Megna estuary, Bangladesh) followed by 13 metres over West Bengal coast on 7th October, 1737 in association with another super cyclone. Past records show that veryheavy loss of life due to tropical cyclones have occurred in the coastal areas surrounding the Bay of Bengal. In the recent past, during the year 1998, the state of Gujarat in India experienced the impact of a very severe cyclonic storm, which crossed coast north of Porbandar (42830) on June 9, 1998 and caused huge damage to public property near Kandla Port (42639). A Super Cyclonic Storm that crossed east coast of India near Paradip (42976) in Orissa state on October 29, 1999 took a toll of 9885 lives and caused huge damage to property in 12 districts of the state. Apart from causing large-scale devastation to agriculture and plantation crops, it also affected entire infrastructure on communication, power and transport. The storm surge of 5-6 m height was experienced in areas close toand southwest of Paradip. This cyclone was century's most intense cyclone and its unusual feature was that it remained practically stationary after crossing coast and battered the State of Orissa for 36 hours. In June, 2007 another super cyclone 'Gonu' developed over southeast Arabian Sea, moved north-westward, crossed Oman coast and then entred into Gulf of Oman and made second landfall over Iran coast. It caused huge damage to the property and loss of lives in Oman and Iran. The very severe cyclonic storm, 'Nargis'crossed Myanmar coast near Irrawaddy delta on 2nd May 2008 and caused loss of about 138,000 lives in Myanmar.

Realising the importance of an effective cyclone warning and disaster mitigation machinery in the region, WMO and ESCAP jointly established the Panel on Tropical Cyclones (PTC) in 1972 as an inter-Governmental body. Its membership comprises the countries affected by tropical cyclones in the NIO. Its founder member countries are Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman and Thailand. Subsequently, Yemen joined in 2016 and Iran, Qatar, Saudi Arabia and United Arab Emirates joined in 2018.

The Panel is one of the six regional tropical cyclone bodies established as part of the WMO Tropical Cyclone Programme (TCP) namely Miami, Honolulu, Tokyo, New Delhi, La Reunion and Nadi that aims at promoting and co-ordinating the planning and implementation of measures to mitigate tropical cyclone disaster.

It also aims to initiate and participate in measures for concerted action towards the development of Asia and the Pacific including social aspects of such developments, to raise the level of economic activity and standards of living and maintain and strengthen the economic relations of countries and territories in the region, both among themselves and with other countries in the world.

The first session of WMO/ESCAP Panel on Tropical Cyclones was convened in Bangkok, Thailand in January 1973. The functions of the Panel are:

► To review regularly the progress in various fields of tropical cyclone damage prevention;

► To recommend to the member countries plans and measures for the improvement ofcommunity preparedness and disaster prevention;

► To promote, prepare and submit to member countries plans for co-ordination ofresearch programmes and activities on tropical cyclones;

► To facilitate training of personnel from member countries in tropical cyclone forecasting and warning, flood hydrology and its control within the region;

- ► To plan for co-ordination of research programmes and activities concerning tropical cyclones within member countries;
- ► To prepare and submit, at the request and on behalf of the member countries requests for technical, financial and other assistance offered under United Nations Development Programme (UNDP) and by other organisations and contributors and
- ► To consider, upon request, possible sources of financial and technical support for such plans and programmes.

In carrying out these functions, the PTC committee maintains and implements action programmes under the five components of meteorology, hydrology, disaster prevention and preparedness, training and research with contributions and co-operation from its members and assistance from the UNDP, ESCAP, WMO and other agencies.

The Panel at its twelfth session in 1985 at Karachi (Pakistan) adopted a comprehensive cyclone operational plan for this region. The basic purpose of the operational plan is to facilitate the most effective tropical cyclone system for the region withexisting facilities. The plan defined the sharing of responsibilities among Panel countries for the various segments of the system and recorded the co-ordination and co-operation achieved. The plan also recorded the agreed arrangements for standardization of operational procedures, efficient exchange of various data and its archival related to tropical cyclone warnings, issue of a tropical weather outlook and cyclone advisories from a central location having the required facilities for this purpose, for the benefit of the region and strengthening of the operational plan. Further the Panel agreed upon the issue of tropical cyclone advisory bulletin for use of aviation as per recommendation No. 1/21 of International Civil Aviation Organisation (ICAO) in its 12th meeting of 161st session held at Montreal, Canada during 09-26 September, 2002
The operational plan is evolutionary in nature. Its motivation is to update or raise the text of the plan from time to time by the Panel and each item of information given in the annexes of the plan to be kept up to date by the member country concerned.

RSMC- Tropical Cyclones, New Delhi:

Regional Specialized Meteorological Centre (RSMC) - Tropical Cyclones, New Delhi, which is co-located with Cyclone Warning Division of IMD and came into existence in 1988 as per the recommendation of first session of WMO/ESCAP Panel on Tropical cyclones held in January,1973. It has the responsibility of issuing Tropical Weather Outlook and Tropical Cyclone Advisories for the benefit of the countries in the World Meteorological Organization (WMO)/ Economic and Social Co-operation for Asia and the Pacific (ESCAP) Panel region bordering the Bay of Bengal and the Arabian Sea, namely, Bangladesh, Maldives, Myanmar, Pakistan, Sultanate of Oman, Sri Lanka and Thailand. It has also the responsibilities as a Tropical Cyclone Advisory Centre (TCAC) to provide Tropical Cyclone Advisories to the designated International Airports as per requirement of International Civil Aviation Organization (ICAO).

The area of responsibility of RSMC- New Delhi covers Sea areas of north Indian Ocean (north of 10^{0}S between 45^0 E and 100^0 E) and includes the member countries of WMO/ESCAP Panel on Tropical Cyclones viz. Bangladesh, India, Maldives, Myanmar, Pakistan, Sri Lanka, Sultanate of Oman, Thailand, Yemen, Iran, Qatar, Saudi Arabia & United Arab Emirates.

The broad functions of RSMC- Tropical Cyclones, New Delhi are as follows:

- Round the clock watch on weather situations over the entire north Indian Ocean. Analysis and processing of global meteorological data for diagnostic and predictionpurposes.
- Detection, tracking and prediction of cyclonic disturbances in the Bay of Bengal andthe Arabian Sea.
- Running of numerical weather prediction models for tropical cyclone track and stormsurge predictions.
- Interaction with National Disaster Management Authority and National Disaster Management, Ministry of Home Affairs, Govt. of India to provide timely information and warnings for emergency support services. RSMC-New Delhi also coordinates with the National Institute of Disaster Management (NIDM) for sharing the information related to cyclone warning.
- Implementation of the Regional Cyclone Operational Plan of WMO/ESCAP Panel. Issue of Tropical Weather Outlook and Tropical Cyclone Advisories to the Panel countries in general.
- Issue of Tropical Cyclone advisories to International airports in the neighbouringcountries for International aviation.
- Collection, processing and archival of all data pertaining to cyclonic disturbances viz. wind, storm surge, pressure, rainfall, damage report, satellite and Radar derived information etc. and their exchange with Panel member countries.
- Preparation of comprehensive annual reports on cyclonic disturbances formed over North Indian Ocean every year.
- Preparation of annual review report on various activities including meteorological, hydrological and disaster preparedness and prevention activities of panel member countries.
- Research on track, structure and intensity monitoring and prediction techniques as well as associated adverse weather including storm surge, heavy rain and gale wind.

COMMITTEE ON WMO/ESCAP PANEL ON TROPICAL CYCLONES (2024)

Chairman	**: Mr. Abdulla AL MANNAI (Qatar)**
Chairman drafting committee:	**Dr. D. R. Pattanaik (India Meteorological Department)**

TECHNICAL SUPPORT UNIT (TSU)New Delhi, INDIA

Co-ordinator	**: Dr. D.R. Pattanaik**
Meteorologist	**: Ms. Monica Sharma**

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Ms Anne-Claire Fontan **Scientific Officer, Tropical Cyclone Programme Tel: + 41 22 730 81 51**

UNITED NATIONS ECONOMIC AND SOCIAL COMMISSIONFOR ASIA AND THE PACIFIC (UNESCAP)

Dr. Sanjay K Srivastava **Chief/UN-ESCAP Disaster Risk Reduction Section of the ICT**

INTRODUCTION

Publication of "WMO/ESCAP Panel on Tropical Cyclones–Annual Review commenced with the review for the year 1997. This was as per the decision of the Second Joint Session of the WMO/ESCAP Panel on Tropical Cyclones and Typhoon Committee held at Phuket, Thailand 20-28, February 1997. The present Annual Review: 2024 contains primary contribution from the Panel member countries.

Chapter I contains detailed information on national programmes and activities related to meteorology, hydrology, disaster prevention and preparedness, training and research as supplied by Panel Members. Technical and administrative support provided and activities undertaken by the Panel.

A summary of Tropical Cyclones during 2024 is given in the first part of Chapter II. Earlier, tropical cyclones were identified by their geographical locations. From post-monsoon season 2004, the practice of naming each tropical cyclone individually has been adopted in the north Indian Ocean basin also. Tropical disturbances are classified as per the practice introduced at Regional Specialized Meteorological Centre (RSMC)–Tropical Cyclones New Delhi. The classification of disturbances is shown in the following Table. The term "Cyclone" used in the present text is a generic term for the five categories of cyclonic disturbances (S.N. 4 to 8) in the Table.

Classification of low-pressure systems at RSMC–Tropical Cyclones, New Delhi

S No.	Maximum sustained surface ind Speed in knot (kmph)	Nomenclature
1.	Less than 17 (31)	Low Pressure Area (L)
2.	17 to 27 (31-49)	Depression (D)
3.	28 to 33 (50- 61)	Deep Depression (DD)
4.	34 to 47 (62 –88)	Cyclonic storm (CS)
5.	48 to 63 (89 – 117)	Severe Cyclonic Storm (SCS)
6.	64 to 89 (118 –166)	Very Severe Cyclonic Storm (VSCS)
7.	90-119 (167-221)	Extremely Severe Cyclonic Storm (ESCS)
8.	120 and above (222)	Super Cyclonic Storm (SuCS)

The second part of Chapter II contains a brief report on tropical cyclones affecting Panel countries during 2024. Based on the real-time and climatological data available with the India Meteorological Department (IMD), India, special features of the 2016 tropical cyclone season are highlighted. It also contains realized weather and damages caused by cyclones. All units used in the chapters are as per standard norms.

In the context of Chapter II, sustained winds refer to wind speeds averaged over a period of 3 minutes. Kilometer per hour (kmph) / knot is the unit used for wind speed as well as the speed of movement of tropical cyclones. The S.I. unit of hecta-Pascal (hPa) is used for atmospheric pressure. Reference time used is primarily in Universal Time Coordinate (UTC). Wherever possible, station names contained in WMO Weather Reporting-Observing Stations (WMO/OMM-No.9 Volume A) are used for geographical reference with code.

Chapter III consists of the 4 years Coordinated Technical Plan (2024-27) Annual Operating Plan (2024-25)

CHAPTER-I

WMO/ESCAP PANEL ACTIVITIES IN 2024

1. METEOROLOGICAL ACTIVITIES

1.1. WMO

Activities of member countries on WMO/ESCAP Panel, WMO and UN-ESCAP for the year 2024 were presented at the **51st session** of the WMO/ESCAP Panel on tropical cyclones held online and hosted by Qatar during **16-19 December, 2024**. Under this item, matters relating to the basic observational network, the telecommunication links and data-processing systems established in the region to fulfill the WMO's World Weather Watch Programme requirements were reviewed.

The WMO representative emphasized strengthening the overall forecasting and early warning framework through improved operational standards, technical guidance and capacity development. Under the Early Warnings for All (EW4All) initiative, WMO noted that the observations and forecasting component of multi-hazard early warning systems continued to improve, although significant gaps remain, particularly in impact-based forecasting. WMO highlighted advances in hardware, software, data-sharing platforms and artificial intelligence offer new opportunities to enhance forecasting capabilities and early warning services.

With respect to forecasting systems, WMO reported ongoing efforts to develop impact-based and probabilistic tropical cyclone forecasting products through the Advisory Group on Tropical Cyclones. It also highlighted the inclusion of tropical cyclone parameters as mandatory products under the WMO Integrated Processing and Prediction System (WIPPS), which would eventually improve the consistency and availability of forecast products generated by WMO centres. WMO indicated that technical webinars on the application of artificial intelligence in tropical cyclone forecasting would be organized to facilitate the adoption of emerging technologies. In addition, WMO successfully organized the Fourth International Workshop on Satellite Analysis of Tropical Cyclones to promote knowledge exchange on the use of satellite observations in tropical cyclone analysis and forecasting. Overall, the emphasis was laid on improving forecasting methodologies, operational coordination, and the application of emerging technologies rather than expanding observational infrastructure or introducing new forecast models.

1.2 Meteorology

(i) India

A brief description of the observational network of IMD and types of observations collected from the network are given below:

1.2.1. Surface Observations

IMD has a good network of surface observatories satisfying the requirement of World Meteorological Organization. There are 547 surface observatories in IMD. Of these, 209 observatories are manned by IMD staff. 141 out of 209 observatories are called Class – 1 observatory where all 8 synoptic observations are taken and all autographic instruments are available and remaining 68 observatories are called Class – 2 observatories where autographic instruments are not available. There are 338 surface observatories which are manned by non-departmental staff. Such observatories are called Part Time Observatories where 2 synoptic observations are taken daily. The data from these stations are used on real time basis for operational, monitoring and forecasting. A number of moored ocean buoys including Meteorological Buoy (MB), Shallow Water (SW), Deep Sea (DS) and Ocean Thermal (OT) buoys have been deployed over the Indian Sea, under the National Data Buoy Programme (NDBP) of the Ministry of Earth Sciences, Government of India. As a routine, a large number of ship observations over Indian seas from about 50 ships per day, both Indian and International are also received and are assimilated in the analysis.

In order to augment the manned surface observational network, IMD has established a network of Automatic Weather Stations (AWS) and Automatic Rain Gauge (ARG) Stations. As on date there are 1008 AWS installed across India. The sensors for parameters, Air Temperature, Relative Humidity, Rainfall, Pressure, Wind and Solar Radiation are interfaced with these stations. In addition to these sensors, 200 AWS called as Agro-AWS are equipped with sensors for Soil Temperature, Soil Moisture at different depths, Leaf Temperature and Leaf wetness. These stations have been installed uniformly in different agro-climatic zones of India and cater to the requirements of agricultural sector for issuing agro-meteorological advisories to the stake holders. This is in addition to the conventional (manual) agromet observatories of IMD. For monitoring of rainfall, IMD has established a network of over 1382 ARG stations. ARG stations are subset of AWS with sensor for only rainfall interfaced with the system. Some stations are also equipped with additional sensor for Air Temperature and Relative Humidity. Satellite and Mobile telemetry are being used for data communication from field stations to central data receiving server. Data are available at measurement interval of 1 hr for satellite telemetry and 15 min for mobile telemetry. About 5860 rain gauges are considered for real time monitoring of daily rainfall at district level. 35 HWSR systems have been installed along the east and west coasts of India for continuous monitoring of high wind speed.

1.2.2 Upper Air Observatories

There are at present 62 Pilot Balloon Observatories, 56 Radiosonde/ Radio wind observatories. All the 56 stations are GPS based observatories. Out of 56, six RS/RW stations at Regional Meteorological Centre (New Delhi, Mumbai, Kolkata, Chennai, Guwahati and Nagpur) are of WMO-GUAN (Global Climatological Observations System Upper Air Network) standards. Out of 56 stations, there are 18 Nos. of stations situated along the Sea coast. The details are given in Table 1.2.2.1 and fig 1.2.2.2.

To monitor the daily ascent status and the stock of various consumables there is observatory performance monitoring system has been started on the intra IMD portal.
The upper air meteorological data collected all over the country are used on real time basis for operational forecasting. The PBOs at New Delhi, Mumbai and Lucknow have been upgraded with GPS based PBO.

IMD has a network of 62 pilot balloon (PB) observatories. At these stations a smaller balloon is tracked for upper air wind data i.e Wind direction and wind speed profiles. Presently these stations are taking manual observations by tracking the balloon using optical theodolites and some of these stations are GPS based. The details of PB observatories near the coast are given in Table 1.2.2.2 and fig 1.2.2.2.

Table 1.2.2.1: List of RS/RW stations along the coast

S. No	Name of the station
1	Bhuj
2	Mumbai
3	Ratnagiri
4	Goa
5	Mangaluru
6	Kochi
7	Thiruvananthapuram
8	Amini Divi
9	Minicoy
10	Karaikal
11	Chennai
12	Kavali
13	Machilipatnam
14	Visakhapatnam
15	Gopalpur
16	Bhubaneshwar
17	Kolkata
18	Port Blair

Network Map

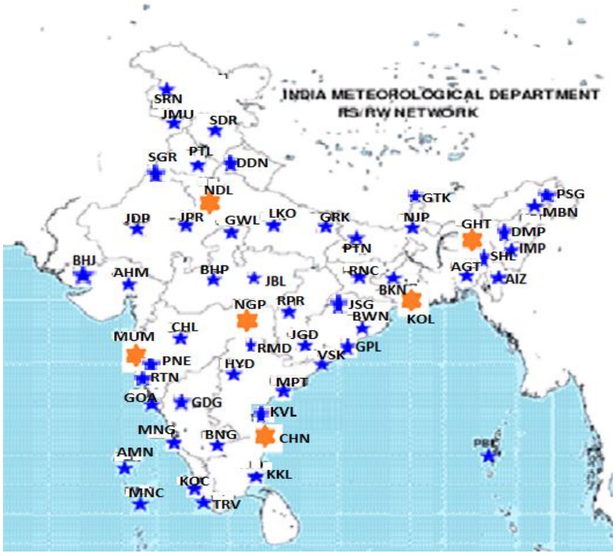

Fig. 1.2.2.1 RS/RW network of India Meteorological Department

Table 1.2.2.2: List of PB stations near the coast

S. No	Name of the station
1	Bhuj
2	Veraval
3	Surat
4	Mumbai
5	Ratnagiri
6	Mangaluru
7	Thiruvananthapuram
8	Amini Divi
9	Minicoy
10	Karaikal
11	Chennai
12	Machilipatnam
13	Visakhapatnam
14	Gopalpur
15	Bhubaneshwar
16	Balasore
17	Kolkata
18	Port Blair

Network Map

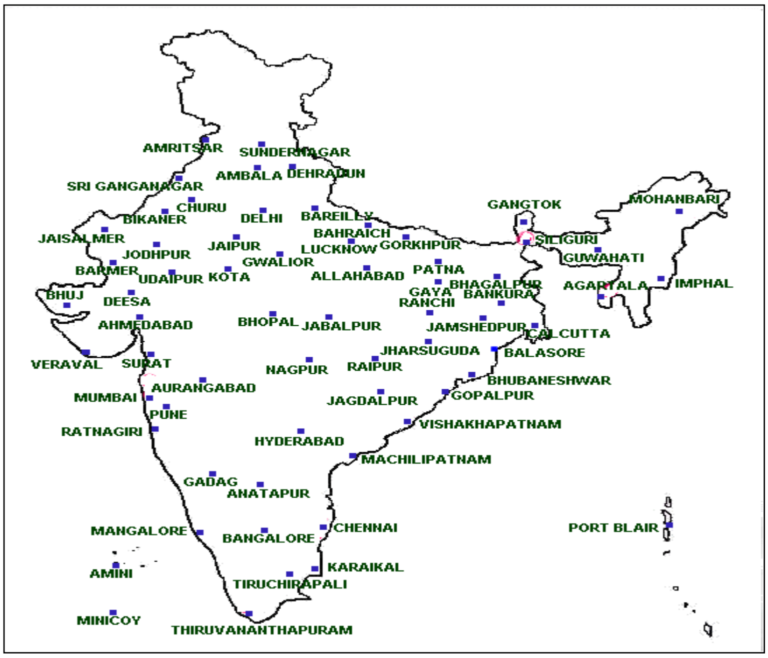

Fig. 1.2.2.2 PB station network of India Meteorological Department

Future Plans:

- Sustenance of 6 Nos of high quality GPS based system- WMO-GUAN standard network.
- Expansion of GUAN standard network from 6 to 12 stations by up-gradation of 6 operational RS/RW stations to GUAN standard.
- Continuation of all 56 RS/RW stations with twice a day observations.
- *Further expansion of operational RS/RW stations from 56 to 63*
- Up-gradation of PB network from manual (optical theodolite based) observations to fully automatic GPS based observations.
- To create an additional buffer stock of consumables for upper air observations dedicated to the cyclone monitoring.

1.2.3 Radars

1.2.3.1 Current Status

Weather radar network of India is managed by IMD, and consists of 39 Doppler Weather Radars (DWRs) presently, spreading across the country (Fig. 1.5). RADAR network includes 5 ISRO and 1 IITM RADARs.

India has a network of 16 RADARs covering the Indian Coast line. Eight radars (Chennai, Kolkata, Machilipatnam, Visakhapatnam, Paradip, Gopalpur, SHAR, Karaikal) on the East Coast and five radars (Kochi, Goa, Mumbai, Bhuj, and Thiruvananthapuram) on West Coast. Recently, two more indigenously developed DWRs: one X-band DWR at Pallikarnai, Chennai and one C-band at Veravali, Mumbai have been added in IMD radar network. Thus there are 16 radars along the coast.
IMD also utilizes the data inputs from DWRs of ISRO located at VSSC Thiruvananthapuram (C-Band), Sohra / Cherrapunji (S-Band) and SHAR (Sriharikota-S Band) and radar set up by India Institute of Tropical Meteorology, Pune at Solapur, Maharashtra.

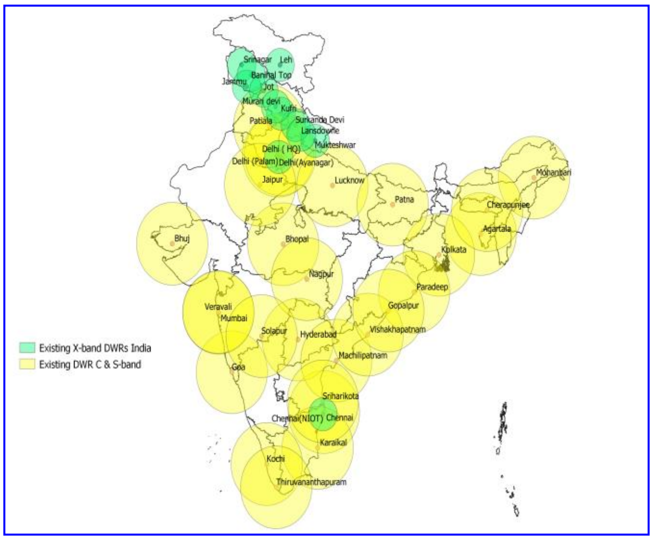

Fig. 1.2.3.1. Network of Doppler Weather Radar used for weather monitoring and forecasting

Radars of IMD are being used for detection of rainfall, hail storm, thunder storms and for tracking of cyclonic storms. Various meteorological and hydrological products derived from RADAR data using algorithms are extremely useful to the forecasters for estimating the storm's center, direction of movement, structure and intensity. The existing RADARs have also been networked to provide near real time data to super computers for ingesting into numerical weather prediction (NWP) models for short range forecasting. Composite images are also being generated centrally. Data is also converted to scientific formats such as NetCDF, HDF5, and Opera BUFR for assimilation in NWP models. A national Radar data centre is at IMD, New Delhi for archival and retrieval of radar data. Radar data products are also provided to various users. Open source GIS platforms are used to display the radar data on the web pages. IMD has combined radar data with lightning data and satellite imagery for a unified display on the website using GIS platform (Fig. 1.2.3.1). This provides accurate positional information of the location of the convective cells centre of storm rainfall.

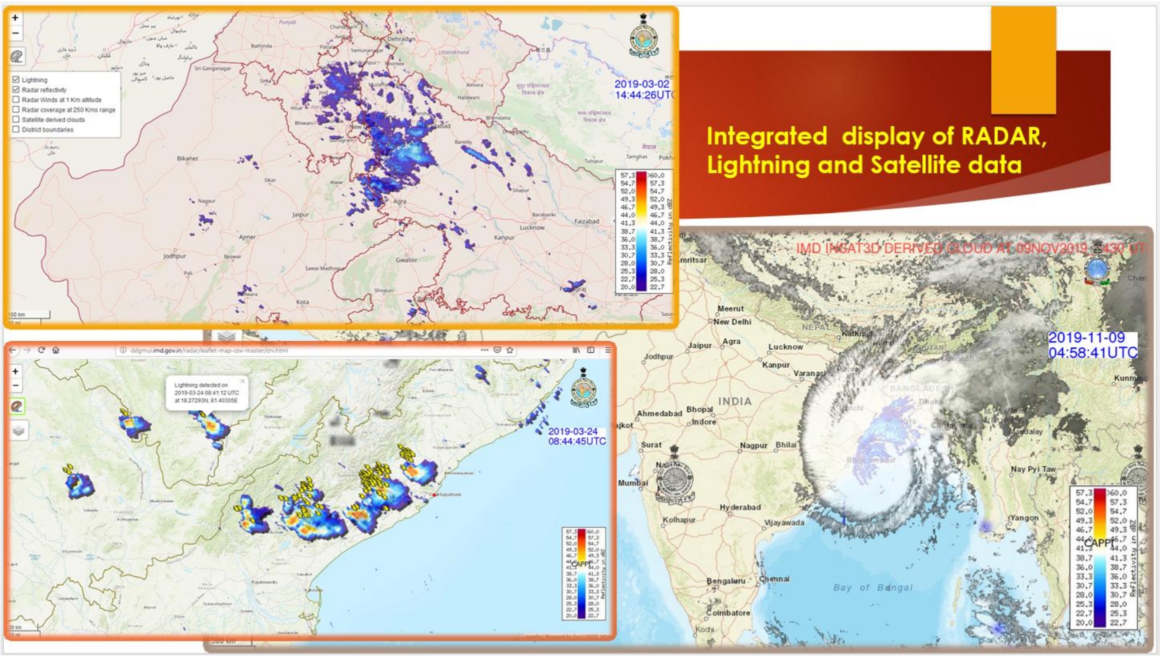

Fig. 1.2.3.2: Integrated display using RADAR, Lightning and Satellite data

Location specific information of lightning is also being generated in the radar data center and is available in the web page. A unique audio alert system announces the location and number of lightning occurrences district wise which alerts the forecaster and other end users to severe weather events.

1.2.3.2. Future Plan:

The Radar division is involved in implementation of modernization of Radar Network by replacing old conventional Radars with state of art DWRs. IMD has a plan to induct more than 73 DWRs in its network in the phased manner to bring entire Country and coasts under radar coverage. It is proposed to install 10 X-band radars in the northwest India including Jammu & Kashmir, Himachal Pradesh & Uttarakhand, and 11 C-band radars in the plains of the country and 8 X-band radars in the northeastern states. The network of proposed radars is presented in **Fig. 1.2.3.2(i) & Fig. 1.2.3.2 (ii).**
X-band DWRs under IHMP Scheme have already been installed at Leh, Kufri, Mukteshwar, Jammu, and Ayanagar & Surkanda Devi.

For improved efficient management, there are also plans, to establish a Weather Radar Operation Center, which would be responsible for weather radar related activities of the department. It will manage radar network, archival, dissemination of data, development of algorithms, network planning and related Research & Development.

IMD has also planned the procurement of Wind profilers under MoU with ISRO, Bangalore. The information on wind profiles improves the weather prediction in the tropics. Therefore, wind profilers are planned to be installed at nine locations **Fig. 1.2.3.3**

Further under Mission Mausam, 53 Radara, 10 wind profilers and 25 microwave radiometers will be procured and 60 numbers of RS/RW stations will be added to the network.

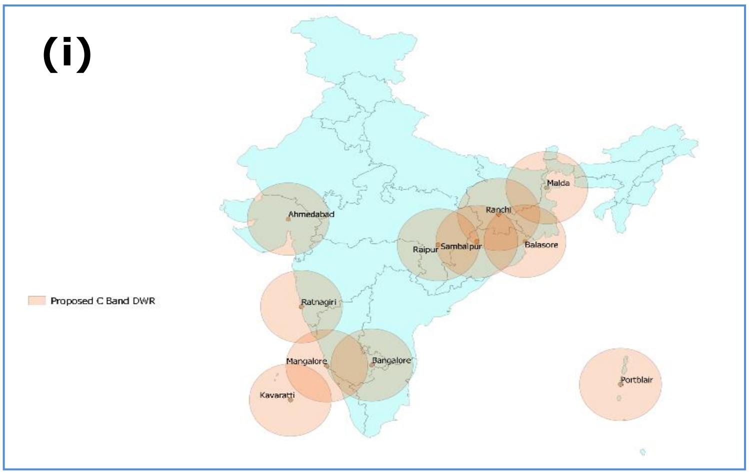

Fig. 1.2.3.2(i): Proposed 11 C band Doppler weather radars

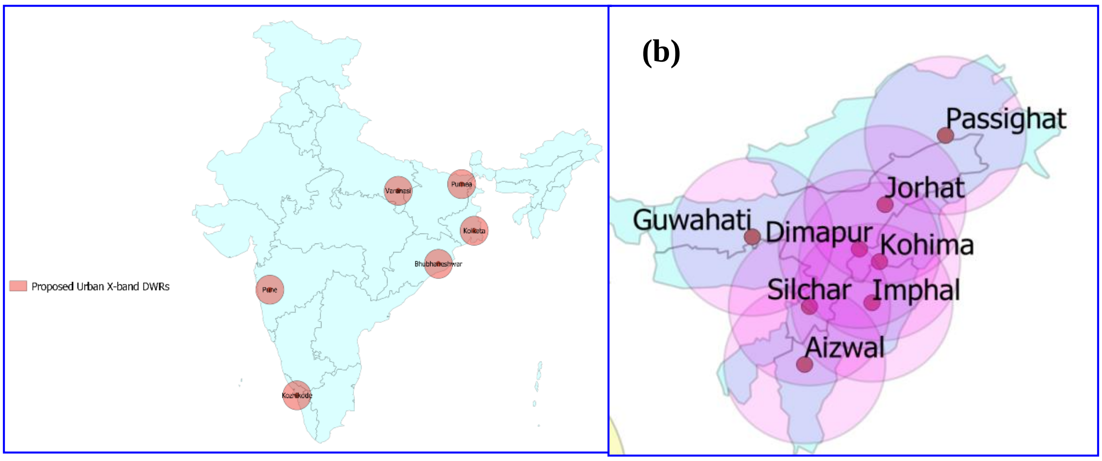

Fig. 1.2.3.2 (ii) Proposed (a) X-band DWRs for Urban Meteorology and (b) Radar network in North East India

IMD has also planned the procurement of Wind profilers under MoU with ISRO, Bangalore. The information on wind profiles improves the weather prediction in the tropics. Therefore, wind profilers are planned to be installed at nine locations. (Fig. 1.2.3.3)

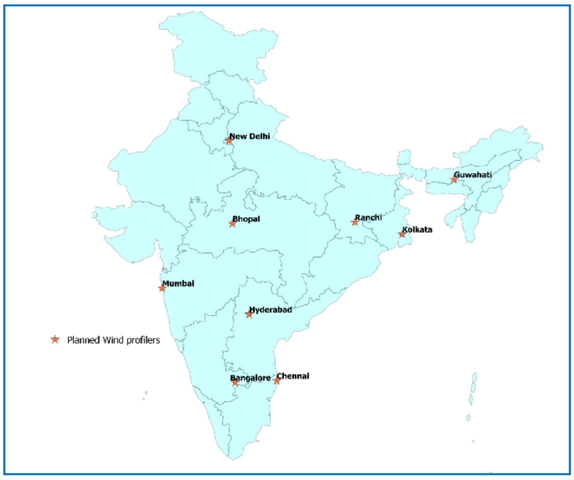

Fig. 1.2.3.3: Proposed Wind profilers

1.2.4 Meteorological Satellite

Multi Mission Meteorological Data Receiving and Processing System (MMDRPS) is being used on an operational basis to receive and process meteorological data from INSAT-3D and INSAT3-DR satellites on round the clock basis in Satellite Meteorological Division. MMDRPS systems consist of advance & latest state of art servers capable to process the complete set of data within 7 minutes after completion of scanning along with the storage capacity of order 2.0/2.0PB (Main/ Mirror) & 324TB SSD which will facilitate online sharing of processed data for all Indian meteorological satellites to the registered users as per IMD data policy through Web based secured satellite Data Supply System.

From MMDRPS, at present IMD is receiving and processing meteorological data from two Indian satellites namely INSAT-3D & INSAT-3DR. INSAT-3D launched on 26 July 2013 is positioned at 82°E and INSAT 3DR launched on 8th Sep 2016 is located at 74°E. INSAT-3D and INSAT-3DR have an advanced imager with six imagery channels {Visible (0.55-0.75 µm), Short wave Infra-Red (SWIR) (1.55-1.70 µm), Medium Infra-Red (MIR) (3.80-4.00 µm), Thermal Infra-Red-1(TIR-1) (10.2-11.3 µm), TIR-2 (11.5-12.5 µm), & WV (6.50-7.10 µm)} and a nineteen channel sounder (18 IR & 1 Visible) for derivation of atmospheric temperature and moisture profiles. It provides 1 km. resolution imagery in visible band, 4 km resolution in IR band and 8 km in WV channel.

Imager payload of these satellites (INSAT3DS/R) are operated in a staggered mode to get images every 15 minutes. Sounder payload of INSAT 3DS and INSAT 3DR satellite is operated in an integrated mode so that every hourly data of Indian land region and every one and half hour hourly data of Indian Ocean region is obtained for generating multi-level imageries and vertical profiles of humidity and temperature. Cloud Imagery and derived products data are disseminated to forecasting offices of the IMD as well as to the other users in India and foreign countries through dedicated web pages and online analysis and visualization tool (RAPID). All the received and processed data from the satellite are archived on a dedicated storage of MMRDPS

The following products derived from the satellite are useful for monitoring of tropical cyclones Enhanced grey scale imagery of cyclone.

1. Enhanced coloured imagery of cyclone.
2. Enhanced coloured imagery of cyclone.
3. Outgoing Long wave Radiation (OLR) at pixel resolution
4. The following Quantitative Precipitation Estimation (QPE)
   - ❖ GPI three hourly accumulated at 1x1 degree resolution,
   - ❖ Hydro estimator (HE) at pixel level

- ❖ INSAT-Multi spectral Rainfall (IMR)at 0.1x0.1-degree resolution
- ❖ Improved IMR at pixel level.

5. Sea Surface Temperature (SST) at pixel resolution
6. Upper Tropospheric Humidity (UTH) at pixel resolution
7. Cloud Motion Vector (CMV)
8. Water Vapour Wind (WVW)
9. Vis/MIR wind
10. Wind derived products such as: Lower level Vorticity, Upper level Divergence, Lower level convergence, Vertical wind shear & Wind shear tendency
11. Temperature, Humidity profile
12. Value added parameters from sounder products

- Geo-potential Height
- Layer Precipitable Water
- Total Precipitable Water
- Lifted Index
- Dry Microburst Index
- Maximum Vertical Theta-E Differential
- Wind Index
- Ozone

At present, Dvorak technique is used but manually applied. Recently, efforts have been made for automation of this technique. Automated Dvorak technique version (8.2.1) is running in experimental mode at Satellite Application Unit. Satellite Application Unit is also using microwave imageries operationally from NOAA, NASA-GPM, AMSR2, Metop, DMSP satellites for locating the tropical systems. Satellite Application Unit issues three hourly bulletins in general, and hourly and half hourly bulletins in case of tropical cyclones and other severe weather events.

ISRO successfully launched EOS-06 in November 2022. Satellite Meteorology Division, IMD had started receiving operational Scatterometer data from ISRO from May 2023. Satellite division, IMD, has indigenously devised a software module for operational handling of the Scatterometer data. Data are fetched between dual swath mode in a calendar day through file transfer protocol (FTP) and end products are generated by utilizing various Python libraries on a real time basis. Satellite division has also established a direct file transfer protocol access to the NRSC data repositories for seamless data transfer and product generation. The data output is currently generated in jpg format. The software code for this visualization has been exclusively made at SATMET division for the forecasters and end users. Typical OceanSat imagery during cyclone "DANA" is presented in Fig. 1.2.4.1.

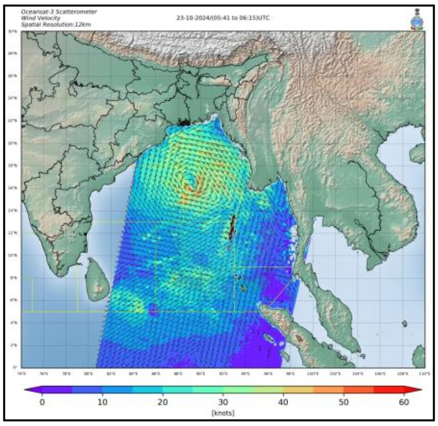

Fig.1.2.4.1: Oceansat-3 image of cyclone Dana on 23rd Oct., 2024

Satellite based Land Surface temperature product is currently generated on a pilot mode for Delhi-NCR region. The region-specific land surface temperature values from INSAT 3D and 3DR are generated for improved understanding of the urban hotspots over the city. This module is also planned for other smart cities in near future. An example is presented is fig 1.2.4.2.

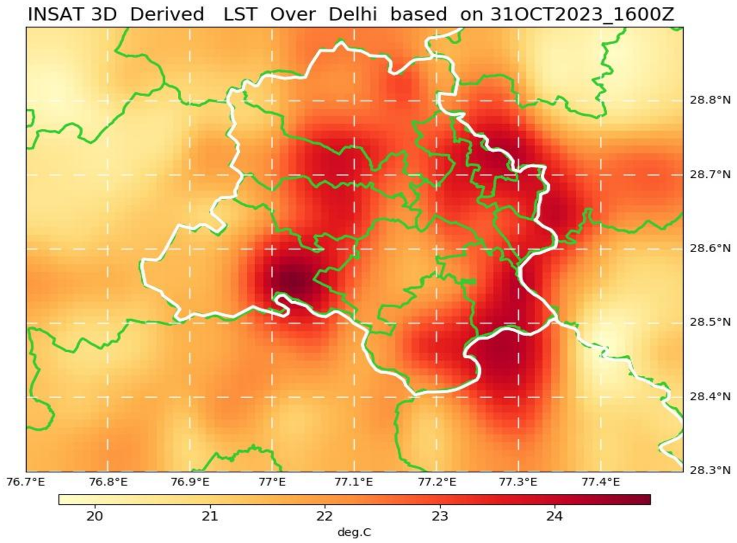

Fig.1.2.4.2: Satellite based land surface temperature

Real-time Analysis of Product and Information Dissemination (RAPID) is a visualization tool developed jointly by IMD & ISRO for monitoring and analysis of satellite imageries and products of INSAT 3D and INSAT-3DR. As RAPID is a geo-reference platform, it provides real time information on genesis, growth and decay along with its location and other geo-physical parameters to help forecasters to provide more objective nowcast. An advanced RAPID tool (Beta) version with ingestion of data from multiple data platforms like NWP, Radar, and Synop is also currently established in Satmet division. These tools are now available in IMD website at the link: http://www.rapid.imd.gov.in/

With the Web Archival System developed at Satmet Division IMD, INSAT-3D and INSAT-3DR products & imageries are archived. Spectral Band images and product images are archived online for last 12 months. These are available to all users through ftp.

