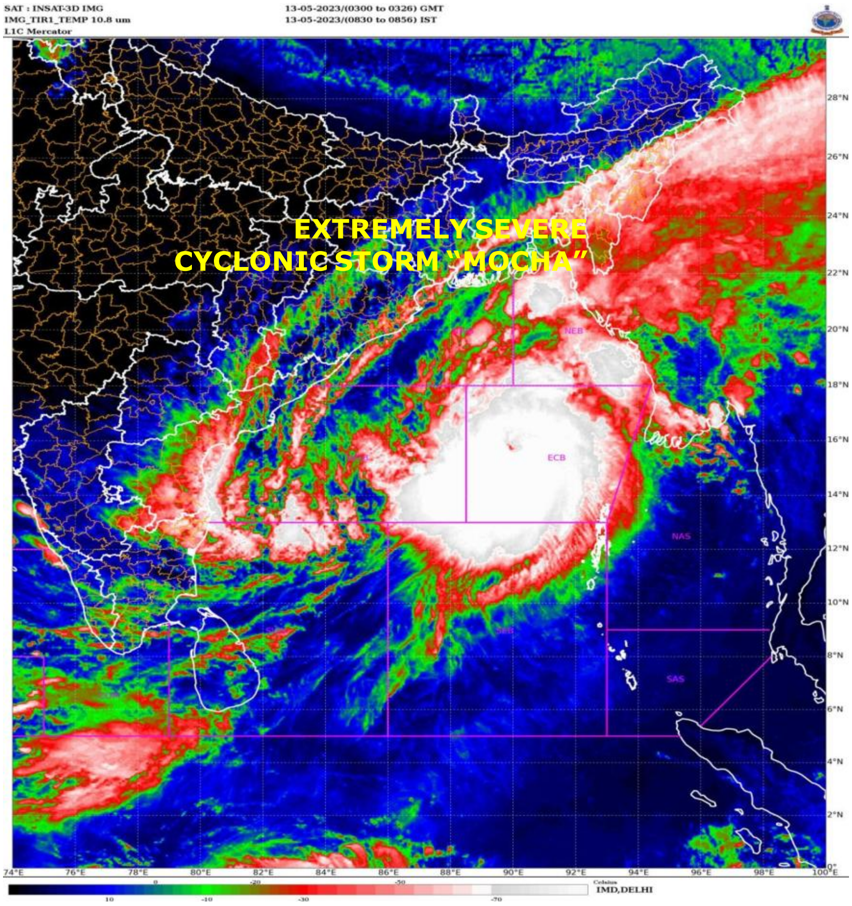
WMO/ESCAP PANEL ON TROPICAL CYCLONES

ANNUAL CYCLONE REVIEW 2023



SATELLITE IMAGERY OF EXTREMELY SEVERE CYCLONIC STORM, MOCHA OVER BAY OF BENGAL, MAY 2023

WMO

ESCAP

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

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PREFACE

First commenced in 1997, the publication of ***WMO/ESCAP Panel*** - *Annual Review* has entered **twenty-first** year of issue for the year 2023. 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, 2023 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 the same 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 Commissionand its subsidiary bodies;
- Undertakes studies, investigations and other activities within the commission's termsof 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 like Atlantic, 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 very heavy 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 to and 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. Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Thailand joined the Panel in 1972. Later Maldives joined the Panel in 1982 followed by Sultanate of Oman in 1997, Yemen in 2016 and Saudi Arabia, United Arab Emirates, Qatar and Iran in 2018. The PTC has thus now 13 countries bordering BoB and AS as the members.

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 of community preparedness and disaster prevention;
- To promote, prepare and submit to member countries plans for co-ordination of research 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 with existing 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 equator 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 and Yemen. The Yemen became member of the Panel in 2016. Iran, Saudi Arabia, United Arab Emirates and Qatar joined in 2018.

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 prediction purposes.
- Detection, tracking and prediction of cyclonic disturbances in the Bay of Bengal and the Arabian Sea.
- Running of numerical weather prediction models for tropical cyclone track and storm surge 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 neighboring countries 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 (2023)

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Chairman drafting committee	**: Dr. D. R. Pattanaik (India Meteorological Department)**

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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: 2023** 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 2023 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 wind 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 2023. 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 (CTP): 2024-2027 and Annual Operating Plan (2024)

CHAPTER-I

WMO/ESCAP PANEL ACTIVITIES IN 2023

1. METEOROLOGICAL ACTIVITIES

1.1. ESCAP

Activities of member countries on WMO/ESCAP Panel, WMO and UN-ESCAP for the year 2023 were presented at the **50th session** of the WMO/ESCAP Panel on tropical cyclones held at Manama, **Bahrain from 19-23 December**. 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 journey from **Risk to Resilience: 50 years of WMO ESCAP Panel on Tropical Cyclone.** The same was presented in the meeting as summarized below.

On 12/13 November 1970, the world's deadliest tropical cyclone 'Bhola' killed more than 300,000 people in Bangladesh. The hard lesson learnt from 'Bhola' was not having an effective cyclone warning system to forewarn at risk communities. It is with this context that WMO/ESCAP Panel on Tropical Cyclone (PTC) came into existence in 1972. The panel started with six member countries and now comprises of 13 member countries from the Bay of Bengal and the Arabian Sea of the North Indian Ocean.

Over the last 50 years, the Panel has successfully tracked and monitored countless tropical cyclones from formation to landfall through cross-border collaboration, involving real-time data sharing and risk information exchange across the common ocean basin. The positive outcomes in managing two recent cyclones emphasize the panel's effectiveness:

Cyclone Mocha over the Bay of Bengal: On 14 May 2023, cyclone Mocha hit Myanmar accompanied by maximum sustained winds of 180-190 km/h, violent gusts, torrential rainfall and flooding. Mocha made the landfall in a most vulnerable context of compounding poverty, inequality and environmental degradation. However, the impact differed significantly from the 2008 devastation caused by Cyclone Nargis, a storm as powerful as Cyclone Mocha, which resulted in the loss of over 138,000 lives in Myanmar.

Cyclone Biparjoy over the Arabian Sea: On 26 June 2023, cyclone Biparjoy with wind speed of 140 km/h hit densely populated of India's west coast of Gujarat State. Despite its ferocity, no casualties (absolute zero) were recorded.

The accuracy of early warnings leading to targeted evacuations during Mocha and Biparjoy saved tens of thousands at risk. The Regional Specialized Meteorological Centre (RSMC), within the India Meteorological Department, had been able to forecast these cyclones precisely five days in advance, which gave sufficient lead time for authorities to maneuver the coastal communities to safer areas. The RSMC monitors cyclones across the Northern Indian Ocean, collaborating with PTC members to provide early warning products and services for tropical cyclones with transboundary origins and impacts, spanning from Oman in West Asia to Myanmar in Southeast Asia.

From the lens of the Sendai Framework for Disaster Risk Reduction, the PTC has made substantial contributions towards building resilience to tropical cyclones (Fig. 1). Despite good progress in a few of the targets, reducing the number of affected people (B) lags, and challenges persist in addressing economic losses (C) and safeguarding critical infrastructure and services (D).

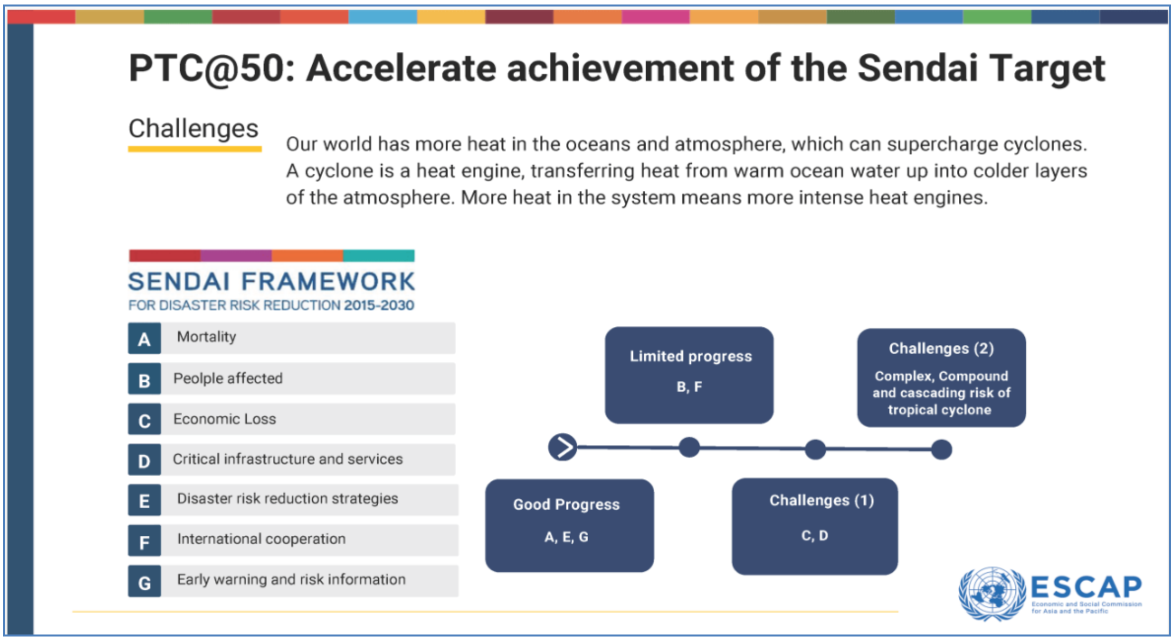


Fig. 1 : *Contributions of the Panel on Tropical Cyclone towards achieving the Sendai targets*

As the panel celebrates 50 years of its journey this month, five key imperatives are flagged for discussion:

- **First,** riskier times ahead: Our world has more heat in the oceans and atmosphere, which can supercharge cyclones. A cyclone is a heat engine, transferring heat from warm ocean water up into colder layers of the atmosphere. More heat in the system means more intense heat engines. ESCAP analysis has identified intensifying and expanding risk hotspots in the Bay of Bengal and Arabian Sea at baseline, 1.5- and 2.0-degree warming, flagging the challenges of resilience in riskier times - informed, comprehensive and forward-looking.

- **Two,** rapid intensification of tropical cyclones: In recent years, tropical cyclones in the Bay of Bengal (Amphan) and Arabian Sea (Tauktae) have shown a rapid intensification, complex tracks and increased curvature. Cyclone Titli (east coast of India, 2018), caused landslides and fatal flooding despite a precise early warning, resulting in over 50 casualties. Further, cyclones that intensify rapidly are difficult to forecast and can lead to forecasting errors. For accurate predictions, advanced surveillance should be deployed to detail monitoring of complex cyclone formation, and high-quality modeling frameworks should be adopted integrating ocean, atmosphere and land phenomena.
- **Three,** impact-based forecasting (IBF): IBF narrows the gaps that exist between forecasters and the end-users. ESCAP has developed a methodology that translates cyclone track, intensity and land fall prediction into impact scenarios. Anticipatory action (AA) is central to early warning and action, intricately tied to IBF. It plays a key role in proactive measures enhancing to preparedness to mitigate the impacts of tropical cyclones. Operationalizing IBF and AA through PTC attachment training and capacity development activities is an important step forward and would see a seven-fold return on

investment.

- **Fourth,** cyclone early warnings for all: The UN Early Warnings for All Executive Action Plan 2023-2027 is based on four pillars – knowledge of risk, monitoring and forecasting, warning dissemination and communication, and preparedness for response. The effectiveness of multi-hazard early warning systems relies on each pillar and needs to be supported by policy, plans and financial mechanisms to enable its availability and accessibility. PTC@50 can take forward cyclone early warnings for all its members.

- **Finally**, strengthening PTC architecture: The secretariat of the PTC is imperative to driving operations and should be strengthened to ensure that the panel is fully owned, funded, administered, and governed by its members. It can be built on the four pillars of cyclone early warnings, following the modality of the Early Warnings for All initiative, through its working groups. The 50th celebration provides an opportunity to rejuvenate PTC ready to manage complex cyclones in riskier times.

UN ESCAP provided the following inputs to PTC in its 50th session.

Impact Based Forecasting for Early and Anticipatory Actions:

- It was recommended scaling up IBF to support early actions through PTC Attachment training and WMO/ESCAP dedicated IBF training. Furthermore, IBF should be scaled up through the UN Early Warnings for All initiative– Pillar 2 – Impact based Forecasting.

- It was also suggested that IBF should be included in Synergized Standard Operating Procedure for Coastal Multi-hazard Early Warning System (SSOP III) in PTC member Countries. PTC should undertake resource mobilization for IBF through Green Climate Fund, CREW, ESCAP Trust Fund and dedicated support from PTC members.

- ESCAP proposed to align its ongoing activity on a regional strategy to early warnings for all in collaboration with PTC secretariat to support PTC members. ESCAP suggested reviving PTC working groups and taking up demonstrative pilot on loss and damage due to the tropical cyclones in PTC region.

- 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.

Specific recommendation

- India was elected to host the PTC Secretariat for the period 2024-27. The newly elected PTC secretariat was requested to develop its vision, mission and goals, and present this to 51st session of the PTC. The PTC secretariat was also requested to develop PTC strategic plan (2024-2028) with its revived working groups – meteorology, hydrology, DRR and training /capacity development.

1.2. Meteorology

1.2.1. India

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

1.2.1.1. 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.

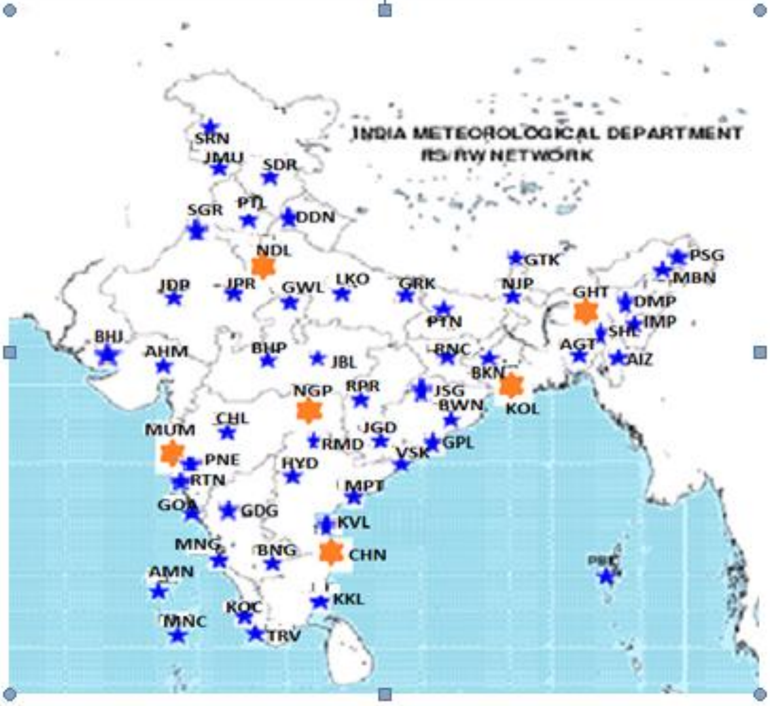
1.2.1.2. Upper Air Observatories

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 2.1 and fig 2.1.

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.

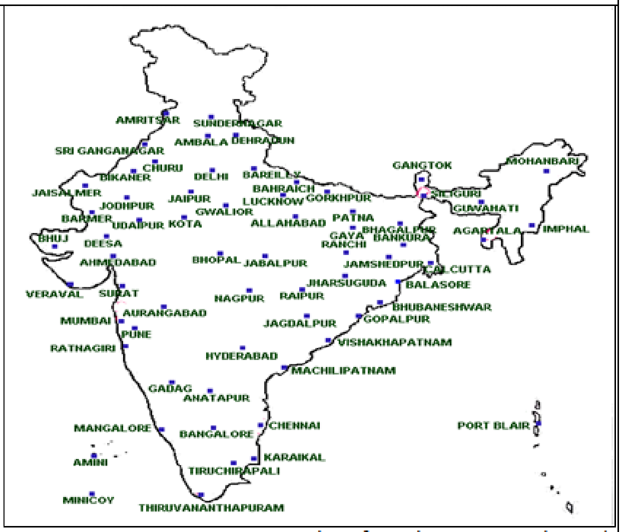
The upper air meteorological data collected all over the country are used on real time basis for operational forecasting. The PBOs at New Delhi, Mumbai and Lucknow have been upgraded with GPS based PBO.

Table 2.1: List of RS/RW stations along the coast

S. No	Name of the station	Network Map
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	Fig. 2.1 RS/RW network of India Meteorological Department

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 2.2 and fig 2.2.

Table 2.2: List of PB stations near the coast

S. No	Name of the station	Network Map
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	Fig. 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.

1.2.1.3 Radars

1.2.1.3.1 Current Status

Weather radar network of India is managed by IMD, and consists of thirty-Nine Doppler weather radars (RADARs) presently, spreading across the country (Fig. 2.3). RADAR network includes 5 ISRO and 1 IITM RADARs.

- ❖ Presently, weather radar network of IMD has increased to thirty-nine Doppler weather radars (RADARs), spreading across the country (Fig. 1) leading to detection of every small and major weather events.
- ❖ Among the radars of IMD, S-band radars are installed at Chennai, Kolkata, Machilipatnam, Visakhapatnam, Paradip, Hyderabad, Nagpur, Patna, Lucknow, Patiala, Karaikal, Bhopal, Agartala, Mohanbari, Delhi (Palam) and Goa.
- ❖ Two C-band Polarimetric RADARs are installed at Delhi (HQ) and Jaipur. Two Dual polarized S-band RADARs installed at Kochi and Gopalpur are also being utilized for severe weather monitoring.

- ❖ IMD has a network of 13 DWRs 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 VSSC) on West Coast. Recently, two more indigenously developed DWRs: one X-band at Pallikarnai, Chennai and one C-band at Veravali, Mumbai have been added in IMD radar network.
- ❖ Recently, 10 state-of-the art X-Band Doppler Weather Radars have been successfully installed and commissioned in the Central and Northern Himalayas at highly remote stations in order to provide better radar coverage in the Himalayas. These radars have been installed at Mukteshwar, Surkanda Devi and Lansdowne in Uttarakhand, at Kufri, Murari Devi and Jot in Himachal Pradesh, at Jammu and Banihal Top in Jammu & Kashmir and at Leh (portable radar) in Ladakh.
- ❖ IMD also utilizes the data input from Doppler weather radars of ISRO located at VSSC Thiruvananthapuram (C band), Sohra (S band) and SHAR (Sriharikota-S band).
- ❖ India Meteorological Department has also played a spectacular role in making a major shift to Indian make DWRs under "Make in India" initiatives.
- ❖ A transportable X-Band Doppler Weather Radar mounted on mobile platform installed at Leh under Integrated Himalayan Meteorology Programme (IHMP) for Western and Central Himalayas. This DWR installed by IMD is at the highest altitude in India.
- ❖ Tower based X-Band DWRs have been installed at Mukteshwar (Uttarakhand), Kufri, (Himachal Pradesh), Jammu (J&K), Ayanagar (New Delhi), Banihal Top (Jammu & Kashmir), Surkanda Devi (Uttarakhand), Jot (Himachal Pradesh), Murari Devi (Himachal Pradesh), DWR Banihal (J&K), DWR Lansdowne (Uttarakhand) under IHMP. Two indigenous DWRs, i.e. X-band DWR at Pallikarnai and C-band at Veravali have also been added in IMD network.