In addition, INSAT-3DR Imager payload is used to conduct rapid scans during active cyclones following a standard operating procedure. Each rapid scan covers up 3 degrees in N-S direction (6 Blocks/240 scan lines) in 4.5 minutes. The rapid scans for all the Tropical Cyclones in India: Since 2022 have been conducted. Rapid scan data are being used to track these cyclones in real-time basis. The processed data is being disseminated on a dedicated webpage

http://satellite.imd.gov.in/rapid/rapid_scan.htm

The occurrence of lightning in India is being monitored with the help of lightning detectors established by the Ministry of Earth Sciences and Indian Air Force. Currently, there are about 300 nos. of lightning detectors in the country. The area of lightning during preceding 5 min, 10 min and 15 min are superimposed with satellite and radar imageries. It helps in enhanced monitoring of thunderstorm and lightning activities and nowcasting of similar extreme events.

Advanced Capabilities of Modern Indian Satellites:

Modern Indian satellites are equipped with sophisticated instruments that provide comprehensive atmospheric observations. These instruments include:

- Multispectral Imagers: These imagers capture images in multiple spectral bands, allowing for detailed analysis of cloud cover, land surface conditions, and ocean features.
- Sounders: Sounders measure the temperature and moisture profiles of the atmosphere, providing crucial information for weather forecasting and climate studies.
- The recently launched **INSAT-3DS**, with its improved blackbody calibration and advanced sounder payload, further enhances India's capabilities in satellite meteorology.
- By harnessing the power of satellite technology, India has significantly improved its weather forecasting and climate monitoring capabilities, contributing to the safety and well-being of its citizens and the global community.
- INSAT-3DS, launched on February 17, 2024, is the latest addition to India's geostationary satellite fleet. It is designed to provide enhanced meteorological observations and monitoring of land and ocean surfaces, significantly improving weather forecasting and disaster warning capabilities.

Key Features of INSAT-3DS:

- Advanced Payloads: Similar to INSAT-3D and INSAT-3DR, INSAT-3DS carries a 6-channel imager and a 19-channel sounder.
- Improved Capabilities: The satellite incorporates advancements in radiometric accuracy, black body calibration, thermal management, and imaging throughput.
- Enhanced Data Quality: Provides higher-quality data for more precise weather analysis and forecasting.
- Real-time Monitoring: Contributes to real-time monitoring of weather systems, including cyclones, thunderstorms, and fog.
- Improved Disaster Warning: Helps in early warning systems for extreme weather events like floods, droughts, and heatwaves.

Contribution to Weather Forecasting:

INSAT-3DS, along with INSAT-3D and INSAT-3DR, plays a crucial role in:

- Accurate Weather Prediction: Provides high-resolution imagery and atmospheric profiles for precise weather forecasting.
- Tropical Cyclone Tracking: Enables real-time monitoring of cyclone formation, intensification, and movement.
- Monsoon Monitoring: Helps in understanding and predicting the Indian monsoon, a vital weather system for the country.
- Extreme Weather Event Monitoring: Detects and tracks extreme weather events like heatwaves, cold waves, and heavy rainfall.
- Climate Studies: Contributes to long-term climate studies and monitoring climate change impacts.
- By leveraging the capabilities of these advanced satellites, India is strengthening its capacity to monitor weather patterns, issue timely warnings, and mitigate the impacts of natural disasters

1.2.5. Performance of operational NWP models during 2024

1.2.5.1 Global Forecast System

The Global Forecast System (GFS), adopted from National Centre for Environmental Prediction (NCEP) USA is operationally run at India Meteorological Department (IMD), New Delhi on Cray XC40 based High Power Computing Systems (HPCS). The IMD-GFS (T1534/L64) global model is run with ~12 km horizontal resolution and 64 hybrid sigma-pressure layers with Ensemble Kalman Filter (ENKF) based Grid Point Statistical Interpolation (GSI) scheme as the global data assimilation to generate 10 days forecast. The model is run four times in a day (00, 06, 12 and 18 UTC). The real-time outputs are made available to the national web site of IMD (https://mausam.imd.gov.in/ under Short to Medium Range Model Guidance).
IMD also makes use of NWP products prepared by some other operational NWP Centers like, European Center for Medium Range Weather Forecasting (ECMWF), GFS (NCEP) USA, Japan Meteorological Agency (JMA), UK Meteorological Office (UKMO) model etc.

1.2.5.2. Regional Forecast System

IMD operationally runs regional models Weather Research Forecast Advance Research for Weather Forecasting (WRFARW) (v3.9) with regional GSI based data assimilation, and Atmosphere-Ocean coupled Hurricane Weather Research and Forecast (HWRF) modelling system for short-range prediction during cyclone.

1.2.5.2.1 Non-hydrostatic mesoscale modeling system WRF-ARW with regional GSI based Data Assimilation system

The mesoscale Weather Research and Forecast WRF (version 3.9.1) with 3DVAR data assimilation is being operated daily twice to generate mesoscale analysis at 8 km horizontal resolution using IMD GFS-T574L64 analysis as first guess and forecasts as boundary condition. Using analysis and updated boundary conditions from the WRFDA, the WRF (ARW) is run for the forecast up to 3 days with 3 km and 45 Eta levels in the vertical 4 times a day at 06 hourly interval.
The model domain covers the area between lat. 5ºS to 40ºN long 50ºE to 102ºE covering India and neighbouring south Asian countries. The model runs with its own regional data assimilation (Com GSI V3.7_EnKF1.3).

1.2.5.2.2. Hurricane WRF Model (HWRF)

Since 2011, time to time the HWRF modelling system is developed and customized atmospheric and ocean models with other associated pre-processing and post-processing components are implemented in IMD under the framework of MoU between Ministry of Earth Sciences (MoES) India and National Oceanic and Atmospheric Administration (NOAA) USA. The HWRF version H217 has been ported on the MHIR HPCS with horizontal resolution of 18 km for parent domain and 6km & 2 km for intermediate and innermost nested domains following the center of cyclonic storm. The model is running with 61 vertical levels with parent domain, intermediate and innermost domain covering area of 80°x80°, 24°x24° and 7°x7° respectively. The special feature modified for tropical cyclone forecasting includes vortex initialization and correction, GSI based regional data assimilation, coupler for two-way coupling between atmosphere and ocean components and fine-tuned physical parameterization schemes. This model is customized specifically to forecast the track, intensity and structure of tropical cyclones. The HWRF modelling system uses the dynamics and infrastructure from the Non-Hydrostatic Mesoscale Model (NMM) WRF modelling system. It uses physics that are proven to be better for the tropics. Also, at this time, it is an Ocean coupled model system with a Moving two-way interactive nest, and advanced data assimilation. IMD is operationally running ocean coupled HWRF models during Tropical Cyclone (TC) events with two ocean models viz. Princeton Ocean Model (POM-TC) and Hybrid Coordinate Ocean Model (HYCOM). HYCOM initial conditions are provided through Indian National Centre for Ocean Information Services (INCOIS) whereas POM-TC is initialized based on climatology.

It is run 4 times a day in cyclic mode with GSI based (hybrid-Ensemble Variation (EnVar)) assimilation (80 members) with 6 hourly cycles in cycling mode with full physics configuration. The Unified Post-Processor (UPP) coverts raw model outputs from all three domains into standard GRIB1/2 format. Moreover, Global Fluid Dynamics Laboratory (GFDL) tracker generates track and intensity information in a standard Automated Tropical Cyclone Forecasting System (ATCF) format processing all GRIB files with a specified time interval (3 or 6 hours) as per requirement.

The modeling system was fully operational and predicted all cyclones during the years. Whenever any low-pressure system intensified and became depression over both sub-basins of North Indian Ocean, the cyclic run of the modelling system had been initiated. The model utilized ocean initial state from the INCOIS Tendral Ocean Prediction System – Indian Ocean Model (ITOPSI) during each cycle to initialize the HYCOM ocean component. All available observed data including conventional and satellite observations were assimilated into the regional GSI system to improve further the initial condition after the vortex initialization of the atmospheric first guess state of the model forecast from previous cycle (except first cycle).

The ocean model provides the SST field to the atmospheric component through coupler during the model integration to update the effect of mixing, cooling as well as advection effect on SST field, whereas the atmospheric component provides the heat fluxes, wind stress, precipitation and surface pressure fields to the ocean model through coupler. The coupled HWRF model uses GFDL vortex tracker and diagnostic software to provide the graphic and text information on track, intensity as well as structure of tropical cyclones for real time operational requirements. The HWRF physics scheme upgrades include updated Scale-Aware Simplified Arakawa-Schubert (SASAS) scheme, Ferrier-Aligo microphysics, GFS Hybrid-EDMF PBL, partial cloudiness for RRTMG scheme, and surface-exchange coefficients in the surface layer.

Within coupled framework of HWRF modeling system, the POM is initialized based on the climatological data whereas the HYCOM is initialized based on the ocean fields from Real-Time Ocean Forecast System (RTOF) of INCOIS, Hyderabad. The atmospheric component of HWRF is initialized based on the analysis and forecast from IMD-GFS (T1534L64) and associated GDAS analysis. The HWRF model uses 3D-EnVAR-GSI as its data assimilation component. The coupled HWRF model is run every 6 hours on real time basis in cyclic mode based on 00, 06, 12, 18 UTC initial conditions to provide track and intensity forecast along with surface wind, rain swaths and other diagnostic products for up to 126 hours.

The coupled HWRF system with both ocean models viz, POM-TC and HYCOM was operational simultaneously and model guidance products were provided from both the configurations. The coupled HWRF model uses TC Vital parameters generated by RSMC, New Delhi every six hour from Deep depression state till landfall of TC

1.2.5.2.3. High Resolution Rapid Refresh Modeling System (HRRR)

The High Resolution Rapid Refresh (HRRR) system based on Weather Research and Forecast (WRF-ARW) model with WRFDA (3DVAR-FGAT) data assimilation is operationalized in IMD in collaboration with Space Application Center (ISRO) from beginning of 2021. The HRRR is hourly updated atmospheric model with horizontal resolution of 2km. The model uses forecast of IMD-GFS (T1534L64) model as first guess and forecast as boundary during cold start and is then cycled providing hourly updates based on Radar Data assimilation. Using analysis and updated boundary conditions from the WRFDA, the HRRR is run to produce forecasts up to 12 hours and forecasts are made available after every two hours on NWP website of IMD.

The model is run in three different domains covering Indian mainland. The three domains are North-West domain, East & North-East domain and South-Peninsular domain. HRRR with hourly updates provide frequent and updated precipitation and reflectivity forecasts with respect to the TC's which could be very useful in planning effective and immediate disaster mitigation strategies in very short range.

1.2.5.2.4. Dynamical statistical models

The method comprises of five forecast components, namely (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decaying intensity after the landfall.

a) Genesis Potential Parameter (GPP)

A cyclone genesis parameter, termed the genesis potential parameter (GPP), for the North Indian Sea is developed (Kotal et al, 2009). The parameter is defined as the product of four variables, namely relative vorticity at 850 hPa, middle tropospheric relative humidity, middle tropospheric instability, and the inverse of vertical wind shear. The parameter is operationally used for distinction between non-developing and developing systems at their early development stages. The composite GPP value is found to be around three to five times greater for developing systems (T 3.0) than for non-developing systems. The analysis of the parameter at early development stage of a cyclonic storm found to provide a useful predictive signal for intensification of the system.

The grid point analysis and forecast of the genesis parameter up to seven days is also generated on real time. Higher value of the GPP over a region indicates higher potential of genesis over the region. Region with GPP value equal or greater than 30 is found to be high potential zone for cyclogenesis. The analysis of the parameter and its effectiveness during cyclonic disturbances in 2022-2023 affirm its usefulness as a predictive signal (4-5 days in advance) for cyclogenesis over the North Indian Ocean.

b) Multi-model ensemble (MME) technique

The multi model ensemble (MME) technique (Kotal and Roy Bhowmik, 2011) is based on a statistical linear regression approach. The predictors selected for the ensemble technique are forecasts latitude and longitude positions at 12-hour interval up to 120-hour of five operational NWP models. In the MME method, forecast latitude and longitude position of the member models are linearly regressed against the observed (track) latitude and longitude position for each forecast time at 12-hours intervals for the forecast up to 120-hour. The 12 hourly predicted cyclone tracks are then determined from the respective mean sea level pressure fields using a cyclone tracking software. Multiple linear regression technique is used to generate weights (regression coefficients) for each model for each forecast hour (12hr, 24hr, 36 hr, 48hr, 60hr, 72hr, 84hr, 96hr, 108hr and 120 hrs) based on the past data. These coefficients are then used as weights for the ensemble forecasts. 12-hourly forecast latitude (LATf) and longitude (LONf) positions are defined by multiple linear regression technique. A collective bias correction is applied in the MME by applying multiple linear regression based minimization principle for the member models GFS (IMD), GFS (NCEP), ECMWF, UKMO and JMA. ECMWF data are available at 24h intervals. Therefore, 12h, 36h, 60h, 84h, 108h forecast positions of ECMWF are computed based on linear interpolation. All these NWP products are routinely made available in real time on the IMD web site: www.rsmcnewdelhi.imd.gov.in.

With the latest version of different models & EPS as well as different tracker used for tracking the centre of TC in models, the IMD has developed another MME for track, intensity & landfall forecasts since 2021. It performs better than the individual models.

c) Statistical Dynamical model for Cyclone Intensity Prediction (SCIP)

A statistical-dynamical model (SCIP) (Kotal et al, 2008) has been implemented for real time forecasting of 12 hourly intensity up to 120 hours. The model parameters are derived based on model analysis fields of past cyclones. The parameters selected as predictors are: Initial storm intensity, Intensity changes during past 12 hours, Storm motion speed, Initial storm latitude position, Vertical wind shear averaged along the storm track, Vorticity at 850 hPa, Divergence at 200 hPa and Sea Surface Temperature (SST). For the real-time forecasting, model parameters are derived based on the forecast fields of IMD-GFS model. The method is found to be provided useful guidance for the operational cyclone forecasting.
The MME based all available NWP models on EPS is also developed by IMD since 2021 for intensity prediction.

d) Rapid Intensification (RI) Index

A rapid intensification index (RII) is developed for tropical cyclones over the Bay of Bengal (Kotal and Roy Bhowmik, 2013). The RII uses large-scale characteristics of tropical cyclones to estimate the probability of rapid intensification (RI) over the subsequent 24-h. The RI is defined as an increase of intensity 30 kt (15.4 ms-1) during 24-h. The RII technique is developed by combining threshold (index) values of the eight variables for which statistically significant differences are found between the RI and non-RI cases. The variables are: Storm latitude position, previous 12-h intensity change, and initial storm intensity, vorticity at 850 hPa, divergence at 200 hPa, vertical wind shear, lower tropospheric relative humidity, and storm motion speed. The probability of RI is found to be increases from 0% to 100% when the total number of indices satisfied increases from zero to eight. The forecasts are made available in real time from 2013.

e) Decay of Intensity after the landfall

Tropical cyclones (TCs) are well known for their destructive potential and impact on human activities. The Super cyclone Odisha (1999) illustrated the need for the accurate prediction of inland effects of tropical cyclones. The super cyclone of Odisha maintained the intensity of cyclonic storm for about 30 hours after landfall. Because a dense population resides at or near the Indian coasts, the decay forecast has direct relevance to daily activities over a coastal zone (such as transportation, tourism, fishing, etc.) apart from disaster management. In view of this, the decay model (Roy Bhowmik et al. 2005) has been used for real time forecasting of decaying intensity (after landfall) of TCs.

1.2.5.3. Ensemble Prediction System

1.2.5.3.1. Tropical Cyclone Ensemble Forecast based on Global Models Ensemble (TIGGE) Data

The THORPEX Interactive Grand Global Ensemble (TIGGE, Philippe Bougeault et al. 2010) is an implementation of ensemble forecasting for global weather forecasting and is part of THORPEX, an international research programme established in 2003 by the World Meteorological Organization (WMO) to accelerate improvements in the utility and accuracy of weather forecasts up to two weeks ahead.
Since 2021, IMD has also implemented IFS TC Tracker (available from ECMWF) for all available TIGGE models (9 in numbers). These 9 models are from Bureau of Meteorology, Australia (BoM), Environment and Climate Change Canada (ECCC), European Centre for Medium-Range Weather Forecasts (ECMWF), India Meteorological Department (IMD), Japan Meteorological Agency (JMA), Korea Meteorological Administration (KMA), Met Office - UK (UKMO), and National Centers for Environmental Prediction, USA (NCEP), and National Centre for Medium Range Weather Forecasting (NCMRWF) are nine International Institutes model outputs (contributing to the TIGGE) are chosen based on availability at the ECMWF-TIGGE web data portal https://apps.ecmwf.int/datasets/data/tigge/levtype=sfc/type=cf/ as on December 2021.

1.2.5.3.2. Global Ensemble Forecast System

The Ministry of Earth Sciences (MoES) has commissioned two very high resolution (12 km grid scale) state-of-the-art global Ensemble Prediction Systems (EPS) for generating operational 10-days probabilistic forecasts of weather. The EPS involves the generation of multiple forecasts using slightly varying initial conditions. The forecast products from these two prediction systems are available at the following links (http://nwp.imd.gov.in/gefspro.php) and (http://www.ncmrwf.gov.in/product_main.php). The frameworks of the new EPSs are among the best weather prediction systems in the world at present. Very few forecasting centres in the world use this high resolution for short-medium range probabilistic weather forecasts.

2.1.5.3.3. The Ensemble Mean and Spread

The ensemble spread is a measure of the difference between the members and is represented by the standard deviation (SD) with respect to the ensemble mean (EM). On average, small (high) spread indicates a high (low) forecast accuracy.

- The ensemble spread is flow-dependent and varies for different parameters.
- It usually increases with the forecast range, but there can be cases when the spread is larger at shorter forecast ranges than at longer ranges. This might happen when the initial days are characterized by strong synoptic systems with complex structures but are followed by large-scale "fair weather" high pressure systems.

1.2.5.4. Models run at NCMRWF

Two global models are also run at NCMRWF, NGFS adapted from NCEP GFS and NCUM unified model adapted from UK Met Office. The observations assimilated at NCMRWF include various in-situ and remote sensing observations. In-situ observations includes measurements come from land weather stations, aircraft, radiosondes, ships and buoys. Satellite observation includes Infrared and microwave radiance measurements from Low Earth Orbiting (LEO) and Geostationary (GEO) satellites, Atmospheric Motion Vectors from LEO and GEO, ocean surface winds from scatterometers, GPS Radio Occultation measurements etc. Indian Doppler Weather Radar (DWR) observation are also assimilated in the NCMRWF NWP systems. NCUM-G (N1024/L70) model features a horizontal resolution of 12km and 70 vertical levels reaching upto an altitude of 80 km. It uses "ENDGame" dynamical core, which provides improved accuracy of the solution of primitive model equations and reduced damping. This was upgraded in June 2018 from the earlier model with a horizontal resolution of 17km. NCUM is a grid point model which has a Non-hydrostatic dynamics with a deep atmosphere suitable for all scales. It has semi-implicit time integration with 3D semi-Lagrangian advection, terrain following height coordinates and high order advection. It features mass-flux for shallow convection with convective momentum transport, non-local mixing and entrainment for boundary layer. The new version of the NCUM has the model physics configuration of GA6.0 (Global Atmosphere version 6.0) and a land surface model configuration of GL 6.0 which is based on JULES land surface scheme (Walters et al., 2017). This helps in producing finer details in the simulations of synoptic scale systems such as cyclones, fronts, troughs and jet stream winds. ENDGame also increases variability in the tropics, which leads to an improved representation of tropical cyclones and other tropical phenomena (Walters et al., 2017). Hybrid 4D-Var data assimilation system prepares initial condition for NCUM. The advantage of the Hybrid 4D-Var is that it uses a blended background error, blend of "climatological" r and day-to-day varying flow dependent background error derived from the 22–member ensemble forecasts at NCMRWF. The hybrid approach is scientifically attractive because it elegantly combines the benefits of ensemble data assimilation with the known benefits of 4D-Var within a single data assimilation system.

NCUM-R is a regional model having a horizontal grid resolution of ~4km with 80 vertical levels reaching up to 38.5 km height. NCUM-R uses the high-resolution analysis prepared by regional 4D-Var system. In addition to most of the in-situ and satellite observation types used in the global NCUM, Indian DWR observations of radial wind and rainfall intensity estimates are also used in the regional NCUM DA system. The model domain of NCUM-R spans entire south Asia covering Bay of Bengal and part of Arabian Sea (5 N-40 N, 65-100 E).

NCMRWF Ensemble Prediction System (NEPS-G) is a global medium range probabilistic forecasting system adapted from UK MET Office. The configuration consists of four cycles of assimilation corresponding to 00Z, 06Z, 12Z & 18Z and 10-day forecasts are made using the 00Z initial condition. The operational NCMRWF Ensemble Prediction System (NEPS) has 22 ensemble members. The horizontal resolution of NEPS is ~12km. The NCUM model analysis is used as the initial condition for the control model forecast. The perturbations are generated by Ensemble Transform Kalman Filter (ETKF) method which are added to the global deterministic analysis to create 22 perturbed initial conditions. These are used for generating ensemble member forecasts. One control and 11 perturbed ensemble members run from initial condition of 00UTC of current day and 11 more perturbed members run from 12 UTC of previous day to give 23 members (11 + 11 + 1 control) ensemble forecasts up to 10 days lead time. More details about NEPS-G are available in Mamgain et al. (2018). The new 12-km NEPS-G is the highest resolution for Ensemble forecasting.

The Coupled Ocean Atmosphere Model at NCMRWF (CNCUM) uses the Nucleus European Modelling of Ocean (NEMO) based global ocean analysis and forecast system at 0.25x0.25degree resolution is used to compute the upper ocean heat content up to 26°C isotherm depth called as Tropical Cyclone Heat Potential (TCHP). It is important oceanic parameter which affects the intensity of the TCs. At NCMRWF, it is produced in real time using the global ocean forecast system up to 10 days using the ocean only model and up to 15 days using the coupled atmosphere-ocean model for monitoring the upper ocean and also for research purpose mainly for Tropical Cyclone (TC) study. Further, the NEMO based temperature and salinity forecast from the Extended Range Prediction (ERP) is also used to compute the TCHP up to 4 week periods.

1.2.5.5. Models run at IITM Pune

Since 2018, Global Ensemble Forecast System (GEFS) T1534 (~12 km) is used for operational short-range probabilistic weather forecast system including cyclone prediction at IITM. It is based on Global Forecast System (GFS v14.1) which is a part of the 'Operational Model' developed at NCEP, USA in 2018. This is a spectral model with semi lagrangian dynamics and semi implicit time scheme. It has a horizontal resolution of 12.5 km. The total number of 21 Ensembles (20 perturbed forecasts + 1 control forecast) constitutes the ensemble system. These 20 ensembles analysis are generated by Ensemble Kalman Filter (EnKF) method from the forecast perturbation of the previous cycles four times a day (00, 06, 12 and 18 UTC) at all 64 model vertical levels. These analysis perturbations are added to the reconfigured analysis obtained from the hybrid four-dimensional Ensemble variational data assimilation system (GDAS-Hybrid4DEnsVar) as part of the suite. The 243 hour forecast of GEFS is routinely generated based on 00UTC and 12UTC initial conditions which include a control forecast starting from GDAS assimilation and 20 (20 perturbations) ensemble members with each perturbed initial conditions.

1.2.5.6. Probabilistic forecasts of quantitative precipitation

- In these charts, the probability that 24-hour precipitation amounts over a 2.5x2.5 lat-long grid box will exceed certain threshold values is given. The forecast probability is estimated directly from the 20-member global ensemble.
- At each grid point the number of ensemble members having a 24-hour precipitation amount within a specified range (e.g. 1-2cm, 2-5cm etc) is counted (M) and the probability is expressed as 100*(M/20).

1.2.5.7. Storm surge forecasting

Storm surge forecasting is the responsibility of the National Meteorological Services. However, storm surge guidance is issued and incorporated in the Tropical Cyclone Advisory bulletin by RSMC- New Delhi based on IIT, Delhi Storm Surge prediction model and INCOIS Advanced Circulation model (AdCirc).

1.2.5.8. Coastal inundation forecasting

The coastal inundation forecast by RSMC, New Delhi commenced from 2013 experimentally with cyclone Phailin. This forecast is provided to disaster managers. It is mainly based on coastal inundation model run by Indian National Centre for Ocean Information Services (INCOIS) Hyderabad. This is ADCIRC model is adapted from USA. This forecast guidance is also provided all member countries.

1.2.5.9. Seasonal Prediction of cyclonic disturbances

Seasonal prediction of cyclonic disturbances is being issued experimentally for the post monsoon season (Oct.-Dec.) since 2014. This contains information about the frequency of cyclonic disturbances (depression and above) over the Bay of Bengal and number of cyclonic disturbance days over the north Indian Ocean. However, it has not been operationalised considering the large inter-annual & intra-seasonal variability and less number of cases over north Indian Ocean region. The accuracy of this prediction system is low.

1.2.6 Operational forecast and warning production

1.2.6.1 Analysis and Prediction system

Various strategies have been adopted in recent years for improvement of analysis and prediction of cyclone. The tropical cyclone analysis, prediction and decision-making process is made by blending scientifically based conceptual models, dynamical & statistical models, meteorological datasets, technology and expertise. Conventional observational network, automatic weather stations (AWS), buoy & ship observations, cyclone detection radars and satellites are used for this purpose. A new weather analysis and forecasting system in a digital environment is used to plot and analyse different weather parameters, satellite, Radar and Numerical Weather Prediction (NWP) model products. An integrated fully automated forecasting environment facility is thus set up for this purpose. The manual synoptic weather forecasting has been replaced by hybrid systems in which synoptic method could be overlaid on NWP models supported by modern graphical and GIS applications to produce

- high quality analyses
- Ensemble of forecasts from NWP models at different scales - global, regional and mesoscale
- Prediction of intensity and track of tropical cyclone

A schematic representation of the monitoring and analysis, forecast and warning procedure is given in Fig.1.2.6.1

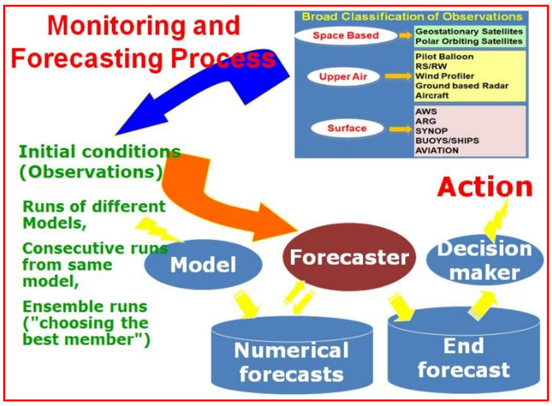

Fig.1.2.6.1. Strategy adopted for cyclone analysis and forecasting

The **indigenously developed decision support system has** following facilities.

- Analysis of all synoptic, satellite, radar and NWP model products for genesis, intensity and track monitoring and prediction
- Preparation of past and forecast tracks upto 120 hrs
- Depiction of uncertainty in track forecast
- Preparation of quadrant wind radii forecast upto 120 hrs.

All the available data and products from various national and international sources are systematically considered for analysis and prediction of cyclones. Various data and products utilized for this purpose are as follows.

❖ Data and analysis Products through digitized system as mentioned above.
❖ Radar data and products from IMD's radar network and neighbouring countries
❖ Satellite imageries and products from IMD and international Centers
❖ Dynamical and statistical Model products from various national and international Centers.
❖ Data, analysis and forecast products from various national and international Centers through internet.

Cloud imageries from Geostationary Meteorological Satellites INSAT-3D and INSAT-3D (R) are the main sources of information for the analysis of tropical cyclones over the data-sparse region of north Indian Ocean. Data from scatteometry based satellites and Ocean buoys also provide vital information. Ship observations are also used critically during the cyclonic disturbance period. When the system comes closer to the coastline, the system location and intensity are determined based on hourly observations from Radar as well as from coastal observatories. The AWS stations along coast are also very useful as they provide hourly observations on real time basis. The WVW and CMV in addition to the conventional wind vectors observed by Radio Wind (RW) instruments are very useful for monitoring and prediction of cyclonic disturbance, especially over the Sea region. The direction and speed of the movement of a tropical cyclone are determined primarily from the three hourly displacement vectors of the center of the cyclone. The consensus forecast that gather all or part of the numerical forecast and used synoptic and statistical guidance are utilised for issue of official forecast.
In addition, IMD has developed GIS based decision support indigenously which has the facility to overlay various model products at a single platform. It is utilized by the forecasters to generate probabilistic area of cyclogenesis, multi model based warnings for fishermen, probabilistic area of winds exceeding 25 knots and 34 knots, probabilistic heavy rainfall warning maps etc.

1.2.7 Bulletins and Products Generated by RSMC, New Delhi

RSMC, New Delhi prepares and disseminates the following bulletins:

1.2.7.1. Extended Range Outlook

IMD started issuing Extended Range Outlook for cyclogenesis during next two weeks every Thursday from 22nd April, 2018. It contains information about large scale features over the region, model guidance on probable cyclogenesis from various global/regional models, probability of cyclogenesis as LOW (0-33%), MODERATE (34-67%) and HIGH (68-100%) alongwith verification of forecast issued during last two weeks. The product is available on RSMC website at http://www.rsmcnewdelhi.imd.gov.in/images/bulletin/eroc.pdf and is also transmitted by email to WMO, WMO/ESCAP panel member countries and various scientists and researchers in the country. All the guidance products are archived since June, 2020.

1.2.7.2 Tropical Weather Outlook

Tropical Weather Outlook is issued daily at 0600 UTC based on 0300 UTC observations in normal weather for use of the member countries of WMO/ESCAP Panel. This contains description of synoptic systems over NIO along with information on significant cloud systems as seen in satellite imageries. It also provides probabilistic genesis forecast (formation of depression) over Bay of Bengal and Arabian sea separately for day 1 (up to 24 hrs), day 2 (24 – 48 hrs), day 3 (48 – 72 hrs), day 4 (72-96 hrs), day 5 (96-120 hrs), day 6 (120-144 hrs) and day 7 (144-168 hrs) since 7th July 2023. The forecast is issued in probabilistic terms like Nil, Low, Moderate and High probability corresponding to expected probability of occurrence of 00, 01 – 33, 34 – 67 and 68 – 100 %. It is based on the consensus developed from various NWP and dynamical statistical guidance coupled with guidance from observations and analyses. This forecast has been introduced since 1st June 2014 upto 72 hrs lead period. The lead period of cyclogenesis forecast was extended to 120 hrs in 22nd April, 2018.

1.2.7.3 Pre-Genesis Forecast:

India Meteorological Department has commenced pre-genesis forecast of probable date, time and location of expected cyclogenesis (formation of depression) over the NIO alongwith 12 hourly forecast of track, intensity and structure upto next 72 hours, once daily from the stage of low pressure area on 17th March, 2022. Typical example of pre-genesis forecast issued during Severe cyclonic storm "REMAL" is presented in Fig. 1.2.7.3.

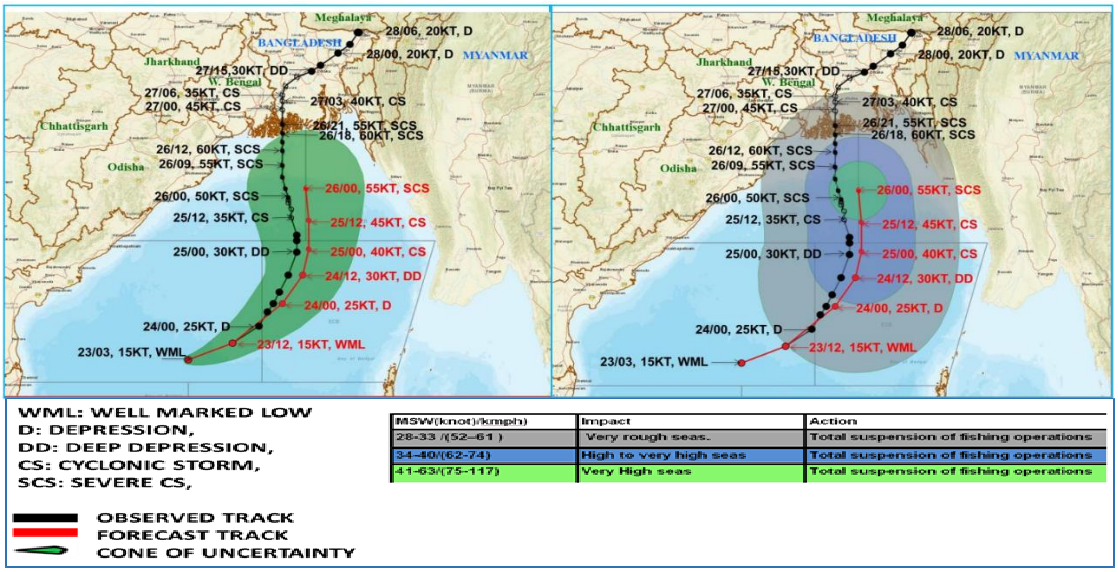

Fig1.2.7.3: Pre-genesis forecast issued at stage of well marked low pressure area on 23rd May, 2024 (3 and 1/2 days prior to landfall on 26th May over Bangladesh) demonstrating accuracy in track and intensity forecast

1.2.7.4. Special Tropical Weather Outlook

The Special Tropical Weather Outlook is issued at +03 hours based on observations of 0000, 0300, 0600, 1200 & 1800 UTC observations when a tropical depression forms over NIO. These bulletins contain the current position and intensity, past movement, central pressure of the cyclone, description of satellite imageries, cloud imageries, expected direction and speed of movement, expected track and intensity of the system up to 72 hrs in case of depression and upto 120 hrs in case of a deep depression. It also includes the description of sea condition. It also includes discussion on various diagnostic and prognostic parameters. The 72 and 120 hours track and intensity forecasts are being issued from the stage of depression and deep depression respectively since 2009 and 2018. The track and intensity forecast are issued for +06, +12, +18, +24, +36, +48, +60, 120 hours or till the system is likely to weaken into a well-marked low pressure area. IMD has initiated to give the quantitative forecast of track & intensity from depression stage for lead period of +12, +24, +48, +72 hours since April 2018. The time of issue of this bulletin is HH+03 hours. The cone of uncertainty in the track forecast is also included in the graphical presentation of the bulletin. Tropical weather outlooks are transmitted to panel member countries through global telecommunication system (GTS) & e-mails and are also made available on real time basis through internet at IMD's website: **www.mausam.imd.gov.in, www.imd.gov.in and www.rsmcnewdelhi.imd.gov.in**. RSMC, New Delhi can also be contacted through e-mail (**cyclonewarningdivision@gmail.com**) for any real time information on cyclonic disturbances over NIO.

1.2.7.5 Tropical Cyclone Advisories

Tropical cyclone advisory bulletin is issued when a deep depression intensifies into a tropical cyclone (wind speed≥34 knots). It replaces the 'special tropical weather outlook' bulletin. Tropical cyclone advisories are issued at 3 hourly intervals based on 00, 03, 06, 09, 12, 15, 18 and 21 UTC observations. The time of issue is HH+03 hrs. These bulletins contain the current position and intensity, past movement, central pressure of the cyclone, description of satellite imageries, cloud imageries, expected direction and speed of movement, expected track and intensity of the system up to 120 hours like that in special tropical weather outlook. The expected point and time of landfall, forecast winds, squally weather and state of the Sea in and around the system are also mentioned. Storm surge guidance is provided in the bulletin as and when required. Tropical cyclone advisories are transmitted to panel member countries through e-mails & GTS and are also made available on real time basis through internet at IMD's website: **www.mausam.imd.gov.in**, **www.imd.gov.in** and **www.rsmcnewdelhi.imd.gov.in**.

1.2.7.6 Storm Surge Guidance

RSMC New Delhi is providing storm surge guidance to the panel member countries since 2009 based on IIT Delhi Storm Surge model and. Recently INCOIS Hyderabad has developed an ADvanced CIRCulation (ADCIRC) Storm Surge and Coastal Inundation model which is running experimentally since 2013. In future it will be used as an input for providing storm surge guidance to member countries. RSMC New Delhi also commenced probabilistic storm surge guidance from Severe Cyclonic Storm "Remal" in May 2024. Typical guidance product is placed at Fig. 1.2.7.6.

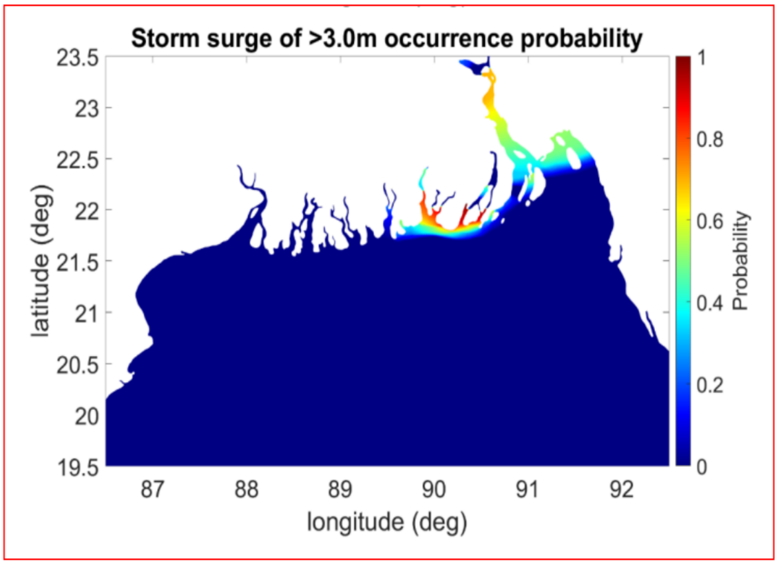

Fig. 1.2.7.6: Probabilistic Storm Surge during SCS REMAL

1.2.7.7 Maritime forecast bulletins

Under Global Maritime Distress and Safety System (GMDSS) Scheme, India has been designated as one of the 16 services providers in the world for issuing Sea area bulletins for vessels on high seas for broadcast through GMDSS for MET AREA VIII (N), which covers a large portion of NIO. As a routine, two GMDSS bulletins are issued at 0900 and 1800 UTC. During tropical cyclones/ depressions, additional bulletins (up to 4) are issued for GMDSS broadcast. In addition, coastal weather and warning bulletins are also issued for broadcast through NAVTEX transmitting stations. Fleet Forecasts for Indian seas are also issued for Indian Navy twice a day with validity period of twelve hours.

Port Warnings & fishermen warnings are also issued for the entire Indian coast as and when the coast is likely to be affected due to disturbances in seas. IMD has initiated to issue the fishermen warning for entire BoB and AS since April, 2018. Further a graphics based fishermen warning is being generated for entire BoB and AS since 26th April 2019.

The fishermen warnings for next 5 days based on multi-model ensemble and probability of exceedance of winds ≥ 45 kmph and 35 knots are available at www.rsmcnewdelhi.imd.gov.in. IMD has also commenced preparation of marine bulletins in graphical format using QGIS tool and these graphical products are also available over GIS platform since January, 2021 based on multi model ensemble guidance. Sample fishermen graphics is placed at Fig. 1.2.7.7

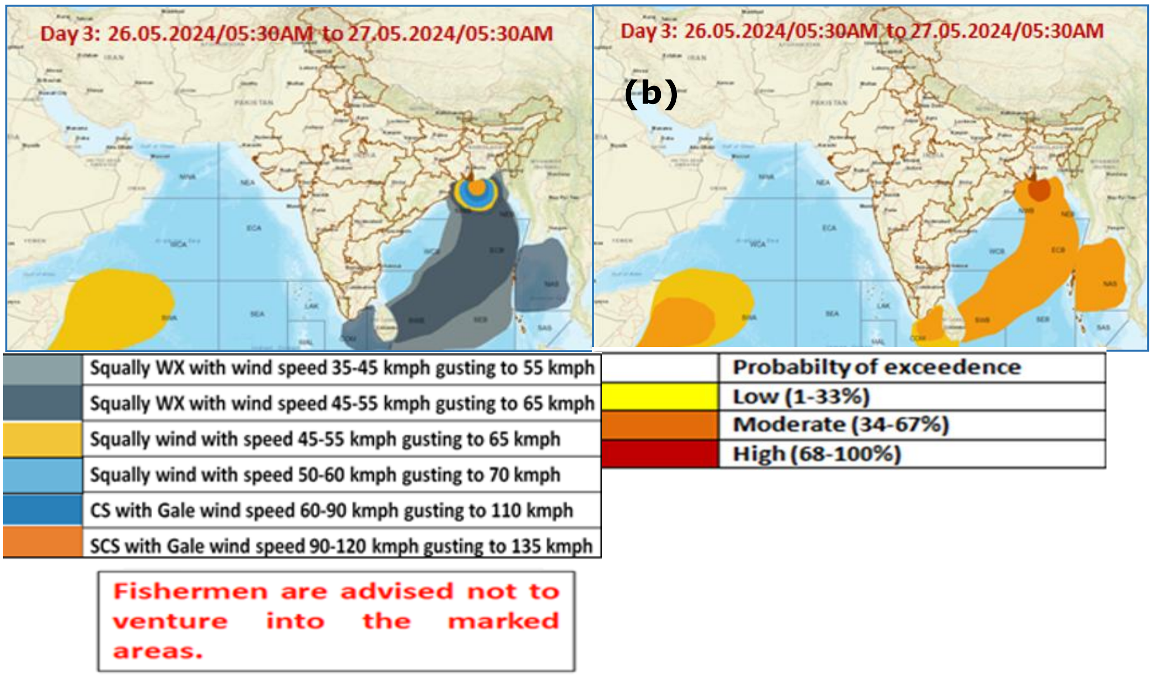

Fig. 1.2.7.7: Typical (a) fishermen warning graphics and probabilistic map for wind exceeding 45 kmph issued on 24th May 2024

1.2.7.8 Tropical Cyclone Advisories for Aviation

Tropical Cyclone Advisories for aviation are issued for international aviation as soon as any disturbance over the NIO attains or likely to attain the intensity of cyclonic storm (maximum sustained surface wind speed ≥ 34 knots) within next six hours. These bulletins are issued at six hourly intervals based on 00, 06, 12, 18 UTC synoptic charts and the time of issue is HH+03 hrs. These bulletins contain present location of cyclone in lat./long., maximum sustained surface wind (in knots), direction of past movement and estimated central pressure, change in intensity, forecast position as Lat./Long (in degree & minutes), and forecast winds in knots valid at HH+6, HH+12, HH+18 and HH+24 hrs. The tropical cyclone advisories are transmitted on real time basis through GTS & AFTN channels to designated International Airports of the region prescribed by ICAO and ftp to ADRR, Hong Kong (WMO's Aviation Disaster Risk Reduction) in coded form. It is also sent in graphics form in **png** format through GTS. The text and graphical bulletins are also uploaded on www.rsmcnewdelhi.imd.gov.in

1.2.7.9. National bulletin

These bulletins are issued from the stage of low pressure area as a "Special Message", once daily. During the stage of depression/deep depression; it is issued 5 times daily based on 00, 03, 06, 12, and 18 UTC observations. When the system intensifies into a cyclonic storm over NIO, these bulletins are issued every three hourly based on 00, 03, 06, 09, 12, 15, 18 and 21 UTC (every three hourly interval) at +03HH. This bulletin contains present status of the system i.e. the location, intensity; past movement and forecast track & intensity for next 120 hours or till the system weakens into a low pressure area, likely landfall point & time and likely adverse weather including heavy rain, gale wind & storm surge. Expected damage and action suggested are also included in these bulletins. This bulletin is completely meant for national users and these are disseminated through various modes of communication including Email, Telephone/FAX, All India Radio, Doordarshan (National TV), SMS and Print & electronic media. It is also posted on cyclone page of IMD website and RSMC website. These are also posted on social networking sites like facebook, tweeter and WhatsApp.

1.2.7.10. Cone of uncertainty forecast

The Cone of uncertainty (COU) represents the uncertainty in forecast centre of a CD/TC's and is made by drawing a set of circles centered at each forecast point—06, 12, 18, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hours for a five-day forecast. IMD introduced COU forecast upto a lead period of 72 hours in 2009 from Cyclone "WARD". The lead period was further extended to 120 hours in 2013 from Cyclone "VIYARU". COU values were revised in 2014 from cyclone "Hudhud" based on the errors during 2009-13. From cyclone FANI, 2019, the COU values have been revised based on the errors during 2014-18. The standard errors (nm) as radius of the circle around the forecast position (lat/long) so as to construct the cone of uncertainty in the track forecast for 00, +06, +12, +18, +24, +36, +48, +60, +72, +84, +96, +108 and +120 hrs lead period have been fixed as 10, 20, 30, 40, 45, 55, 70, 85, 95, 115, 130, 145 and 160 nm since April, 2019. Typical observed and forecast track alongwith cone of uncertainty demonstrating accuracy in track forecast during Severe Cyclonic Storm "REMAL" is presented in Fig. 1.12 (a). This product is uploaded on various websites of IMD viz. www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in in .png format and appended with the national and tropical cyclone advisory bulletins. Since, severe cyclonic storm "Nisarga" in June, 2020, this product was also made available on GIS based platform at www.rsmcnewdelhi.imd.gov.in

1.2.7.11 Wind forecast for different quadrants

The forecast of the radius of maximum sustained wind in four quadrants of a cyclone commenced with effect from the cyclone, GIRI during October 2010. In this forecast, the radius of 28, 34, 50 and 64 knot winds are given for various forecast periods like +06, +12, +18, +24, +36, +48, +60, … 120 hrs. A typical graphical presentation of this forecast is shown in Fig.1.12 (b). This product is uploaded on various websites of

IMD viz. www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in in .png format and appended with the national and tropical cyclone advisory bulletins. Since, severe cyclonic storm "Nisarga" in June, 2020, this product was also made available on GIS based platform at www.rsmcnewdelhi.imd.gov.in. It is also uploaded on RSMC, New Delhi website in textual form.

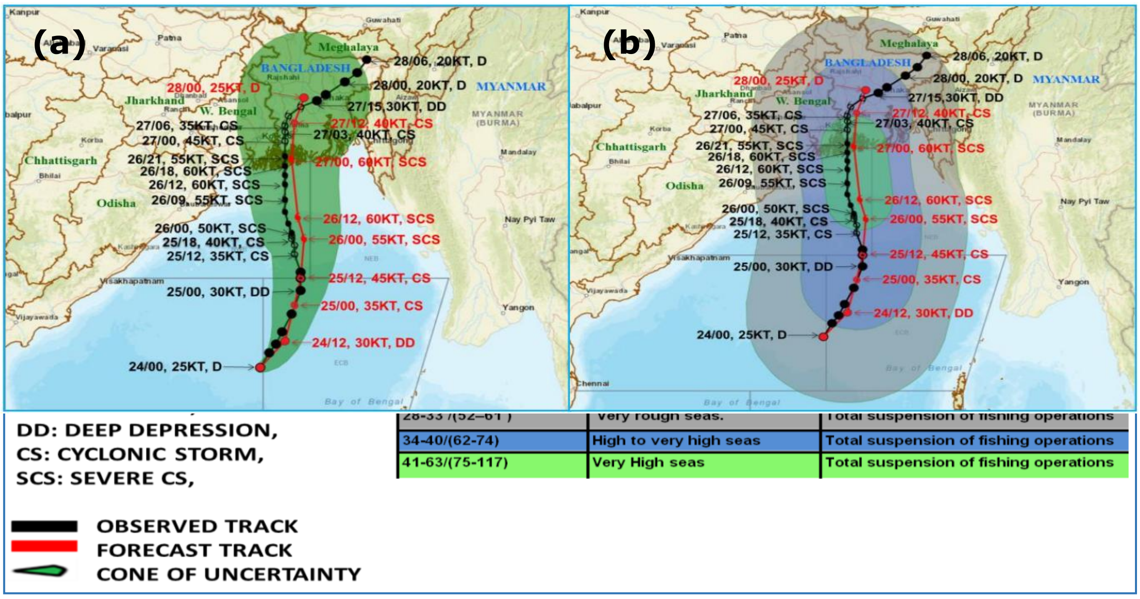

Fig.1.2.7.10: Observed and Forecast track alongwith (a) cone of uncertainty and (b) issued at 0915 hrs IST/0345 UTC of 24th May demonstrating accuracy in track and intensity forecast about 62 hours ahead of landfall.

1.2.7.12 Hourly Update

On the day of landfall IMD issues hourly updates on the landfalling cyclone over the Indian coast since October, 2014. It contains information about the centre, its distance & direction from the station, landfall point and time, current maximum sustained wind speed (MSW), MSW at the time of landfall. These bulletins are available at http://www.rsmcnewdelhi.imd.gov.in/images/bulletin/hourly.pdf on the day of landfall.

1.2.7.13 TC Vital

The TC Vital is issued by RSMC New Delhi to various NWP Centers in coded form for their use in creating the synthetic vortex in NWP models and running storm surge and coastal inundation model. It is issued 4 times a day based on 00, 06, 12 and 18 UTC. This bulletin contains the information on location (Latitude/Longitude), intensity (MSW and estimated central pressure), movement (Speed/Direction), size, the radius of maximum wind and wind radii of 34kts wind in 4 geographical quadrants namely NE, NW,SE and SW quadrants etc. This bulletin has been introduced in 2012.

1.2.7.14 Impact Based Forecast and Risk Based Warning for heavy rainfall over cities and districts

India Meteorological Department introduced impact based forecasts (IBF) & warnings for cyclonic Storms since long. Recently, since 2014, IMD introduced colour coded IBF for other severe weather events as per WMO guidelines. However, since 2019, IMD started issuing IBF & suggested actions for severe weather events at District level. It was further enhanced for all severe weather events at city & District level in 2020. It is a four stage warning system which includes advisories, alert and warnings in a pre-defined colour coded format. It has also provision of 3-hourly updates of the bulletin during the warning stage that includes a record of realised rainfall, probable impacts and action suggested. It has been made mandatory to provide 3-hourly observations and warnings information to disaster authorities and other state users through WhatsApp group, website, E-mail and all other possible means of communication.

- Stage - 1 comprises of Heavy rainfall advisory (Watch) issued with a lead time of often 3-4 days, with 12 hourly updates and is disseminated mainly to the disaster managers of the City.
- Stage -2 is the Heavy rainfall Alert, issued nearly 48 hours prior to the occurrence of the event with 12 hourly updates. Alert will be disseminated via E-Mail, website, Social media, WhatsApp etc.
- Stage -3 will contain the Heavy rainfall warning issued 24 hours prior to the commencement of the event with frequent updates (06 hourly or as the situation demands). This bulletin will be disseminated to all user communities including local media using web page, e-mails, various social media, WhatsApp, etc.
- Stage-4 warning bulletins are issued 12 hours prior to the occurrence of the maximum rainfall spell. In this, warnings and all accompanying information including situation reports are updated to the users on a 3 hourly or hourly basis depending on the situation. This will also contain more specific information like which part of the city is likely to have intense rain spells in the ensuing three hours etc.

1.2.7.15 Web Based Dynamic Composite Risk Atlas (Web-DCRA) & DSS Tool

Web-DCRA&DSS Tool for Cyclone impacts forecasting for the area falling within 10 m elevation above mean sea level in 13 Coastal States/UTs of the Country has been developed under National Cyclone Risk Mitigation Project (NCRMP) Phase II and is installed/hosted at IMD, HQ, and New Delhi. The responsibility for operating the DSS Tool at central level has been entrusted to IMD, being Nodal Agency for cyclone warning, while outputs of Web-DCRA & DSS Tool is being accessed by States through State specific credentials and utilized by Disaster Management Deptt. In all 13 coastal States/UTs for mitigation planning and decision making during cyclonic event. The Web-DCRA & DSS Tool has been operationalised during the cyclone 'Biparjoy' in 2023.

The outputs of Web-DCRA & DSS Tool are probabilistic and real-time hazard layer of cyclonic wind, storm surge and cyclone induced rainfall flooding, which can be used by Disaster Management Authorities of the 13 cyclone-prone States and Union Territories (UTs) of India in advance mitigation planning as well as dynamic response during a real time cyclonic event. Using this Tool, dynamic and impact-based cyclone warnings will be release by IMD aiming to minimize economic losses and damage to property due to the intense weather system. The Offline version of Web-DCRA has been installed in State Disaster Management Authority (SDMA) for routine updation of exposure database by the coastal States.

1.2.8 Tele-communication Network in IMD

Telecommunication Division was set up in IMD at New Delhi in 1969 to cater the need of National Meteorological Service and strengthen the meteorological telecommunication in India. It has been renamed as Information System and Services Division (ISSD) in 2009.

It provides the support needed for exchange of meteorological data and processed weather products to the users, both national and international (including aviation data/ products) round the clock in near real time. It also provides administration of IT systems including management, processing and storage of operational data, workflow and system integration. A WMO recognised international training centre named as International Communication and Instrumentation Training Centre (ICITC) was established in New Delhi in 1977 for imparting training to departmental and extra-departmental (national/ international) officials in Meteorological Telecommunication.

1.2.8.1. Present Status of Circuits in the GTS connected with RTH, New Delhi

India Meteorological Department has its National Meteorological Telecommunication Centre (NMTC) with an Automatic Message Switching computer System (AMSS) which is connected to WMO Centers on the GTS. The existing RTH switching system "TRANSMET" is the state-of-the-art technology system. It consists of two Separate Automatic Message Switching System (AMSS) for National and International data exchange. Each AMSS works in hot standby mode for 100% redundancy in case of any failure.

1.2.8.2. RMDCN Link

RMDCN link has been upgraded to 6 Mbps RMDCN-NG (Next Gen) which handles 6 circuits viz. Tokyo, Moscow, Beijing , Germany, Exeter and Toulouse. This has improved the data exchange between these GTS centres.

1.2.8.3. VPN Circuits

MPLS VPN link at HQ New Delhi has been upgraded to 10 Mbps for smooth catering of data requirements to the national users. This will help in faster data reception at Head Quarter from DWR stations & NWP Centres to various users. Fifty five, IMD stations are connected with MPLS VPN connectivity speeds ranging from 512 kbps to 10 mbps. These VPN circuits are connected with forecasting Systems at various out stations, Doppler Weather Radar Stations, AMSS Centres and Regional Centres.

1.2.8.4. Internet Services

At present IMD has two independent Internet leased links of 150 Mbps from different Internet service providers. IMD is also connected to 1 Gbps NKN (National Knowledge Network) link of NIC for internet, data exchange within Close User Group (CUG), Video conferencing & Telepresence services.

1.2.8.5. GMDSS

India has been designated as an issuing authority under the GMDSS program for Meteorological Area VIII (N). This covers the area of the Indian Ocean enclosed by the lines from Indo-Pakistan frontier in 23°45'N 68°E; 12°N 63°E, thence to Cape Gardafui; the east African coast south to equator, thence to 95°E to 6°N, thence to the Myanmar / Thailand frontier in 10° N 98° 30' E.

India Meteorological Department is transmitting daily two GMDSS bulletins for Met. Area VIII (N), one at 0900 UTC and other at 1800 UTC. During the period of cyclonic storms, upto four additional bulletins are also issued for GMDSS broadcast depending on the requirement. GMDSS bulletins are transferred to Earth Station of Bharat Sanchar Nigam Ltd (BSNL) at Ghaziabad through email and is also uploaded on IMD Website at URL:https://www.mausam.imd.gov.in and http://www.rsmcnewdelhi.imd.gov.in/. Ghaziabad Earth Station uplinks this information to INMARSAT for broadcast to all ships on high seas in Met Area VIII (N).

1.2.8.6. Regional Telecommunication Hub (RTH)

Regional Telecommunication Hub (RTH), New Delhi came into existence in the year 1971. The latest system has been installed in the year 2009 by Meteo France International (MFI). This is connected to WMO Centres on the GTS. The existing RTH computer system is driven primarily by dual HP server working on the state-of-the-art distributed networking technology. The whole system has been designed to handle high speed data circuits, message exchange through web interface, SMS & Email. It has also fax interface and audio alarm. NMTC New Delhi is connected to HPCS of NCMRWF Noida, IITM Pune through NKN and the HPCS computer at Regional Specialised Meteorological Centre (RSMC) New Delhi for instantaneous transmission of global observational data and processed information received via GTS. Moreover, NWP division of IMD is utilizing the resources of IITM HPCS to run their various models for product generations through CUG link of NKN. As regards the Meteorological Telecommunication Networks within the GTS, New Delhi telecommunication center is a designated RTH located on the Main Trunk Network (MTN). The MTN is the core network of GTS. It links together three World Meteorological Centers (WMCs) and 15 other RTHs on the MTN. The Centre is also a National Meteorological Centre (NMC) for telecommunication purposes within the framework of GTS. RTH New Delhi is directly connected with Tokyo, Exeter, Offenbach, Cairo, Jeddah, Beijing, Dhaka, Bangkok, Karachi, Male, Moscow, Oman, Colombo, Melbourne, Toulouse, Tehran, Katmandu, Bhutan and Yangon with different protocol and speed. Automatic Message Switching Systems (AMSS) are also operational at the major International airports of India viz. Mumbai, Delhi, Kolkata, Chennai, Nagpur and Guwahati. The circuits linking New Delhi (Palam), Mumbai, Kolkata, Chennai, Nagpur and Guwahati Airport computers with the NMTC New Delhi are working at 1 mbps speed.

The Mirror RTH at Pune is functional to act as Disaster Recovery Centre (DRC) which would be able to take over all the responsibilities of RTH New Delhi in case of any catastrophe at RTH New Delhi. This will also function as WMO WIS GISC for South East Asia and cater to all data needs for Indian users and all other WMO GISC centres in real time with 24 hours

1.2.8.7. Open WIS

WMO Information System (WIS)

The WMO Information system (WIS) is the single coordinated global infrastructure responsible for the telecommunications and data management functions. It is the pillar of the WMO strategy for managing and moving weather, climate and water information in the 21st century. WIS provides an integrated approach suitable for all WMO Programmes to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water and related data produced by centers and Member countries in the framework of any WMO Programme. WIS is an enhanced information system capable of exchanging large data volumes, such as new ground- and satellite based systems, finer resolutions in numerical weather prediction and hydrological models and their applications.

GISC New Delhi is operational from 2016. This can be access through url http://wis.imd.gov.in. As per Resolution 51(Cg-XIV), following two centres have been designated as WIS DCPC under the principal GISC New Delhi: RTH (New Delhi) and RSMC- Tropical Cyclones New Delhi. The India Meteorological Department has joined the OpenWIS Association AISBL as Strategic Partner in July 2018. In coordination with KMA OpenWIS has been implemented in India. WIS 2.0 Strategy was approved at EC-69 in 2017(revised at EC-70). Under WMO WIS2 pilot project India also participated and installed the wis2.0 box. The urls are http://demo.wis2box.wis.wmo.int and http://wis2box.imd.gov.in. **IMD started deployment by ingesting SYNOP data into WIS 2 Box. Synoptic stations** in Aug 2023 **-** Around 419 stations data integrated in WIS 2 Node. Later, IMD added TEMP. After inclusion of software update with WIS 2.0 1.07b version, Satellite data is incorporated in WIS2BOX.

1.2.8.8. On line Briefing System at Chennai & Delhi (Palam)

IMD being only authorised meteorological service provider, provides the meteorological services to all the aviation operators at all the major airports. Earlier the service was provided manually and switched to online services w.e.f. 2008 on test basis. As the service got well appreciation from Aviation operators, IMD started Online Meteorological services through dedicated OLBS from AMO Palam and AMO Chennai since 2012-2013.

1.2.8.9. Weather Forecast Decision Support System:

IMD has introduced an in-house **Web-GIS-based Decision Support System (DSS)** designed to deliver tailored meteorological products and enhance dissemination methods.

Key Features of DSS:

- **Advanced Visualization Platform**
  - It is a visualization platform to compare, comprehend and analyse various meteorological observations, prediction model products and arrive at a decision with respect to current status of weather system, their past evolution and the future characteristics, especially with respect to severe weather phenomenon and their socio economic impact.
- **Four-Layer Architecture**
  - DSS has four-layer structure, comprising the Meteorological Information Communication System, Data Information and Processing System, Synthesized Integrated Visualization System, and Public Weather Information System. It has been developed by IMD entirely with open-source technologies
- **Sector-Specific Applications**
  - Adhering to the principle of **"Sarvajan Hitay, Sarvajan Sukhay"** (For the welfare of all), DSS supports socio-economic sectors under the umbrella of **UPHHEATT** (Urban, Power, Hydrology, Health, Energy, Agriculture, Transport, and Tourism).

Tailored tools for weather-sensitive sectors, including agriculture, energy, health, transport, and urban planning have been developed as the part of DSS.

- **Accessibility for All**

  - Dissemination of forecasts through platforms like Twitter, Facebook, YouTube, and RSS feeds, SMS, email, and mobile apps are improved through DSS.

- **User-Centric Modules**:

  - The "Mausamgram" feature provides localized observations, forecasts, and warnings based on user inputs such as place name, pin code, or geographic coordinates.

Future Directions

IMD envisions a robust upgrade of its forecasting and warning services to meet national needs through cutting-edge technologies and improved outreach mechanisms:

❖ The DSS incorporates impact-based forecasting for severe weather events like cyclones, heatwaves, thunderstorms, etc with sufficient lead time.

❖ **Enhanced Dissemination** through multilingual and multimedia formats (text, 2D, 3D, 4D visuals) across platforms accessible to all, including specially-abled users.

❖ **Impact-Based Forecasts and Risk based** customized bulletins and warnings for the general public, disaster management authorities, and stakeholders with higher spatiotemporal resolution and better accuracy.

❖ **Adoption of AI/ML and Big Data Analytics** for precise weather predictions and better understanding of weather impacts.

❖ **Automation** in streamlined generation of forecast and waring bulletins and products, forecast verification, and dissemination of forecasts and warnings to all stakeholders.

❖ **Data Archival and Retrieval**: Long-term storage and accessibility of products as per data retention policies to ensure easy access of data to all stakeholders including students, scientists, researchers.

❖ **Feedback Mechanism**: Continuous improvement of services based on user inputs will be ensured through automated feedback mechanism including submission of feedback by users, its evaluation and report generation.

1.2.8.10. Short Message Service (SMS)

India Meteorological Department has taken various initiatives in recent years for improvement in dissemination of weather forecast and warning services based on latest tools and technologies. Since 2009, IMD has started SMS based weather and alert dissemination system through AMSS (Transmet) at RTH New Delhi. To further enhance this initiative, India Meteorological Department has taken the leverage of Digital India Programme to utilise “Mobile Seva” of Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology, Govt. of

India for SMS based Warnings /Weather information for wide range of Users through the URL: https://services.mgov.gov.in/logout.do. Since 2014. Services Portal provides three modes of sending SMS depending on the user's needs. These modes are Quick SMS, Group SMS and Bulk SMS

1.2.8.11. Website of IMD

Website of IMD is operational since 1st June, 2000. A new redesigned IMD website has been made operational w.e.f.15.12.2015 It contains static & dynamically updated information on all India Weather and forecasts, special monsoon report, local weather forecasts for 300+ cities, satellite cloud pictures (updated every half an hour), animated satellite cloud pictures, NWP models like GFS, WRF etc. and prognostic charts, special weather warnings, tropical cyclone information and warnings, daily, weekly and monthly rainfall distribution maps, etc. This also contains a brief overview of the activities and services rendered by India Meteorological Department. This site can be accessed round the clock with the URL: http://www.imd.gov.in by the registered users. The list of email addresses of senior officers is available at IMD website.

The new IMD website dedicated to general public of URL: https://mausam.imd.gov.in/ was launched by Hon'ble Minister of Earth Sciences, Dr Harsh Vardhan on 27th July at the eve of Foundation Day Function of Ministry of Earth Sciences. It is designed in such a way that the information can be communicated without any technical failure to meet the requirement of general public.

There is a dedicated website http://www.rsmcnewdelhi.imd.gov.in/ for Regional Specialized Meteorological Center (RSMC), New Delhi. The Regional Meteorological Centres and meteorological centers have also their own websites. IMD is also providing 100 Indian city forecast on the WMO Website daily at http://worldweather.wmo.int/066/m066.htm .

India Meteorological Department developed its own intranet website with the address https://metnet.imd.gov.in exclusively for the use of IMD officials. All employees can access this site using their login ID. This is a very useful site and all IMD officials are accessing this site all over the country for numerous applications on official matters.

Apart from the national website Mausam, dedicated website are also being available for the respective Meteorological and Regional Meteorological centers all over India.
Since 2022, IMD is also providing severe weather guidance for all severe weather events including cyclone, heavy rainfall, wind, storm surge, heat/cold wave, thunderstorm, marine weather etc in GIS platform through dedicated web pages.

1.2.8.12. Mobile App

India Meteorological Department, Ministry of Earth Sciences has taken various initiatives in recent years for improvement in dissemination of weather forecast and warning services based on latest tools and technologies. To further enhance this initiative, the mobile App "Mausam" was launched by Hon'ble Minister of Earth Sciences, Dr Harsh Vardhan on 27th July 2020 at the eve of Foundation Day Function of Ministry of Earth Sciences.

IMD has also taken the leverage of Digital India Programme to utilise "UMANG App". The weather Services from IMD is also now available on "UMANG" App- Users can access observed weather, forecasts, radar images and be proactively warned of impending weather events."Meghdoot" App for Agrometeorological advisories is linked to Mausam website.

On the occasion of 150th year of establishment and service to the Nation at Vigyan Bhawan. Honorable Vice President of India Shri Jagdeep Dhankar Ji graced the occasion and launched unified mobile app Mausam caters to the need of all categories of services including urban, power, health, hydrology, environment, agriculture, surface, transport, aviation, navigation and tourism sectors. The mobile app provides specialised services on current weather including temperature, humidity, wind, rainfall, sunrise/sunset, moonrise/moonset and AQI. MAUSAM app is freely available on mSeva AppStore, Google Play store, Apple App store. This app also have the Crowd sourcing module also.

1.2.8.13. Application Programming Interface (API's)

API stands for Application Programming Interface. It is like messenger that takes our request to a system and returns a response back to us via seamless connectivity. IMD has developed API's for cyclone forecast, Nowcast warning, Rainfall warning, City & district weather forecast/warning and Current weather. API's of IMD are being used by various stakeholders to extract data from our server and utilize the same for further applications developed by them. The stakeholders who are using IMD API's are Uttar Pradesh Government, Telangana Government, Kerala Government, Umang App, DD News, NDMA, Incredible India, KRC Network, NITI Aayog, Kerala State Disaster Management, Chandigarh Smart City Limited, Apple.com, Tomorrow.io, Uttarakhand Toursim, National Rice Research Institute Odisha, Madhya Pradesh Government, RMSI private limited, TV-9, CDAC etc.The details of the APIs can be found at the following link:-https://mausam.imd.gov.in/imd_latest/contents/api.pdf

1.2.8.14. Introduction to Crowd sourcing Interface

India Meteorological Department has launched its Crowd source web interface in the month of January 2021 to allow users to make their own observations. This feature can be found in the "Public Observation" section of Mausam website of IMD (https://city.imd.gov.in/citywx/crowd/enter_th_datag.php). There is no need to register to send observations and the associated weather damages caused. User can report their observations along with their state, district, location and time of the events. Following weather phenomena such as **Rain, Thunder/lightning, Hailstorm, Duststorm, Fog, Snow, Gusty wind** and the associated damage caused such as breaking of tree branches, uprooting of small/big trees, Telephone pole / Transmission tower damaged by bending, Telephone pole / Transmission tower uprooting, Damage to Kutcha structures (houses, cowsheds), Damage to Pukka structures (houses, shelters), Flooding of land, Damage/Death to livestock, Damage/Death to Humans, Damage to vegetation/crops.
User can share their location (lat. /lon) by allowing the location through browser. Each phenomenon also includes additional information field that can be filled with free text. It is also possible to attach photos in jpg, jpeg, png & gif format.

1.2.8.15. Implementation of Common Alert Protocol (CAP)

India Meteorological department has started the dissemination of weather information through Common Alerting Protocol (CAP). These feeds automatically aggregated to the WMO Alert Hub at https://cap-sources.s3.amazonaws.com/in-imd-en/rss.xml. These alerts are also disseminated to Google, AccuWeather, Global Multi-Hazard Alert System

(GMAS) portal (https://gmas.asia/).
IMD also participates as one of the alert generating agencies for the CAP alert projects of NDMA developed by CDOT. CAP has been implemented in India. During the cyclone 'Biparjoy' 32.67 cr, 'Michaung' 6.7 cr messages were disseminated through this CAP platform.

1.2.8.16. Information Technology Applications

Considering the ever growing influence of Information Technology in day–to-day affairs of the department, IT cell carries out the following activities:-
a) Coordination of IT initiatives of the department.
b) Supervise various IT projects to be implemented.
c) Asserting the IT literacy and imparting suitable mechanisms for its improvement.
d) Development of various in-house softwares for routine activities.
e) Dealing with the issue related to cyber security.
Conforming to these objectives, IT Division has developed an intra - IMD Portal, which is considered as the first step towards e-governance implementation in the department.
f) The e-office has been implemented to enable better environment friendly administration with an objective of paperless work.

1.2.8.17. Video Conferencing System

IMD has also implemented desktop video conferencing solution of NIC for all offices.

1.2.8.18. Social Networking sites

IMD has started its social media services through
Facebook (https://www.facebook.com/India.Meteorological.Department/) and
Twitter (https://twitter.com/Indiametdept),
Instagram (https://www.instagram.com/mausam_nwfc/),
Youtube:
(https://www.youtube.com/channel/UC_qxTReoq07UVARm87CuyQw/featured?view_as=subscriber) and Blog (https://imdweather1875.wordpress.com/) accounts to disseminate its forecast and warnings etc. timely to the public as well as get back their feedback which may be used to know their needs to further improve the weather services. These accounts provide general information such as highlights of weather bulletins, satellite and Radar images, air quality of some major Indian cities and earthquake information. The social media platform is being used by IMD only for sharing the information among the public.

1.2.8.19. LAN Upgradation

In Upgraded LAN, several networking devices are being installed and integrated. The system connectivity is required to be made available to various units at HQ over LAN. Keeping in view of the operational requirement, new upgraded LAN with latest state-of-the-art technology to cover future requirement of more than 1500 nodes parallel to present setup to accommodate increased voluminous data/product flow un-interruptedly over LAN at IMD HQ. A 10 Gbps optical fibre backbone support is used to provide high availability of LAN as well as high volume of data flow.

1.2.8.20. Video Wall

The video wall system has been installed in all forecasting offices of IMD for visualization of weather observations, forecasts and products.

1.2.8.21. Cyber Security –

Load Balancer – IMD has installed the load balancer with WAF (Web application Firewall) which prevents the website from the attack of Web application security parameters tampering, cookie poisoning, SQL injection, Session Hijacking, Cross site scripting (XSS), Cross site Request Forgery (CSRF).

SSL Certificate - An SSL certificate is a digital certificate that authenticates a website's identity and enables an encrypted connection. SSL stands for Secure Sockets Layer, a security protocol that creates an encrypted link between a web server and a web browser. IMD has installed the SSL certificate to all the national websites of IMD. All websites are running on HTTPS.

1.2.8.22. Ongoing projects:

Provision of adequate communication system for data and product transmission:

a. Up Gradation of AMSS (Automatic Message Switching Systems) at Delhi-Palam, Kolkata, Mumbai and Chennai.

c. Implementation of cloud based services at IMD.

d. Implementation of all mode of communications including GPS Aided Geo Augmented Navigation-(GAGAN) Message Service (GAMES) for warning Dissemination through CAP (Common Alerting Protocol).

e. Early Warning Dissemination System (EWDS).

f. Upgradation of LAN with 100 Gbps optical fibre backbone support.

g. Implementation of SIEM and SOAR services at IMD.

h. Transmission of GMDSS bulletins through IRIDIUM satellite

(ii) Myanmar

The reporting period from **November 2023 to October 2024** was marked by significant meteorological, hydrological and seismological events in Myanmar, highlighting the country's increasing exposure to hydro-meteorological hazards and the growing importance of effective multi-hazard early warning systems. Throughout the period, the Department of Meteorology and Hydrology (DMH) continued to strengthen its operational forecasting, warning dissemination, disaster risk reduction, hydrological services, and capacity-building initiatives despite the occurrence of several high-impact weather events.

During the reporting period, the Bay of Bengal remained highly active, with a total of 16 Low Pressure Areas forming between November 2023 and October 2024. Several of these systems intensified into Depressions, Deep Depressions, Cyclonic Storms and Severe Cyclonic Storms, including Cyclonic Storm MIDHILI, Severe Cyclonic Storm MICHAUNG, Severe Cyclonic Storm REMAL, Severe Cyclonic Storm DANA, and multiple monsoon depressions. Although most cyclonic systems made landfall outside Myanmar, their indirect influence significantly affected the country's weather through heavy rainfall, strong winds, enhanced monsoon activity, and widespread flooding.

The 2024 Southwest Monsoon exhibited notable variability. The monsoon advanced across Myanmar during 22-30 May 2024 and withdrew between 18 September and 15 October 2024, resulting in a monsoon duration of 130 days, which was approximately nine days longer than the climatological normal. Strong monsoon conditions, enhanced moisture transport, and interactions with tropical weather systems produced widespread rainfall across the country, while several regions experienced above-normal precipitation and numerous new rainfall records.

One of the most significant events of the year was the remnants of Typhoon YAGI, which traversed Myanmar in September 2024 before re-intensifying over the Bay of Bengal. This event produced exceptionally heavy rainfall across central and eastern Myanmar, leading to catastrophic flooding and landslides. Several stations recorded their highest rainfall in decades, including 302 mm at Thazi (Hlaingtat), representing the highest daily rainfall in more than fifty years. The disaster resulted in extensive damage to infrastructure, severe agricultural losses, and more than 520 deaths or missing persons, emphasizing the devastating consequences of compound weather hazards.

The year also witnessed remarkable climatic extremes. Numerous stations established new maximum temperature records during the exceptionally hot pre-monsoon season, with temperatures reaching 48.2°C at Chauk, among the highest values ever observed in Myanmar. In addition, several stations recorded new minimum temperature records as well as unprecedented rainfall amounts during different seasons, reflecting the increasing frequency of extreme weather events that are consistent with emerging regional climate variability.

DMH continued to provide comprehensive operational meteorological services through the issuance of a large number of warnings and advisories covering low pressure systems, depressions, cyclonic storms, heavy rainfall, untimely rainfall, southwest monsoon conditions, temperature extremes and special weather situations. The dissemination of timely warnings through multiple communication channels including the DMH website, social media platforms, television, radio, newspapers, dedicated weather studios, call centres and coordination with local authorities significantly enhanced public awareness and supported disaster preparedness across the country.

In the hydrological sector, flood forecasting services remained an essential component of national disaster risk management. River forecasts and flood warnings were regularly issued for 49 hydrological stations along 16 major river systems. During the 2024 monsoon season, widespread flooding occurred across many river basins, with several stations recording the first, second or third highest flood levels in their observation history. More than 128 flood warnings and 653 flood bulletins were issued, demonstrating the operational capability of DMH in providing timely flood guidance. Continued expansion of telemetry networks, adoption of hydrological models such as HEC-HMS, and operational utilization of the Myanmar Flash Flood Guidance System (FFGS) further strengthened flood forecasting capability.

Significant progress was also achieved in disaster risk reduction, research, training and international cooperation. DMH actively participated in regional and international programmes including the South Asian Climate Outlook Forum (SASCOF), ASEAN Climate Outlook Forum (ASEANCOF), BIMSTEC Centre for Weather and Climate (BCWC) activities, South Asia Hydromet Forum (SAHF), RSMC New Delhi Forecaster Attachment Training, and several WMO-sponsored technical workshops. National initiatives such as the 32nd National Monsoon Forum, public awareness programmes, operational weather broadcasting and academic collaborations further strengthened institutional capacity and improved the delivery of meteorological services.

The hydrological division also expanded the application of Geographic Information Systems (GIS), Google Earth Engine and discharge measurement programmes for improved flood mapping and water resource management. Meanwhile, the seismological division continued enhancing earthquake and tsunami monitoring capabilities through international cooperation, communication exercises, equipment modernization supported by CTBTO, and participation in regional tsunami warning system activities.

Overall, the reporting period demonstrates Myanmar's continued commitment to strengthening its meteorological, hydrological and seismological services in accordance with the objectives of the WMO/ESCAP Panel on Tropical Cyclones. While the increasing frequency and intensity of extreme weather events present growing challenges, sustained investments in observation networks, forecasting systems, numerical weather prediction, flood forecasting, early warning dissemination, international collaboration and human resource development have substantially enhanced the country's disaster preparedness and resilience.

Going forward, continued modernization of forecasting infrastructure, expansion of automatic observation networks, integration of impact-based forecasting, enhanced climate services, improved flash flood guidance, and strengthened regional cooperation among National Meteorological and Hydrological Services (NMHSs) will remain critical for reducing disaster risks and safeguarding lives, livelihoods and sustainable development across Myanmar.