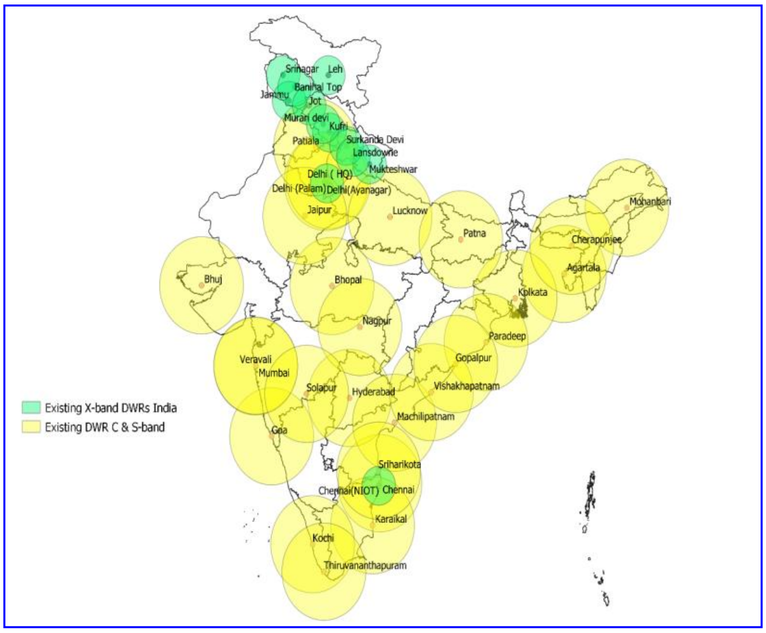


Fig. 2.3. Network of Doppler Weather Radar used for weather monitoring and forecasting

Radars of IMD are being used for detection of rainfall, hailstorm, 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. 2.4). This provides accurate positional information of the location of the convective cells centre of storm rainfall.

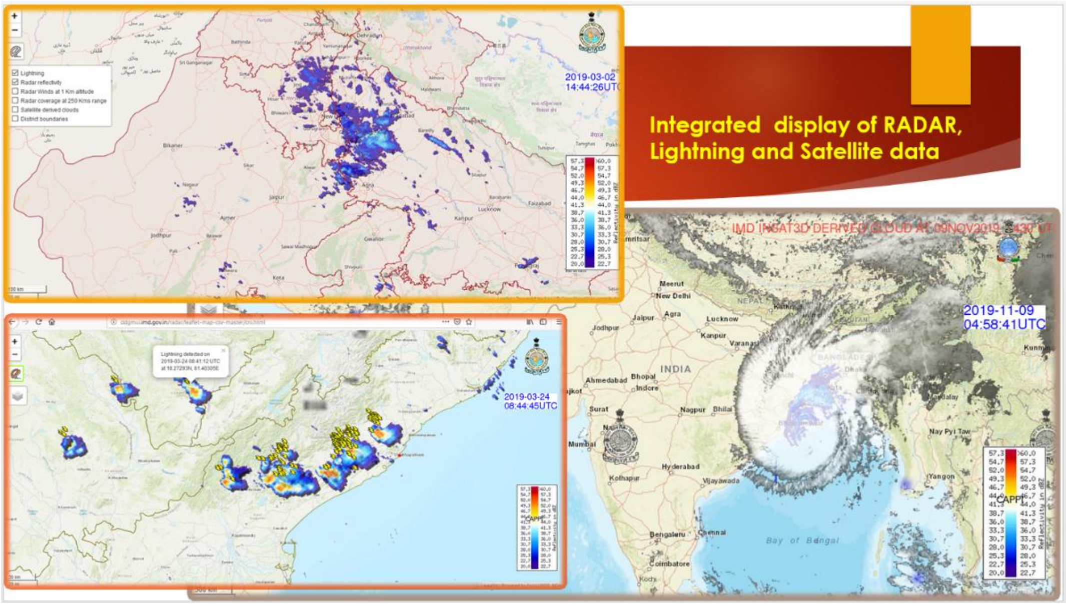


Fig. 2.4: Integrated display using RADAR, Lightning and Satellite data

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.

1.2.1.3.2. Future Plan:

The Radar division is involved in implementation of modernization of Radar Network by replacing old conventional Radars with state of art RADARs. IMD has a plan to induct more than 73 RADARs in its network in a phased manner to bring the 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, 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. 2.5.**

X-band DWRs under IHMP Scheme have already been installed at Leh, Kufri, Mukteshwar, Jammu, 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 R&D.

IMD is working relentlessly on the path for the country to have 34 more DWRs by 2026 covering the major parts of the country. These installations shall take the count of DWRs in IMD's network to 73 in number.

In addition to these radars, it is proposed to install 53 more DWRs across Indian region under Mission Mausam bringing the country under coverage range of total 126 DWRs.

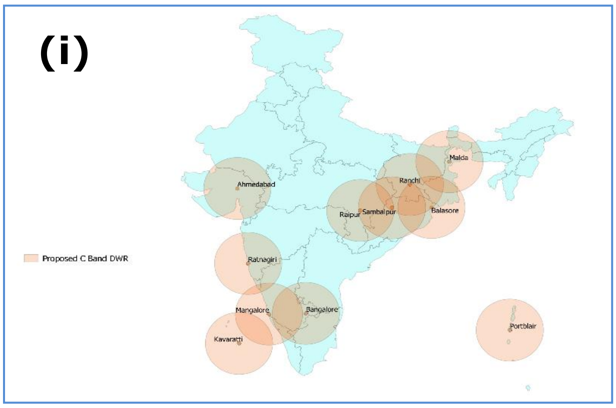


Fig. 2.5(i): Proposed 11 C band Doppler weather radars

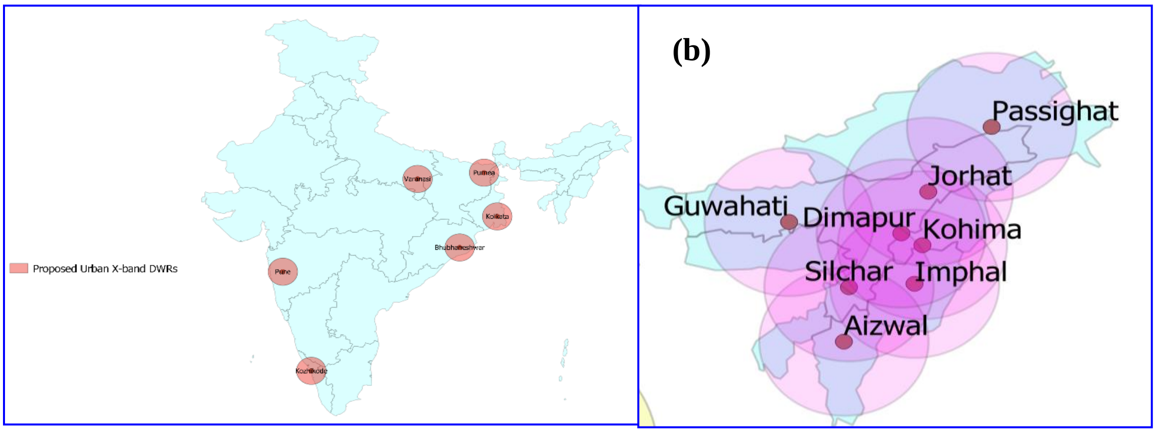


Fig. 2.5 (ii) Proposed (a) X-band DWRs for Urban Meteorology and (b) Radar network in North East India

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. 2.6)

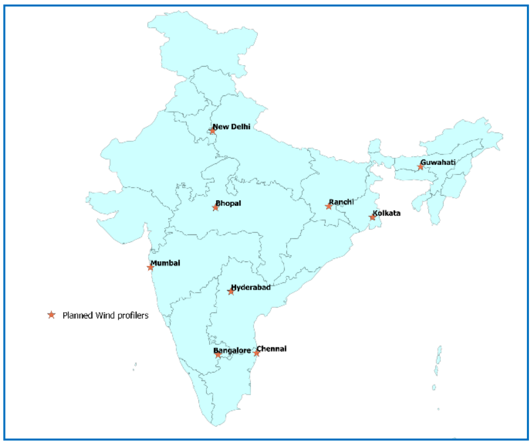


Fig. 2.6: Proposed Wind profilers (9)

1.2.1.4 Meteorological Satellite

At present, IMD is receiving and processing meteorological data from two Indian geostationary satellites namely, INSAT-3D & INSAT-3DR. INSAT-3D launched on 26th 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), & Water Vapour (WV, 6.50-7.10 μm)**]** and a nineteen channel sounder (18 IR & 1 Visible) for derivation of atmospheric temperature and moisture profiles. The imagers onboard INSAT-3D and INSAT-3DR provide imageries at 1 km spatial resolution in visible and SWIR bands, at 4 km spatial resolution in MIR and IR bands, and at 8 km spatial resolution in WV band.

At present, about 48 nos. of satellite images scans are taken daily from Imager payload of each satellites (INSAT-3D and INSAT-3DR). Imager payload of these satellites is operated in a staggered mode to get images every 15 minutes. Currently, sounder onboard the INSAT-3DR satellite is providing data at hourly interval. It provides hourly data 20 times a day for Sector A (Indian land region) and 4 times a day for Sector B (Indian ocean region) for generating multi-level imageries and vertical profiles of humidity and temperature. The Multi-mission Meteorological Data Receiving and Processing System (MMDRPS) is used on an operational basis to receive, process and disseminate meteorological data from INSAT-3D and INSAT-3DR satellites on round the clock basis in Satellite Meteorology Division of IMD. Cloud Imageries and derived products 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 known as RAPID. All the received and processed data from the satellite are archived on a dedicated storage of the MMRDPS.