(iii) Oman

The reporting period of **2024** reflected the continued commitment of the **Directorate General of Meteorology (DGMET), Oman**, to strengthening national meteorological, hydrological, and tsunami early warning capabilities while enhancing public safety through modern forecasting systems, technological advancements, and proactive disaster risk reduction initiatives. Despite several significant weather events affecting the Sultanate during the year, DGMET demonstrated a high level of operational readiness through timely forecasting, effective dissemination of warnings, and close coordination with national stakeholders.

A major milestone during the year was the continued implementation of the Muzn Strategic Program, which has significantly accelerated the modernization of DGMET. The programme focuses on strengthening institutional capacity through improvements in human resources, forecasting systems, infrastructure, research capabilities, and service delivery. The successful renewal of ISO 9001, ISO 27001, and ISO 17025 certifications further demonstrated DGMET's commitment to maintaining internationally recognized standards in quality management, information security, and laboratory competence. Compliance with the requirements of organizations such as ICAO, WMO, and IOC-UNESCO reinforces Oman's position as a reliable provider of meteorological and early warning services within the region.

Throughout the reporting period, DGMET continued to provide a comprehensive suite of operational forecasting and warning services covering aviation, marine, public weather, climatology, and tsunami monitoring. Daily weather bulletins, marine forecasts, city and governorate forecasts, aviation meteorological services, seasonal outlooks, and specialized forecasts for government agencies and critical sectors ensured that weather information reached diverse user communities in a timely manner. The integration of multiple dissemination platforms, including the official website, mobile application, social media, SMS, Cell Broadcast Services (CBS), call centres, television, and radio, significantly enhanced the accessibility and effectiveness of weather warnings and public advisories.

The year 2024 was characterized by several significant weather events that tested the resilience of forecasting and early warning systems. The Al-Riyan Trough brought widespread rainfall accompanied by hail and strong downdrafts across several governorates during March. Subsequently, the Al-Mutayr Low Pressure System in April produced one of the most remarkable weather events of the year, generating exceptionally heavy rainfall, destructive flash floods, and damaging winds. Some stations recorded extraordinary rainfall intensities, including 91.6 mm within one hour at Wadi

Bani Khalid and 180.2 mm daily rainfall at Shinas, while wind gusts reached 69.9 knots at Ibri. DGMET responded through continuous monitoring, extensive media engagement, multilingual awareness campaigns, and the timely issuance of reports and alerts, demonstrating the critical value of an integrated impact-based warning system.

Later in the year, Tropical Storm Asna and the Al Sayyal weather system, involving the interaction of a tropical depression with an upper-air trough, further highlighted the importance of continuous monitoring of tropical weather over the Arabian Sea. Although Tropical Storm Asna weakened before making a direct impact, it generated rough seas, cloud development, and rainfall over parts of Oman. In contrast, the Al Sayyal event produced rainfall exceeding 200 mm in some locations and triggered severe flash flooding, again emphasizing the country's vulnerability to extreme rainfall associated with tropical systems and synoptic-scale interactions. These events further demonstrated the necessity of continuous improvements in numerical weather prediction, hydrological forecasting, and impact-based warning services.

Considerable progress was also achieved in strengthening forecasting infrastructure and technical capabilities. Ongoing projects such as upgrading the Flash Flood Guidance System, enhancing computational resources to 80 teraflops, improving local numerical weather prediction models with higher spatial resolution, introducing additional global forecasting models including ECMWF, ICON, and Unified Model, and expanding the national observing network will substantially improve forecast accuracy and lead times. Planned modernization of the DGMET website and mobile application, together with the installation of additional weather stations and radar systems, will further enhance operational efficiency and service delivery in the coming years.

Public awareness remained an important pillar of disaster risk reduction throughout the year. DGMET organized national awareness campaigns in North Al Batinah and Dhofar Governorates, conducted lectures, workshops, practical exercises, exhibitions, and outreach programmes involving thousands of participants from schools, government agencies, and local communities. These initiatives strengthened public understanding of weather hazards, tsunami preparedness, and the appropriate response to official warnings. Such community engagement complements technical forecasting improvements by ensuring that early warning information translates into timely protective action by the public.

Research, climatological services, staff training, and international collaboration also remained central components of DGMET's activities. Continued investment in numerical weather prediction, satellite applications, climatological studies, and forecaster training contributes to building a highly skilled workforce capable of addressing increasingly complex forecasting challenges. The Directorate's role as a regional centre for satellite applications further supports knowledge sharing and capacity development across the region.

Overall, the achievements during 2024 demonstrate Oman's steady progress toward developing a modern, resilient, and technologically advanced National Meteorological and Hydrological Service. The successful combination of improved forecasting capability, advanced observation networks, robust quality management systems, effective communication strategies, and strong public awareness programmes has significantly enhanced the country's ability to prepare for and respond to high-impact weather events. Looking ahead, continued investment in emerging technologies, high-resolution numerical modelling, impact-based forecasting, multi-hazard early warning systems, and regional cooperation under the framework of the WMO/ESCAP Panel on Tropical Cyclones will further strengthen Oman's resilience to weather, climate, and water-related hazards while contributing to the sustainable development and safety of communities across the Sultanate.

(iv) Pakistan

Tropical Cyclone Monitoring

During the reporting period, the Pakistan Meteorological Department (PMD) effectively monitored and issued timely forecasts and warnings for **Cyclonic Storm ASNA**, an exceptionally rare tropical cyclone that developed over the northern Arabian Sea during August 2024. Through continuous surveillance by the Tropical Cyclone Warning Centre (TCWC), Karachi, supported by satellite observations, Doppler Weather Radar, numerical weather prediction models, and international coordination, PMD issued a series of advisories that enabled government agencies and coastal communities to undertake timely preparedness measures. The successful monitoring of ASNA demonstrated the capability of Pakistan's tropical cyclone forecasting system to respond effectively even to unusual meteorological developments. PMD also closely monitored the tropical depression over the Arabian Sea during October 2024 and continued providing regular updates throughout its lifecycle.

Severe Weather and Flood Monitoring

Flood forecasting and severe weather monitoring remained one of PMD's highest operational priorities throughout 2024. Using an integrated network of synoptic observatories, rain gauges, automatic weather stations, Doppler Weather Radars, satellite observations, telemetric river stations, and high-resolution numerical weather prediction models, PMD continuously monitored heavy rainfall events and river basin conditions across the country.

The flood routing models, coupled with hydrological observations from WAPDA and provincial irrigation departments, enabled timely flood outlooks, warnings, and impact-based advisories. Continuous coordination with the National Disaster Management Authority (NDMA), Provincial Disaster Management Authorities (PDMAs), and other stakeholder’s strengthened preparedness and response activities, reducing the potential impacts of flood-related disasters.

Drought Monitoring

PMD further strengthened its drought monitoring programme through a multi-parameter approach integrating meteorological observations, satellite-derived products, soil moisture assessments, reservoir conditions, and field information. Operational use of indices such as the Standardized Precipitation Index (SPI), precipitation anomalies, Normalized Difference Vegetation Index (NDVI), Temperature Vegetation Dryness Index (TVDI), and land surface temperature provided comprehensive assessment of drought conditions across Pakistan.

Regular weekly, fortnightly, monthly, and quarterly drought bulletins supported the agriculture, water resources, and disaster management sectors by providing early warning of emerging drought conditions and facilitating timely mitigation planning.

GLOF Monitoring

Considering the increasing vulnerability of northern Pakistan to glacier-related hazards, PMD continued strengthening its **Glacial Lake Outburst Flood (GLOF)** monitoring and early warning system. Continuous monitoring of high mountain meteorological conditions, persistent heat episodes, heavy rainfall events, glacier melt conditions, and fluctuations in lake and river water levels formed the basis of operational GLOF advisories.

The ongoing UNDP-supported GLOF project, involving installation of additional Automatic Weather Stations, river level sensors, and early warning equipment, is expected to further improve forecasting capability and community resilience in vulnerable mountain regions.

Heatwave Monitoring

Heatwave forecasting remained an important component of PMD's early warning services during the summer season. PMD continued implementing its nationally adopted heatwave criteria developed after the devastating Karachi heatwave of 2015. Continuous monitoring of temperature anomalies, numerical weather prediction guidance, and real-time observations enabled the issuance of heatwave outlooks and public advisories well in advance.

These services supported health authorities, local administrations, and the public in minimizing heat-related risks while contributing to improved preparedness against extreme temperature events that are becoming increasingly frequent under changing climatic conditions.

Capacity Building and Technological Advancement

During the reporting period, PMD continued modernizing its forecasting infrastructure and observation network. Expansion of Automatic Weather Stations, enhancement of High Performance Computing (HPC) capacity, implementation of advanced numerical weather prediction models, and modernization of radar infrastructure significantly improved forecast accuracy and lead time.

The department also strengthened regional cooperation through training programmes for neighbouring National Meteorological and Hydrological Services (NMHSs), while continuing research activities related to climate change, sea-level rise, and multi-hazard early warning systems.

(v) Sri Lanka

During the reporting period (2023–2024), Sri Lanka experienced the indirect impacts of several tropical cyclones and depressions over the Bay of Bengal and Arabian Sea, including Extremely Severe Cyclonic Storm Mocha, Severe Cyclonic Storm Michaung, Severe Cyclonic Storm Remal, Cyclonic Storm Asna, Severe Cyclonic Storm Dana, and Cyclonic Storm Fengal. Although none of these systems made direct landfall over Sri Lanka, they significantly influenced the country's weather by producing heavy rainfall, strong winds, rough seas, and thunderstorms. The Department of Meteorology (DoM) continuously monitored these systems using satellite observations, global Numerical Weather Prediction (NWP) models, and guidance from RSMC New Delhi, issuing timely cyclone advisories, warnings, and track forecasts to support preparedness and minimize disaster impacts.

Severe Weather and Flood Monitoring

Severe weather monitoring remained one of the Department's primary operational responsibilities throughout the reporting period. Several tropical systems generated widespread heavy rainfall that resulted in floods and landslides across different parts of the country. Particularly significant were the impacts associated with Cyclonic Storm Fengal in November 2024 and the extreme rainfall event of 1 June 2024, during which several stations recorded exceptionally high rainfall exceeding 450 mm in 24 hours. These events affected hundreds of thousands of people, causing fatalities, displacement, and damage to infrastructure and property. Continuous monitoring, timely weather bulletins, and close coordination with disaster management agencies enabled early preparedness and effective response to these high-impact weather events.

Early Warning and Forecast Services

The Early Warning Centre of the Department of Meteorology continued to strengthen its impact-based forecasting and warning services through continuous monitoring of tropical disturbances from the low-pressure stage onwards. Cyclone alerts, warnings, and special weather bulletins were issued based on observations, satellite imagery, global forecasting models, and guidance from RSMC New Delhi. Graphical forecast products, cone of uncertainty, wind forecasts, and adverse weather warnings for heavy rainfall, strong winds, rough seas, and storm surges were disseminated through the Department's website, social media platforms, electronic media, and marine communication channels. These services significantly enhanced the effectiveness of disaster preparedness for the general public, fishermen, shipping operators, and emergency response agencies.

Coordination and Warning Dissemination

An important strength of Sri Lanka's early warning system was the close coordination among the Department of Meteorology, the Disaster Management Centre (DMC), the Department of Irrigation, the National Building Research Organization (NBRO), the Department of Fisheries, and other national stakeholders. Regular stakeholder meetings, ministerial briefings, media interactions, and continuous dissemination of warnings through websites, social media, SMS, and electronic media ensured that weather information reached decision-makers and vulnerable communities promptly. This integrated multi-agency coordination significantly improved emergency preparedness and response during severe weather events.

Challenges

Despite continued improvements in forecasting capability, several operational challenges remain. The limited availability of real-time observations over the surrounding ocean restricts accurate assessment of tropical cyclone structure and intensity. Furthermore, the absence of operational Doppler Weather Radar continues to limit the precise prediction of localized heavy rainfall, severe winds, and storm surge associated with tropical weather systems. Addressing these observational gaps remains essential for further improving forecast accuracy and lead time.

Future Outlook

Sri Lanka continues to modernize its meteorological services through the implementation of the Meteorological Modernization Project supported by the World Bank and the installation of two C-band Doppler Weather Radars with assistance from JICA. These initiatives are expected to substantially strengthen observation capabilities, improve high-resolution forecasting, enhance impact-based early warning services, and increase national resilience to tropical cyclones and other severe weather hazards.

(vi) Bangladesh

Tropical Cyclone Monitoring

During the reporting period (November 2023 to December 2024), the Bangladesh Meteorological Department (BMD) successfully monitored and issued timely forecasts and warnings for all tropical cyclones that developed over the Bay of Bengal, including Cyclonic Storm Midhili, Very Severe Cyclonic Storm Remal, and Cyclonic Storm Dana. Round-the-clock monitoring was carried out from the initial low-pressure stage using satellite observations, Doppler Weather Radar, buoy and ship observations, numerical weather prediction (NWP) models, and guidance from RSMC New Delhi. The successful forecasting of cyclone genesis, track, landfall, intensity, storm surge, and associated adverse weather significantly enhanced preparedness and contributed to minimizing the loss of life and property. In particular, the effective monitoring and warning dissemination during Very Severe Cyclonic Storm Remal, which made landfall along the Bangladesh coast in May 2024, demonstrated the operational capability of BMD in providing reliable tropical cyclone forecasting services.

Severe Weather Monitoring

Apart from tropical cyclones, Bangladesh experienced several high-impact weather events during the reporting period, including widespread heavy rainfall, thunderstorms, strong winds, and an unusual heatwave. Heavy rainfall associated with Cyclones **Midhili** and **Remal** resulted in localized flooding and significant disruption in several parts of the country. BMD continuously monitored these events using Doppler Weather Radar, satellite imagery, ECMWF, WRF, and other global forecasting models, enabling timely issuance of weather forecasts, rainfall alerts, and severe weather advisories. Continuous improvement of high-resolution numerical weather prediction models has further strengthened the Department's capability in forecasting heavy rainfall and other hazardous weather phenomena.

Heatwave Monitoring

The year 2024 was marked by an **unusual and prolonged heatwave** affecting large parts of Bangladesh during both the pre-monsoon and monsoon seasons. BMD closely monitored the evolution of extreme temperatures through observational networks and numerical weather prediction guidance while issuing regular heatwave forecasts and public advisories. Future initiatives involving machine learning-based bias correction and advanced forecasting techniques are expected to further improve the accuracy of heatwave prediction and enhance public preparedness against extreme temperature events.

Impact-Based Forecasting and Early Warning Services

BMD continued strengthening its impact-based forecasting capability by integrating meteorological forecasts with disaster risk information. The use of the **Integrated Forecast and Risk Information Portal (RIMES)**, customized impact maps, storm surge prediction, rainfall guidance, wind gust alerts, and location-specific forecast products significantly enhanced decision-making for disaster managers and emergency responders. Warning messages were disseminated through multiple communication channels, including the BMD website, Weather App, SMS, IVR services, television, radio, social media platforms, electronic and print media, ensuring rapid dissemination of life-saving information to vulnerable communities.

Forecasting Infrastructure and Technological Advancement

BMD continued to enhance its operational forecasting capability through the use of multiple observation systems, including Himawari, GK-2A, FY-2 satellite imagery, Doppler Weather Radars, conventional observations, and advanced numerical weather prediction models such as WRF and ECMWF. Forecasts were generated through a consensus approach by combining observational data, model guidance, and expert analysis, resulting in improved prediction of cyclone track, intensity, heavy rainfall, and associated severe weather. These technological advancements have substantially improved the accuracy and lead time of weather forecasts across Bangladesh.

Future Outlook

BMD remains committed to further strengthening its multi-hazard early warning system through modernization of forecasting technologies and greater application of emerging tools. Future priorities include automation of impact-based cyclone forecasting, application of **Artificial Intelligence (AI)** and **Machine Learning (ML)** for improving heatwave and cold-wave forecasts, development of lightning nowcasting systems, and enhanced flash flood prediction capabilities. These initiatives will further strengthen Bangladesh's resilience against tropical cyclones and other hydro-meteorological hazards while supporting disaster risk reduction and sustainable development.

(vii) United Arab Emirate

Tropical Cyclone and Depression Monitoring

During the reporting period, the National Center of Meteorology (NCM), United Arab Emirates, maintained continuous monitoring of tropical weather systems over the Arabian Sea and surrounding regions. Particular attention was given to the Depression during 9–19 October 2024, which was closely tracked using satellite observations, numerical weather prediction models, radar data, and regional meteorological information. NCM issued timely weather forecasts, advisories, and warnings to support national preparedness and minimize the potential impacts of heavy rainfall, strong winds, and associated hazards. Continuous monitoring of tropical disturbances and close coordination with regional meteorological centres further strengthened the UAE's operational forecasting capability.

Severe Weather Monitoring

Severe weather monitoring remained a core operational function of NCM throughout the reporting period. A comprehensive observation network comprising automatic weather stations, rain gauges, Doppler weather radars, upper-air observations, lightning detection systems, marine observation stations, and satellite products enabled continuous surveillance of hazardous weather conditions across the country. Advanced numerical weather prediction models, including COSMO, ICON, WRF, ECMWF, GFS, WRF-Hydro, and WATCH III, provided high-resolution guidance for forecasting heavy rainfall, thunderstorms, dust storms, strong winds, and other severe weather phenomena, thereby improving forecast accuracy and operational decision-making.

Multi-Hazard Early Warning and Disaster Risk Reduction

NCM continued to strengthen its Multi-Hazard Impact-Based Forecast and Warning Services through close coordination with the Ministry of Interior (MOI) and the National Emergency, Crisis and Disaster Management Authority (NCEMA/NDMO). Hazard warnings were issued using an impact-based framework that categorizes events according to severity, likelihood, and expected impacts. The implementation of standardized attention reports, warnings, and regular forecast updates enabled timely activation of the National Disaster Response Plan whenever required. This integrated approach significantly enhanced national preparedness and response capabilities for hydro-meteorological hazards.

Meteorological Services and Forecasting Capability

The National Center of Meteorology continued providing a wide range of operational meteorological services, including public weather forecasting, aviation meteorology, marine weather services, air quality monitoring, meteorological research, weather modification operations, and climate-related studies. Daily weather forecasts for more than 200 locations, combined with advanced numerical weather prediction systems and extensive observational infrastructure, enabled NCM to deliver accurate and timely weather information to government agencies, critical sectors, and the general public. Regional cooperation through GCC meteorological networks and international data exchange further strengthened forecasting capability and operational resilience.

Infrastructure and Technological Advancement

The UAE continued investing in the modernization of its meteorological infrastructure through the expansion of weather observation networks, Doppler weather radars, lightning detection systems, upper-air observations, marine stations, air quality monitoring stations, and advanced computing facilities. Operational implementation of multiple high-resolution numerical weather prediction models, together with continuous improvements in web-based applications, mobile platforms, and digital dissemination systems, significantly enhanced the country's capability to monitor, forecast, and communicate weather-related hazards. These technological advancements provide a strong foundation for further development of impact-based forecasting services.

Future Outlook

The National Center of Meteorology remains committed to further strengthening the UAE's multi-hazard early warning system through continuous modernization of forecasting infrastructure, enhancement of numerical weather prediction capabilities, expansion of observation networks, and greater integration of impact-based forecasting techniques. Continued collaboration with regional and international meteorological organizations, together with ongoing investment in advanced technologies and digital weather services, will further improve forecast accuracy, lead time, and disaster preparedness across the country.

(viii) Iran

Tropical Cyclone and Marine Weather Monitoring

During the reporting period, the **Islamic Republic of Iran Meteorological Organization (IRIMO)** continued to provide continuous monitoring of tropical weather systems, low-pressure areas, and marine hazards affecting the **Persian Gulf**, **Sea of Oman**, and the northern Arabian Sea. Operational forecasting was supported through the **SWAN wave model**, global numerical weather prediction models including **GFS** and **ECMWF**, satellite observations, marine observations, and Doppler weather radar products. Marine weather bulletins were issued four times daily, providing information on system location, intensity, movement, expected adverse weather, and marine conditions to support maritime safety and coastal operations.

Severe Weather Monitoring

IRIMO continued to strengthen its capability for monitoring severe weather events through an extensive nationwide observational network comprising synoptic stations, automatic weather stations, rain gauges, upper-air observatories, Doppler weather radars, and buoy observations. Radar-derived products, including rainfall estimation, storm tracking, hail detection, flood monitoring, wind field analysis, and dust storm detection, significantly enhanced real-time monitoring and forecasting of hazardous weather phenomena. The integration of these observations with high-resolution numerical weather prediction models has improved the accuracy and lead time of severe weather forecasts across the country.

Agrometeorological and Climate Monitoring

IRIMO continued to provide comprehensive agrometeorological services through a dedicated network of agricultural meteorological stations and climatological observation systems distributed across different agro-climatic regions of the country. Continuous monitoring of meteorological parameters, soil temperature, soil moisture, precipitation, and other environmental variables supports the preparation of agrometeorological advisories for the agricultural sector, contributing to improved agricultural planning, resource management, and climate resilience.

Forecasting, Communication and Early Warning Services

Operational forecasting services were further strengthened through the use of advanced numerical weather prediction systems, satellite observations, radar products, and an integrated decision support system for forecasters. Marine weather bulletins and operational forecasts were disseminated through multiple communication channels, including national television, radio, SMS, telephone, fax, print and electronic media, ensuring timely delivery of weather information to government agencies, marine users, aviation authorities, and the general public. Continuous operation of the meteorological telecommunication network enabled near real-time exchange of meteorological observations and forecast products both nationally and internationally.

Infrastructure and Technological Advancement

IRIMO continued to modernize its meteorological infrastructure through expansion of its observation network, Doppler weather radars, upper-air stations, automatic weather stations, rainfall monitoring systems, and marine observation platforms. The operational use of advanced forecasting models, implementation of the Automatic Message Switching System (AMSS), participation in the WMO Information System (WIS 2.0), establishment of the Regional Telecommunication Hub (RTH) Tehran, and installation of an advanced video wall for operational forecasting have substantially strengthened national forecasting capability and international data exchange. Participation in international initiatives such as the ICAO APAC SIGMET Tests 2024 further reflects IRIMO's commitment to continuous improvement of operational meteorological services.

Capacity Building and International Cooperation

Capacity development remained an important component of IRIMO's activities during the reporting period. The organization continued conducting professional training programmes while strengthening regional and international cooperation through operational data exchange, aviation meteorology, WMO Information System implementation, and meteorological telecommunication services. These initiatives have enhanced technical expertise and operational readiness while contributing to regional collaboration in meteorological forecasting and early warning services.

1.3 HYDROLOGICAL ACTIVITIES

1.3.1 WMO activities

WMO continued to strengthen hydrological services in support of the Panel on Tropical Cyclones through integrated multi-hazard early warning initiatives and regional capacity development. Recognizing that tropical cyclones frequently result in severe flooding, WMO promoted the integration of hydrological forecasting with meteorological and tropical cyclone warning services under the Early Warnings for All (EW4All) initiative. Particular emphasis was placed on strengthening interoperability among meteorological, hydrological and disaster management agencies to enhance end-to-end multi-hazard early warning systems.

As part of these efforts, WMO organized the Regional Training on Multi-Hazard Early Warning Systems (MHEWS) Interoperability in New Delhi in December 2024, hosted by the India Meteorological Department. The training brought together experts from South Asian countries and showcased good practices for strengthening collaboration among Regional Centres for Severe Weather Forecasting, Tropical Cyclone Forecasting and Flash Flood Guidance Systems (FFGS). The programme also included practical sessions to improve coordination among National Meteorological and Hydrological Services and other stakeholders in support of the Early Warnings for All initiative.

WMO also continued to support hydrological resilience through regional projects, including the Multi-Hazard Hydrometeorological Early Warning and Capacity Building (FFGS) programme benefiting several Panel Member countries. In addition, WMO reported planned implementation of the HydroSOS BaNe (Hydrological Status and Outlook System) project for the Ganga–Brahmaputra–Meghna Basin, which aims to strengthen integrated water resources management and climate resilience across the basin. These initiatives demonstrate WMO's commitment to integrating hydrological information with tropical cyclone forecasting and warning services to reduce flood risk and enhance disaster preparedness in the region.

1.3.2 India

1.3.2.1Services provided by Central Water Commission

Central Water Commission (CWC) under Ministry of Water Resources, Government of India is entrusted with the task of formulating and disseminating flood forecasting in various locations in inter-state rivers. Absolute or permanent immunity from flood damage is not physically attainable by known methods of flood control. Flood Plain Zoning and Flood Forecasting and Warning and like measures do not require large capital investments. Flood forecasting is one of the effective low cost non-structural methods for mitigating the loss due to flood. Flood Forecasting is the process of estimating the future stages or flows and its time sequence at selected points along river during flood. The prediction of water level in advance is called the Level Forecasting while the prediction of flows into Dams/ Reservoirs/ Barrages is called the Inflow Forecasting.

1.3.2.1.1 Flood Forecasting Network in India

Central Water Commission (CWC) under Ministry of Water Resources, Government of India is entrusted with the task of formulating and disseminating flood forecasting in various locations in inter-state rivers. CWC maintains 338 flood forecasting stations which include 200 level and 138 inflow forecast stations spread across 22 States and 2 Union Territory and NCT, Delhi, 20 major river systems in the country. The work of formulation and dissemination of flood forecasts under various inter-state river basins is carried out directly by 36 Flood Forecasting Divisions which are designated as Divisional Flood Control Rooms (DFCR). The forecasts formulated are issued to various User Agencies who include the Engineering and Revenue authorities of the concerned flood affected states. In addition, the hydro-meteorological data and flood forecast issued by DFCR are also sent to Central Flood Control Room (CFCR) operated in CWC Headquarters under RM wing and Flood Management Organisation. State-wise flood forecasting network in the country is as under:

No	Name of State/UT	Number of flood forecasting Stations		
		Level	**Inflow**	**Total**
1	Andhra Pradesh	10	10	20
2	Arunachal Pradesh	3	1	4
3	Assam	30	0	30
4	Bihar	40	3	43
5	Chhattisgarh	1	2	3
6	Gujarat	6	8	14
7	Haryana	1	1	2
8	Himachal Pradesh	1	0	1
9	Jammu & Kashmir	3	0	3
10	Jharkhand	2	15	17
11	Karnataka	1	14	15
12	Kerala	4	2	6
13	Madhya Pradesh	2	12	14
14	Maharashtra	8	14	22
15	Odisha	12	7	19
16	Rajasthan	4	11	15
17	Sikkim	3	5	8
18	Tamil Nadu	4	11	15
19	Telangana	5	10	15
20	Tripura	2	0	2
21	Uttar Pradesh	39	5	44
22	Uttarakhand	4	5	9
23	West Bengal	12	4	16
24	Daman & Diu	1	0	1
	NCT of Delhi	2	0	2
	Total	**200**	**140**	**340**

1.3.2.1.2. Flood Monitoring

Central Water Commission monitors the flood by observing hydrological and hydro-meteorological data during flood on hourly basis at about 1730 (1543 hydrological stations and 187 met stations) stations manually and transmitting it to divisional offices through HF/VHF wireless sets, mobiles, etc. Under modernization, automatic data acquisition and satellite based transmission system for hourly data collection is being deployed. Presently, 1121 such stations are installed and installation of another 38 stations is under progress. Central Water Commission is also collecting reservoir related data from project authority under State Govt, Meteorological data from India Meteorological Department, etc. Data collected are managed by web based application, WIMS for archival and real time display of flood trends in the web site http://ffs.india-water.gov.in.

1.3.2.1 .3. Formulation of Flood Forecast:

Flood forecast are formulated by the Divisional Flood Control Room using hydro-meteorological data from various upstream locations of the flood forecasting station and rainfall forecast from India Meteorological Department. These data are processed either graphically or mathematically using computers and flood forecasts are generated. Generally flood forecasts are issued whenever the Water Level in a river is expected to cross the Warning Level as fixed by State Authorities in consultation with CWC. Forecasts formulated from the conventional statistical correlation methodology are issued with a warning time of 6 to 24 hours while flood advisories formulated using mathematical models based forecasting methodology are being issued with the lead time of up to 168 hours. The forecasts are issued at pre-designated times to the user agencies well in advance so that sufficient time is available for the authorities to carry out mitigation works. In the case of level forecast, the expected water level at the given location is given in the forecast and based on the topography and submergence of areas for that level, the revenue authorities take necessary action. In the case of inflow forecast the volume of water likely to be flowing into the reservoir during the succeeding period is given based on which the project authorities plan their release schedules into the canals and river.

1.3.2.1.4. Dissemination of Flood Forecast

The formulated flood forecasts have to be sent to the concerned user agencies by the quickest possible mode of communication to ensure that the forecast is useful for flood fighting measures. In CWC, the flood forecasts are disseminated by various communication methods. CWC uses various communication modes including HF Wireless Sets/ whatsapp/Fax/ Telephone/ e-mail/ updating the CWC's flood forecasting web site (http://www.india-water.gov.in), Facebook, Twitter as well as through Google platforms Google public alerts etc. In case of floods above Danger Level, SMS are issued to mobile numbers of various concerned users who are directly responsible for relief and rehabilitation measures in the State.

1.3.2.2. Services provided by India Meteorological Department

1.3.2.2.1. Rainfall Monitoring:

Real time monitoring of district wise daily rainfall is one of the important functions of IMD. A network comprising of 6495 rain gauge stations is utilized under District wise Rainfall Monitoring Scheme (DRMS) for preparing the maps and rainfall statistics. Based on real time daily rainfall data, different temporal scales such as daily, weekly, monthly, seasonal and annual and different spatial scales such as district wise, Met-subdivision wise, state wise and homogeneous region wise rainfall distribution summaries are prepared in the form of rainfall departure tables, maps and graphs. District wise, state wise and Met. Subdivision wise rainfall statistics provides important information to the agricultural scientists, planners and decision makers.

During the year 2024, rainfall statistics for the meteorological sub-divisions (36), states

& UT (36), districts (729), four broad homogenous regions of India (i) North-West India, (ii) Central India, (iii) South Peninsula and (iv) North East India and for the country as a whole was prepared Daily, Weekly, Monthly, Seasonal and Annual basis and was supplied to various stakeholders including the PMO, Ministries and other important Govt. authorities. District wise reports for last 5 years (2018-2022) were uploaded on IMD Website.

A technical report titled "Rainfall statistics of India-2024" has been published and uploaded on IMD website at the link https://hydro.imd.gov.in/hydrometweb/. "Rainfall statistics of India-2025" is under process.

The seasonal statistics for the year 2024 are as follows:

• Winter Season (January-February) 2024:

During the winter season, the country as a whole received 68% of its Long Period Average (LPA) rainfall (39.8 mm), i.e., 32% below normal. Out of 36 Meteorological Sub-divisions, 05 recorded Large Excess rainfall (>60%), 03 recorded Excess rainfall (20% to 59%), 05 recorded Normal rainfall (-19% to +19%), 17 recorded Deficient rainfall (-59% to -20%), 06 recorded Large Deficient rainfall (-99% to -60%), and none recorded No Rain (-100%).

• Pre-Monsoon Season (March-May) 2024:

During the pre-monsoon season, the country as a whole received 97% of its LPA (130.5 mm), i.e., 3% below normal. Out of 36 Meteorological Sub-divisions, 09 recorded Large Excess rainfall, 06 recorded Excess rainfall, 12 recorded Normal rainfall, 08 recorded Deficient rainfall, 01 recorded Large Deficient rainfall, and none recorded No Rain.

• Southwest Monsoon Season (June-September) 2024:

During the Southwest Monsoon season, the country as a whole received 108% of its LPA (868.5 mm), indicating an Above Normal Monsoon. Out of 36 Meteorological Sub-divisions, 14 recorded Excess rainfall, 22 recorded Normal rainfall, and none recorded rainfall in the Large Excess, Deficient, Large Deficient, or No Rain categories.

• Post-Monsoon Season (October-December) 2024:

During the post-monsoon season, the country as a whole received 111% of its LPA (121.0 mm), i.e., 11% above normal. Out of 36 Meteorological Sub-divisions, 09 recorded Large Excess rainfall, 05 recorded Excess rainfall, 14 recorded Normal rainfall, 06 recorded Deficient rainfall, 02 recorded Large Deficient rainfall, and none recorded No Rain.

• Design Storm Studies (2024-25):

Design Storm Studies continued to be undertaken to estimate Standard Project Storm (SPS), Probable Maximum Precipitation (PMP), rainfall time distribution, and other design parameters for hydraulic structures, irrigation projects, reservoirs, dams, and flood control works. These studies provide essential inputs for estimating design floods and ensuring the safe and economical design of hydraulic infrastructure.

During 2024, two (02) design storm studies for the Poshir Project and Shilar Medium Irrigation Project in Maharashtra were completed, and the design storm values along with detailed project reports were supplied to the respective project authorities. In addition, the Technical Report entitled "Design Storm Studies undertaken during 2024" was published and uploaded on the IMD website during July 2025.

A Technical Report on 'Design Storm Studies undertaken during 2024' is published in IMD website.

1.3.2.2.2.

Flood Meteorological Activities: In 1970, India suffered number of severe floods caused huge loss of life & property and Govt. of India constituted a committee of Ministers to look into the problem. The committee in 1972 recommended that Central Water Commission (CWC) to establish Flood Forecasting Division and India Meteorological Department to establish Flood Meteorological Offices (FMO). Accordingly, India Meteorological Department's (IMD's) contribution in flood warning is mainly in the form of Quantitative Precipitation Forecast (QPF) used in the preparation of flood warning/forecast issued to Flood Forecasting Division of Central Water Commission (CWC) / State Governments. IMD caters this service through its 15 Flood Meteorological Offices (FMOs) situated in the different flood prone areas. These FMOs issue daily QPF and Hydromet Bulletin (HM) during Flood Season for respective sub-basins under their jurisdiction. HM Bulletin contains prevailing synoptic situation, average areal rainfall occurred during past 24 hrs. Heavy rainfall warning, observed station-wise significant rainfall (≥5cm) and the important component, river sub-basin-wise QPF for a lead time of 7-days. QPF is also issued in case of cyclone during non-flood season. During flood season of 2023, 27,301 numbers of QPF over 157 river sub-basins are issued to Central Fold Forecasting Divisions (CFFDs) of CWC.

Model based Sub-basin-wise Quantitative Precipitation Forecast (QPF) using dynamical model WRF ARW (3kmx3km) for day-1 to day-3, NCUM-R (4kmx4 km) for day-1 to day-3, GFS (12kmx12km) for day-1 to day-7, NCUM(12kmx12km) for day-1 to day-7 are uploaded in the IMD's website. Also, Model based Sub-basin wise Probabilistic Quantitative Precipitation Forecast (PQPF) using dynamical model NEPS (12kmx12km) for day-1 to day-7 and GEFS (12kmx12km) for day-1 to day-7 uploaded in the IMD website at the link http://hydro.imd.gov.in/hydrometweb/ for all 157 river sub-basins. Also, WRF ARW and GFS gridded model rainfall forecast are shared with Central Water Commission for their flood forecasting purposes. A technical document on 'Verification of River Sub-basin-wise Quantitative Precipitation Forecast during SW Monsoon 2023' is published as Met Monograph in IMD web site.

1.3.2.3. South Asia Flash Flood Guidance System

The WMO Commission for Hydrology (CHy) jointly with the WMO Commission for Basic Systems (CBS) and in collaboration with the US National Weather Service, Hydrologic Research Center (HRC), and USAID/OFDA have developed the concept of the Flash Flood Guidance System (FFGS) with global coverage. Flash Flood Guidance System Project has global coverage of 64 countries with more than two billion people around the world gets benefitted in saving lives and decreasing economic losses.

The South Asia Flash Flood Guidance System comprises of 5 countries (Bangladesh, Bhutan, India, Nepal and Sri Lanka) wherein India Meteorological Department (IMD) is recognised as the Regional Centre for providing the EWS guidance alerts on flash floods in South Asia. IMD commissioned this system for catering flash flood guidance services on 23 Oct 2020 and put into full operations during the flood season 2021.

Hydromet division of IMD viz. Regional Centre (SASIAFFGS) provides location specific flash flood guidance alerts every 6 hours up to watershed level on pluvial flash floods in the form of **risks with 24 hour lead time** based on deterministic numerical weather forecasts from IMD GFS (12km×12km), NCUM (4km×4km) and IMD WRF (3km×3km), and **threats with 6 hour of lead time** by integrating near real-time gauge observations along with the satellite and IMD Radar rainfall estimates. It is being recognised as an impact based forecasters' tool using a GIS based interactive dynamic MAPSERVER complimented by the outputs from the Doppler Weather based NOWCAST for issuing impact based flash flood guidance alerts at watershed level. These guidance alerts used along with the real- time socio economic data by the disaster managers would help in making effective impact-based decision management at critical times.

1.3.3. Myanmar:

The hydrological activities undertaken by the Department of Meteorology and Hydrology (DMH), Myanmar, during the reporting period demonstrated continued progress in strengthening flood forecasting, hydrological monitoring, early warning services, and capacity development despite the occurrence of several high-impact flood events. Through an operational network of 49 flood forecasting stations covering 16 major river basins, DMH continued to provide timely river stage forecasts, flood warnings, and hydrological information to support disaster preparedness and water resources management across the country.

The 2024 flood season was characterized by widespread flooding across several major river systems. Flood peaks at numerous hydrological stations reached the first, second, and third highest levels in their historical records, including stations along the Ayeyarwady, Chindwin, Sittoung, Bago, Thanlwin, Thaungyin, and Ngawun rivers. These extreme hydrological conditions highlighted the increasing vulnerability of Myanmar to high-impact flood events and reinforced the importance of maintaining an efficient operational flood forecasting and warning system.

One of the most significant hydrological disasters during the reporting period resulted from the remnants of Typhoon Yagi in September 2024, which produced prolonged heavy rainfall, widespread flash floods, and landslides across nine states and regions of Myanmar. The event caused extensive damage to agriculture, transportation networks, communication infrastructure, and public utilities. Timely hydrological monitoring and dissemination of flood information played an important role in supporting disaster response and emergency management during this extreme event.

In addition to flood monitoring, DMH also continued to strengthen drought and low-flow monitoring services. During the 2024 dry season, the Ayeyarwady River at Mandalay recorded water levels approximately 128 cm below the minimum alert level, prompting the timely dissemination of low-flow advisories to relevant organizations and stakeholders. Such services are increasingly important for supporting water resource management, navigation, irrigation planning, and drought preparedness in vulnerable regions of the country.

Significant progress was also achieved in improving hydrological observation and measurement techniques. The Hydrological Division successfully conducted river discharge measurements and riverbed profiling using Acoustic Doppler Current Profiler (ADCP-M9) at several important stations, including Seiktha, Pyay, NgathaingChaung, and Maubin. These activities contribute to improving river hydraulic assessments, flood forecasting models, and long-term water resource planning.

Further strengthening of the national early warning system was achieved through enhanced regional cooperation. As part of bilateral collaboration between Myanmar and Thailand, four telemetry systems were installed along the Mae Sai River during 2024 to improve real-time hydrological monitoring and support flash flood early warning in the border region. This initiative represents an important step toward strengthening transboundary flood risk management and regional cooperation.

Capacity building also remained an important priority throughout the reporting period. DMH organized training programmes on Geographic Information Systems (GIS) and Hydrological Grade III courses aimed at enhancing technical knowledge, operational skills, and human resource development within the Hydrological Division. Continuous investment in professional training will further strengthen the country's capability to deliver accurate hydrological forecasts and effective early warning services.

Overall, the reporting period demonstrated Myanmar's continued commitment to strengthening hydrological forecasting, flood early warning, river monitoring, and regional cooperation. Continued modernization of observation networks, expansion of telemetry systems, and adoption of advanced hydrological measurement technologies, improved flood forecasting models, and sustained capacity building will further enhance Myanmar's resilience to floods, flash floods, droughts, and other water-related hazards while contributing to sustainable water resources management and disaster risk reduction.

1.3.4. Oman:

The hydrological activities undertaken by the Directorate General of Meteorology (DGMET), Sultanate of Oman, during the reporting period reflected significant progress in strengthening flood forecasting, hydrological early warning services, and disaster risk reduction. Continued investments under the Muzn Strategic Program, together with modernization of forecasting systems and observation networks, have substantially enhanced the country's capability to monitor, forecast, and respond to hydrological hazards associated with extreme weather events.

The year 2024 witnessed several high-impact hydrometeorological events that highlighted the importance of robust flood forecasting and early warning systems. The Al-Mutayr Low-Pressure System during April 2024 generated exceptionally heavy rainfall, severe flash floods, and destructive winds across several governorates. Some locations recorded extraordinary rainfall intensities, including 91.6 mm in one hour at Wadi Bani Khalid and 180.2 mm in 24 hours at Shinas, leading to widespread flooding and disruption. Later in the year, the interaction of a Tropical Depression with an Upper Air Trough (Al Sayyal) produced rainfall exceeding 200 mm in several areas, triggering severe flash floods and emphasizing the increasing vulnerability of Oman to short-duration, high-intensity rainfall events.

To improve preparedness against such hazards, DGMET continued strengthening its hydrological monitoring and early warning capability through the operation of an extensive observation network comprising weather stations, tide gauge stations, wave radar stations, weather radars, GPS stations, and upper-air observation systems. These observation platforms, integrated with advanced numerical weather prediction models and real-time forecasting systems, provide the foundation for timely flood forecasting and impact-based warning services across the Sultanate.

A major milestone during the reporting period was the ongoing upgrade of the Flash Flood Guidance System (FFGS) together with significant enhancement of computational infrastructure, including expansion of the High Performance Computing (HPC) facility to 80 teraflops, modernization of local numerical weather prediction models, and integration of additional global forecasting models such as ECMWF, ICON, and Unified Model. These initiatives are expected to substantially improve rainfall forecasting, flash flood prediction, and lead time for hydrological warnings, thereby strengthening national resilience against flood disasters.

Hydrological risk reduction was further supported through effective dissemination of forecasts and warnings using multiple communication platforms, including the official DGMET website, mobile application, Cell Broadcast Services (CBS), SMS, social media, television, radio, and call centres. During major flood events, multilingual awareness campaigns and continuous media engagement ensured rapid communication of flood risks to emergency management agencies, decision-makers, and the general public, enabling timely preparedness and response.

Public awareness and stakeholder engagement also remained integral components of Oman’s flood risk management strategy. National awareness campaigns, workshops, exhibitions, and practical exercises conducted across various governorates enhanced public understanding of flood hazards, early warning information, and appropriate response measures. These initiatives complement technical forecasting improvements by strengthening community preparedness and resilience to hydrological disasters.

Overall, the reporting period demonstrated Oman's continued commitment to strengthening hydrological forecasting, flash flood early warning, and integrated disaster risk management. Continued modernization of observation networks, enhancement of flash flood guidance systems, investment in high-performance computing, adoption of advanced numerical weather prediction technologies, and expansion of impact-based forecasting will further improve the country's capability to manage flood risks, protect lives and infrastructure, and support sustainable water resources and disaster resilience in the years ahead.

1.3.5. Pakistan:

The hydrological activities of the Pakistan Meteorological Department (PMD) during the reporting period demonstrated continued progress in strengthening integrated hydrological monitoring, flood forecasting, drought assessment, glacier hazard monitoring, and multi-hazard early warning services. Through a comprehensive observation network comprising 110 meteorological stations, 334 rain gauge stations, 85 Automatic Weather Stations (AWSs), 34 agrometeorological stations, Doppler Weather Radars, satellite observations, and hydrological monitoring networks, PMD continued to provide timely forecasts and early warnings for flood, drought, heatwave, glacial lake outburst flood (GLOF), and other hydrometeorological hazards across the country.

Flood forecasting remained one of the key operational priorities during the year. PMD continued monitoring riverine flooding through an integrated hydrological forecasting system incorporating 100 Automatic Weather Stations located in river catchments, 45 telemetric stations, and 130 river discharge monitoring sites operated in collaboration with the Water and Power Development Authority (WAPDA) and provincial irrigation departments. These observations, combined with flood routing models and high-resolution numerical weather prediction guidance, enabled the timely issuance of flood outlooks, alerts, and warnings to support disaster preparedness and emergency response across vulnerable river basins.

PMD also strengthened its drought monitoring and early warning programme through a comprehensive multi-source assessment framework. Operational drought monitoring integrated meteorological indicators such as the Standardized Precipitation Index (SPI), cumulative rainfall anomalies, soil moisture conditions, and dry spell analysis with satellite-derived products including Normalized Difference Vegetation Index (NDVI), Temperature Vegetation Dryness Index (TVDI), land surface temperature, reservoir storage information, and field observations. Based on these datasets, weekly, fortnightly, monthly, and quarterly drought bulletins and advisories were issued to support agricultural planning, water resource management, and drought risk mitigation.

Recognizing the growing risks associated with climate change in the northern mountainous regions, PMD continued to enhance its Glacial Lake Outburst Flood (GLOF) monitoring and early warning capability. Operational GLOF advisories were prepared by integrating forecasts of extreme precipitation, prolonged high-temperature episodes, glacier melt conditions, and continuous monitoring of lake and river water levels. These services contribute significantly to reducing disaster risk in glacier-fed river basins and improving the resilience of vulnerable mountain communities.

The department also maintained operational monitoring of heatwave conditions through nationally adopted impact-based criteria developed after the 2015 Karachi heatwave. Continuous surveillance of temperature anomalies and numerical weather prediction guidance enabled the issuance of timely heatwave forecasts and advisories, supporting public health preparedness and reducing the impacts of extreme temperature events that are becoming increasingly frequent under a changing climate.

Looking ahead, PMD continues to invest in strengthening hydrological forecasting infrastructure through the expansion of Doppler weather radar coverage, installation of 300 additional Automatic Weather Stations, enhancement of High Performance Computing (HPC) capacity to 220 teraflops, and implementation of the UNDP-supported GLOF Project, which includes additional AWSs, river water-level gauges, and early warning equipment. These initiatives will substantially improve flood forecasting, drought assessment, glacier hazard monitoring, and impact-based hydrological early warning services throughout Pakistan.

Overall, the reporting period demonstrated Pakistan's continued commitment to strengthening hydrological monitoring, flood forecasting, drought assessment, glacier hazard early warning, and climate resilience through the integration of advanced observation systems, hydrological modelling, satellite technology, and multi-agency collaboration. Continued modernization of forecasting infrastructure, expansion of hydrological observation networks, and adoption of emerging technologies will further enhance the country's capability to protect lives, livelihoods, water resources, and critical infrastructure from floods, droughts, GLOFs, heatwaves, and other water-related hazards.

1.3.6. Sri Lanka:

The hydrological activities of the **Department of Meteorology (DoM), Sri Lanka**, during the reporting period demonstrated continued progress in strengthening hydrometeorological monitoring, flood forecasting support, and multi-hazard early warning services. Despite the increasing frequency of extreme rainfall events associated with tropical cyclones, depressions, and monsoon systems, the Department continued to provide timely forecasts, rainfall warnings, and hydrometeorological advisories to support disaster preparedness and risk reduction across the country.

During the reporting period, several tropical weather systems, including **Severe Cyclonic Storm Remal**, **Cyclonic Storm Fengal**, **Severe Cyclonic Storm** Michaung, and the Depression over the Southwest Bay of Bengal, produced widespread heavy rainfall over Sri Lanka. In addition, the extreme rainfall event of 1 June 2024 resulted in exceptional 24-hour rainfall totals, with 490.0 mm at Kalatuwawa, 464.8 mm at Labugama, and more than 300 mm at several other stations. These intense rainfall events triggered flash floods, river flooding, landslides, and severe disruptions to transportation, agriculture, and public infrastructure, highlighting the country's increasing vulnerability to hydro-meteorological hazards.

The hydrological impacts were particularly severe during Cyclonic Storm Fengal in November 2024, when prolonged heavy rainfall affected all nine provinces of the country. According to the Disaster Management Centre (DMC), nearly 469,000 people were affected, while thousands were displaced and significant damage occurred to houses and public infrastructure. Similarly, the June 2024 extreme rainfall event affected approximately 118,000 people, causing fatalities, injuries, and widespread flooding in the Ratnapura, Kalutara, and Matara districts. These events emphasized the critical importance of timely hydrometeorological forecasting and effective early warning dissemination.

The Department of Meteorology continued to strengthen its early warning capability through continuous monitoring of tropical disturbances from the low-pressure stage using satellite observations, global Numerical Weather Prediction (NWP) models, and guidance from **RSMC New Delhi**. Regular adverse weather bulletins, heavy rainfall warnings, gale wind forecasts, storm surge advisories, and graphical forecast products were disseminated through the Department's website, social media platforms, electronic media, and coordination with the Disaster Management Centre, the Department of Irrigation, the National Building Research Organisation (NBRO), and other stakeholder agencies. This integrated approach significantly improved preparedness and response to flood and landslide hazards.

Recognizing the growing challenges posed by extreme rainfall, Sri Lanka continues to modernize its hydrometeorological services under the Meteorological Modernization Project supported by the World Bank, while the installation of two C-band Doppler Weather Radars with assistance from JICA is expected to substantially improve rainfall estimation, flood forecasting support, and impact-based early warning services. These initiatives will strengthen real-time monitoring of heavy rainfall and enhance the capability to forecast localized extreme precipitation events more accurately.

Overall, the reporting period demonstrated Sri Lanka's continued commitment to strengthening hydrological monitoring, flood forecasting support, and multi-hazard early warning services through improved forecasting techniques, enhanced stakeholder coordination, and modernization of meteorological infrastructure. Continued investment in advanced observation systems, Doppler weather radar, numerical weather prediction, and integrated flood early warning mechanisms will further enhance the country's resilience to floods, landslides, and other water-related disasters while contributing to sustainable disaster risk reduction and climate resilience.

1.3.7. Bangladesh:

The hydrological activities of the Bangladesh Meteorological Department (BMD) during the reporting period demonstrated significant progress in strengthening hydrometeorological monitoring, flood forecasting support, and impact-based early warning services. Through continuous monitoring of tropical cyclones, heavy rainfall events, and associated flood hazards, BMD continued to provide timely forecasts and warnings that supported disaster preparedness and minimized the impacts of hydro-meteorological disasters across Bangladesh.

The reporting period was marked by several high-impact hydrological events, particularly Very Severe Cyclonic Storm Remal in May 2024, which produced widespread heavy rainfall, strong winds, and storm surges that inundated large parts of the coastal districts. Rainfall exceeding 220 mm was recorded at several stations, while storm surges of 5–8 feet caused extensive flooding in low-lying coastal areas. In addition, Cyclonic Storm Midhili and other tropical disturbances contributed to heavy rainfall and localized flooding over different parts of the country, highlighting Bangladesh's continued vulnerability to tropical cyclone-induced flood hazards.

BMD continued to strengthen its hydrological forecasting capability through the operational use of multiple observation platforms, including Doppler Weather Radars, satellite observations (Himawari, GK-2A, INSAT, FY-2), ship and buoy observations, together with advanced numerical weather prediction models such as WRF and ECMWF. These forecasting tools enabled continuous monitoring of rainfall distribution, cyclone evolution, and associated flood-producing weather systems, thereby improving the accuracy and lead time of heavy rainfall and flood-related forecasts.

A major achievement during the reporting period was the operational application of the Integrated Forecast and Risk Information Portal (RIMES) for impact-based forecasting. The system provides location-specific forecasts, customized impact maps, and risk information for vulnerable areas, particularly the southeastern region of Bangladesh, including Cox's Bazar. The integration of meteorological forecasts with impact assessments has significantly enhanced decision-making for disaster managers, emergency responders, and local authorities, contributing to more effective flood preparedness and response.

Hydrological early warning services were further strengthened through an extensive multi-channel dissemination system comprising the BMD website, Weather App, SMS, IVR services, television, radio, social media platforms, electronic and print media, and government communication networks. The rapid dissemination of heavy rainfall forecasts, cyclone warnings, and flood-related advisories ensured that vulnerable communities and emergency management agencies received timely information for appropriate preparedness and response actions.

Looking ahead, BMD remains committed to further enhancing its hydrological services through the automation of impact-based cyclone forecasting, application of Artificial Intelligence (AI) and Machine Learning (ML) for improving temperature and flash flood prediction, development of lightning nowcasting systems, and continued research on high-impact weather forecasting. These initiatives are expected to substantially improve flood forecasting accuracy, increase warning lead times, and strengthen Bangladesh's resilience against floods and other water-related hazards.

Overall, the reporting period demonstrated Bangladesh's continued commitment to strengthening hydrological monitoring, flood forecasting, and impact-based early warning services through the integration of advanced observation systems, numerical weather prediction, risk-based forecasting, and modern communication technologies. Continued investment in forecasting infrastructure, digital early warning systems, and innovative forecasting techniques will further enhance the country's capacity to reduce flood risk, protect vulnerable communities, and support sustainable disaster risk reduction in the face of increasing climate variability and extreme weather events.

1.3.8. United Emirate Arab:

The hydrological activities of the National Center of Meteorology (NCM), United Arab Emirates, during the reporting period reflected significant progress in strengthening hydrometeorological monitoring, flood forecasting support, and impact-based early warning services. Continued investment in modern observation infrastructure, advanced numerical weather prediction systems, and integrated disaster risk management has substantially enhanced the country's capability to monitor, forecast, and respond to hydrological hazards associated with extreme weather events.

Hydrological monitoring during the year focused on the continuous surveillance of heavy rainfall events, flash flood potential, and the Depression over the Arabian Sea during 9–19 October 2024, which had implications for weather conditions across the UAE. Using an extensive observation network comprising 140 weather stations, 110 Automatic Weather Stations (AWSs), 22 rain gauge stations, 30 marine stations, 7 Doppler weather radars, upper-air observations, lightning detection systems, wind profiler, and satellite products, NCM continuously monitored rainfall distribution and evolving weather systems to support timely flood preparedness and emergency response.

Hydrological forecasting capability was further strengthened through the operational use of advanced numerical weather prediction and hydrological models, including WRF-Hydro, COSMO, ICON, ECMWF, GFS, and WATCH III. The integration of these models with real-time observational data has significantly improved quantitative precipitation forecasting, flash flood guidance, and the prediction of high-impact rainfall events, thereby enhancing the accuracy and lead time of hydrological forecasts across the country.

A major achievement during the reporting period was the continued implementation of Multi-Hazard Impact-Based Forecast and Warning Services, developed in accordance with WMO Guidelines. Hydrological hazards are assessed using a standardized risk matrix based on the severity and likelihood of impacts, enabling the issuance of graded attention reports, warnings, and regular forecast updates. Close coordination between NCM, the National Emergency, Crisis and Disaster Management Authority (NCEMA/NDMO), and the Ministry of Interior (MOI) ensures timely activation of disaster response mechanisms and effective communication of flood risks to emergency managers and the public.

NCM also continued to strengthen hydrological information dissemination through a range of digital platforms, including dedicated web and mobile applications, the Early Warnings for All (EW4All) platform, social media, and other communication channels. These services provide timely weather and flood-related information to government agencies, emergency responders, critical infrastructure operators, and the general public, thereby improving preparedness and reducing the impacts of flash floods and other hydrometeorological hazards.

Overall, the reporting period demonstrated the UAE's continued commitment to strengthening hydrological forecasting, flash flood monitoring, and integrated early warning services through the adoption of advanced forecasting technologies, modern observation networks, and impact-based disaster risk management. Continued investment in hydrological modelling, high-resolution numerical weather prediction, real-time monitoring systems, and multi-agency coordination will further enhance the country's resilience to floods and other water-related hazards while supporting sustainable disaster risk reduction and climate adaptation.

1.3.9. Iran:

The hydrological activities of the Islamic Republic of Iran Meteorological Organization (IRIMO) during the reporting period demonstrated continued progress in strengthening hydrometeorological observation, flood monitoring, marine forecasting, and early warning services. Through an extensive nationwide observation network and advanced forecasting systems, IRIMO continued to provide timely hydrological and meteorological information to support disaster risk reduction, water resources management, agriculture, and marine operations.

IRIMO further enhanced its hydrological monitoring capability through a comprehensive network comprising over 2,566 rainfall monitoring stations, including 387 Automated Rain Gauge (ARG) stations, 52 Automatic Weather Stations (AWSs), 380 climatological stations, 33 agrometeorological stations, 15 upper-air observatories, 10 Doppler Weather Radars, and 6 marine buoys deployed across the country. These observation systems provide continuous real-time information on precipitation, river-producing rainfall, soil moisture, atmospheric conditions, and marine weather, forming the foundation for effective hydrological forecasting and early warning services.

Flood monitoring remained an important operational component of IRIMO's hydrological services. Doppler Weather Radars operating across the country provide high-resolution products for rainfall estimation, storm tracking, flood detection, hail monitoring, wind field analysis, and identification of severe weather systems. The integration of radar observations with surface monitoring networks has significantly improved the capability to monitor intense rainfall events and issue timely flood-related warnings, thereby enhancing national preparedness against hydrometeorological disasters.

Marine hydrological forecasting also continued to be strengthened through the operational implementation of the SWAN (Simulation Wave Nearshore) model for the Persian Gulf and the Sea of Oman. Marine weather bulletins, issued four times daily, provide forecasts of wave conditions, low-pressure systems, tropical storms, heavy rainfall, strong winds, and adverse sea conditions. These services play a vital role in supporting maritime safety, coastal management, offshore activities, and disaster preparedness along Iran's southern coastline.

Hydrological forecasting services were further supported by advanced numerical weather prediction systems, including the operational use of GFS and ECMWF model outputs, together with an integrated weather forecast decision support system. Continuous real-time exchange of meteorological and hydrological observations through the Regional Telecommunication Hub (RTH) Tehran, Global Information System Centre (GISC), and WMO Information System (WIS 2.0) has strengthened operational forecasting capability and facilitated efficient dissemination of forecasts and warnings at both national and regional levels.

Capacity development remained an integral part of IRIMO's hydrological programme during the reporting period. Several national and regional training programmes and workshops on flood forecasting and early warning, marine forecasting, climate services, meteorological observations, and disaster risk reduction were organized through the WMO Regional Training Centre (RTC) Tehran and the Atmospheric Sciences and Meteorological Research Center (ASMERC). These initiatives have contributed to strengthening technical expertise and enhancing institutional capacity for hydrological forecasting and water-related disaster management.

Overall, the reporting period demonstrated IRIMO's continued commitment to strengthening hydrological monitoring, flood forecasting, marine hydrological services, and early warning systems through modernization of observation networks, advanced numerical modelling, enhanced telecommunication infrastructure, and capacity building. Continued investment in automated hydrological observations, radar technology, forecasting systems, and regional cooperation will further enhance Iran's resilience to floods, marine hazards, and other water-related disasters while supporting sustainable water resources management and climate adaptation.

1.4. DISASTER RISK REDUCTION ACTIVITIES

1.4.1. WMO activities

During 2024, the World Meteorological Organization (WMO) continued to advance disaster risk reduction (DRR) initiatives across the Panel on Tropical Cyclones (PTC) region by strengthening multi-hazard early warning systems, enhancing operational preparedness and supporting Member countries under the United Nations Early Warnings for All (EW4All) initiative. WMO promoted a country-driven approach to improve end-to-end early warning systems through the development of technical guidance, monitoring and evaluation frameworks, system effectiveness assessment tools and strengthened coordination among national agencies responsible for disaster risk management.

During the year, WMO emphasized the need to strengthen impact-based forecasting and anticipatory action, noting that while forecasting capabilities have improved, further efforts are required to integrate risk information into warning services. The Organization also highlighted the increasing role of advanced technologies, including artificial intelligence, improved software and data-sharing platforms, in enhancing forecasting capabilities and supporting more effective disaster risk reduction.

A major DRR initiative during 2024 was the Regional Training on Multi-Hazard Early Warning Systems (MHEWS) Interoperability held in New Delhi during 9–13 December 2024 and hosted by the India Meteorological Department. The training brought together participants from South Asian countries to strengthen collaboration among meteorological, hydrological and disaster management agencies, promote interoperability among severe weather, tropical cyclone and flash flood guidance systems, and support implementation of the Early Warnings for All initiative.

WMO also strengthened disaster preparedness by promoting Business Continuity Management (BCM) for National Meteorological and Hydrological Services. During 2024, guidelines on BCM were approved, a dedicated task team continued the development of training materials, and Members were encouraged to develop regional business continuity arrangements, share best practices and enhance the resilience of operational forecasting and warning services during emergencies.

In addition, WMO continued to support disaster risk reduction through regional projects, including the Flash Flood Guidance System (FFGS), CREWS initiatives and other hydrometeorological capacity development programmes benefiting several PTC Member countries. The Organization also encouraged wider implementation of the Common Alerting Protocol (CAP) to improve standardized dissemination of warnings and promoted the translation of the COPE awareness materials into local languages to strengthen public outreach and community preparedness across the region.

1.4.2 India

1.4.2.1 Disaster Risk reduction:

At the national level, the Ministry of Home Affairs is the nodal Ministry for all matters concerning disaster management. The Joint Secretary, Disaster Management, Ministry of Home Affairs is the Central Relief Commissioner (CRC) and the nodal officer to coordinate relief operations for natural disasters. The CRC receives information relating to forecasting/warning of a natural calamity from IMD or from Central Water Commission of Ministry of Water Resources on a continuing basis. The Ministries/ Departments/ Organizations concerned with the primary and secondary functions relating to the management of disasters include:

India Meteorological Department (under Ministry of Earth Sciences), Central Water Commission, Ministry of Home Affairs, Ministry of Defence, Ministry of Finance, Ministry of Rural Development, Ministry of Housing and Urban Affairs, Ministry of Communications, Ministry of Health & Family Welfare, Ministry of Water Resources, River Development & Ganga Rejuvenation, Ministry of Petroleum & Natural Gas, Department of Agriculture Cooperation and Farmers' Welfare, Ministry of Power, Ministry of Railways, Ministry of Information and Broadcasting, NITI Aayog, Cabinet Secretariat, Ministry of Road Transport and Highways, Ministry of Social Justice & Empowerment, Ministry of Women & Child Development, Ministry of Environment, Forest & Climate Change, Department of Food & Public Distribution. Each Ministry/Department/ Organization nominates their nodal officer to the Crisis Management Group chaired by Central Relief Commissioner. The nodal officer is responsible for preparing sectoral Action Plan/Emergency Support Function Plan for managing disasters.

1.4.2.2 National Crisis Management Committee (NCMC):

Cabinet Secretary, who is the highest executive officer, heads the NCMC. Secretaries of all the concerned Ministries /Departments as well as organizations are the members of the Committee. The NCMC gives direction to the Crisis Management Group as deemed necessary. The Secretary, Ministry of Home Affairs is responsible for ensuring that all developments are brought to the notice of the NCMC promptly. The NCMC can give directions to any Ministry/Department/Organization for specific action needed for meeting the crisis situation.

1.4.2.3 Crisis Management Group (CMG):

The Central Relief Commissioner in the Ministry of Home Affairs is the Chairman of the CMG, consisting of senior officers (called nodal officers) from various concerned Ministries/Departments. The CMG's functions are to review every year contingency plans formulated by various Ministries/ Departments/ Organizations in their respective sectors, measures required for dealing with natural disasters, coordinate the activities of the Central Ministries and the State Governments in relation to disaster preparedness and relief and to obtain information from the nodal officers on measures relating to above. The CMG, in the event of a natural disaster, meets frequently to review the relief operations and extend all possible assistance required by the affected States to overcome the situation effectively. The Resident Commissioner of the affected State is also associated with such meetings.

1.4.2.4. Control Room (National Emergency Response Centre):

A National Emergency Response Centre (Control Room) exists in the nodal Ministry of Home Affairs, which functions round the clock, to assist the Central Relief Commissioner in the discharge of his duties. The activities of the Control Room include collection and transmission of information concerning natural calamity and relief, keeping close contact with governments of the affected States, interaction with other Central Ministries/Departments/Organizations in connection with relief, maintaining records containing all relevant information relating to action points and contact points in Central Ministries etc., keeping up-to-date details of all concerned officers at the Central and State levels.

1.4.2.5 National Disaster Management Authority (NDMA)

As mandated by Disaster Management Act, 2005, the Government of India (GoI) created a multi-tiered institutional system consisting of the National Disaster Management Authority (NDMA) headed by the Prime Minister, the State Disaster Management Authorities (SDMAs) headed by the respective Chief Ministers and the District Disaster Management Authorities (DDMAs) by the District Collectors and co-chaired by Chairpersons of the local bodies. These bodies have been set up to facilitate a paradigm shift from the hitherto relief centric approach to a more proactive, holistic and integrated approach of strengthening disaster preparedness, mitigation and emergency response.

About 8% of the area in the country is prone to cyclone-related disasters. Recurring cyclones account for large number of deaths, loss of livelihood opportunities, loss of public and private property and severe damage to infrastructure, thus seriously reversing developmental gains at regular intervals.

Broad-scale assessment of the population at risk suggests that an estimated 32 crore people, which accounts for almost a third of the country's total population, are vulnerable to cyclone related hazards. Climate change and its resultant sea-level rise can significantly increase the vulnerability of the coastal population.

1.4.2.6. Guidelines for the Management of Cyclones

The NDMA had issued Guidelines for the Management of Cyclones to assist ministries and departments of GoI and state governments to prepare their DM plans. The guidelines are presented in nine chapters as detailed below:

i. Chapter 1 provides an introductory overview that reflects the risk and vulnerability of the country to cyclones, including the dimensions and magnitude of the problem.
ii. Chapter 2 discusses the Early Warning Systems (EWS) for cyclones. In this chapter, the present status of EWSs has been discussed and the gaps have been identified. Requirement to bring them up to international standards and making them state-of-the-art systems has been recommended.
iii. Chapter 3 deals with the present status of Warning Communication and Dissemination, its gaps and future improvements required towards making it fail-proof and modern.
iv. Chapter 4 covers structural measures for preparedness and mitigation, covering cyclone shelters, buildings, road links, culverts and bridges, canals, drains, saline embankments surface water tanks, cattle mounds and communication/power transmission networks.
v. In Chapter 5, important aspects of the management of coastal zones and its relevance to CDM, including some other non-structural mitigation options have been presented. This chapter discusses issues related to coastal zone management, sustainability of coastal resources, bio-shields, coastal flood plain management, coastal erosion, natural resources management, etc.
vi. Chapter 6 deals with various aspects of awareness generation related to CDM as an important preparedness measure.
vii. Chapter 7 covers Disaster Risk Management (DRM) issues, risk assessment and vulnerability analysis, hazard zoning and mapping, data generation, including the use of GIS tools, and capacity development.
viii. Chapter 8 deals with CDM-related response and relief strategies. A detailed account of several issues related to effective response such as response platforms, linking

risk knowledge with response planning, evolving disaster response capabilities, etc., is brought out in this chapter.

ix. In Chapter 9, guidelines and implementation strategies have been discussed.

x. Salient initiatives recommended for implementation as part of the National Guidelines for Management of Cyclones are listed for undertaking action by various relevant Departments.

xi. The guidelines are hosted in NDMA website at (https://ndma.gov.in/images/guidelines/cyclones.pdf

1.4.2.7 Current Status

1.4.2.7.1 National Cyclone Risk Mitigation Project (NCRMP)

Government of India has initiated the **National Cyclone Risk Mitigation Project (NCRMP)** with World Bank assistance with a view to address cyclone risks in the country. The overall objective of the Project is to undertake suitable structural and non-structural measures to mitigate the effects of cyclones in the coastal States and UTs of India. National Disaster Management Authority (NDMA) under the aegis of Ministry of Home Affairs (MHA) is entrusted with implementation of this Project in coordination with participating State Governments.

Phase I was approved for implementation in two coastal states viz **.**Andhra Pradesh & Odisha at a cost of Rs.1496**.**71 crore in January 2011 with the date of completion as January 2016, with World Bank Assistance. It was further revised to Rs. 2541.60 Crore with the date of completion as December 2018. Phase I stands completed with an expenditure of Rs. 2,524.84 crore.

Phase II was approved for implementation in six coastal States viz; Goa, Gujarat, Karnataka, Kerala, Maharashtra, and West Bengal with World Bank assistance at an outlay of Rs. 2361.35 crore in July 2015 with the date of completion as 31st March 2020. With subsequent revisions in the light of the scheme performance, ratings, cancellation of non-started activities as well as surrendering of savings of US$ 80 Million, the outlay was finally revised to Rs. 1864.38 crore with the date of completion as 14th March 2023. Phase II stands completed with an expenditure of Rs. 1806.84 crore.

1.4.2.7.2 Details of the structural and non-structural measures implemented under NCRMP are as follows:

Structural Measures

A. Early Warning Dissemination System (EWDS):-The EWDS, the state-of-the-art multi-technology option (Alert Siren, Satellite Radio, Mass Messaging, etc.) to provide reliable communication by ensuring last-mile connectivity during disasters has been commissioned and is operational in coastal districts of Andhra Pradesh and Odisha. The physical work has been completed in Goa, Karnataka, and Kerala and the testing for commissioning the same is under process. The activity would be launched very soon in these three States. Further, EWDS would be taken up in Gujarat, Maharashtra and West Bengal in the next phase of NCRMP.

B. Cyclone Risk Mitigation Infrastructure (CRMI):- The CRMI enhances the preparedness and mitigates the vulnerability of coastal communities through investments for the construction of multi-purpose cyclone shelters (MPCS), roads, bridges, underground electric cabling and saline embankments. The infrastructure created under the project is as under:

Sub-component	**Total**
MPCS (No.)	795

Roads (Km)	1291.52
Bridge (No.)	36
Saline Embankment (Km)	118.18
Underground Electric Cabling (Km)	1387.76

Non-Structural Measures

C. Capacity Building Training (CBT)/ Shelter Level Training (SLT):

A total of 24,007 Government officials from various priority sectors viz., Health, Education, Panchayat Raj Institutions, Urban Local Bodies, and Rural Development have been trained through 925 Capacity Building Training. Similarly, 68,988 community representatives have been trained on various disaster response skills viz., First Aid, Search & Rescue, and Shelter Management through 3421 Shelter Level Training.

D. Technical Studies:

i. **Coastal Hazard, Risk and Vulnerability Assessment (HRVA):** To analyse risk at village level, a Web-based Composite Risk Atlas (CRA) has been developed under NCRMP-I which has been shared with all 13 coastal States & UTs for mitigation planning.

ii. **Post Disaster Needs Assessment (PDNA):** National Institute of Disaster Management (NIDM) has developed PDNA tools under NCRMP-I with an objective to establish a standardized mechanism based on scientific approach for conducting post disaster needs assessment for long term recovery and reconstruction. The newly developed tools are based on the existing damage assessment system in India and an internationally-accepted methodology.

iii. **Development of Web based Dynamic Composite Risk Atlas (DCRA) & Decision Support System (DSS) Tool for Cyclones & Associated Hydro-meteorological Hazards:** A Web-DCRA & DSS Tool for Cyclone impacts forecasting covering all 13 coastal States and Union Territories of the Country has been developed which provides real-time forecast for location specific cyclonic wind and inundation level due to storm surge, cyclone induced rainfall and riverine flood.

iv. **Hydro-meteorological Resilient Action Plans (HmRAP):** HmRAP study has been taken up to strengthen the capacity of National/States and ULB entities to effectively plan for and respond to significant hydro-met hazards/extreme events and climate change affecting urban areas in six selected cities of the project States of NCRMP-II.

v. **Design of Comprehensive Multi-hazard Risk Financing Strategy (CMhRFS):**

CMhRFS has been taken up with an objective to work out risk transfer financial instruments and to develop risk financing strategies in 4 States (Gujarat, Odisha, Kerala and Uttarakhand).

1.4.2.7.3 (**DCRA Mobile App)**

A DCRA Mobile App. is also being developed for faster outreach to populations at risk. The existing mobile applications, namely, Meghdoot, Damini, Mausam, TNSMART, Thoondil as well as Navik have been studied to benchmark functionality for this application.

The DCRA Mobile App. is a hybrid application which would be available on both the IOS and Android platforms. The DCRA app will enable users to access features of Web-DCRA and cyclonic events specific to the area through location based technology. Registered users can access all the forecast, warnings and advisories through the Mobile App. This application provides live updates features such as safe / emergency shelter, raised platforms, nearest evacuation routes, additional resources if any for general public as well as for state & district administration officials and Disaster Management Authorities. It also provides local weather forecast and near real-time risk reports of an impending cyclone.

Design of the Hybrid Mobile Application has been completed with the development of modules including Registration, Login, User Management, I'm Safe, I'm not safe, Crowd Sourcing & Map Module. The Mobile App. also has Social Media feature including WhatsApp for registration process as well as sending these alerts apart from SMS.

1.4.2.8. National Disaster Response Force (NDRF)

1.4.2.8.1. Vision

To be one of the most effective & modernized disaster response forces in the world.

1.4.2.8.2. Mission

- To consistently provide effective disaster response in India (and out of India if called upon)
- To facilitate Pan-India capacity building empowerment and awareness in disaster response.
- To develop into a high-tech, modernised force with equipment, protocols and standards which are world class.

1.4.2.8.3. History

India experienced heavy loss of life & property in last three decades due to mammoth natural calamities like the Odisha Super Cyclone of 1999, Gujarat Earthquake of 2001, and Indian Ocean Tsunami of 2004 - a succession of events that demanded comprehensive disaster management. This led to the enactment of the Disaster Management (DM) Act on December 26, 2005. This Act provides for effective management of disasters and for matters connected therewith or incidental thereto. Consequently, as mandated in the DM Act, the National Disaster Response Force (NDRF) was formed in the year 2006 as a federal first-responder Force.

The multi skilled, highly professional "National Disaster Response Force" comprising of 08 Nos. of battalions (Bns) (02 Bn each from BSF, CRPF, ITBP and CISF) was raised as per Chapter VIII, Section-44 of DM Act- 2005 to tackle/mitigate all types of disaster. In a short span of time, the Force became known for its proactive approach to disaster response, ready availability and assistance to the States and its preventive pre-positioning in disaster situations, resulting in rapid response and minimal damage during natural calamities. Further, two more Bns (one each from CRPF & BSF) were added on 13 Oct' 2010 and in 2015, two more Bns from SSB were added in NDRF. In 2018, GoI approved raising of four Additional Battalions, out of which 01 Battalion of Assam Rifles is inducted in 2020, 02 Battalions of ITBP and 01 Battalion of BSF are inducted in 2021. Presently NDRF is 16 Battalion strong.

1.4.2.8.4 Roles and Responsibility

The NDRF aims toward proactive deployment in impending disaster situations, followed by specialized response during disasters. In non-disaster periods, the NDRF focuses on capability building, acquiring new skills through constant training. The force imparts basic and operational level training to State Disaster Response Forces, Police, Civil Defence and Home Guards. It also engages in Community Capacity Development, wherein it facilitates and empowers communities in disaster preparedness. Other than mock drills, activities include co-ordination with other stakeholders, reconnaissance, vulnerability and disaster mapping, and rehearsals. The NDRF consistently spreads awareness about disaster management in the community at large and amongst school children.

1.4.2.8.5 Organisational Structure

At present, NDRF has a strength of 16 Battalions including four battalions each from BSF & ITBP, three battalions from CRPF, two each from CISF & SSB and one from Assam Rifles. Each Battalion consists of 1149 personnel. Each battalion has 18 specialist search and rescue teams, which are self-contained and have specialists like engineers, technicians, electricians, dog squads and medical and paramedical personnel. Each battalion is equipped and trained for man-made and natural calamities. They are also capable of responding to chemical, biological, radiological, and nuclear emergencies (CBRN). There is an NDRF Academy at Nagpur. The National Civil Defence College also has been merged with NDRF Academy. The location of the NDRF battalions is determined by the vulnerability profile of the country, with the intention of cutting down response times in times of disaster.

1.4.2.8.6 Working of NDRF

NDRF responds within the minimum time frame and reaches the place of disaster with the required equipment. As per the Standing Operating Procedure (SOP) for deployment of NDRF teams, approved by MHA, NDRF teams can be requisitioned for deployment during pre-disaster/ impending disaster phase as well during actual disaster. During floods, cyclones, tsunamis and other disasters where forecast or early warning is available, NDRF prepositions its team in consultation with the respective state authorities and as per the forecast of early warning agencies like IMD, CWC, and INCOIS etc. In addition, when disaster is of larger magnitude, NDRF teams are mobilized even on telephonic request to save time, as timely response is of essence.

Each NDRF unit conducts FAMEx in respective Area of Operations (AOR) to provide opportunity to the personnel to acquaint themselves about topography, demography, route, terrain and availability of resources such as medical support, water points, earth moving equipment etc. It also provides opportunity to the Commanders to familiarise themselves with local inhabitants and liaise/ coordinate with the officials who invariably are the first responders or stakeholders at the time of disaster.

1.4.2.8.7 Capabilities & Strength

- CSSR (Collapsed Structure Search & Rescue) operations.
- MFR (Medical First Response).
- CBRN emergency response.
- Flood Disasters.
- Mountain Search & Rescue.
- Deep Diving Search & Rescue.
- Canine and Technical Search.
- Animal disaster response.

1.4.2.8.8. Equipment

NDRF has been equipped with latest state of the art equipment required for the rescue and relief work. An inventory of State of the art equipment have been authorized to NDRF which broadly consists of Medical First Responder (MFR) Equipment, Collapsed Structure Search & Rescue (CSSR), Flood Water Rescue, CBRN equipment and specialist vehicles etc.