The following products derived from the satellite are useful for monitoring of tropical cyclones

1. Enhanced grey scale imagery of cyclone.
2. Enhanced coloured imagery of cyclone.
3. Outgoing Long wave Radiation (OLR) at pixel resolution
4. Quantitative Precipitation Estimation (QPE)
   - Three hourly accumulated precipitation at 1x1 degree resolution,
   - Hydro estimator (HE) at pixel level
   - INSAT Multi-spectral Rainfall (IMR) at 0.1x0.1 degree resolution
   - Corrected IMR (IMC) 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 profiles
12. Value added parameters from INSAT-3DR sounder
    - 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 (Oceanssat 3) 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 "TEJ" is presented in Fig. 2.7.

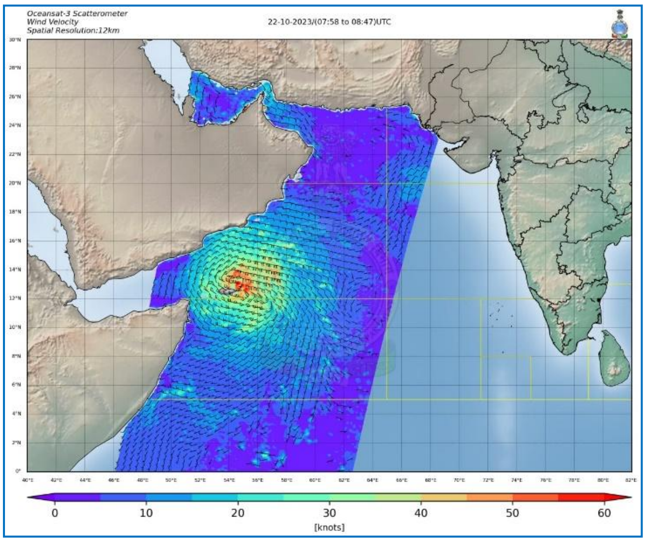


Fig.2.7: Oceansat-3 image of Extremely Severe Cyclonic Storm-Tej during 22nd October 2023

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 2.8.

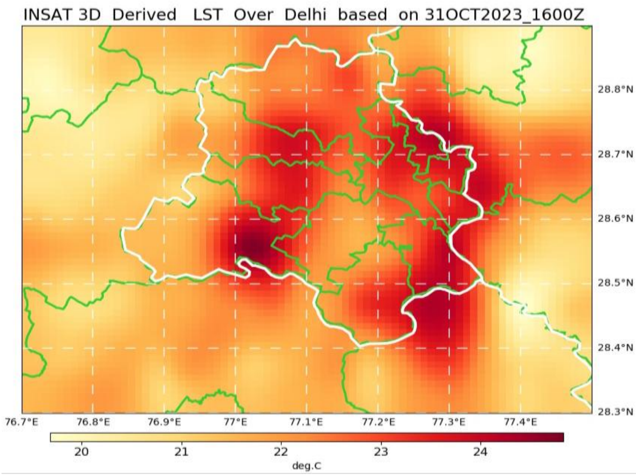


Fig.2.8: Satellite based land surface temperature

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, 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

1.2.1.5. Performance of operational NWP models during 2023

1.2.1.5.1 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.

1.2.1.5.2. 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.

1.2.1.5.2.1. 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).

1.2.1.5.2.2. 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^ox80^o, 24^ox24^o and 7^ox7^o 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

1.2.1.5.2.3. 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.

1.2.1.5.2.4. 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, 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.

1.2.1.5.3. Ensemble Prediction System

1.2.1.5.3.1. 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.

1.2.1.5.3.2. 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.

1.2.1.5.3.3. 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.

1.2.1.5.4. 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.

1.2.1.5.5. 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.

1.2.1.5.6. 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).

1.2.1.5.7. 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).

1.2.1.5.8. 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.

1.2.1.5.9. 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.

1.2.1.6 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.2.9.

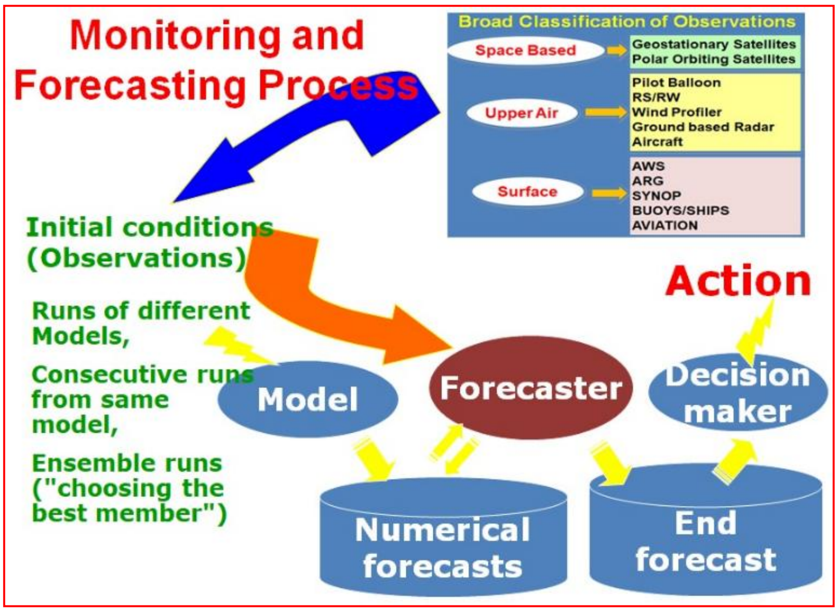


Fig.2.9. Strategy adopted for cyclone analysis and forecasting

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.

1.2.1.7 Bulletins and Products Generated by RSMC, New Delhi

RSMC, New Delhi prepares and disseminates the following bulletins:

1.2.1.7.1. 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.

1.2.1.7.2 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.

1.2.1.7.3 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 Well Marked low pressure area on 8th May, 2023. Typical example of pre-genesis forecast issued during Extremely Severe cyclonic storm "MOCHA" is presented in Fig. 2.10.

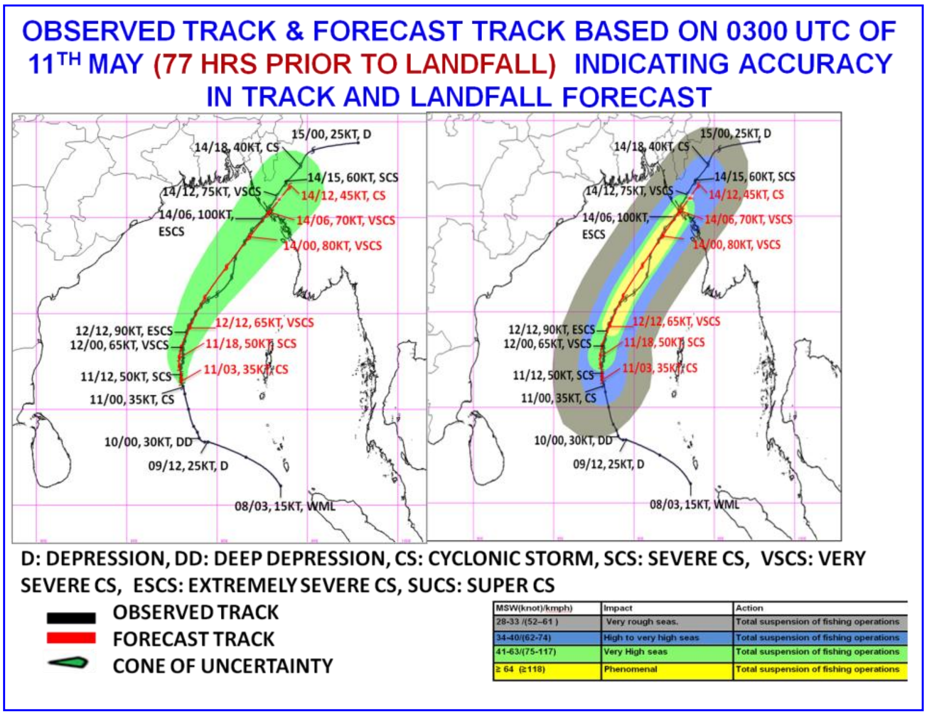


Fig2.10: Pre-genesis forecast issued at stage of well marked low pressure area on 8th May, 2023 (6 days prior to landfall on 14th May over Bangladesh) demonstrating accuracy in track and intensity forecast

1.2.1.7.4. 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.

1.2.1.7.5 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**.

1.2.1.7.6 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 Extremely Severe Cyclonic Storm "Mocha " in May 2023. The realised storm surge as reported by DMH, Myanmar was 5-10 feet (1.5-3.0m) along Myanmar coast near landfall. IMD predicted storm surge of height about 3.0-3.5m above astronomical tide. **Thus, the forecast genesis, track, landfall time, landfall point and associated surge were predicted very accurately with sufficient lead time.**

Typical guidance product is placed at Fig. 2.11.