1.4.2.8.9. Notable Operations

Year	Operations
2008	Kosi Floods in Bihar
2009	Cyclone Aila (West Bengal) and Building collapse Bellary (Karnataka)
2010	Train accident in Jhargram (WB), Chlorine leakage at Shiwadi Mumbai(MH), Leh Cloud Burst, Mayapuri Radiation, New Delhi.
2011	Sikkim earthquake and Triple disaster at RifuCho, Japan
2012	Shital Febric Factory Collapse (Jalandhar, Punjab) and Assam Floods
2013	Uttarakhand Flash Floods, Mumbai Building Collapse, Cyclone Phailin, and General Floods
2014	J&K Floods, Cyclone Hudhud, Cyclone Nilofar, Malin (Pune) Land Slide (MH), Assam Floods and Meghalaya Floods
2015	Gujarat Floods, Chennai Urban Floods, Cyclone Komen and Andhra Pradesh Floods
2016	Kolkata Flyover Collapse, Shavitri Bridge Collapse Mahad (MH), Kanpur-Dehat Train derailment (UP) and Cyclone Vardah
2017	Kanpur Building Collapse (UP), Cyclene Ockhi
2018	Murshidabad Bus accident (WB), Varanasi Flyover Collapse (UP), Shahberi (G/Noida, UP) Building Collapse, Kerala Floods, Cyclone 'Titli', Cyclone Gaja, Cyclone Phethai, Cyclone Pabuk.
2019	Ksan Coal Mine incident (Meghalaya), Gurugram Building collapse (Haryana), Pune Bore-Well incident (MH), Hissar Bore-Well incident, Dharwad (Karnataka) Building Collapse, Mathura Bore-Well incident (UP), Cyclone "FANI", Cyclone "VAYU", Kesarbai (Dongri, Mumbai) Building Collapse, Mahalaxmi Express Ops (Thane, MH), Mallapuram & Waynad Landslide (Kerala), Kerala Floods, Kachuluru Devipatnam Boat Capsize East Godavari (AP), Malda Boat capsize (WB), Sant Kabir Nagar Boat capsize (UP), Cyclone "Maha" and Cyclone "Bulbul"
2020	Gas Leakage at L.G Polymer, Vishakhapatnam (A.P), Super Cyclone 'Amphan', Cyclone 'Nisarga', Building Collapse at Mumbai (Maharashtra), Idukki Landslide (Kerala), Plane Crash, Kozhikode Airport (Kerala), Building Collapse Raigarh (Mahtrashtra), Assam Floods & Bihar Floods, Cyclone 'Nivar' and 'Burevi'
2021	Forest Fire at Dzukou Valley Manipur & Nagaland, Glacier burst & Flash Flood at Tapovan, Chamoli, Uttrakhand, Cyclone 'Tauktae' and 'Yaas', Landslide-Village-Taliye, Tehsil-Mahad, Distt.-Raigarh (Maharashtra)
2022	Train Derailment at Do-Muhani, Maynaguri, Alipurdwar (WB), Rescue of a Trekker Stranded on cliff ot Pallakad (Kerala), Building Collapse in Gurugram (Haryana), Trikut Hills Ropeway Incident, Deoghar (Jharkhand)

2023	Building collapse at Lucknow, UP, Building collapse at Thane (MH), Gas leakage at Ludhiana, Punjab, Train accident at Balsore, Odisha, Extremely Severe Cyclonic Storm Biparjoy (Gujarat, Rajasthan, Maharashtra, Karnataka, Diu), Delhi Floods, Landslide at Shimla, Severe Cyclonic Storm “Michaung”, Tunnel collapse at Silkyara, Uttrakshi, Tamilnadu Flood.
2024	North Delhi, Building collapse Kolkata, West Bengal, Building collapse Rupnagar, CSSR Ghatkopar, Mumbai, Floods-Imphal, West Medinipur, Train accident Darjeeling, CSSR, Surat, Gujarat, CSSR Deogarh, Jharkhand, land Slide Wayanad, Kedarnath Landslide/Floods, Jharkhand Floods, Cloudburst Shimla, Kullu, mandi (HP), Tripura Floods, Gujarat Floods, Andhra Pradesh Floods, Bihar, West Bengal Floods.

Summary of International Operations:

2011: For the first time NDRF was deployed in Japan post Tsunami

2015: 16 USAR teams of NDRF were deployed to provide assistance in Nepal Earthquake

2023: 03 NDRF teams mobilised for Turkiye after the earthquake struck Turkiye and northwest Syria

1.4.2.8.10. Summary of operational activities (since 2006 till date)

Human lives Rescued by NDRF	1,58,700
Human lives evacuated by NDRF	8,62,084
Dead bodies retrieved	7,466
Total No. of Operation	10,471
Livestock	19,380
Familiarization exercises conducted by NDRF	2844

1.4.2.8.11. Capacity Building initiatives for disaster resilience

i) School Safety Programmes
ii) Capacity Building Programmes for states and local agencies
iii) Community Awareness Programmes
iv) Mock Exercise

1.4.2.8.12. Summary of Capacity Building initiatives

Community Awareness Programmes (CAPs)	No. of CAPs conducted	12543
	No. of beneficiaries	63,89,537
School Safety Programmes (SSPs)	No. of SSPs conducted	7310
	No. of beneficiaries	26,00,086
Mock Exercise	No of Exercise conducted	5,394
	No. of beneficiaries	17,81,999

1.4.2.8.13. Accolades

- Police Medal for Gallantry - 09
- Jeevan Raksha Padak - 10
- Prime Minister Life Saving Medal - 40
- NDRF is the first recipient of the Subhash Chandra Bose Aapada Prabandhan Medal in 2019.

1.4.2.9 National Institute of Disaster Management (NIDM)

- The National Institute of Disaster Management (NIDM) was constituted under an Act of Parliament with a vision to play the role of a premier institute for capacity development in India and the region. The efforts in this direction that began with the formation of the National Centre for Disaster Management (NCDM) in 1995 gained impetus with its redesignation as the National Institute of Disaster Management (NIDM) for training and capacity development. Under the Disaster Management Act 2005, NIDM has been assigned nodal responsibilities for human resource development, capacity building, training, research, documentation and policy advocacy in the field of disaster management.
- Both as a national Centre and then as the national Institute, NIDM has performed a crucial role in bringing disaster risk reduction to the forefront of the national agenda. It is our belief that disaster risk reduction is possible only through promotion of a "Culture of Prevention" involving all stakeholders. We work through strategic partnerships with various ministries and departments of the central, state and local governments, academic, research and technical organizations in India and abroad and other bi-lateral and multi-lateral international agencies.
- NIDM is proud to have a multi-disciplinary core team of professionals working in various aspects of disaster management. In its endeavour to facilitate training and capacity development, the Institute has state-of-the-art facilities like class rooms, seminar hall, a GIS laboratory and video-conferencing facilities etc. The Institute has a well-stocked library exclusively on the theme of disaster management and mitigation. The Institute provides training in face-to-face, on-line and self-learning mode as well as satellites based training. In-house and off-campus face-to-face training to the officials of the state governments is provided free of charge including modest boarding and lodging facilities.
- NIDM provides technical support to the state governments through the Disaster Management Centres (DMCs) in the Administrative Training Institutes (ATIs) of the States and Union Territories. Presently NIDM is supporting thirty such centres. Six of these centres are being developed as Centres of Excellence in the specialised areas of flood risk management, earthquake risk management, cyclone risk management, drought risk management; landslides risk management and management of industrial disasters. Eleven larger states (Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal and Odisha) have been provided with additional centres to cater their needs in this area.
- The vision is to create a Disaster Resilient India by building the capacity at all levels for disaster prevention and preparedness.

1.4.3 Myanmar:

Main responsibility of Department of Meteorology and Hydrology (DMH) is to provide early warning to the higher authorities, local government, and disaster risk reduction relevant agencies, media, INGOs, NGOs, social Medias and general public. Whenever the significant weather condition news and warnings are issued by DMH, the messages were sent to the respective stations by telephone or Single Side Band (SSB) transceiver, email and fax. As soon as head of the station received the message of warning, then immediately informed the local authorities and other related departments in order to carry out the necessary actions. At the same time, the warnings and bulletin are disseminated through DMH Website, Facebook, DMRS, Radio and Television as well as through the Newspaper for general public.DMH owns weather studio for effective communication with clear understandable weather information warnings, two automatic weather answering machines and call center for the early warning system to update warnings and news. DMH cooperated with MRTV, MWD and Radio Channels for live broadcasting about early warning and advisories while Cyclone/Depression approaching Myanmar Coastal Areas. Early Warning decision making processes were accomplished with valuable support and close cooperation with WMO and its Regional office, RSMC(New Delhi), WMO GTS, GFS forecast, INCOIS, ECMWF, WMO LC, APEC, CIMSS's analysis, WMO SWFD Pproducts and neighboring NMHSs.

During November 2023 to October 2024, DMH organized the public awareness for disaster risk reduction and participated workshop and meetings as follows;

32nd National Monsoon Forum organized by Department of Meteorology and Hydrology was held in Multi Hazard Early Warning Center of Department of Meteorology and Hydrology, Naypyitaw on 6th May, 2024. The forum was discussed on the reviewing of seasonal outlook for the Weather and Water Level forecasts in 2024 Rainy Season (Southwest Monsoon Period), condition of Agro-meteorology, Terms and Terminology of Meteorology, Seismic Disaster in Myanmar, presenting on sectorial lessons learned during 2023-2024 Winter Season (Northeast Monsoon Period) and sectorial preparedness for 2024 Southwest Monsoon Season and discussing on suggestions for seasonal weather forecasts.

DMH staffs participated from 26th to 29th South Asian Climate Outlook Forum (SASCOF) and Climate Service User Forum (CSUF), from 21st to 22ndSession of the ASEAN Climate Outlook Forums (ASEANCOF), third Governing Body (GB) and Scientific Advisory Committee (SAC) Meeting of the BIMSTEC Centre for Weather and Climate (BCWC).

DMH staffs attended Seventy-Eighth Session of The Executive Council (EC-78) and 60th Session of the Intergovernmental Panel on Climate Change (IPCC-60).

DMH staffs participated workshop on Weather Radar Quality Control and Radar Data Exchange, seminar on the Application of FY Meteorological Satellites Products for Belt and Road Countries and seminar on Emergency Search and Rescue for Developing Countries.

DMH staffs attended also South Asia Hydromet Forum (SAHF): Country-wise Working Group Meeting, Weekly SAHF Forecaster Forum, Weekly BIMSTEC Centre for Weather and Climate (BCWC) Online Map Discussion, Asean Specialized Meteorological Centre (ASMC) Fortnightly Discussion, BIMSTEC Centre for Weather and Climate (BCWC)-Scientific Advisory Committee (SAC): Science Strategy Meeting, Australian VLab Centre of Excellence Regional Focus Group Meeting and Drought Resilience +10 Conference by Online.

1.4.4 Sri Lanka:

The Department of Meteorology (DoM), Sri Lanka, continued to play a pivotal role in strengthening disaster risk reduction (DRR) through timely forecasting, impact-based early warning services, and close coordination with national disaster management agencies during the reporting period. The occurrence of several high-impact weather events, including the extreme rainfall event of 1 June 2024 and the widespread flooding associated with Cyclonic Storm Fengal in November 2024, highlighted the importance of an integrated multi-hazard early warning system in reducing the impacts of hydro-meteorological disasters.

A key strength of Sri Lanka's disaster risk reduction framework was the strong institutional coordination between the Department of Meteorology, the Disaster Management Centre (DMC), the Department of Irrigation, the National Building Research Organisation (NBRO), the Department of Fisheries, and other stakeholder agencies. Regular stakeholder meetings, emergency briefings, virtual consultations, media interactions, and continuous communication with government authorities ensured that weather forecasts and impact information were rapidly translated into preparedness and response actions during severe weather situations.

The Early Warning Centre of the Department of Meteorology further strengthened its operational capability by continuously monitoring tropical disturbances from the low-pressure stage using satellite observations, global Numerical Weather Prediction (NWP) models, and guidance from RSMC New Delhi. Cyclone alerts, warnings, heavy rainfall advisories, gale wind forecasts, storm surge information, and graphical forecast products were issued according to well-defined operational procedures based on the proximity and intensity of tropical systems. The use of colour-coded warning levels and clearly defined response actions enabled disaster managers, coastal communities, fishermen, and the general public to undertake timely preparedness measures.

Warning dissemination remained a major component of the country's disaster risk reduction strategy. Forecasts and warnings were communicated through the Department's website, social media platforms, press releases, television, radio, email, SMS services operated through the Disaster Management Centre, and dedicated advisories for the fisheries, marine, and aviation sectors. During 2024 alone, the Department issued 4,557 public weather forecasts, 505 weather warnings, and 1,316 specialized forecasts for government agencies and private institutions, demonstrating its commitment to providing timely and reliable weather information to support national preparedness and emergency response.

Capacity building and stakeholder engagement also remained integral to strengthening disaster resilience. The successful organization of the 30th and 31st Monsoon Forums in collaboration with the Regional Integrated Multi-Hazard Early Warning System (RIMES) provided an effective platform for sharing seasonal climate outlooks, discussing emerging risks, and improving the application of climate information by disaster management agencies and climate-sensitive sectors. Continuous professional training programmes, international workshops, operational research, and climate studies further enhanced institutional capacity and forecasting capability.

Overall, the reporting period demonstrated Sri Lanka's continued commitment to advancing disaster risk reduction through improved forecasting capability, effective multi-agency coordination, impact-based early warning services, and sustained investment in capacity development. Continued modernization of meteorological infrastructure, implementation of the Meteorological Modernization Project, installation of Doppler Weather Radars, strengthening of impact-based forecasting, and enhanced collaboration with national and regional partners will further improve the country's resilience to tropical cyclones, floods, landslides, and other hydro-meteorological hazards, thereby safeguarding lives, livelihoods, and critical infrastructure.

1.4.5 Bangladesh:

Bangladesh has made significant progress in strengthening disaster risk reduction through continuous improvements in weather monitoring, forecasting, early warning dissemination, and multi-agency coordination. The experiences from recent extreme weather events, including Cyclones Midhili, Remal, Dana, severe heat waves, and heavy rainfall episodes, demonstrate that timely forecasts and impact-based warnings play a crucial role in minimizing the loss of life and reducing damage to property.

The Bangladesh Meteorological Department (BMD) has enhanced its forecasting capability by integrating satellite observations, Doppler weather radar, numerical weather prediction (NWP) models, and guidance from regional and global forecasting centers. The adoption of impact-based forecasting, dynamic risk mapping, and location-specific warning systems has further strengthened preparedness and response at national and local levels.

Despite these achievements, increasing climate variability and the growing frequency of extreme weather events require continuous investment in forecasting technology, observation networks, communication systems, and capacity building. Future efforts should focus on expanding artificial intelligence and machine learning applications, improving nowcasting for high-impact weather, automating impact forecasting, and enhancing community-based early warning systems to ensure that vulnerable populations receive timely and actionable information.

An effective Disaster Risk Reduction strategy depends on the seamless integration of scientific advances, technological innovation, institutional coordination, and public awareness. Strengthening these pillars will enhance resilience, support sustainable development, and safeguard lives, livelihoods, and critical infrastructure against future weather and climate-related disasters.

1.4.6 United Emirates Arab:

The United Arab Emirates continues to strengthen its Disaster Risk Reduction (DRR) framework through a proactive, science-based, and impact-oriented approach to weather and climate hazards. The National Center of Meteorology (NCM), in close coordination with the Ministry of Interior (MOI) and the National Emergency, Crisis and Disaster Management Authority (NCEMA), has established an integrated system that combines advanced observation networks, high-resolution numerical weather prediction models, and multi-hazard impact-based forecasting to support timely decision-making and emergency response.

The implementation of an Early Warning System (EWS), hazard impact matrix, and severity-based warning protocols has significantly enhanced the country's capability to anticipate and manage hydro-meteorological hazards. The adoption of impact-based forecasting ensures that warnings are not only scientifically accurate but also actionable, enabling authorities and the public to take appropriate preparedness measures before hazardous events occur.

Recent weather events, including the October 2024 depression, demonstrated the importance of coordinated monitoring, continuous forecast updates, and effective communication among national agencies. These efforts contributed to improved situational awareness, timely emergency actions, and enhanced public safety during high-impact weather events.

Looking ahead, the UAE remains committed to further advancing disaster resilience by expanding the use of artificial intelligence, improving high-resolution forecasting systems, strengthening multi-hazard early warning services, and enhancing collaboration with regional and international partners. Continued investment in observation infrastructure, forecasting technologies, capacity building, and public awareness will further reduce disaster risks and strengthen national resilience.

An effective Disaster Risk Reduction strategy relies on the integration of scientific innovation, technological advancement, institutional coordination, and community preparedness. By continuing to enhance these capabilities, the UAE is well positioned to protect lives, infrastructure, economic activities, and the environment while contributing to the global objectives of the Sendai Framework for Disaster Risk Reduction and the WMO Early Warnings for All initiative.

1.5 TRAINING

1.5.3.1 Training Component

The Human Resource Development has always been one of the prime thrust areas of the India Meteorological Department for capacity building and to keep pace with the latest trends in various activities in the department. Meteorological Training Institute IMD Pune component of RTC India is the main centre of IMD for capacity development in the field of operational Weather and Climate Services. Training Facilities at this center has been recognized by WMO to function as a RTC in the WMO RA-II region in the disciplines of General Meteorology (Forecasting- Non Aviation & Aviation both), Surface Instrumentation and Agricultural Meteorology, since 1986.

Like previous years, MTI Pune conducted various training programs in 2023. The course curricula of various training courses have been modified keeping in view the latest developments. In every regular training program in General Meteorology discipline, a sizable portion on Tropical cyclone is there, which consists of basic concepts on Tropical cyclone genesis, structure, life cycle, dynamics & thermodynamics aspects of tropical cyclone, different prediction & warning methods of Cyclone and techniques providing impact-based cyclone forecasting.

During 2023-24, MTI has organized 8 regular long term (2-12 months duration) certificate training courses (5 BIP-M & 2 BIP-MT), with approximately 294 national participants and 2 overseas participants from Mauritius Met. Services and during 2024-25 (till November 2024), 4 regular long term (2-12 months duration) certificate training courses (3 BIP-M & 1 BIP-MT), with approximately 164 national participants. In addition, RSMC New Delhi conducted its regular cyclone training program. Various other divisions of IMD such as Satellite Meteorological Division, Radar Division, NWP Division and Instrument division conducted training programs in their respective areas for national and international participants. Customized training course on Aviation Meteorology for Meteorological Personnel of Bhutan was conducted in virtual mode in 2023-2024. A Joint IMD-WMO group fellowship training on "Development of Competency in Weather forecasting" was conducted in Physical mode during the period 26.08.2024 to 27.09.2024. Customized training course on Basic Meteorology for Meteorological Personnel of Bhutan is going on for the period 04.11.2024 to 29.11.2024 in physical mode.

E-learning method in training program is used for some courses. Initiative is being taken up for distant learning program through virtual classroom facilities and sharing of digital content of lectures in broadcast mode.

Trainings conducted during 2023-24 along with ongoing and planned activities for 2024-25

S.N.	***Name of Training***	***No. of Trainees during 2023-24***	***No. of Trainees during 2024-25 (Till November 2024)***	***Ongoing trainees***
1.	Advanced Meteorological Training Course (AMTC)	11 (7 Indian Navy, 2 Coast Guard & 2 Mauritius) (Hybrid mode)	2 (2 Coast Guard (Physical mode)	5 (2 Coast Guard & 3 Mauritius) (Physical mode)
2.	Forecasters Training Course (FTC)	109 (E-learning & Hybrid mode)	39 (E-learning & Hybrid mode)	49 (E-learning & Hybrid mode)
3.	Integrated Meteorological Training Course (IMTC)	147 (Online / V.C.)	110 (Online / V.C.)	--
4.	Direct Recruited Scientists Training Course (DRSTC)	12 (Online / V.C.)	13 (Hybrid mode at New Delhi Centre)	--
5.	Basic / Modular Training Course	17 (Physical mode)	--	--

Future Plan:

1. Customized training course on Intermediate / Advanced Meteorology for Meteorological Personnel of Bhutan will be conducted during the period 02.12.2024 to 30.12.2024 in physical mode.
2. Next Batch of Integrated Meteorological Training Course (IMTC) will be conducted from 2nd December 2024.
3. Next Batch of Forecasters Training Course (FTC) will be conducted from 24th March 2025.
4. Next Batch of Advanced Meteorological Training Course (AMTC) will be conducted from 8th September 2025.

1.5.1.2 Training conducted by RSMC, New Delhi

India Meteorological Department (IMD) is one of six Regional Specialised Meteorological Centres (RSMCs) in the world recognised by WMO under a global system for issue of warnings and advisories in association with cyclonic disturbances over north Indian Ocean. As an international commitment, TC advisories are issued by RSMC, New Delhi, to WMO/ Economic and Social Commission for Asia and Pacific (ESCAP) Panel member countries including Bangladesh, India, Iran, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, Qatar, Saudi Arabia, United Arab Emirates, Thailand and Yemen. IMD also conducts training for cyclone forecasters in the region annually.

IMD started conducting tropical cyclones forecasters training for WMO sponsored participants from ESCAP Panel member countries since 2005. From 2008, onwards the forecasters from various Area Cyclone Warning Centres (ACWCs) and Cyclone Warning

Centres (CWCs) were also included. In 2015, International Training on Workshop on Tropical Cyclones Forecasting was organised with participants from WMO/ESCAP Panel countries, Australia, Switzerland, Cambodia, Lao PDR and Philippines.

This year, the WMO's Tropical Cyclones Forecasters Training 2024 was conducted by Regional Specialised Meteorological Centre (RSMC), New Delhi during 19-30 August in hybrid mode. This was the 20th training programme conducted every year since 2005 for the cyclone forecasters of the member countries. This year there were 106 participants including 26 International participants from Thailand, Myanmar, Bangladesh, SriLanka, Maldives, Pakistan, Iran, Oman, United Arab Emirate & Saudi Arabia, and 80 participants from various sub-offices of IMD. There are a total of 43 international participants with 9 joining in -person and remaining 34 joining online from various PTC member countries apart from the participants from India. The training aimed at building capacity of the TC forecasters in the region by understanding the latest developments in observations, monitoring, modeling, prediction and early warning services of TCs over the Bay of Bengal and the Arabian Sea and carrying out the case studies as practical examples in these aspects. The training included resource persons from UN-ESCAP, RSMC Tokyo, IMD, National Centre for Medium Range Weather Forecasting (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS) and IIT Delhi. During the training special sessions were organised for storm surge & ocean state forecasts and monsoon circulations.

(2) 1st Regional Training workshop on Multi-Hazard Early Warning System (MHEWS) Interoperability Implementation

India Meteorological Department (IMD) and World Meteorological Organisation (WMO) jointly organized the 1st Regional Training workshop on Multi-Hazard Early Warning System (MHEWS) Interoperability Implementation at New Delhi during 9-13 December 2024. The training aimed to enhance the capacity of the National Meteorological and Hydrological Services (NMHSs) in South Asia on the interoperability and integration of early warning initiatives, programmes, and activities as feasible into a coordinated and sustainable, multi-hazard interoperable environment, to enhance the capacities of NMHSs. With the regional level collaboration and coordination, the participants will learn to develop a coordinated and sustainable, multi-hazard interoperable environment through:

- sharing good practices
- improve regional collaboration (e.g., among regional and national centres for guidance product, data, training etc.)
- maximizing available resources (e.g., computing, IT and manpower etc.) • developing synergized standard operating procedures
- strengthen national institutional coordination and arrangements for MHEWS (to ensure national governance and commitment)
- sharing of data and products (in standards and formats) compatible to various systems to contribute to MHEWS interoperability
- integrate various services into one package
- minimization of number of warning bulletins and development of consolidated bulletin as per user's requirements. There were 9 international participants and 38 national participants.

1.5.1.3 Future Plans:

a) Attachment training at RSMC New Delhi during April, 2025
b) User specific training for various stakeholders
c) Training on Standard Operation Procedure for Bulletins associated with Tropical Cyclones and Marine Weather Services for forecasters in IMD

1.6. Research and publication

1.6.1. India

India Meteorological Department remained involved in extensive research activities. The achievements during 2024 were:

• Annual RSMC Report on Cyclonic Disturbances during 2023
• Annual Tropical Cyclone Operation Plan (TCP-21) (Edition 2024)
• Annual Report of Cyclone Warning Division, IMD and MoES
• News Letters: IMD and Ministry of Earth Sciences
• Preliminary and detailed reports of cyclonic disturbances during 2024
• Paper published in Mausam Journal in 2024

1.6.2.1. List of publications on cyclone in reviewed journals

❖ Nadao Kohno, Cody Fritz, Monica Sharma, Robbie Berg, Diana Greenslade, Devon Telford, Sakeasi Rabitu, PLN Murty, M Mohapatra, Maria Cristina C Uson, 2024, TCRR,
❖ Yerni Srinivas Nekkali, Krishna Kishore Osuri, M Mohapatra, 2024, Physical understanding of the tropical cyclone intensity and size relations over the North Indian Ocean, Climate Dynamics, pp 1-14 5.
❖ Mrutyunjay Mohapatra, 2024, Climate and Weather Forewarning Systems for Disaster Preparedness and Response, Disaster Risk and Management Under Climate Change, Springer, pp39-54 6.
❖ Chinmay Rajendra Khadke, Mrutyunjay Mohapatra, Namit Nandwani, 2024. Satellite-based analysis of rapid intensification of Super Cyclone Amphan.
❖ Satya Prakash, M Mohapatra, 2024, Vertical structure of tropical cyclone precipitation over the North Indian Ocean: a spaceborne precipitation radar perspective, Remote Sensing Letters, 17 (1), pp 77.

1.6.2.2 Panel News

1.6.2.3

❖ Panel News letter of PTC is a bi-annual document, which is issued after every six months. During 2016-2017 two (02) publications of PTC newsletter "Panel News" Issue No. 42, 43 were published and the same were uploaded / distributed among PTC Members and other concerned.

- ❖ THE PTC news letter is revived and the 2024 issue has been published and uploaded in the PTC website.

- ❖ The PTC Secretariat requested the Panel Member countries to carefully review the current Panel News issues, and send their views/comments to PTC Secretariat for further improving the quality of the Panel News.

1.6.2.4 Annual Report on cyclonic disturbances over north Indian Ocean

Dr. D. R. Pattanaik, Head, RSMC, New Delhi informed that Annual Report on cyclonic disturbances over the North Indian Ocean during 2023 and reports of all cyclonic disturbances during 2024 have been prepared and uploaded on website (www.rsmcnewdelhi.imd.gov.in).

1.7 REVIEW OF THE TROPICAL CYCLONE OPERATIONAL PLAN (2024)

The Tropical Cyclone Operation Plan (TCP-21) document defines the responsibilities of Member countries and standardizes operational procedures for the preparation, exchange and dissemination of tropical cyclone information and warnings, and serves as the primary operational reference for regional tropical cyclone forecasting and warning activities over the North Indian Ocean. The Panel appreciated Ms. Monica Sharma, RSMC New Delhi for her valuable services extended in updating the Operational Plan of the PTC. The updated The document also has a list of important addresses and telephone numbers connected with Tropical Cyclone Warning in the Panel Countries (ANNEX V-A-1 of the WMO/Tropical Cyclone Programme Report No. TCP-21).

<u>Support for the Panel’s programme from ESCAP</u>

ESCAP suggested the PTC secretariat to conceptualize and develop Synergized Standard Operating Procedures (SSOP) for Coastal Multi-Hazards Early Warning System. This should be an effort for resource mobilization to support related PTC activities through the ESCAP Trust Fund for Tsunami, Disaster and Climate Preparedness.

ESCAP informed supporting the RIMES to ‘Enhance Weather and Climate Resilience in RIMES Member States through Capacity Building on Impact Forecasting’. This is leading to the development of an online learning platform for IBF to support EW4All in PTC members. This activity was supported by the ESCAP Trust Fund for Tsunami, Disaster and Climate Preparedness.

<u>The decision regarding the PTC Logo</u>

The Panel had decided during PTC-50 to use the loge with the years of establishment and completion of 50 years (1973 and 2023) till December 2024. Thereafter, the logo without mention of years would be used by the secretariat as mentioned below:

1.8. SUPPORT FOR THE PANEL’S PROGRAMME

1.8.1. PTC Trust Fund

1.8.1.1. The WMO representative presented to the Panel the final statement for 2016 of the PTC Trust Fund. The Panel endorsed the statements. A detailed financial report of the Trust Fund as of 31 December 2023 as submitted by WMO to the Panel is given below**.**

Final Statement of Panel’s Trust Fund

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale
Organización Meteorológica Mundial
Всемирная метеорологическая организация
المنظمة العالمية للأرصاد الجوية
世界气象组织

Secretariat
7 bis, avenue de la Paix – Case postale 2300
CH 1211 Genève 2 – Suisse
Tel: +41 (0) 22 730 81 11
Fax: +41 (0) 22 730 81 81
wmo@wmo.int – public.wmo.int

PANEL ON TROPICAL CYCLONE TRUST FUND
Trust Fund 421313
Final Statement of Income and Expenditure
For the period 1 January to 31 December 2023
Amounts in US dollars

1.	Balance of fund at 1 January 2023				193,281
2.	Income:				
	2.1 Contributions				
	2.1.1 Myanmar (30 May 2023)		3,133		
	2.1.2 Thailand (9 June 2023)		3,000		
	2.1.3 India (16 June 2023)		2,924		
	2.1.4 Pakistan (5 July 2023)		3,000		
	2.1.5 Maldives (9 November 2023)		3,000		
	2.1.6 Sri Lanka (13 December 2023)		3,000		
	2.1.7 Total contributions			18,057	
	2.2 Interest			2,655	
	2.3 Unrealized Gain on currency exchange	a/		17,136	
	2.4 Total income				**37,848**
3.	Total available funds during reporting period				**231,129**
4.	Expenditure:				
	4.1 Direct project costs			-	
	4.2 Indirect project costs				
	4.2.1 Bank charges		80		
	4.2.2 Total indirect project costs			80	
	4.3 Total project expenditure				80
5.	**Balance of fund at 31 December 2023**				**231,049**

a/ WMO’s official currency is the Swiss Franc (CHF). Accordingly, all transactions completed in currencies other than the CHF are converted to Swiss Francs at the United Nations Operational Rate of Exchange (UNOR) in force on the day of the transaction. Project account balances (in CHF) are revaluated to applicable donor reporting currencies based on UNORs in force at the end of the month to facilitate reporting to donors. As the Swiss Franc has been appreciating against the US Dollar (the reporting currency for the Panel on Tropical Cyclone Trust Fund), foreign exchange gains resulted from conversion of net asset balances from CHF to USD as of the reporting date. This explains the foreign exchange gain. It should be noted that the gain was not realized as of the reporting date, i.e. they were not actual, as they resulted from (a) revaluing the Fund’s assets and liabilities as of that date, and (b) converting the resulting CHF balances to USD.

The financial statement has been prepared on the accrual basis of accounting in accordance with the International Public Sector Accounting Standards (IPSAS)

Certified Correct:

Brian Cover

Digitally signed by Brian Cover
DN: cn=Brian Cover, o=WMO, ou=Finance Division, email=bcover@wmo.int, c=CH
Date: 2024.12.02 10:15:32 +01'00'

Brian Cover
Controller
2 December 2024

Certified Correct:

A. Fontan

Anne-Claire Fontan
Scientific Officer
2 December 2024

1. Final Statements of Incomes and Expenditure for the Period 1 January to 31 December 2023
2. Contribution from Members from 1 January to today (22 December 2023).
3. External auditors’ auditing certificate/ report is available to PTC Members, on request
4. Meeting all requirements in following WMO Financial Regulations and the Rules of PTC Trust Funds.

“In our opinion, the accompanying financial statements present fairly, in all material respects, the financial position of the Panel on Tropical Cyclone (PTC) as at 31 December 2023, and its financial performance, its changes in net asset/equity, its cash flows and its comparison of budget and actual amounts for the year then ended, in accordance with International Public Sector Accounting Standards (IPSAS) and the WMO Financial Regulations and Rules”

CHAPTER - II

CYCLONIC ACTIVITIES OVER NORTH INDIAN OCEAN DURING 2024

The salient features of the cyclonic disturbances (CDs) over the north Indian Ocean (NIO) during the year 2024, the operational forecast performance of India Meteorological Department (IMD) and new initiatives during the year are presented below:

2.1.Salient features of CDs over the NIO

Following CDs developed over the NIO during 2024:

1. Severe Cyclonic Storm Remal over Bay of Bengal (24-28 May, 2024)
2. Depression over Bay of Bengal (19-20 July, 2024)
3. Deep Depression over North Jharkhand & neighbourhood (02-06 August, 2024)
4. Cyclonic Storm Asna over Arabian Sea (25 August-02 September, 2024)
5. Depression over Westcentral Bay of Bengal (31 August-02 September, 2024)
6. Deep Depression over Westcentral and adjoining Northwest Bay of Bengal (08-10 September, 2024)
7. Depression over Northeast Madhya Pradesh (11-13 September, 2024)
8. Deep Depression over Northeast Bay of Bengal and adjoining Bangladesh (13-17 September, 2024)
9. Depression over central Arabian Sea (13-15 October, 2024)
10. Depression over southwest Bay of Bengal during (15-16 October, 2024)
11. Severe Cyclonic Storm Dana over Eastcentral Bay of Bengal (22-26 October, 2024)
12. Cyclonic Storm Fengal over Southwest Bay of Bengal (25 November – 01 December, 2024)
13. Depression over westcentral Bay of Bengal (20-21 December, 2024).

Observed tracks of the CDs during 2024 are presented in **Fig. 2.1.**

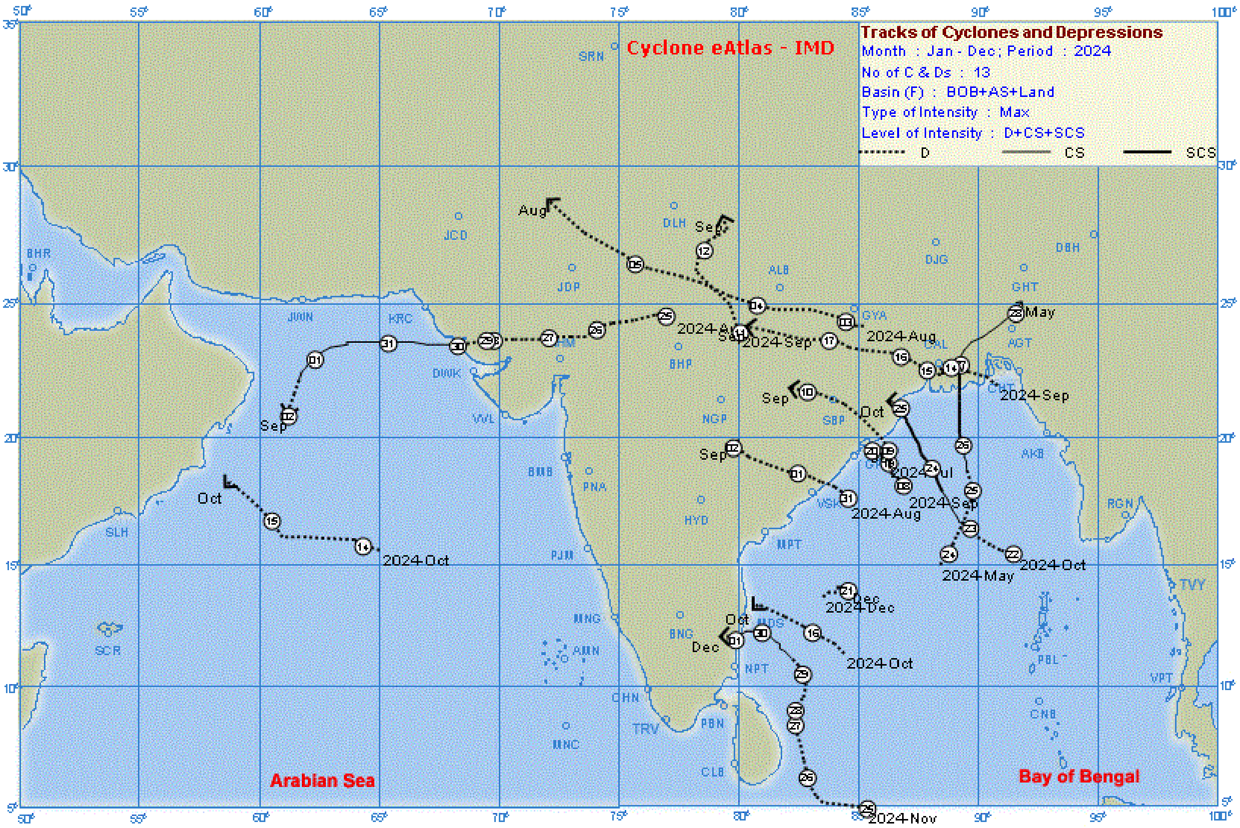

Fig 2.1: Observed Tracks of all cyclonic disturbances during 2024.

- Annual Frequency of CDs: During 2024, 13 cyclonic disturbances (CDs) (maximum sustained wind speed (MSW) ≥ 17 knots) developed over the North Indian Ocean (NIO) against the normal of 11.2 per year during 1965-2023. Thus, annual activity of formation of CDs was above normal.
- Frequency of different categories of CDs: There were 6 depressions and 3 deep depressions (MSW: 17-33 knots) (Normal: 6.5 per year) (Above Normal), 2 cyclonic storms (MSW: 34-47 knots) (Normal: 1.8 per year) (Above Normal), 2 severe cyclonic storms (MSW: 48-63 knots) and 0 Extremely Severe Cyclonic Storms (Normal: 2.9 per year) (Less than Normal).
- Frequency of CDs over Bay of Bengal and Arabian Sea: There were 2 CDs over Arabian Sea (Normal: 2.3 per year) (Less than Normal), 9 over Bay of Bengal (Normal: 7.8 per year) (Above Normal).
- Frequency of cyclones over Bay of Bengal (BoB) and Arabian Sea (AS): There was 1 CD over Arabian Sea (Normal: 2.3 per year) (Below Normal), 3 over Bay of Bengal (Normal: 7.8 per year) (Below Normal). Overall activity was below normal over Bay of Bengal and Arabian Sea.
- Frequency of CDs in different seasons: There was no CD during Winter Season (Normal: 0.2 per year), 1 CD during pre-monsoon season (Normal: 1.4 per year), 7 CDs during monsoon season (Normal: 4.9 per year) which was above normal, 5 CDs during post-monsoon season (Normal: 4.8 per year). Overall activity was above normal during monsoon season. Also, the total number of Low-pressure systems (Low Pressure Area + CDs) was 16 against the normal of 13.5 during monsoon season. It led to above normal rainfall over India (10% of long period average) during the season.
- Landfall: Out of the 4 cyclones, 3 (Remal, Dana and Fengal) crossed the coast as cyclones (Normal: 3.2 per year) and Asna emerged into northeast Arabian Sea from land, then intensified into a cyclone and weakened over Sea.
- Tracks (Straight/recurving): All 4 cyclones had recurving tracks.

Statistics of bulletins issued during 2024:

- Daily Tropical Weather Outlook for 13 WMO/ESCAP Panel Member Countries: 296
- National Bulletin for national disaster managers, media and general public: 255
- RSMC Bulletin including daily Tropical Weather Outlook for WMO, ESCAP, 13 PTC member countries: 551
- Tropical Cyclone Advisory Centre Bulletin for International Civil Aviation (TCAC Bulletin): 56
- Bulletin under Global Maritime Distress and Safety System: 602
- Fleet Forecast for Indian Navy: 602
- Fishermen Warning for entire North Indian Ocean: 410
- Press Release: 93

Table 2.1.1 Some Characteristic features of cyclonic disturbances formed over north Indian Ocean and adjoining region during 2024

S N.	Cyclonic storm/ Depression	Date, Time& Place of genesis (Lat.°N/Long °E)	Date, Time (UTC) Place (Lat./Long.) of Landfall	Estimated lowest central pressure, Time & Date (UTC) &(Lat°N/Long° E)	Estimated Maximum wind speed (kt), Date & Time	Max T. No. Attained
1.	Severe Cyclonic Storm REMAL over westcentral& adjoining south Bay of Bengal (24-28 May, 2024)	0000 UTC of 24th May, 2024 over westcentral& adjoining south Bay of Bengal (15.0/88.4)	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/1700 UTC of 26 th and 0030 hours IST/1900 UTC of 27th May 2024.	978hpa at 1200 UTC of 26th May, 2024. (21.1/89.2)	60kt at 1200 UTC of 26th May, 2024. (21.1/89.2)	3.5
2.	Depression over Bay of Bengal (19-20 July, 2024)	0300 UTC of 19th July, 2024 over Bay of Bengal (19.2/86.2)	Weakened into a Well-Marked Low-Pressure Area over Coastal Odisha.	990hpa at 1200 UC of 19th July, 2024 (19.4/85.7)	25 kts at 0300 UTC of 19th July, 2024 (19.2/86.2)	1.5
3.	Deep Depression over North Jharkhand &neighbourhood(02-06 August, 2024)	1200 UTC of 02nd August, 2024 over North Jharkhand (24.2/85.2)	Weakened into a Well-Marked Low-Pressure area over central parts of Pakistan and adjoining northwest Rajasthan.	988 hpa at 1200 UTC of 3rd August, 2024 (24.8/83.0)	30 kts at 0300 UTC of 3rd August, 2024 (24.4/84.4)	-
4.	Cyclonic Storm Asna over Arabian Sea (25 August-02 September, 2024)	0000 UTC of 25th August, 2024 over Northwest MP (24.5/77.3)	Weakened into a well-marked low-pressure area over Northwest Arabian Sea.	990 hpa at 0000 UTC of 31st August, 2024 (23.6/65.8)	40 kts at 0000 UTC of 31st August, 2024 (23.6/65.8)	2.5

5.	Depression over Westcentral Bay of Bengal (31 August-02 September, 2024)	0000 UTC of 31st August, 2024 over Westcentral Bay of Bengal (17.5/84.6)	Weakened into a well-marked low-pressure area over central parts of Vidarbha and neighbourhood.	996 hpa at 1200 UC of 31st August, 2024 (18.1/84.0)	25 kts at 0000 UTC of 31st August, 2024 (17.5/84.6)	1.5
6.	Deep Depression over Westcentral and adjoining Northwest Bay of Bengal (08-10 September, 2024)	0000 UTC of 08th Sept, 2024 over Westcentral and adjoining Northwest Bay of Bengal (17.9/87.0)	Crossed Odisha coast close to Puri between 0500 to 0600 UTC of 9th September (1030 to 1130 hrs IST of 9th September) as a deep depression with wind speed of 55-65 gusting to 75 kmph	991 hpa at 0000 UTC of 09th Sept, 2024 (19.3/86.2)	30 kts at 1800 UTC of 08th Sept, 2024 (18.9/86.3)	1.5
7.	Depression over Northeast Madhya Pradesh (11-13 Sept, 2024)	0300 UTC of 11th Sept, 2024 over Northeast MP (24.0/80.0)	Weakened into a well-marked low-pressure area over northwest Uttar Pradesh & neighborhood.	993 hpa at 0000 UTC of 12th Sept, 2024 (26.7/78.3)	20 kts at 0300 UTC of 11th Sept, 2024. (24.0/80.0)	-
8.	Deep Depression over Northeast Bay of Bengal and adjoining Bangladesh (13-17 September, 2024)	1200 UTC of 13th September, 2024 over Northeast Bay of Bengal and adjoining Bangladesh (22.0/90.8)	Crossed Bangladesh coast close to Patuakhali (Bangladesh) between 1700 to 1800 UTC of 13th September (2230 to 2330 hrs IST of 13th September) as a depression with wind speed of 45-55 gusting to 65 kmph	989 hpa at 1200 UTc of 14th Sept, 2024 (22.4/88.5)	30 kts at 0000 UTC of 14th Sept, 2024 (22.8/89.2)	1.5
9.	Depression over central Arabian Sea (13-15 October, 2024)	1200 UTC of 13th Sept, 2024 over central Arabian Sea. (15.6/65.0)	Crossed North Oman coast close to Duqm (41291, Oman) between 1700 to 1800 UTC of 15th October (2230 to 2330 hrs IST of 15th October) as a depression with wind speed of 40-50 gusting to 60 kmph	1004 hpa at 1200 UTC of 13th Sept, 2024 (15.6/65.0)	30 kts at 1200 UTC of 13th Sept, 2024 (15.6/65.0)	1.5

10	Depression over southwest Bay of Bengal during (15-16 October, 2024)	1200 UTC of 15thOctober, 2024 over southwest Bay of Bengal (11.4/84.4)	Crossed north Tamil Nadu – south Andhra Pradesh coast between Puducherry & Nellore, close to north of Chennai around 2300 UTC of 16th October	1002 hpa at 1200 UTC on 15th October, 2024. (11.4/84.4)	25 knots at 1200 UTC on 15th October, 2024. (11.4/84.4)	T 1.5
11	Severe Cyclonic Storm "DANA" over Eastcentral Bay of Bengal (22-26 October, 2024)	0000 UTC of 22ndOctober , 2024 over eastcentralBay of Bengal (15.4/91.6)	Crossed North Odisha coast close to Habalikhati Nature Camp (Bhitarkanika) &Dhamara between 2000 to 2200 UTC of 24th October as a Severe Cyclonic Storm	986 hpa at 0900 UTC on 24th October, 2024. (19.4/87.6)	60 knots at 0900 UTC on 24th October, 2024. (19.4/87.6)	T 3.5
12	Cyclonic Storm "Fengal" over Southwest Bay of Bengal (25 Nov – 01 December, 2024)	0300 UTC of 25th November, 2024 over southwest Bay of Bengal (5.0/85.3)	Crossed North Tamil Nadu and Puducherry coast near lat. 12.05N and long 79.9E close to Puducherry between 1700-1800 UTC of 30th November 2024.	992 hpa at 0900 UTC on 30th November, 2024. (12.3/80.5)	45 knots at 0000 UTC on 30th November, 2024. (12.2/81.2)	T 3.0
13	Depression over westcentral Bay of Bengal (20-21 December, 2024)	1200 UTC of 20thDecember, 2024 Over westcentralBay of Bengal (13.7/83.5)	Weakened into a well-marked low-pressure area over westcentral Bay of Bengal.	1002 hpa at 1200 UTC on 20th December, 2024 (13.7/83.5)	25 knots at 1200 UTC on 20th December, 2024 (13.7/83.5)	T 1.5

Table 2.1.2 Statistical data relating to cyclonic disturbances over the north Indian Ocean during 2024

A) Monthly frequencies of cyclonic disturbances(C I .≥1.5)

S.No	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	D							↔	↔	↔ LD	↔ ↔		↔
2.	DD								LD ↔	↔ ↔			
3.	CS								↔			↔	
4.	SCS					↔					↔		
5.	VSCS												
6.	ESCS												
7	SuCS												

↔ Peak intensity of the system, LD: Land Depression

B) Life time of cyclonic disturbances during 2024 at different stages of intensity

For NIO Region

S.No.	Type	Life Time in (Days)
1	D	18 days12 hours
2.	DD	15 days 18hours
3.	CS	6 days 6 hours
4.	SCS	2 days 9 hours
	Total Life Time in(Days)	42 days 21 hours

For Bay of Bengal Region

S.No.	Type	Life Time in (Days)
1	D	11 days 15 hours
2.	DD	8 days 21 hours
3.	CS	4 days 0 hours
4.	SCS	2 days 9 hours
	Total Life Time in(Days)	26 days 21 hours

For Arabian Sea Region

S.No.	Type	Life Time in (Days)
1	D	3 days6 hours
2.	DD	5 days 0 hours
3.	CS	2 days 6 hours
	Total Life Time in (Days)	10 days 12 hours

For Land Region

S.No.	Type	Life Time in (Days)
1	D	3 days 15 hours
2	DD	1 days 21 hours
	Total Life Time in(Days)	5 days 12 hours

C) Frequency distribution of cyclonic distribution with different intensities based on satellite assessment

CI No (≥)	**≥1.5**	**.≥2.0**	**.≥2.5**	**.≥3.0**	**.≥3.5**	**.≥4.0**	**.≥4.5**	**.≥5.0**	**≥5.5**	**≥6.0**
No of Disturbances	11	4	4	3	2	0	0	0	0	0

D) Basin-wise distribution of cyclonic distribution

Basin	**Number of cyclonic disturbances**
Bay of Bengal	2
Arabian Sea	9
Land depression	2

Table 2.1.3 Cyclonic disturbances formed over the north Indian Ocean and land areas of India during 1997-2024

Year	**Basin**	**D**	**DD**	**CS**	**SCS**	**VSCS**	**ESCS**	**SuCS**	**Total**
1997	BOB	1	4	1	1	1	0	0	8
	ARB	1	0	0	0	0	0	0	1
	Land	0	0	0	0	0	0	0	0
	Total					**9**			
1998	BOB	0	3	0	1	2	0	0	6

	ARB	0	1	1	1	1	0	0	4
	Land	1	0	0	0	0	0	0	1
	Total					**11**			
1999	BOB	2	2	1	0	1	0	1	7
	ARB	0	0	0	0	1	0	0	1
	Land	1	0	0	0	0	0	0	1
	Total					**9**			
2000	BOB	1	1	2	--	2	0	0	6
	ARB	0	0	0	0	0	0	0	0
	Land	1	0	0	0	0	0	0	1
	Total					**7**			
2001	BOB	2	0	1	0	0	0	0	3
	ARB	0	0	2	0	1	0	0	3
	Land	0	0	0	0	0	0	0	0
	Total					**6**			
2002	BOB	1	1	2	1	0	0	0	5
	ARB	0	0	0	0	0	0	0	1
	Land	0	0	0	0	0	0	0	0
	Total					**6**			
2003	BOB	2	2	0	1	1	0	0	6
	ARB	0	0	0	1	0	0	0	1
	Land	0	0	0	0	0	0	0	0
	Total					**7**			
2004	BOB	2	0	0	0	1	0	0	3
	ARB	0	2	0	3	0	0	0	5
	Land	2	0	0	0	0	0	0	2
	Total					**10**			
2005	BOB	2	3	4	0	0	0	0	9
	ARB	2	0	0	0	0	0	0	2
	Land	1	0	0	0	0	0	0	1
	Total					**12**			
2006	BOB	5	2	1	0	1	0	0	9
	ARB	0	1	0	1	0	0	0	2
	Land	1	0	0	0	0	0	0	1
	Total					**12**			
2007	BOB	3	4	1	0	1	0	0	9
	ARB	0	1	1	0	0	0	1	3
	Land	0	0	0	0	0	0	0	0
	Total					**12**			
2008	BOB	1	2	3	0	1	0	0	7
	ARB	1	1	0	0	0	0	0	2
	Land	1	0	0	0	0	0	0	1
	Total					**10**			
2009	BOB	0	2	2	1	0	0	0	5
	ARB	2	0	1	0	0	0	0	3
	Land	0	0	0	0	0	0	0	0
	Total					**8**			

2010	BOB	2	1	0	2	1	0	0	6
	ARB	0	0-	1	0	1	0	0	2
	Land	0	0	0	0	0	0	0	0
	Total					**8**			
2011	BOB	2	2	0	0	1	0	0	5
	ARB	1	2	1		0	0	0	4
	Land	1	0	0	0	0	0	0	1
	Total					**10**			
2012	BOB	0	2	1	0	0	0	0	3
	ARB	0	1	1	0	0	0	0	2
	LAND	0	0	0	0	0	0	0	0
	Total					**5**			
2013	BOB	3	0	1	1	3	0	0	8
	ARB	0	1	0	0	0	0	0	1
	Land	1	0	0	0	0	0	0	1
	Total					**10**			
2014	BOB	2	2	0	0	1	0	0	5
	ARB	0	0	1	0	1	0	0	2
	Land	1	0	0	0	0	0	0	1
	Total					0			
2015	BOB	1	1	1	0	0	0	0	3
	ARB		2	1	0	0	2	0	5
	Land	2	2		0	0	0	0	4
	Total					**12**			
2016	BOB	1	2	3	0	1	0	0	7
	ARB	2	0	0	0	0	0	0	2
	Land	1	0	0	0	0	0	0	1
	Total					**10**			
2017	BOB	4	1	1	1	1	0	0	**8**
	ARB	0	0	0	0	0	0	0	**0**
	Land	2	0	0	0	0	0	0	**2**
	Total					**10**			
2018	BOB	3	2	1	2	1	0	0	**9**
	ARB	1	0	0	0	1	2	0	**4**
	Land	1	0	0	0	0	0	0	**1**
	Total					**14**			
2019	BOB	0	1	1	0	1	1	0	**4**
	ARB	2	1	1	0	2	1	1	**8**
	Land	0	0	0	0	0	0	0	**0**
	Total					**12**			
2020	BOB	1	1	1	0	1	0	1	**5**
	ARB	2	0	0	1	1	0	0	**4**
	Land	0	0	0	0	0	0	0	**0**
	Total					**9**			
2021	BOB	3	1	2	0	1	0	0	**7**
	ARB	1	0	0	1	0	1	0	**3**

	Land	0	0	0	0	0	0	0	**0**
	Total					**10**			
2022	BOB	4	3	1	2	0	0	0	**10**
	ARB	2	1	0	0	0	0	0	**3**
	Land	2	0	0	0	0	0	0	**2**
	Total					**15**			
2023	BOB	1	1	1	1	1	1	0	**6**
	ARB	1	0	0	0	0	2	0	**3**
	Land	0	0	0	0	0	0	0	**0**
	Total					**9**			
2024	BOB	4	2	1	2	0	0	0	**9**
	ARB	1	0	1	0	0	0	0	**2**
	Land	1	1	0	0	0	0	0	**2**
	Total					**13**			

Table 2.1.4 Average translational speed of Tropical cyclones over the NIO during 2024

TC Name	Basin	Period	Average Translational Speed (kmph)		
			6 Hr	**12 Hr**	**24 Hr**
REMAL	BoB	24-28 May, 2024	12.2	18.3	11.8
ASNA	AS	25 August-02 September, 2024	9.3	9.3	9.2
DANA	BoB	22-26 October, 2024	10.8	11.5	11.5
FENGAL	BoB	25 November – 01 December, 2024	7.7	7.6	7.6

Table 2.1.5 Velocity Flux of Tropical cyclones over the NIO during 2024

TC Name	Velocity Flux (10^2 kt)	Accumulated Cyclone Energy (10^4 kt^2)	Power Dissipation Index (10^6 kt^3)
REMAL	4.1	1.95	0.97
ASNA	5.1	1.78	0.63
DANA	4.8	2.36	1.21
FENGAL	2.8	1.09	0.44

2.2.Severe Cyclonic Storm "REMAL" over the Bay of Bengal during 24th- 28th May, 2024

2.2.1 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 BoB.
- 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 (1700 UTC) of 26th May and 0030 hrs IST of 27th May 2024 (1900 UTC of 26th May) as an SCS with wind speed of 110 to 120 kmph gusting to 135 kmph.
- Continuing to move northwards after landfall, 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. 2.2**

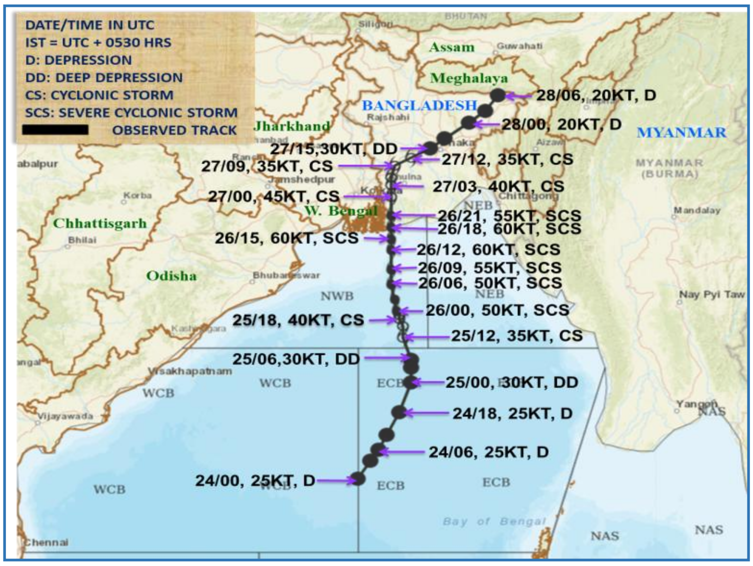

Fig. 2.2: Observed track of severe cyclonic storm 'REMAL" over Bay of Bengal during 15th – 18th November, 2024.

2.3. Cyclonic Storm "ASNA" over the Arabian Sea during 25th August-2nd September, 2024

2.3.1 Life History of "ASNA":

- A **Low-pressure area** formed over northwest Bay of Bengal (BoB) and adjoining areas of West Bengal and Bangladesh in the morning (0530 hrs IST/0000 UTC) of 16th August 2024. It lay over South Bangladesh during 17th to 19th August, over Central Bangladesh on 20th and over North Bangladesh on 21st and 22nd August. Thereafter it moved westwards and lay over West Bengal & adjoining Northeast Jharkhand on 23rd August.
- While moving westwards, it concentrated into a well-marked low-pressure area over Southeast Uttar Pradesh (UP) & adjoining areas of northeast Madhya Pradesh (MP) in the morning of 24th August.
- Continuing to move further westwards, it intensified into a **Depression** over Northwest MP in the morning (0530 hours IST/0000 UTC) of 25th August.
- It then moved west-south-westwards and intensified into a **Deep Depression** over East Rajasthan & adjoining West MP in the same midnight (2330 hours IST/1800 UTC) of 25th August. The deep depression continued to move west-south-westwards and lay centred over North Gujarat region by evening (1730 hours IST/1200 UTC) of 26th August.
- It then moved westwards across Gujarat state during 27th -29th August. It emerged into the Northeast Arabian Sea off Kachchh and the adjoining Pakistan coast on 30th August morning (0830 hrs IST/0300 UTC).
- It intensified into a **cyclonic storm (CS) "ASNA"** over northeast Arabian Sea off Kachchh and adjoining Pakistan coast around noon (1130 hours IST/0600 UTC) of 30th August. It then moved nearly westwards, intensified slightly and lay cantered over Northeast Arabian Sea in the morning (0530 hours IST/0000 UTC) of 31st August.

- It then gradually moved south-south-westwards and weakened into a **Deep Depression** in the evening (1730 hours IST/1200 UTC) of the 1st September, 2024 over northwest Arabian Sea.
- Continuing to move further south-south-westwards, it weakened into a **Depression** in the morning (0530 hours IST/0000 UTC) of the 2nd September, 2024 over the northwest Arabian Sea and into a **well-marked low-pressure area** over the same region in the afternoon (1130 hours IST/0600 UTC) of 2nd September, 2024.
- It further weakened into a **low-pressure area** over westcentral & adjoining northwest Arabian Sea in the morning (0830 hours IST/0300 UTC) of 3rd September, 2024.
- The observed track of the cyclonic storm "ASNA" since its inception from a low-pressure area over Northwest Bay of Bengal on 16th August is presented in Fig. 2.3.1a and from the stage of depression on 25th August to weakening into a depression on 2nd September is presented in Fig. 2.3.1b and table 2.3.1.

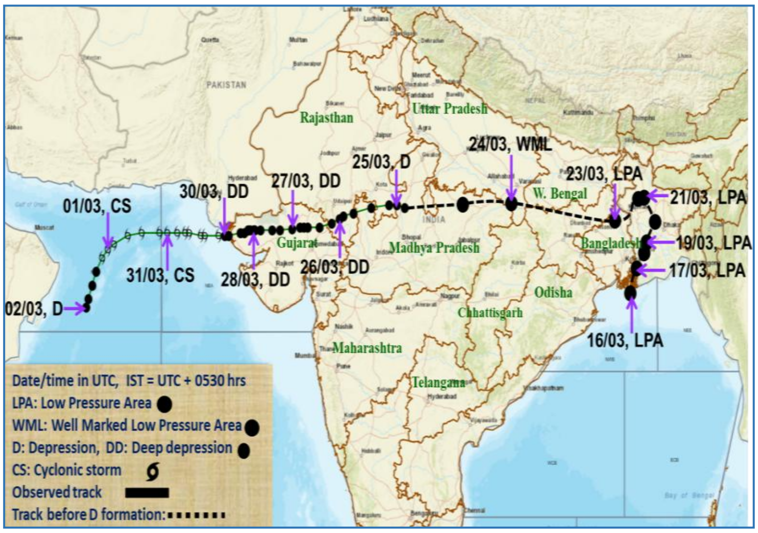

Fig. 2.3.1a: Track of Cyclonic Storm "ASNA" during 16th August-02nd September from the stage of low-pressure area

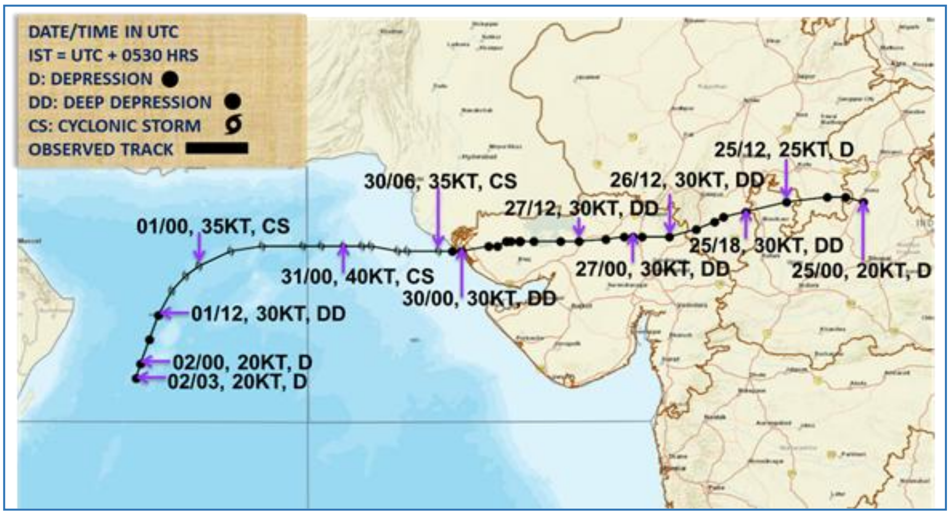

Fig. 2.3.1b: Observed track of cyclonic storm "ASNA" over the land/Arabian Sea during 25th August– 2nd September, 2024

2.4 Severe Cyclonic Storm "DANA" over the Bay of Bengal (22nd – 26th October, 2024)

Life History of "DANA":

- A cyclonic circulation was seen over central Andaman Sea in the early morning (0530 hours IST/0000 UTC) of 19th October and it lay over North Andaman Sea in the early morning (0530 hours IST/0000 UTC) of 20th October 2024.
- Under its influence, a Low-Pressure Area formed over the Eastcentral Bay of Bengal (BoB) and adjoining north Andaman Sea in the evening (1730 hours IST/ 1200 UTC) of 20th October.
- Moving west-northwestwards, it concentrated into a well-marked low-pressure area over Eastcentral BoB in the noon (1130 hours IST) of 21st October.
- Continuing to move west-northwestwards, it intensified into a Depression over Eastcentral BoB in the early morning (0530 hours IST/0000 UTC) of 22nd October. It then moved northwestwards and intensified into a deep depression over Eastcentral BoB in the same evening (1730 hours IST/ 1200 UTC).
- Continuing to move further northwestwards, it intensified into a cyclonic storm (CS) "DANA" over eastcentral BoB in the early morning (0530 hours IST/ 0000 UTC) of 23rd October.
- It then moved north-northwestwards and intensified into a severe cyclonic storm (SCS) over central & adjoining northwest BoB in the mid-night (2330 hours IST/1800 UTC) of 23rd October, 2024.
- Continuing to move north-northwestwards, it crossed north Odisha coast close to Habalikhati Nature Camp (Bhitarkanika) and Dhamara during 0130 hrs IST to 0330 hrs IST of 25th October (2000 to 2200 UTC of 24th October) as a severe cyclonic storm with a wind speed of 100-110 kmph gusting to 120 kmph.
- The landfall process commenced in the midnight (2330 hours IST/1800 UTC) of 24th October and continued for 9 hours till 0830 hours IST/ 0300 UTC of 25th October.
- Continuing to move further north-northwestwards slowly, it weakened into a CS over north coastal Odisha in the forenoon (0830 hours IST/0300 UTC) of 25th October, into a deep depression in the afternoon (1430 hours IST/0900 UTC). Thereafter, it gradually moved westwards, weakened into a depression over interior Odisha in the midnight (2330 hours IST/1800 UTC) of 25th October and into a well-marked low-pressure area over North Odisha in the early morning (0530 hours IST/ 0000 UTC) of 26th October.
- The observed track of the severe cyclonic storm "DANA" is presented in **Fig. 2.4.1**.

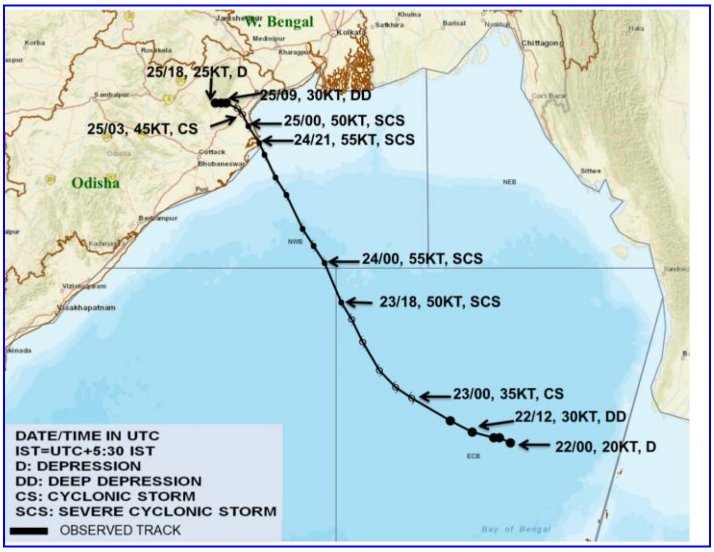

Fig. 2.4.1: Observed track of severe cyclonic storm "DANA" over eastcentral Bay of Bengal during 22-26 October, 2024

2.5 Cyclonic Storm "FENGAL" over the BoB (23rd November- 02th December, 2024):

- A low-pressure area formed over East Equatorial Indian Ocean (EEIO) and adjoining Southeast BoB (BoB) in the morning (0830 hours IST/0300 UTC) of 23rd November.
- Moving west-northwestwards, it became a well-marked low pressure area in the morning (0830 hours IST/0300 UTC), of 24th November over southeast BoB and adjoining EEIO.
- It moved west-northwestwards, intensified into a depression in the morning (0830 hours IST/0300 UTC) of 25th November over central parts of south BoB and adjoining EEIO.
- Moving west-northwestwards, it intensified into a Deep Depression in the morning (0830 hours IST /0300 UTC), of 26th November over southwest BoB.
- Continuing to move west-northwestwards, it intensified into a cyclonic storm "FENGAL" [pronounced as FEINJAL] over southwest BoB in the afternoon (1430 hours IST/ 0900 UTC) of 29th November.
- It then moved initially westwards & then west-southwestwards and crossed North Tamil Nadu & Puducherry coasts close to Puducherry between 2230 hours IST/ 1700 UTC and 2330 hours IST/1800 UTC of 30th November as a cyclonic storm with wind speed of 70-80 kmph gusting to 90 kmph.
- Thereafter, it remained practically stationary for almost 12 hours and weakened into a deep depression in the forenoon (1130 hours IST/ 0600 UTC) of 1st December over north coastal Tamil Nadu.
- Continuing to move further west-northwestwards, it weakened into a depression over the same region in the evening (1730 hours IST/ 1200 UTC) of 1st December.
- Thereafter, it moved nearly westwards and weakened into a Well-Marked Low-Pressure Area over North Interior Tamil Nadu in the early morning (0530 hours IST/ 0000 UTC) of 2nd December. The observed track of the system is presented in Fig.2.5.1.

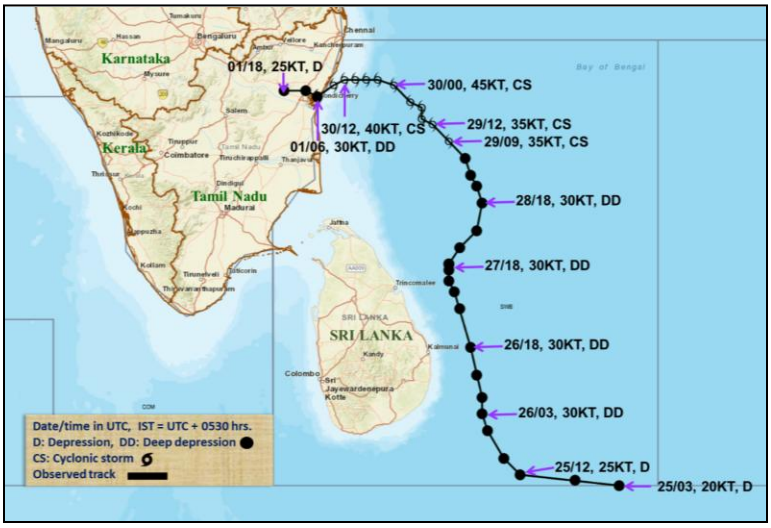

Fig. 2.5.1: Observed track of severe cyclonic storm "FENGAL" over Southwest BoB during 24th November- 02th December, 2024

CHAPTER-III
COORDINATED TECHNICAL PLAN (CTP): 2024-2027

3.1. INTRODUCTION AND BACKGROUND

Hydro-meteorological disasters account for approximately 70-80% of disaster losses in the world. Among them, tropical cyclone-associated disasters remain serious threats to people in both developed and developing countries in the tropical cyclone-prone regions. This is true for the North Indian Ocean region, where the devastating disasters repeated during the past decades proved that this region is extremely vulnerable to tropical cyclone risks.

WMO/ESCAP Panel on Tropical Cyclones for the Bay of Bengal and Arabian Sea has been exerting its effort to mitigate the impact of tropical cyclones in this region since its inauguration in 1973. The Panel's activities are a fundamental contribution to improving regional and national resilience against tropical cyclone threats.

Because of the growing demand for further mitigation of tropical cyclone disasters in this region as well as enhancement of the visibility of its activities, the CTP (2009-2011) was developed by the PTC Policy Working Group chaired by Dr. Qamar-uz-Zaman Chaudhry, Secretary of PTC and adopted by the PTC during its 36th Session (Muscat, Oman, 2-6 March, 2009).

The present CTP (2024-2027) is an updated version of previous Coordinate Technical Plans and has also taken into consideration the WMO Strategic Plan 2023-2027 and the Strategic Plan for the Enhancement of National Meteorological and Hydrological Services in Regional Association II (2023-2027).

3.1.1 Panel Region

Currently, the Panel is composed of 13 Members; Bangladesh, India, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, Thailand, Yemen, Iran, Saudi Arabia, United Arab Emirates and Qatar.

The Panel region covers a vast expanse of the North Indian Ocean and contains a large and diverse range of ecosystems, including deserts, forests, rivers, lakes and seas. The desert extends from Middle East into Pakistan and northwest India. Compared to other WMO tropical cyclone regions, this region includes the highest mountains, the rainiest areas and the driest deserts, with their associated variation in culture and biodiversity. Over the long period of human occupation in the region, exploitation of natural resources, urbanization, industrialization and economic development have led to land degradation and environmental pollution. Climate change and climate variations also represent present and future stress.

Tropical cyclone warning services of Members vary in duties, size and status of advancement, geography and state of development. Therefore, they are highly differentiated in capabilities and vulnerabilities. Some Members have very advanced facilities while others have limited budgets; shortage of observation instruments, spare parts, and consumables; lack of calibration, data collection, processing and communication facilities; insufficient qualified staff; and old technology.

3.1.2. Vision and mission of the Panel

3.1.2.1. Vision of the Panel

To promote and coordinate the planning and implementation of the multi-hazard early warning based Disaster Risk Reduction system to attain sustainable development measures through minimizing loss and damage caused by tropical cyclones and associated meteorological, hydrological and other ocean hazards in the Bay of Bengal and the Arabian Sea.

3.1.2.2. Mission of the Panel

a. *To review regularly the progress made in the various fields.*
b. *To recommend measures to improve the multi-hazard early warning systems in the Bay of Bengal and the Arabian Sea, including necessary training and*

research, with regard to meteorological, hydrological and other ocean hazards such as storm surges and tsunamis

c. *To recommend measures to improve information dissemination system to ensure timely provision of warnings for community preparedness and disaster risk management.*

d. *To advise on possible sources of financial and technical support for such measures.*

e. *To coordinate the activities among the Panel Members, including all other activities carried out as part of or in conjunction with the WMO and regional tropical cyclone programmes.*

f. *To encourage and carry out capacity building.*

3.1.3 Priorities of the Panel

The Panel agreed that the following are priority issues:

a. Maintenance of existing system and further development of land, Ocean and atmosphere observing and telecommunications systems and data processing facilities for better information sharing;

b. Natural disaster reduction, mitigation and prevention through the implementation of improved detection, prediction and warning systems of tropical cyclones, depressions and associated storm-surge, high waves, flash/urban floods, tsunamis etc.;

c. Implementation of CTP to provide better services to the public, governments and users, through improved infrastructure and modern technology in a user-friendly manner;

d. Enhancement of capacity building and technology transfer for early warning dissemination and response at the national and community levels to bridge the gap between the Members through bilateral and multilateral arrangements;

e. Enhancement of the collaboration and cooperation among the Members and RSMC New Delhi by exchange of information and knowledge and research studies related to tropical cyclones including numerical modeling and climate change impacts. Member countries to encourage and promote research on Multi hazards associated with tropical cyclones

f. Encouragement to improve hydrological forecasting and warning services for flood prone areas;

g. Encouragement to plan and manage water resources, including assessment of surface and ground water resources in relation to tropical cyclones;

h. Improvement of the operational linkages between hydrological and meteorological services and disaster management agencies with the aim of minimizing the impacts of natural disasters;

i. Facilitation of tropical cyclone disaster risk assessment at the country level, especially along the coast, delta, and urban areas where risks are the highest to reach sustainable development goals

j. Increase tropical cyclone risk awareness at the community level through awareness events, school education, training, and drills where technical knowledge could be properly supplied and adopted by authorities;

k. Strengthening information exchange with various disaster-related information systems in the region;

l. Strengthening partnerships with relevant international and regional bodies, such as UN-ISDR, UNDP, UNESCO/IOC, UNEP, ESCWA, ASEAN, SAARC, IFRC, ADRC,

ADPC, ICHARM, JICA, KOICA, TICA, USAID, ADB, ICAO, RIMES, BIMSTEC and WB;

m. Enhanced public & private partnerships including industries, non-governmental organizations (NGOs) etc. for awareness, feedback and information dissemination etc. aiming at disaster risk reduction (DRR);
n. Enhancement of resource mobilization activities for implementation of CTP.

3.1.4 Challenges and Opportunities

The panel is facing challenges and opportunities that have been raised in recent years in its implementation of the activities to fulfil its vision, such as rapid changes in technology, globalization, commercialization, urbanization, and emerging scientific research results. This section identifies in broad terms the challenges and opportunities of which the Panel Members could take advantage through a strategic regional approach.

3.1.4.1 Meteorology

3.1.4.1.1. Observation systems

Observation systems are fundamental to the operations of National Meteorological and Hydrological Services (NMHSs). Standardization of observation ensures that data collected by each country are compatible with other countries. This includes accuracy, instrument response times and other characteristics of instruments, frequency of observations, exposure, network densities and other related matters.

The existing gaps in the observational data coverage of the Panel region continue to be due to the deficiencies in the operations of both land, Ocean &atmosphere observing systems and telecommunication networks, high cost and therefore the lack of consumables and spare parts.

New types of earth-observing satellites including meteorological satellites which are useful for weather monitoring, forecasting, and research have been launched from time to time. However, no single receiving system is capable of receiving and processing the data from all these satellites. This poses difficulty to some Members who may not afford to have more than one satellite receiver. It would be useful if imageries and data from different satellites can be put under and distributed through one or two low-cost distribution channels.

3.1.4.1.2. Telecommunication

The WMO Information system (WIS) is the single coordinated global infrastructure responsible for the telecommunications and data management functions. It is the pillar of the WMO strategy for managing and moving weather, climate and water information in the 21st century. WIS provides an integrated approach suitable for all WMO Programmes to meet the requirements for routine collection and automated dissemination of observed data and products, as well as data discovery, access and retrieval services for all weather, climate, water and related data produced by centres and Member countries in the framework of any WMO Programme. WIS is an enhanced information system capable of exchanging large data volumes, such as new ground- and satellite-based systems, finer resolutions in numerical weather prediction and hydrological models and their applications.

The GTS part includes the national meteorological telecommunication networks (NMTNs) and the regional meteorological telecommunication networks (RMTNs), respectively. The NMTNs are implemented and operated by each country according to both the telecommunication services available and the financial and technical capacities of each country.

3.1.4.1.3. Data-processing and forecasting systems

While there had been considerable improvements in the infrastructure and models in some WMO Integrated Processing and Production System (WIPSS) centers of the

Region, there are still large deficiencies in the capabilities of some Members in their forecasting function, i.e., the production of forecasts and warnings. Some of the data processing systems of NMHSs have not been automated and the Members concerned were not able to derive full benefits from the technological advances that have taken place in the recent past. Some WIPSS centres in the Region still plot stations and produce weather charts manually.

As regards the generation and dissemination of the WIPSS products, the Regional Specialized Meteorological Centre (RSMC) New Delhi produces a large number of products on a daily basis. The availability on the Internet of high-quality products from advanced high-resolution NWP systems operated by major WIPSS centers within and outside the Region has opened up new opportunities for NMHSs to enhance their capability in providing weather forecast service to their respective users.