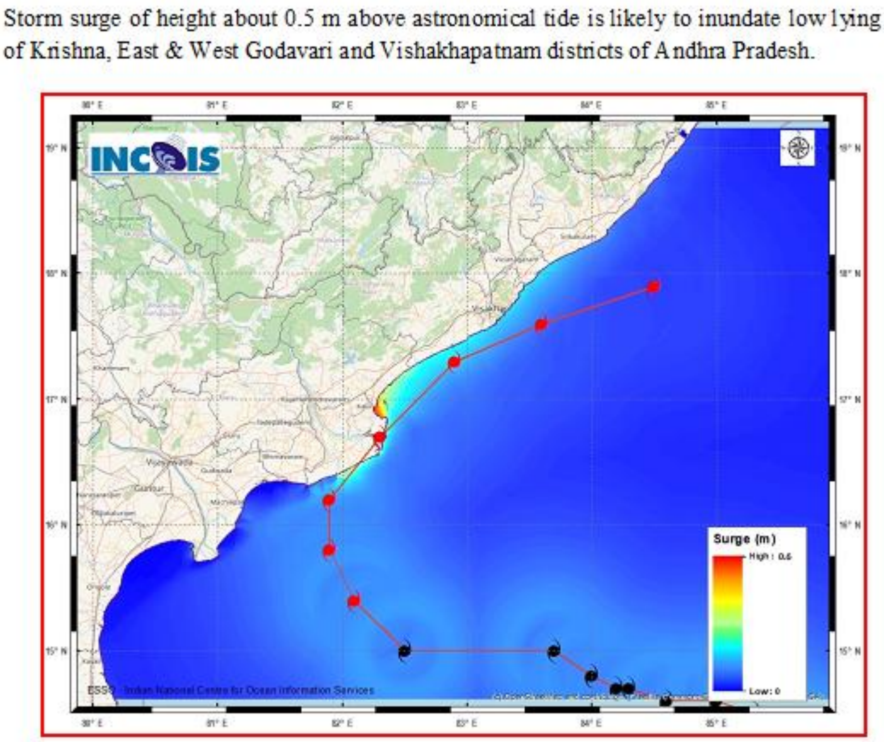


Fig. 2.11: : Probabilistic Storm Surge during ESCS REMAL

1.2.1.7.7 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. 2.12

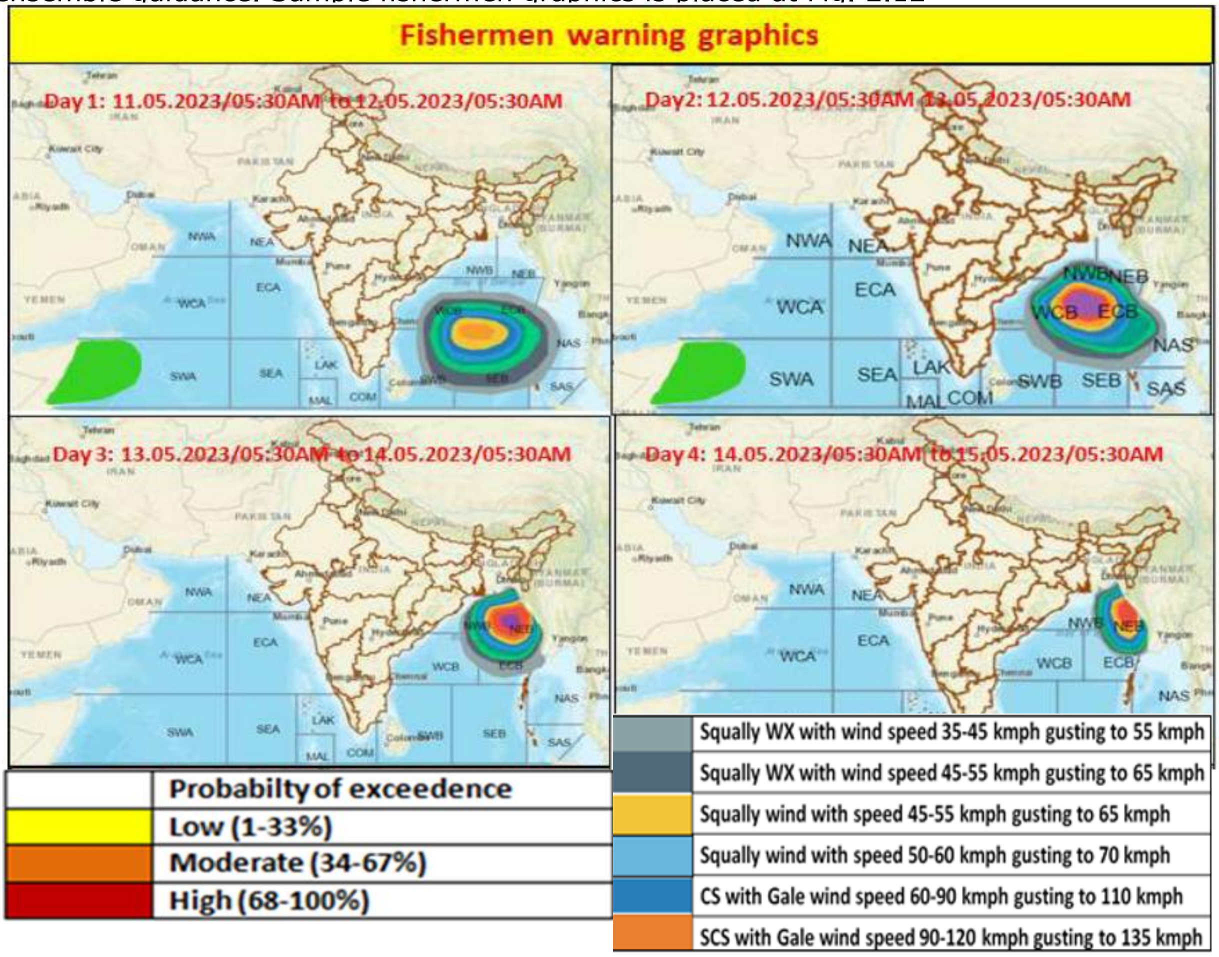


Fig. 2.12: Typical fishermen warning graphics for wind exceeding 45 kmph issued on 11th May 2023

1.2.1.7.8 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

1.2.1.7.9. 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.

1.2.1.7.10. 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 "Mocha" 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

1.2.1.7.11 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.

1.2.1.7.12 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, it's 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.

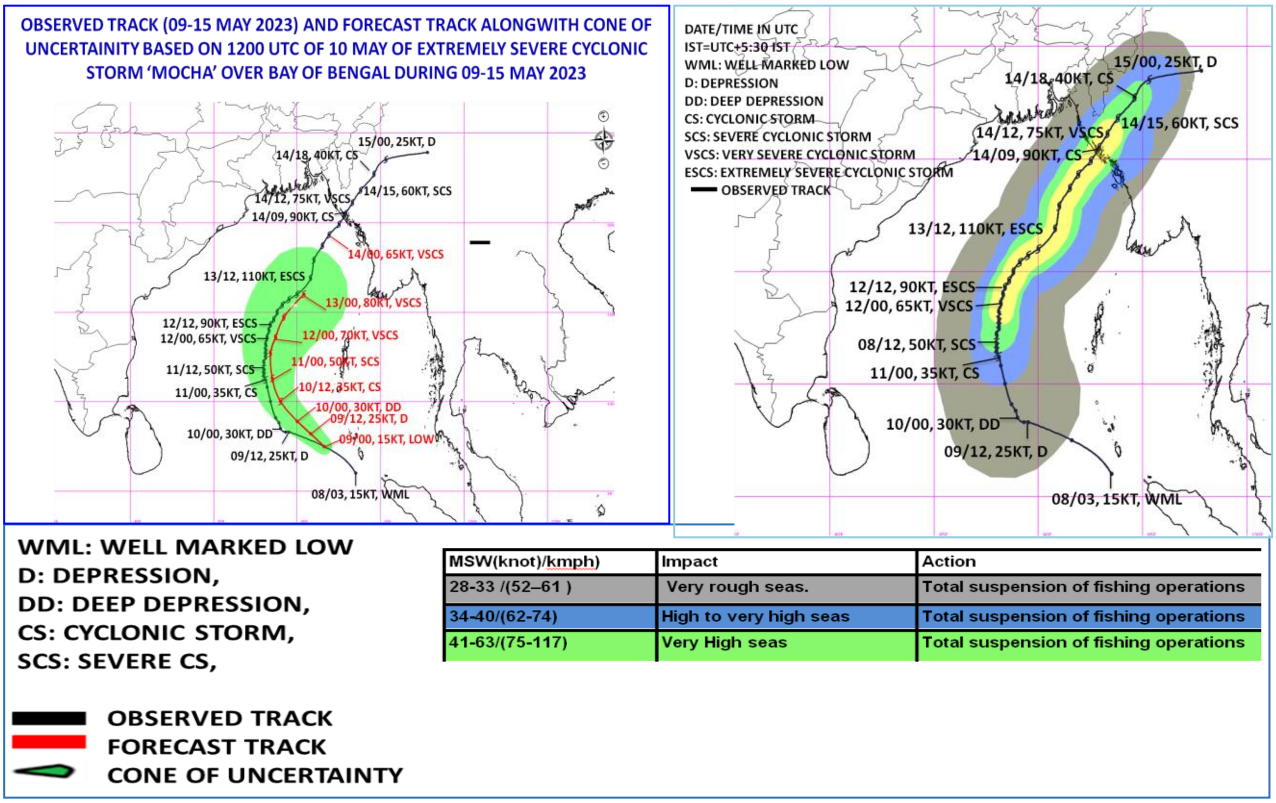


Fig.1.12: Observed and Forecast track in association with ESCS MOCHA during 9th-14th May alongwith (a) cone of uncertainty and (b) estimated maximum sustained wind speed demonstrating accuracy in track and intensity forecast about 6 days ahead of landfall.

1.2.1.7.13 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.

1.2.1.7.14 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.

1.2.1.7.15 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, 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.

1.2.1.8 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.

1.2.1.8.1. 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.

1.2.1.8.2. 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.

1.2.1.8.3. 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.

1.2.1.8.4. 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.

1.2.1.8.5. 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).

1.2.1.8.6. 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

1.2.1.8.7. 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.

1.2.1.8.9. 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, 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:

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

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

3. **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.

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

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

6. **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.

7. **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.

1.2.1.8.10. 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

1.2.1.8.11. 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.

1.2.1.8.12. 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.**

1.2.1.8.13. 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

1.2.1.8.14. 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.

1.2.1.8.15. 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.

1.2.1.8.16. 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.
f) 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.
g) The e-office has been implemented to enable better environment friendly administration with an objective of paperless work.

1.2.1.8.17. Video Conferencing System

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

1.2.1.8.18. 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.

1.2.1.8.19. 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.

1.2.1.8.20. Video Wall

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

1.2.1.8.21. 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.

1.2.1.8.22. 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

1.2.2. <u>Myanmar</u>

Myanmar delegate presented the detailed information of Cyclonic Storm during 2022 June to 2023 October. She introduced classification of tropical cyclone of Myanmar with the wind speed and she explained the check list for tropical cyclone and TC monitoring followed by Department of Meteorology and Hydrology (DMH). And then she explained the details of CS during June to December of 2023. A total of 12 low pressure areas formed over the Bay of Bengal. Out of them, some further intensified into five Depressions, one Deep Depression, one Cyclonic Storm and one Severe Cyclonic Storm. Almost all cyclones during June to December did not directly affect Myanmar. All made landfall over India and Bangladesh coasts. However, Myanmar got some rainfall over Northwest coast. And then she said that for 2023, Jan to October period: the total frequency of low-pressure areas over the Bay of Bengal was 13, and they further intensified into one Well Marked Low Pressure Area, one Depression, one Deep Depression, one very severe cyclonic storm and one Extremely Severe Cyclonic Storm. She said that one deep depression, ESCS 'MOCHA' and VSCS 'HAMOON' affected Myanmar coast. She explained about the severe weather monitoring and forecasting of Myanmar, DMH. DMH also issued related warning before the significant weather conditions. There was (26) times significant weather events all over the country during January to October 2023. She also explained about the communication and co-ordination with national and international organization and training and research activities DMH.

1.2.3. <u>Oman</u>

The representative from Directorate General of Meteorology (DGMet) Civil Aviation Authority (CAA), Sultanate of Oman presented the country report in three parts:

Part I: The representative from Oman presented the status of meteorological observatories and numerical models at DGMet Oman and the monitoring and forecasting process for TCs, Severe Weather & Tsunami. He also informed about the program launched by DGMet for development and modernization. The presentation included ways of communication and cooperation between DGMet, stakeholders and the public.

Part II: He presented some extreme cases that generated over the Arabian Sea and the challenges faced by DGMet.

Part III: Cyclone Tej, which affected Oman indirectly, was also presented. The methods of monitoring, analysis used by Oman Meteorology and the methods of publishing bulletins and warnings to everyone, especially to the public was presented. He informed that bulletins were issued in several languages, especially the languages of foreigners residing in Oman and are disseminated using different ways such as social media platforms. Precise information in simple language alongwith infographics and appropriate radar images and satellite imagesare also shared with the public and disaster managers.

<u>Part I : Introduction to Oman Meteorology</u>

- ➢ There are two Meteorological centers in the Sultanate of Oman
    - The main center (National Multi Hazards Early Warning Center) was launched in 2015.
    - A regional center in the south of Oman, Salalah.
- ➢ Oman Meteorology holds an ISO certificate to achieve international standards for both the World Meteorological Organization and the Civil Aviation Organization.
- ➢ Oman Meteorology launched a three-year program under the name Muzn to develop meteorology in all aspects.
- ➢ Oman Meteorological systems and devices were also presented.
- ➢ Oman Meteorology works to communicate and cooperate on three levels to deliver its services:-
    - On the practical level, Meteorology cooperates with the system of the National Committee for Managing Emergency Situations, as the Early Warning Center is one of the members of this system, and with the stakeholders.
    - Omani Meteorology launches its services through social media platforms attractively and easily, which achieves the highest and shortest ways to communicate information, especially about early warning.
    - Regular Media.

<u>Part II :Severe Weather</u>

- ➢ Some of the extreme cases that generated some rare phenomena in the region and have become a challenge in the region were briefly presented,.
- ➢ A case of Tornado on April 22, 2023 was also discussed.
- ➢ Episode of very heavy rain in a short time in the city of Salalah on November 10, 2023 was also presented.

<u>Part III:Tropical Cyclone “Tej”</u>

- ➢ DGMet deals with tropical conditions with a clear procedure and guidelines for public are published in an understandable format.
- ➢ The National Multi Hazards Early Warning Center holds a meeting at the center, and via video conferencing with the regional center and weather forecasters, where their three main teams provide a daily briefing.
    - NWP Team.

- Remote Sensing Team.
- Synoptic Team.
- Oman Meteorology 3 R (**Right** information at the **Right** Time for the **Right** decision).

➢ Oman Meteorology works to communicate and cooperate on three levels to deliver its services.

- On the practical level, meteorology cooperates with the National Committee for Emergency Management, as the National Early Warning Center is one of the members of this system and a strategic partner.
- Oman Meteorology launches its services through social media platforms attractively and easily, which achieves the best and shortest ways to convey information, especially regarding early warning.

➢ The various methods used by Oman Meteorology to publish bulletins and warnings to everyone, especially the public.

➢ Examples of Warnings have been published in several languages, especially for foreigners residing in Oman, and are summarized in easy ways such as an infographic supported by pictures of the occasion, satellite images, etc.

➢ Media communication.

➢ Presented the development of Cyclone 'Tej' in detail and the remarkable movement and development that was observed.

➢ Presented graphically the areas affected in terms of:

- Rain.
- Maximum winds.
- Atmospheric pressure.

1.2.4. Pakistan

The presentation made by Pakistan Meteorological Department (PMD) explained that 2022 was an exceptionally abnormal year for Pakistan from hydromet hazards point of view. From a severe snowstorm in the month of January to a massive heatwave across large swaths of the country during March - June, followed by unprecedented torrential monsoon rains (Jul-Sep) and huge GLOF (Glacial Lake Outburst Flood) events. The snowstorm at a hilly station Murree caused about 30 human lives, though the PMD issued a weather alert. There were six heatwaves (maximum temperatures been 5-12°C above average) which parched the country plains badly affecting the crops, livestock and human health and then the incessant monsoon rains in July (181% above normal) and August (243% above normal) triggered massive flooding that took over 1700 lives, affected 33 million people displacing 7.9 million and causing $32m economic loss. The annual national mean temperature for 2022 was 0.84 °C above average, placing it as fifth-warmest year on record with March and April being the hottest ever months on record. Daily maximum temperatures set new records at several locations in the country. Contrary to 2022, the year 2023 remained relatively calm with Jan, Feb, Aug & Sep being rain- deficient months, while, March to July and Oct-Nov being largely surplus rain months. For temperature, Jan and Apr-July were cooler than average while Feb and Aug-Nov were warmer than average months.

Tropical Cyclones (TC) Monitoring

During 2023, two TCs formed over the Arabian Sea *BIPARJOY* in June and *TEJ* in October. The Cyclonic Storm (CS) *BIPARJOY* formed on 7 June, intensified first into a Severe Cyclonic Storm (SCS) on 8 June then into a Very Severe Cyclonic Storm (VSCS) on 11 June and further into an Extremely Severe Cyclone storm (ESCS) on 13 June. The *BIPARJOY* kept meandering along north-northwest course until 14 June; thereafter it recurved towards northeast and weakened into VSCS on June 15. Moving further northeast ward, it made landfall at Indian Port, Jakhau, between Keti Bandar, Southeast Pakistan and Gujarat (India) on 16 June evening as a VSCS. It kept its CS strength intact and stationed over Tharparker, Sindh-Pakistan and adjoining Indian Rann of Kutch for the whole day before changing into deep depression over west Rajasthan, India. It caused severe heatwave conditions over Karachi and other adjacent districts from 09-12 June, culminating into a dust-thunderstorms and widespread heavy rains in Southeast Sindh with light/moderate rainfall in Karachi during 13 - 17 June 2023. *BIPARJOY* incidentally happened to be the longest lasting (for 13 days) cyclone in the history of Arabian Sea. PMD's cyclone warning centre, Karachi monitored it from 5-17 June with conventional surface and upper air observations, satellite FY-4, NWP models (ICON, ECMWF, GFS and RSMC, New-Delhi advisories) and Doppler Weather Radar, Karachi and kept the authorities well informed. Following the PMD's alerts, the Govt authorities for the first time evacuated over 84000 people from the vulnerable coastal areas to avoid the potential human loss (source: www.pdma.gos.pk).

TC *TEJ*

TC TEJ formed over the southwest Arabian Sea on 21 October. Tracking along northwest direction, it first intensified into a Severe Cyclonic Storm, next day into a Very Severe Cyclonic Storm and further into an Extremely Severe Cyclonic Storm. Keeping its northwest course, it crossed the Yemen coast as a Very Severe Cyclonic Storm. Although the TC TEJ was far away from Pakistani coast but due to its presence and track along the Metarea IX, PMD closely monitored it and issued nine alerts until it crossed the Yemen coast.

Severe Weather (Flood) Monitoring

PMD monitors the other severe weather phenomena like flood, drought, heatwave, heavy rains and GLOF with the network of 110 Meteorological data stations, 334 RG (Rain Gauge) stations, 85 AWSs, 34 Agromet stations, 28 Pilot Balloon Observatories (PBO), 7 Weather Surveillance Radars (with 2 DWR) installed across the country besides FY-4 satellite products. The Numerical Weather Prediction (NWP) products from the models ICON, ECMWF, GFS and JMA are also used for the purpose. For riverine flood, there are additional 100 AWS installed over river catchment areas, 45 Telemetric stations and 130 water discharge data sites (maintained by the WAPDA, water and power development authority, and Irrigation department) whose data are incorporated into a flood routing model to generate the flood alerts and warning.