3.1.4.1.4. Hydrology and Water resources

Freshwater is a natural resource vital to the survival of all living things; however, it is limited. The sources of freshwater are river basins, groundwater reserves, lakes and manmade reservoirs. These are increasingly under pressure to meet increased domestic needs as well as demands from agriculture, industry and other human activities.

Weather is the most important factor in water availability as it determines the timing and the location of precipitation and the amount lost to evaporation. Some arid countries in the region like Oman, Yemen, Southern Pakistan and Northwest India have such low precipitation (as little as a few millimetres per year) and high evaporation, that only a small amount of freshwater can be captured for human use. By contrast, some countries receive abundant rainfall each year (thousands of millimeters). Seasonality is particularly pronounced throughout the region and, in most cases, plays a major role in water availability; those countries which receive high rainfall - Bangladesh and India for example - are inundated with rainfall during the monsoon season, but lack rainfall the rest of the year.

This seasonality problem can be tackled by preventing the precipitation during the wet season from running off into the sea. The traditional method of rain harvesting, that is, retaining water through construction of ponds/lakes etc in individual villages or towns could ensure the optimum use of precipitation. Many demonstration projects have established that with proper storage techniques, rainfall during a season could be utilized throughout the year for agriculture and other human activities. It is such mini projects, rather than big dams, that are most cost-effective in conserving freshwater resources.

The decline of hydrological networks in the region is a challenge at a time when more high-quality hydrological data are required, often in near real-time. Hydrological networks need to be improved together with the capacity of Hydrological Services to provide relevant information to a variety of users of hydrological data. In this respect, the need for improving forecasting systems particularly to predict floods and droughts that could lead to disasters is a high priority in the region. The management of international rivers in the region is a most challenging problem as well. In the context of integrated water resources management, the joint management of river basins opens a window of opportunity for transnational collaboration in hydrology.

The potential extension of several HYCOS projects into the region are expected to foster this process and contribute to the capacity building of National Hydrological Services as well as integrated water resources management on the basis of timely, reliable hydrological data. Especially for prediction and forecasting of extreme events, the data collection and forecasting capacities of the meteorological and hydrological branches of national Services need to be integrated to provide the results required by the general public.

Likewise, the introduction of rational water resources assessment methods, promoted by WMO and the United Nations Educational, Scientific and Cultural Organization (UNESCO), are expected to enhance the capacity of National Hydrological Services in the region to act as service providers for planning, decision-making and implementation of water resources projects. A crucial issue for much needed regional collaboration between national Hydrological Services is the free exchange of hydrological data and information which has been documented in Resolution 25 of the Thirteenth Congress of WMO.

3.1.4.2 Disaster Risk Reduction

The Panel region is one of the most disaster-prone regions in the world. It has a very high frequency of disaster events and suffers from immense damage due to various types of disaster such as tropical cyclones, storm surges, floods, landslides, drought, earthquakes, volcanic eruptions, tsunamis, etc.

A large percentage of these disasters has occurred in many countries of the Region. A rapid urbanization, high population increase rates, and high population densities without reducing the poverty levels led their societies to be with high vulnerability to disasters, resulting in heavy loss of life and property damage. The Disaster Risk Reduction component of the CTP will aim at reducing tropical cyclone disaster risks at the community level by enhancing the local and institutional capacities to cope with the risks.

3.1.4.2.1. Tropical cyclone related disaster risks

In the Bay of Bengal, tropical cyclones usually form over the southern end and then move either towards the east coast of India, Myanmar or to Bangladesh and a few of them emerge into the Arabian Sea after crossing the Indian Peninsula and Sri Lanka. A few tropical cyclones form in the Arabian Sea and move to the north affecting the western part of India, southern Pakistan, Yemen, Oman, Iran and indirectly UAE, Qatar and Saudi Arabia. These tropical cyclones can generate very heavy rainfall and cause severe flooding and landslides, high wind and waves, and are often accompanied by devastating storm surges which are the most common risk factor to the tropical cyclone deaths. Quantification of associated risks might help to plan appropriate DRR actions.

3.14.3. Regional technical coordination on tropical cyclones

Regional cooperation and coordination in disaster prevention and mitigation among the Members are gaining importance in the region. India Meteorological Department was designated by WMO a Regional Specialized Meteorological Centre (RSMC) to monitor and forecast the track and intensity of all tropical cyclones in this region, associated severe weather like high waves, storm surge and coastal inundation and heavy rainfall to provide the track and intensity information to the international community, and to provide real-time advisory information and guidance to NMSs in the region. Mechanism may be set up to foster tele conference (audio/video) for consultation among members and RSMC, New Delhi, though there has been video conferencing in recent years with individual countries by RSM and RSMC has constituted a WhatsApp group for exchange of information, data and views.

3.1.4.3.1. Inter Regional Co-operation on Tropical Cyclones (done)

There exist a synergised SOP between the RSMC, New Delhi and RSMC, Tokyo for monitoring and prediction of cyclonic disturbances migrating into each other's area of responsibility and naming nomenclature to be followed. Additionally, both agencies also support each other in capacity-building initiatives and the resource persons from both organizations participate in the training programs organized by the RSMCs.

3.1.4.3.2. Risk assessment and management

Accurate and timely tropical cyclone forecast and warnings issued by the NMHSs is crucial information to reduce risks. The challenge is that such information needs to be reached to the communities at risk for prompt action. This is quite a challenge, especially in rural areas in developing countries where the communication system is limited. Even if reached on time, false information or technical information lacking clear directions and guidance for a specific location may mislead response to the warning and hinder people's willingness to take action for the next events. It is vital to understand the perception of individual and collective behaviors when receiving the warning. Another important issue is whether people have a safe place when responding to the warning. Without such places, people would be ended up facing the risks. Whether they can move quickly to a safe place is an additional issue, particularly, for infants, small children, the elderly, and the handicapped.

Risk level needs to be evaluated based on the tropical cyclone forecast over a region utilizing the past climatology. The assessed risk level needs to be communicated to the disaster managers for suitable actions at their levels. Post-disaster risk assessment based on loss and damage survey is also essential to identify the gaps and improve the risk assessment for the future.

3.1.4.3.3. Linkages with International Framework Initiatives

Activities of the Panel on Tropical Cyclones may be linked appropriately with important initiatives such as the ESCAP/WMO Typhoon Committee, International Network for Multi-Hazard Early Warning Systems (IN-MHEWS) established at the Third United Nations Conference on Disaster Risk Reduction in March 2015, and the Climate Risk Early Warning System (CREWS), Early Warning for All, Impact Based Forecasting and risk-based warning initiatives of WMO and UN launched at the Conference of the Parties of the United Nations Framework for Climate Change in December 2015-2022. In this regard, WMO and ESCAP may extend institutional support the Panel on Tropical Cyclones.

3.1.4.4. Capacity Building

In considering the rapid changes in technology and the social, political and economic circumstances in addition to the global environmental issues, Members need to respond to these challenges in such a way as to enable them to properly manage their meteorological and hydrological services, and to have qualified and trained manpower and adequate facilities. Therefore, proper management, continuing training and development are important for the advancement of those services.

RSMC New Delhi, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and academic institutions to support the plans and requirements related to capacity building and transfer of technology in close cooperation with the Members.

Capacity building is to be underpinned by infrastructure and human resource development through training and technology transfer in the areas of:

- Forecasting of tropical cyclone intensity and track, and associated storm surge, inland flooding and coastal inundation
- Observing and processing data and interpretation of outputs from regional centres;
- Information and communication technology (ICT);
- Equipment maintenance;
- Provision of weather services for the public, including service-oriented media/communication skills;
- Provision of weather services for aviation and shipping, including marketing of services and liaison with clients;
- Provision of climate information services;
- Application of NWP products;

- Nowcasting of severe weather; and
- High level and middle management skills.
- Climate change impacts on tropical cyclones and associated phenomenon
- Maintenance of competency standards

- Training through fellowships, seminars and workshops with assistance from outside the region needs to be also intensified.

3.1.4.5 International and regional projects relevant to the Panel's activities

The following international/ regional projects with significant potential benefits to Members especially the developing ones are worth pursuing:

3.1.4.5.1. *Early Warning System for Tsunamis*

After the devastating tsunami which affected most of the countries of the Panel towards the end of December in 2004, there has been an urgent need to establish an Early Warning System for the Panel region. In this connection, WMO, along with other International Organizations, worked towards bringing the countries of the region to work together in identifying an ideal mechanism that will support an Early Warning System for the region. The Panel should take advantage of this situation and participate in all the forums that are called upon by WMO in this regard.

It is important that the Panel collaborates with the adjacent regions in establishing this project. It should then draw up a plan for implementation having all the Members participate.

3.1.4.5.2. Storm Surge Watch Scheme

In view of the fact that storm surges associated with the recent tropical cyclones Sidr and Nargis in the Bay of Bengal, which caused widespread flooding in the exposed coasts of Bangladesh and Myanmar, were the major cause of devastation and loss of lives in the most populous and low-lying areas of these countries, the WMO Executive Council, at its 60th session in 2008 (EC-LX), addressed the need for the provision of storm surge guidance information to the WMO Members exposed to these risks as a matter of priority.

The Council therefore agreed that a storm surge scheme attached to the tropical cyclone advisory arrangements would help to increase advisory lead-time and thus contribute to saving lives and properties, and would be the first step towards a comprehensive and integrated marine multi-hazard forecasting and warning system for improved coastal risk management. It appealed to all the regional tropical cyclone bodies to develop Storm Surge Watch Scheme (SSWS) that will make available to WMO Members concerned with the storm-surge advisories including daily marine processed data and information they require for real-time uses.

In the Panel region, efforts have to be continued under CTP for attachment training on country-specific advanced storm surge forecasting and inundation modeling.

***3.1.4.5.3* Hindu Kush-Himalayan Hydrological Cycle Observing System (HKH-HYCOS) Phase II project**

The Hindu Kush-Himalayan Hydrological Cycle Observing System (HKH-HYCOS) Phase II project, which was funded by the government of Finland, was successfully completed on December 31, 2015. The HKH-HYCOS Phase III project proposal has been prepared and is being circulated to potential donors.

***3.1.4.5.4*. Mekong-HCOS project**

The Mekong-HCOS project was successfully completed on 30 November 2012. The project was financially supported by the Agence Francaise de Developpement (AFD). AFD is further supporting additional efforts with the Mekong River Commission on extending the MRC-HYCOS network and improving its sustainability, as well as improving data usage based on statistical hydrological analyses

3.1.4.5.5. WMO's Severe Weather Forecasting Programme (SWFP)

The World Meteorological Organization's (WMO's) Severe Weather Forecasting Programme (SWFP) previously known as Severe Weather Forecasting Demonstration Project (SWFDP) is aimed to enable all National Meteorological and Hydrological Services (NMHSs) to issue effective severe weather warnings to disaster management and civil protection authorities in their respective countries. Using a 'Cascading Forecasting Process', the Programme makes global-scale products from Global Data Processing & Forecasting System (GDPFS) Centres available to Regional Centres. The Regional Centres in turn interpret model guidance and provide guidance products to National Meteorological and Hydrological Services (NMHSs). These NMHSs liaise with regional centres, disaster management agencies & media and issue advisories for general public. The primary objective of this programme is to enable the NMHSs to have greater capability to identify hazardous weather conditions in the short- and medium-range and issue forecasts and warnings accordingly. Capacity development through regular trainings on forecasting and service delivery aspects has also been a critical component of the subproject. Forecasters need to know how to make optimal use of the various numerical weather prediction (NWP) products and satellite information coming from the contributing centres. First ever SWFDP regional subproject was initiated in 2006 with involvement of just five countries in south-eastern Africa. The success story of this subproject provided basis for expansion of SWFDP into whole Southern Africa in 2009 with involvement of sixteen countries and later into other sub-regions of the world including Eastern Africa and South Pacific. Currently, SWFP involves over 85 developing countries, least developed countries (LDCs) and small island developing states (SIDS) in nine sub-regions of the world including Southern Africa, Eastern Africa, West Africa, Central Africa, Southeast Asia, South Asia, Central Asia, Eastern Caribbean and South Pacific, with contributions from the WMO Centers, Regional Centers and support from development partners and donors. There are three SWFP regional subprojects in WMO Regional Association (RA) II (Asia) region Viz., SWFP-Southeast Asia; SWFP-South Asia; and SWFP-Central Asia.

India Meteorological Department (IMD), New Delhi is acting as a Regional Specialised Meteorological centra (RSMC), leading WMO's SWFP-South Asia to predict the severe weather namely heavy rain, strong winds, high waves, cyclonic disturbances and storm surge. IMD issues forecast for 9 member countries including Bangladesh, Bhutan, India, Maldives, Myanmar, Nepal, Pakistan, Sri Lanka, and Thailand since May, 2016. The domain covered for monitoring, analyzing and predicting various severe weather events under RSMC New Delhi is bounded by 10°S to 45°N and 45°E to 110°E. In 2019, textual products were also added with inclusion of guidance in short & medium range, risk tables in short range and probability tables in medium range. 2023 marked the introduction of impact-based forecast and risk-based warnings in GIS and QGIS for heavy rainfall, strong winds, significant wave height, cyclonic disturbance and storm surge for 95 met-subdivisions in the region covering the land areas of member countries and the entire Bay of Bengal and Arabian Sea.

3.1.4.5.6. Flash Flood Guidance System with Global Coverage (FFGS)

In collaboration with NOAA-National Weather Service, the US Hydrologic Research Centre, WMO, and USAID/OFDA, this project is currently being implemented in the Mekong River Basin in collaboration with MRC. Other areas under development for the implementation of the project are South Asia, southern Africa and near/middle East. The reference project has been implemented over the past years in Central America. The success of the project there was the basis to expand it globally where feasible. The core of the project is to provide flash flood guidance (not forecasting!) to disaster managers based on real-time satellite-derived precipitation estimates merged with resolution GIS and hydraulic conditions of rivers that trigger an alert once "bankful" flow conditions are to be expected based on the precipitation estimate for a given time under prevailing ground and hydraulic conditions. The first Steering Committee meeting held in New Delhi recommended linking flash flood guidance provided by regional flash flood guidance centers for South Asia with SWFDP-BOB. The South Asian flash flood guidance system, New Delhi has been operational since 2020.

3.1.4.5.7. WMO Programme for the Least Developed Countries (LDCs)

This Programme was established by the Fourteenth Meteorological Congress in May 2003 to contribute efficiently and in a timely manner to the social and economic development efforts of LDCs through the enhancement of the capacities and capabilities of their NMHSs. A number of activities are being carried out in support of NMHSs of most of the 50 LDCs under the WMO Programme for LDCs and through the other WMO scientific and technical programmes. This includes the development and implementation of Internet connection projects in LDCs; provision of fellowships; supporting the participation of experts from LDCs in WMO meetings; carrying out special advocacy and project-formulation activities; and the organization of innovative capacity-building initiatives including workshops on good practices in the beneficial and effective use of weather-, climate-, and water-related services in sustainable socio-economic development.

Planned activities include the following:

- Development and organization of demonstration/pilot projects on the contribution of meteorological and hydrological and related environmental information, products and services to the sustainable development of the LDCs and Small Island Developing States (SIDS), especially in poverty alleviation, disaster risk reduction, environmental protection, food security, health, energy and water resources management;
- Organization of capacity-building activities for senior- and middle-level staff of LDC NMHSs, particularly in leadership, management, resource mobilization, strategic planning, marketing and communication;
- Preparation and implementation of development and modernization plans of NMHSs of LDCs and SIDS, including projects that are of relevance to, and consistent with, national development strategies and programmes and of high impact value to the relevant commitments enshrined in the Brussels Programme of Action for the LDCs;
- Promoting the awareness of policy- and decision-makers and other stakeholders of the socio-economic benefits of weather-, climate- and water-related services;
- Preparation of guidelines for promoting the contributions of NMHSs and WMO towards the attainment of internationally agreed development goals including those contained in the Millennium Declaration.

*3.1.4.*6. WMO Programmes and other Regional/International Programmes in support of the Panel Members

3.1.4.6.1. WMO Programmes

The major WMO Programmes concerned are the World Weather Watch (WWW), the World Climate Programme (WCP), Tropical Cyclone Programme (TCP), PWS (Public Weather Service), DPFS (Data Processing and Forecasting System), MMO (Marine Meteorology and Oceanography), DRR (Disaster Risk Reduction), SP (Satellite Program), AEM (Aeronautical Meteorology), HWR (Hydrology and Water Resources), RAP (Regional Office for Asia and the Pacific), ETR (Education and Training), WWRP (World Weather Research Programme), Global Framework for Climate services (GFCS).

3.1.4.6.2. Regional and international programmes

Programmes of the following organizations are of interest:

ESCAP; the ASEAN Subcommittee on Meteorology and Geophysics (ASCMG); the

Interstate Council on Hydrometeorology of the Countries of the Commonwealth of Independent States (ICH CIS); the Coordinating Committee on Hydrometeorology and Pollution Monitoring of the Caspian Sea (CASPCOM); the UNESCO Intergovernmental Oceanographic Commission (IOC); the United Nations Environment Programme (UNEP); UNDP; the Global Environment Facility (GEF); the Economic Cooperation Organization (ECO); the Economic and Social Commission for Western Asia (ESCWA); the South Asia Association for Regional Cooperation (SAARC); the League of Arab States (LAS); the Permanent Meteorological Committee; (BIMSTEC);Regional Integrated Multi- hazard Early Warning System (RIMES);(ADPC); and the Regional Organization for the Protection of the Marine Environment (ROPME).

***3.1.4.6*. Agreements and conventions**

Members are encouraged to undertake national responsibilities or contribute to national obligations under many regional and international agreements and conventions. Some of the most important ones are the WMO Convention; Agenda 21 adopted at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992; the 1994 Global Conference which adopted the Barbados Programme of Action for Sustainable Development of Small Island Developing States; Resolution 40 of Twelfth Congress (1995) on the policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities; Resolution 25 of Thirteenth Congress (1999) on the exchange of hydrological data and products; the Geneva Declaration of Thirteenth Congress (1999); Millennium Development Goals (2000); Sustainable Development Goals 2015-2030; Hyogo Framework for Action 2005-2015; Sendai Framework for Disaster Risk reduction (2015-2030); the United Nations Framework Convention on Climate Change (UNFCCC); the United Nations Convention to Combat Desertification (UNCCD); the Convention of the International Civil Aviation Organization (ICAO); the Convention of the International Maritime Organization (IMO); the International Convention for the Safety of Life at Sea (SOLAS); and the Convention on the Protection of the Ozone Layer and most recent and important Paris agreement on Climate Change 2015.

There are also a number of United Nations programmes and agencies having activities related specifically to meteorology, climate or hydrology or providing financial support to countries. These include UNEP, the United Nations Development Programme (UNDP), the Food and Agriculture Organization (FAO) of the United Nations and others.

3.2. DEVELOPMENT OF COORDINATED TECHNICAL PLAN

3.2.1 Purpose of Coordinated Technical Plan

The coordinated Technical Plan aims to promote and coordinate the planning and implementation of the measures required to minimize damages caused by tropical cyclones and associated floods and storm surges in the Bay of Bengal and the Arabian Sea. It is expected to establish an effective integrated regional early warning system for those hazards in the region covering all five components; meteorology, hydrology, disaster prevention and preparedness, training and research.

Specific purposes of the Coordinated Technical Plan are:

- To develop an understanding among the Panel Members on the priorities and objectives for their individual development and the overall development of the Panel region through cooperation; and to guide the implementation of Panel's programmes and activities for achieving these objectives;

- To develop and provide access to appropriate databases, resources and expertise to produce appropriate advice and products required for forecasting and warning

services to the private and public sectors as well as to the decision-makers and ordinary people;
- To encourage the development of joint projects by all Members or some of them with the projects under formulation and/or consideration by the Members;

- To raise general awareness of the status of the work of the Members and to have a framework under which development assistance would be provided and coordinated among the Members and the various contributing agencies; and
- To develop a system for training specialists of the Members, transferring and exchanging experience in observation and data processing, and taking advantage of advances in science and technology.

3.2.2 Institutional Arrangement

A coordinated Technical Plan needs institutional arrangements for successful implementation. Such arrangements should include a mandate, program management, human resources, funding, sectoral and organizational linkages, and reporting. These are to be considered when formulating the Plan.

3.2.2.1 Countries and organizations involved

Members will work together to contribute towards the implementation of joint programs and activities, deriving benefits from the pooling of resources within the region with the support of WMO and ESCAP.

3.2.2.2 Duration of the Coordinated Technical Plan

Coordinated Technical Plan is to cover a four-year term to keep pace with the financial periods of WMO (4 years) and ESCAP (2 years). The present Coordinated Technical Plan, therefore, covers the period from 2016- to 2019 to coincide with the financial periods of WMO and ESCAP as mentioned above. Coordinated Technical Plan is a live document and continues to be reviewed and updated by the PTC every four years.

3.2.2.3. Regional programmes and projects

Regional programmes or projects involved in the Plan are those that address problems that are common to the whole Panel region. Initial pilot phases may be undertaken in a limited number of countries only. Sub-regional programmes and projects are those which address problems that are common to only a few Members. Country-specific projects are those that are specifically required by a particular Member to address a problem in that country, given its particular circumstances. Country-specific projects are unique to individual countries and are identified through in-country consultations.

3.2.2.4. Steps for the implementation of the Coordinated Technical Plan

The steps for implementing the Coordinated Technical Plan include:

a. Panel, WMO and ESCAP, through cooperative efforts to assist and/or support the implementation of the Coordinated Technical Plan;
b. Development of projects for implementation by Panel and its Members, and other regional and sub regional economic groups and institutions to implement effectively the Coordinated Technical Plan to enable Members to play their full role in sustainable socio-economic development of their countries.

3.2.3 Reporting

As part of implementation of the Coordinated Technical Plan, Members will report on progress on the implementation of the Plan to the PTC at annual sessions.

3.3. EXPECTED RESULTS AND STRATEGIC ACTIONS

3.3.1 Meteorology

3.3.1.1 Expected Result 1

- Developed capabilities of Members to produce and provide impact-based forecasts and risk-based warnings of tropical cyclones, storm surges and associated hazards

This is expected to be achieved based on the development of an efficient and expanded observation and telecommunication network and with the acquisition of the latest forecasting technology, improved exchange of data and development of skills of personnel through national, bilateral and regional programs.

3.3.1.2 Strategic Actions

1-a To further improve and expand the observing system of surface, upper-air, ship, buoy, aircraft, radar and satellite observations in the Member countries.

1-b To ensure the real-time operational use of the WMO Information System (WIS) for operation-critical data exchange through dedicated telecommunication means of the GTS, and through broadband Internet access for Data Discovery, Access and Retrieval service.

1-c To further increase the accuracy, timeliness and usefulness of tropical cyclone forecasts and warnings.

1-d To develop the capacity of member countries for providing impact-based forecasts and risk-based warnings

1-e To extend the operational use of ensemble prediction techniques and probabilistic forecasts for more effective disaster risk assessment and management.

1-f To continue to upgrade the computing facility of RSMC New Delhi and NMHSs so as to facilitate efficient data processing and data assimilation from different observing systems/platforms to suit the national and regional needs.

1-g To ensure the operational use of the recently established a regional storm surge watch scheme to provide Members with the storm-surge advisories including daily marine processed data and information they require for real-time uses

3.3.2 Hydrology

3.3.2.1 Expected Result 2

- Enhanced capabilities of Members to produce and provide better hydrological forecasts and assessments

Members will formulate accurate and timely forecasts and warnings on floods and other water related hazards with a view to supporting preparedness and response mechanisms of their governments and the public.

3.3.2.2 Strategic Actions

2-a To further improve regional cooperation in real time monitoring and exchange of relevant data and information, forecast/products and technical expertise related to hydrological hazards.

2-b To improve flood forecasts and warnings particularly in deltaic and coastal areas by coupling meteorological storm surge forecasts with river flow forecasting.

2-c To enhance regional capabilities relating to flood hazard mapping in delta and coastal regions through continued interaction with the user agencies.

2-d To further improve management of water resources, including assessment of surface and ground water resources in relation to cyclonic disturbances;

3.3.3 Disaster Risk Reduction (DRR)

3.3.3.1 Expected Result 3

- Enhanced capabilities of Members to promote tropical cyclone disaster resilient communities through providing guidance on multi-hazard early warning dissemination and response mechanism

Disaster risk reduction in the region will be improved through the establishment of institutional and legal frameworks at the country level involving improved multi-hazard early warning and Decision Support Systems (DSS) of vulnerability and community-based disaster risk management (CBDRM) initiatives aiming at enhanced public awareness, and participation of stakeholders to be more effective. These are expected to be achieved through improvement in standard procedures on DRR and the exchange of national and international experiences and information on disaster management among the Members.

3.3.3.2 Strategic Actions

3-a To improve regional cooperation in policies and strategies on DRR, especially those related to tropical cyclones, coastal hazards and other extreme weather events.

3-b To establish a regional information system to support the development of policies and strategies on DRR as well as interfacing with the national level systems by creating an updated comprehensive database on disaster information and best practices on DRR.

3-c To further enhance public awareness and appreciation of the impacts of tropical cyclones and other extreme weather events, for possible mitigation and response actions through effective communication with the media before, during, and after such events.

3-d To further strengthen coordination and interaction between meteorological/hydrological services on the one hand and emergency management/disaster response agencies on the other through integrated emergency management, disaster response and preparedness programmes.

3-e To strengthen regional cooperation on DRR information exchange through networking by making available disaster preparedness and mitigation information through Internet web sites, involving web GIS tools and other means.

3-f To enhance disaster risk management, especially those related to cyclone-related disaster preparedness by developing and implementing pilot projects on multihazard disaster risk management programmes into the development plan of the Panel Members in the next four years.

3.3.4 Training

3.3.4.1 Expected Result 4

- *Development of a strategic approach to capacity building with a regional perspective*

Training activities will be enhanced by strengthening the skills of personnel engaged in various aspects of cyclone prediction and early warning through regular training programs including the organization of workshops, seminars, etc.

3.3.4.2 Strategic Actions

4-a To promote training programs on the use of NWP model products and their application in cyclone (track and intensity) and storm surge prediction.

4-b To promote training programs on media coordination during disasters and their effectiveness on "human response".

4-c To promote training programs on the use of remote sensing data including satellite and Doppler Weather Radar products in cyclone forecasting.

4-d To promote visits of experts among Member countries to share their experiences and expertise in cyclone-related fields.

4-e To enhance WMO's fellowship support on tropical cyclones and other multi-hazard risk reduction-related programs.

To set up a small group of its Members to develop a draft training plan. The training plan could identify the training needs and available opportunities as well as the gaps that will need to be addressed to support the successful implementation of the Coordinated Technical Plan.

4-f To develop TC Forecasting Competency as per the recommendation of EC-65 & EC-66.

The Panel noted that the Executive Council at its 66th session stressed the need for, and urged the Secretariat to support the, development of TC forecasting competencies in all tropical cyclone basins by regional tropical cyclone committees under the initiativeof RSMCs. Implementation of tropical cyclone competencies is an essential component of improving service delivery as it sets common global recommended practises providing a safety net of "our staff are trained to at least the minimum recommended standards" and providing a leverage for members to obtain funding of "we need to train our staff to at least the minimum recommended standards" to provide quality services. Development and implementation of a competency framework is part of a quality approach to ensuring service delivery as it requires parallel reviews of policies and forecasting processes and procedures to be successful.

The Panel also noted that Members in RAI, RA IV and RA V and the ESCAP/WMO Typhoon Committee have already undertaken considerable work in the development and implementation of tropical cyclone forecasting competencies at national and regional level. The Panel was informed that RSMC New Delhi had developed a set of tropical cyclone forecasting competencies, and circulated among the Panel Members a draft version of the tropical cyclone forecasting competencies for the Panel. The Panel is invited to discuss further this document and provide recommendations to implement these competencies.

3.3.5 Research

3.3.5.1 Expected Result 5

- *Enhanced capabilities of Members to cope with high-impact weather through research*

The collaboration will be promoted on research activities related to updating forecasting technologies, including NWP, storm surge and flood forecasting models.

3.3.5.2 Strategic Actions

5-a To assess the impact of climate change on tropical cyclones in the region.

5-b To further improve monitoring capabilities to characterize physical and dynamical characteristics of tropical cyclones.

5-b To further improve regional NWP models for tropical cyclone track, Intensity and structure predictions.

5-c To develop and further improve the storm surge and river flood coupling model over specific river basins for forecasting of coastal inundation.

5-d To update vulnerability maps for various parameters like wind force/peak storm surge etc., based on latest available database.

5-e To identify research issues and develop research proposals for technical and funding support

3.3.6 Partnership

3.3.6.1. Expected Result 6

- *Enhanced cooperation among Members and with partner organizations in the provision of forecasts and warnings for tropical cyclones and storm surges*
- Partnerships will be further developed both within and outside the region to take advantage of experience, expertise, infrastructure and other resources, and for future initiatives and development projects.

3.3.6.2 Strategic Actions

a To promote the exchange of information and data among Members and with regional bodies to enhance regional cooperation in the five components: meteorology, hydrology, DRR, training and research.

b To enhance cooperation with other regional bodies, organizations, service providers and sectors for more effective provision of the forecasts and warnings.

c To develop and implement joint projects in the areas of the above five components and resource mobilization.

3.3.7 Management and Governance

3.3.7.1 Expected Result 7

- *Effective management and functioning of the Panel.*

Effective management and governance will be pursued to ensure the fulfilment of Panel's vision, mission and strategic objectives.

3.3.7.2 Strategic Actions

a To further improve the coordination and decision-making process of the Panel.
b To enhance effectiveness in the implementation of CTP and AOPs.
c To continue to ensure effective and collaborative relationships among working groups of Meteorology, Hydrology and DRR.
d To further improve the coordinated technical planning process as well as monitoring and evaluation.

3. 4. ANNUAL OPERATING PLAN

The Annual Operating Plan (AOP) is designed to turn the expected results into specific initiatives and projects that are needed to achieve the expected results. The AOP will contain detailed actions and performance indicators to meet the Strategic Actions of each of the expected results. The AOP will be prepared and adopted at the annual PTC sessions and the detailed actions and performance indicators are subject to revision by PTC during its sessions. Annual Operating Plan for 2024-25 is presented below:

Expected Result	Strategic Goal	Activity
ER-1 (Meteorology) Enhanced capabilities of Members to produce better forecasts and warnings of tropical cyclones and storm surges.	1-a To improve and expand the observing system of surface, upper-air, ship, buoy, aircraft, radar, wave radar and satellite observations in the Member countries.	To strengthen the cooperative relationship with the Airlines for the development of the regional Aeronautical Meteorological Data Relay (AMDAR) programme (WMO).
	1-b To implement and operate adequate Members' connection to the WMO Information System (WIS) for operation-critical data exchange through dedicated telecommunication means.	Members to implement plans to deploy WIS functionality.
	1-c To increase the accuracy, timeliness and usefulness of tropical cyclone forecasts and warnings.	1) To establish and enhance the communication between the operational forecasters in RSMC and the Members (RSMC, PTC-S). 2) To develop collaborative links with the Severe Weather Forecasting Programme and the Coastal Inundation Forecasting Programme of WMO (Members, RSMC, BMD, PTC-S, WMO) 3) To promote implementation of Common Alerting Protocol (CAP) in partnership with WGDRR (WMO, Members).

		4) To implement TC Landfall Forecast programme (RSMC, Members) 5) To prepare an assessment report on the current status and needs of the Members with respect to data, products, analytical and forecasting procedures.(Working Group on Meteorology in association with RSMC, New Delhi) 6) To arrange the training on Dvorak's technique, microwave imageries & products and application of Ensemble Prediction System (EPS) for tropical cyclone monitoring and prediction with the support of WMO. 8) WMO/PTC may facilitate training on the utilization of INSAT-3DR and S data and products including RAPID and Nowcasting tools among the Member countries. (in conjunction with some other training activity of WMO).
	1-d To upgrade the computing facility of RSMC New Delhi and NMSs so as to facilitate efficient data processing and data assimilation from different observing systems/platforms to suit the national and regional needs.	RSMC New Delhi may inform the Panel Member countries about the changes/upgradation in their telecommunication systems so that necessary measures taken by the members.
ER-2 (Hydrology) Enhanced capabilities of Members to provide better hydrological forecasts and assessments.	2-a To improve regional cooperation in real-time monitoring and exchange of relevant data and information, derived (forecasting) products and technical expertise related to hydrological hazards.	1) To develop and implement a regional information exchange strategy during 2024-2025. 2) To organize regional workshops on data transmission mechanisms with special reference to water-related hazards. 3) To collaborate with the Commission for Hydrology (CHy) and RA-II to carry out the activity on actions 1 and 2.

	2-b To improve flood forecasts and warnings, particularly in deltaic and coastal areas by coupling storm surge forecasts with river flow forecasting.	1) To develop delta hydraulic models for river forecasting by coupling any hydrodynamical model being used in the countries) with the storm surge forecasts for at least one river delta in each country. 2) Developing/application of coastal flood models and associated flood hazard and risk maps in the line as mentioned above. 3) To organize workshops for enhancing the capabilities of the countries (in conjunction with WMO training etc.)
	2-c To enhance regional capabilities relating to urban floods/ riverine flood risk reduction in delta and coastal regions through continued interaction with the member countries and user agencies.	1) To undertake flood hazard mapping at least in one major delta/coastal area in each country during the next four years. 2) To organize workshops for capacity building (in conjunction with WMO training activity etc). 3) To collaborate and share experiences with the Typhoon Committee (WMO, ESCAP, PTC-S)
ER-3 (DRR) Enhanced capabilities of Members to promote tropical cyclone disaster resilient communities through providing guidance on multi-hazard early warning dissemination and response mechanism.	3-a To improve regional cooperation in policies and strategies on DRR, especially those related to tropical cyclones, coastal hazards and other extreme weather events.	1) ESCAP, WMO and PTC to organize capacity development training programme for PTC member countries particularly in the areas of impact-based forecasting, risk-based warning. 2) ESCAP and WMO to work with PTC member countries for developing a regional component of International Network of Multi Hazard Early Warning System (IN-MHEWS) and implementation of MHEWS Interoperability Environment (MIE)
	3-b To establish a regional information system to support development of policies and strategies on DRR as well as interfacing the national level systems by creating an updated comprehensive database on disaster information and best practices on DRR.	1) To strengthen regional cooperation on DRR information exchange through networking by making available disaster preparedness and mitigation information through Internet websites, involving web GIS tools and other means. The web link may be provided to GMAS. WMO will provide a guideline to the member countries.

		2) ESCAP to support PTC member countries in attending regional co-operation related activities including IN-MHEWS, Asian Pacific Centre for Development of Disaster Information Management (APDIM).
	3-c To improve public awareness and appreciation of the impacts of tropical cyclones and other extreme weather events, for possible mitigation and response actions through effective communication with the media before, during, and after such events.	ESCAP and WMO to support strengthening multi-stakeholder forums such as monsoon forums, and national climate outlook forums in PTC member countries.
	3-d To improve coordination and interaction between meteorological/hydrological services on the one hand and emergency management/disaster response agencies on the other through integrated emergency management, disaster response and preparedness programmes.	ESCAP and WMO to continue supporting initiatives such as Common Alerting Protocol (CAP) in PTC member countries.
	3-e To improve disaster risk management, especially those related to cyclone-related disaster preparedness by developing and implementing pilot projects on multi-hazard disaster risk management programmes into the development plan of the Panel Members in the next four years.	WMO and ESCAP to support piloting a standard methodology project on impact based forecasting and risk based warning in PTC member countries.
ER-4 (Training) Training plan for capacity building with a regional perspective.	4-a An expert group of members (Bangladesh, India, Maldives & Sri Lanka) to prepare a draft training plan from 2024-25.	1) Expert Group (Sri Lanka, Oman and Thailand) to produce a training plan including a prioritized list of training needs and opportunities of PTC Members through a survey and advise WMO for reporting, planning and implementation purposes. PTC will write to member countries regarding the constitution of the expert group and request for the nomination of experts and focal persons.

		2) The plan is to be submitted to PTC Secretariat by the end of December 2024. PTC will forward the report to WMO with a request to organize training as per the plan.
	4-b To arrange training programmes on the use of NWP model products and their application in Cyclone (track and intensity) and storm surge prediction.	1) To continue the attachment training programme in RSMC, New Delhi for cyclone forecasters. 2) PR of India with WMO to arrange training on storm surge forecasting in India for the PTC member countries. 3) To continue to organize a training programme at INCOIS, Hyderabad in India on the utilization of Ocean data and wave forecasting. 4) ESCAP to continue supporting training programme for information dissemination and media coordination in multi-hazard early warning system.
	4-c To arrange training programmes on the use of Satellite and Doppler Weather Radar (DWR)data & products in Cyclone forecasting as well as DWR calibration and maintenance	
	4-d To arrange training programmes on information dissemination tools and media coordination during disasters and their effectiveness on "human response".	
	4-e To exchange visits of experts among Member countries to share their experiences and expertise on cyclone & related disaster management aspects.	-
	4-f To enhance WMO's fellowship support on tropical cyclone related programmes.	-
ER-5 (Research) Enhanced capabilities of Members to cope with high impact weather through research.	5-a To produce regional assessment of the impact of climate change on tropical cyclones.	To collect data/materials/papers from the Member countries which are relevant to the regional assessment.
	5-b To develop storm surge and river flood coupling model over specific river basins for forecasting of coastal inundation.	-
	5-c To update vulnerability maps for various parameters like wind force/peak storm surge etc., based on latest available database.	-

ER-6 (Partnership) Enhanced use of forecasts and warnings for tropical cyclones and storm surges for decision making and implementation by Members and partner organizations.	6-a To promote exchange of information and data among Members to enhance regional cooperation in meteorology, hydrology, DRR, training and research.	-
	6-b To enhance cooperation with other regional bodies, organizations, service providers and sectors for more effective provision of the forecasts and warnings.	-
	6-c To develop proposals for joint projects in the areas of five components including resource mobilization.	-
ER-7 (Management and Governance) Effective management and functioning of the Panel.	7.a To improve the coordination and decision-making process of the Panel.	-
	7.b To enhance effectiveness in implementation of CTP and AOPs.	-
	7.c To ensure effective and collaborative relationships among working groups of Meteorology, Hydrology and DRR.	-
	7-d To improve coordinated technical planning process as well as monitoring and evaluation.	-

3.5. CONCLUSION

Coordinated Technical Plan (CTP) for the WMO/ESCAP Panel on Tropical Cyclones for the Bay of Bengal and Arabian Sea (2024-27) has been developed based on the general framework of CTP adopted at the 31st session and the draft CTP submitted to the 50th session by the CTP Working Group, as well as suggestions from the Panel Members. It also took into account Sendai Framework for Disaster Risk Reduction (2015-2030) adopted during the World Conference on Disaster Reduction in 2015.

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