Drought Monitoring,

For drought monitoring the:

i. Meteorological Indices (Cumulative Precipitation Index, Percent of Normal of Rainfall, SPI (Standard Precipitation Index), Length of dry period, Soil moisture anomaly and monthly precipitation/soil moisture outlook),
ii. Satellite Indices (Normalized Difference Vegetation Index, NDVI, Temperature Vegetation Dryness Index, TVDI and Land Surface Temperature LST),
iii. Water availability in reservoirs and
iv. Field reports are used. Based on these indices, the drought bulletins, reports, advisories and alerts are issued on weekly, fortnightly, monthly & quarterly basis.

GLOF Monitoring

Meteorological & Geomorphological based GLOF alerts area issued considering the

i. Expected Precipitation events,
ii. Persistent high temperature over couple of days,
iii. Persistent high temperatures followed by rain spells in following days and
iv. Monitoring the fluctuation in the discharge from Lake level (with river and lake level sensors installed).

Heatwave

Following the WMO criteria, a heatwave is given when the maximum temperature of a place rises 5°C above average temperature for consecutive 5 days. Since the 2015 killer heatwave of Karachi, new criteria have been followed as:

- Hot Day: Tmax=>35°C but < 40°C
- Heatwave:
  i. Tmax=>40°C
  ii. Departure from Normal = 5-6°C, persisting for at least 3-days
- Severe Heatwave:
  i. Tmax=>40°C
  ii. Departure from Normal= 7°C or more, persisting for at least 3-days

1.2.5. Sri Lanka

Early warning practice of the Early Warning Center of the Department of Meteorology (DOM), Sri Lanka is presented below:

- Advisory/special bulletins are issued for the General public and fishing/ Navel community from the stage of low-pressure level for preparedness activities based on observations, global NWP models (IMD/ECMWF/NCEP/NCMRWF) outputs and guidance from the RSMC.
- Track, Intensity and Landfall Forecast:
  - ✓ DoM continuously monitors, predicts and issues bulletins containing track, intensity, and landfall forecasts with the guidance of RSMC New Delhi till the system moves away enough /no effect.
  - ✓ The frequency of issuing warnings for cyclones depends on the distance to the country and the criteria are as follows. If a cyclone moving toward or closer to Sri Lanka
  - ✓ If cyclone is 600kms away from Sri Lanka ➔ Cyclone alert (every 12 hrs)
  - ✓ If cyclone is 500kms away from Sri Lanka ➔ Cyclone Warning (every 6 hrs)
  - ✓ If cyclone is 300kms away from Sri Lanka ➔ Cyclone Warning (every 3 hrs)
- Cyclone structure forecast for shipping and coastal hazard management
  - ✓ The radius of maximum wind and radius of Maximum Sustained wind, state of sea
- Stages of Warning: Information/Advisory /warning /No threat

- Adverse weather warning bulletins:

The tropical cyclone forecasts along with expected adverse weather like heavy rain, gale wind and storm surge will be issued with updates during cyclone. The bulletin also contained the suggested action for disaster managers and the general public in particular for fishermen.

- Warning graphics:

The graphical display of the observed and forecast track with a cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the DoM Web site. The adverse weather warnings related to heavy rain, and gale/squally wind will be presented in graphics along with color codes on the website.

- Synoptic and upper air Observations**:**

Data reception from 23 operational stations with the two stations that commenced in 2009 namely, Polonnaruwa and Moneragala and at the new international airport in Hambanthota, operating from 2014 was very good but still unable to receive WMO numbers for these three stations. The automatic weather system network in Sri Lanka consists of a total of 38 stations and 20 telemeter rain gauges which installed in areas prone to exceptionally heavy rain events, particularly in the central highlands of Sri Lanka. Another 100 telemeter rain gauges are planned to be installed with the increasing frequency of flood and landslide events. In addition, agro-meteorological Network consists of 35 stations and they are based mostly at agricultural agencies. The total number of stations measuring only 24-hour accumulated rainfall in Sri Lanka using manual rain gauges is approximately 500. Pilot balloon observations are made at 04 synoptic meteorological stations (Colombo, Trincomalee, Hambantota and Mannar) at 00, 06 and 12 UTC and currently radiosonde (GPS-based) observation is done at Colombo headquarters three times (06 UTC) per week due to financial constrain. The satellite imageries through the satellite receiving system of CMACAST and the imageries and products from INSAT, HIMAWARI and EUMETSAT downloaded through the internet were utilized.

- Coordination with emergency managers and other stakeholders

  ❖ Online stakeholder meetings with the Disaster Management Centre (DMC), the Department of Irrigation which is responsible for flood warnings, the National Building Research Organization, which is responsible for landslides warnings and the Department of Fisheries for dissemination of warnings to fishery community, are being arranged in a short notice and discuss the situation with them at the Department of Meteorology (DoM).

  ❖ Regular virtual meetings were conducted with stakeholders during extreme weather events. Possible adverse weather conditions and impacts were discussed. The daily briefing is being done for the Minister and secretary to the Ministry of Disaster Management and the disaster managers in a critical situation.

  ❖ Media briefing also is being done when it is required.
  ❖ Military troops are deploying with the coordination of the Disaster Management Centre (DMC) in the most affected areas. Thereafter, the District and Divisional Administration together with disaster management authorities take over the response

- **Warning Dissemination**

Warnings and advisories through DMC Sri Lanka are communicate through:

❖ *Warning and advisory through Web & Social Media:*
Daily updates are uploaded on Web & Facebook regularly during the life period of the system.

❖ *Press release and press briefing:*
Press and electronic media are given daily updates since the inception of the system through press releases, e-mail, and websites (SMS by DMC).

❖ *Warning and advisory for marine community*:
The Warning and advisories are issued for fishermen, and coastal and high sea shipping communities.

❖ *Advisory for international Civil Aviation :*
The meteorological watch office at Katuanayake International Airport issues significant meteorological information (SIGMET).

- **Challenges**

❖ The lack of observational data in the sea area hinders the accurate identification of the system's behavior.
❖ Prediction of intense rains, strong winds and storm surges are challenging without Doppler Radar.

- **Future Plans**

❖ *Modernization of Met services*: Modernization Project of Sri Lanka Meteorological Department under World Bank Funds

❖ *Weather Radar*: Two C-Band Doppler Radar granted by JICA (expected to complete next two years).

1.2.6. Bangladesh

Four cyclonic storms in the year 2023 formed over the Bay of Bengal and three cyclones made landfall over Bangladesh and had major impacts which were reported. The forecast and warning services by the BMD were provided with adequate lead time to prepare and execute mitigation actions. The damages and loss to properties could not avoided but minimized with proper preparedness by the disaster manager, relevant authorities and the public following the warning guidelines. A brief of impact information for individual cyclones is discussed in the country presentation. In 2023 a deep depression also formed over the Bay of Bengal in August and Bangladesh experienced a high amount of rainfall and gas a great impact on agriculture. This year unusual heat wave swept over Bangladesh from April to September due to it different impacts occurred in Bangladesh especially in the agriculture, transportation, power and health sectors.

There has been a further expansion in the monitoring network of observations (Doppler weather RADARs, upper Air, automatic weather stations and surface-based observations etc.). The more specifically lightning detectors along with Satellite Observational facilities (Himawari, Feng Yang, Meteosat and GK-2A receiving systems) data has been portrayed. The future enhancement in various observation networks have also been presented separately. Performance of operational NWP models were discussed with a focus on the rapid/slow intensity, track and landfall processes & time and location specific landfall forecasts. Bangladesh utilizes various NWP (WRF, NHM, ECMWF model visualized by Diana, MRI storm surge) models to attain at the final official forecasts for a specific cyclonic disturbance. The forecast products of the NWP modeling systems in other agencies such as RSMC, NCMRWF and IITM, Pune for different spatial and temporal scales were also followed in an integrated manner in delivering final forecasts. A systematic workshop with different stakeholders was arranged by Balderdash Meteorological Department with the support of RIMES on Impact Based Forecasts (IBF) to move from hazard-based forecast to IBF but still some challenges on implementation of IBF in Bangladesh due to lack of sector-wise good data sets.

The Government of Bangladesh, which has sophisticated Disaster Management Systems in place, and together with the humanitarian community worked extensively on preparing for the worst-case scenario on a 'no regrets' basis. Years of planning and training paid off and all efforts were made to protect the most vulnerable communities. The Government and its partners in the United Nations (UN), Red Cross/Red Crescent family, and Non-Governmental Organizations (NGO) community have worked to reinforce preparedness activities such as early warning protocols, community outreach messages and signals, establishment of Disaster Management Committees, organized relocations, coordinated cash and food distribution and much more. In the aftermath of the Cyclone, the Government also led efforts to provide immediate assistance.

The improvements made in the Tele-communication system for data reception & dissemination were discussed with respect to various components. The progress is done in terms of warning product design and dissemination procedure with different communication media including SMS, Social Media platforms, mobile Apps, Fax, Website : www.bmd.gov.bd, Telephone, Bangladesh Betar and Television, E-mail, BMD Weather APP, IVR, direct call 1090, Facebook, Twitter, GOVT. Help Line 333, Electronic and Print media etc., Bangladesh has a plan to start Common Alert Protocol (CAP) and crowd sourcing as early as possible for effectively utilized to reach out to the users.

Training activities are continued via offline as well as online (virtual) modes for national and regional forecasters and others employees by Meteorological Training Institute of BMD. Different regular long term training courses and many short-term refresher courses have been conducted by the training institute. Two training workshop on 'Impact based forecast' and 'Numerical Weather Prediction (NWP)' were conducted by storm warning center of BMD.

1.2.7. Thailand

Thailand is located in the central Indo-China Peninsula of Southeast Asia between the Bay of Bengal, the North Indian Ocean, and the South China Sea.
The country is under the influence of:

- SW monsoon in rainy season (mid-May to mid-Oct);
- NE monsoon in the winter time (mid-Oct to mid-Feb)
- Tropical Cyclone (TC) from both sides of the Bay of Bengal and the South China Sea impact on Thailand.

Tropical cyclones in the Bay of Bengal have a significant impact on Thailand, with the highest frequency occurring in May and November. The southern part of Thailand is at risk of facing tropical cyclones during the period from October to January, especially those originating in the South China Sea and crossing through Thailand towards the Bay of Bengal.

❖ Key Activities and Technical Components of Meteorology

The Technology System Concerning to Warning System in the Thai Meteorological Department (TMD), together with the Instrument and observing system, weather forecasting and NWP system, Aeronautical Met observing and forecasting, marine observing and forecasting, Earthquake, data and telecommunication, and data and information services system. The Thai Meteorological Department (TMD) has implemented and provided alerts/warnings on severe weather in CAP format since 2019 and has participated in the RAII pilot to enhance the Meteorological Disaster Risk Reduction Capability. During, 2020 - 2021, TMD continued to provide warnings on severe weather in CAP which have been linked and made available on the GMAS-A platform. The warnings and alerts in the CAP format have been disseminated immediately and updated twice a day if events comply with TMD's criteria. TMD has also improved our website to display the locations of disseminated CAP warnings and alerts on the map (https://www.tmd.go.th/en/CAP).

❖ TC monitoring and forecasting

From October 2022 to 19 December 2023, two Tropical Clones over the Bay of Bengal affected/impacted Thailand but not directly. However, tropical cyclones, originating over the Bay of Bengal, Cyclonic Storm named “SITRANG” in October 2022 and Extremely Severe Cyclonic Storm “MOCHA” (01B) in May 2023 had some effects on rainfall in Thailand during that time. These caused strong sea and wave heights in the Andaman Sea and there was heavy to very heavy rain in the upper part of Thailand.

The aspects of the early warning system for Tropical Cyclones have been standardized in the document “SOP” for Cyclone Warning in the TMD. The TMD uses input data from observation data, GTS, satellite data, radar network, AWS, and National Hydro Informatics and Climate Data Center, Thailand (Hydro and Agro Informatics Institute (HAII), Royal Irrigation Department (RID), Water Resource Department (WRD), etc.) then into the forecasting process by analyzing the weather maps, and cloud satellite images with their application platform, GsMAP, and radar composite together with NWP products and ultimately the weather forecast products, Met alarm guidance, and advisory and warnings which are then provided to the public. In addition, TMD also generates storm track forecast maps using the TMD-WRF model and Himawari Request from the Japan Meteorological Agency (JMA) for fulfillment.

For the Tropical Cyclone warning in Thailand Standard Operation Procedure (SOP), In the event of a developing low-pressure system intensifying into a tropical depression over the Bay of Bengal, and anticipating potential impacts on Thailand. A three-day warning will be issued and urge the public to stay informed, and TMD will closely monitor the situation.

❖ For Severe weather monitoring and forecasting

The TMD utilizes the GEO (Geostationary Earth Orbit) satellites for severe weather and TC monitoring and forecast by using RDCA (Rapidly Developing Cumulus Areas) technique with the collaboration and support from the JMA, and issuing warnings and producing the risk map area for severe weather events. Moreover, TMD also uses satellite data from GsMAP to display hourly and 24-hour cumulative rainfall estimation (Quantitative Precipitation Estimation, QPE) for the early warning system.

❖ Warning communication and coordination

TMD provides weather warnings to the public and sends information to relevant agencies, social media, Line Alert, TMD official website (www.tmd.go.th), TMD weather radio, and Hotline 1182. The TMD also established a storm monitoring center at the headquarters and communicated via video conference system with the regional centers, provincial stations, and coordination of relevant agencies. The flow chart below shows the SOP process of normal weather conditions and severe weather conditions with the Coordination of relevant agencies.
TMD closely cooperates with the Office of National Water Resources (ONWR) of Thailand is the main organization that systematically regulates and manages the policies of integrated national water resource management. The National Water Administration Center (NWAC) was established under ONWR to monitor and integrate coordination on water situation with 38 water-related agencies, to make plans and preparations for dealing with floods and drought situations. The Royal Irrigation Department (RID) During the rainstorm-flood events, the Thai Meteorological Department (TMD), ONWR, and Royal Irrigation Department (RID) took effective measures to enhance weather and flood forecasting and early warning for disaster prevention and mitigation. Together with the Department of Disaster Prevention and Mitigation (DDPM) by the National Disaster Warning Center (NDWC) has implemented the following activities on Disaster Risk Reduction (DRR).

The ONWR followed up on the Weather Advisory from the TMD and integrated operations with related government agencies under the NWAC to carry out the measures of preparation for the rainy season, to monitor rain forecast, especially about the storms, to prepare water traffic planning based on the severity of the disaster, focusing on risk monitoring and plans to support the situation in risk areas whole the country. In 2022-2023, the DDPM installed telemeters to collect weather data or "telemeters" at 555 points in risk-prone areas of Thailand, developed an information system to support analysis and decision making or the Decision Support System (DSS) by improving the model of the disaster forecast analysis system. In addition, the DDPM also implemented the Cell Broadcast System (CBS) to enhance the public warning capacity to the public by making connections coordinated with the Office of The National Broadcasting and Telecommunications Commission (NBTC), related public and private sectors such as the TMD, National Hydro-informatics Data Center (NHC), the RID, ONWR, National Telecom Public Company Limited (NT), and leading mobile network service providers. The DDPM Notification and Warning Dissemination Process**.**

1.2.8. United Arab Emirates

The Nation Center Of Meteorology in UAE has presented the infrastructure, which includes more than 140 Automatic Weather Stations, 7 Weather Radar, 31 Air Quality Stations, 1 Ozone Monitoring Station, 4 satellite images from 4 different sources, 2 Upper-Air (Radiosonde), 2 Wind Profilers and 1 Lightning Detection Station all those information and data send to one a Unified data based and distributed and feeding the different services need to provide.

Numerical Weather Prediction*:*
The NCM runs 4 different NWP (COSMO- WRF GFS – WRF ECWF – Watch III) 4 times a day, up to 10 days forecast, and up to 1 km resolution.

Meteorological Services:

The Meteorological services are provided to more than 200 destinations locally. Other services are also provided globally.
NCM develops several mobile applications, web portals, and websites targeting a wide range of customers with innovative ideas.

Disaster Risk Reduction*:*

NCM collaborates and coordinates with the MOI and NCEMA, the NDMO in the UAE. The Natural Disasters Response Plan is activated based on the severity of the situation. NDMO can take action if needed using Early Warning System (EWS).

Tropical Cyclone Biparjoy

On 13 – 14 June 2023, the east coast of UAE was affected by a long swell with a wave period reaching 10 seconds. The wave height offshore was 2.5 meters. The Tide during the high tide period was 2.8 meters. The estimated wave setup reached 0.6 meter, which led to inundation over some beaches and coastal areas.

1.9: Iran

A presentation was made on TC monitoring and forecasting, severe weather monitoring and forecasting, Warning communication and co-ordination by Islamic Republic of Iran Meteorological Organization (IRIMO) of Iran.

The presentation covered the three parts viz., (i) Weather Forecasting System including Data and Information Receiving & Tools and Production, (Ii) Information Dissemination and Early Warning System and (iii) Recommendations to Enhance Capacities

The Main Natural Disaster in IRAN are: Flood, Flash Flood, Storm Surge, Strong wind and lightning.

For further improvements in forecast accuracy and services, the following suggestions were proposed:

- Member countries were requested to share observational data through GTS.
- After each cyclone lessons learned to be consolidated and shared with forecasters for further improvements
- RSMC shares the report with all members. Members may also share with RSMC the feedback for further improvements.
- RSMC will share the difficult case statistics with members for further research & development
- RSMC New Delhi is sharing cyclone data through APIs. The same can be shared with members as per request
- IMD conducts regular training on Satellite, Radar, NWP Models, and Severe Weather Forecasting. Can be arranged for member countries as well as per request.

Recommendations: The PTC appreciated RSMC, New Delhi for providing real-time tropical weather outlooks and tropical cyclone advisories during 2022 and 2023 to the member countries.

The PTC while noting the improvement suggestions urged upon NMHSs and RSMCs to enhance the real-time and past data sharing and improve the R&D on tropical cyclone monitoring and forecasting.

1.3 HYDROLOGICAL ACTIVITIES

1.3.1 India

1.3.1.1 Flood monitoring and forecasting mechanism

1.3.1.1.1 Services 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.

(a) 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
25	NCT of Delhi	2	0	2
	Total	**200**	**140**	**340**

(b) 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.

(c) 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.

(d) 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.

1.3.1.1.2. Services provided by India Meteorological Department

(a) 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 2023, 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-2022" has been published and uploaded on IMD website at the link https://hydro.imd.gov.in/hydrometweb/. "Rainfall statistics of India-2023" is under process.

The seasonal statistics for the year 2023 are as follows:

- **Winter Season (Jan-Feb) 2023:-** During Winter season, the country as a whole received 44% less rainfall of its long period average (LPA)(39.8mm). Out of 36 Met sub-divisions, 02 Met subdivision recorded large excess rainfall (>60%), 01 recorded excess rainfall (20% to 59%), 02 recorded normal rainfall (-19% to +19%), 09 recorded deficient rainfall (-59% to -20%), 19 recorded large deficient rainfall (-99% to -60%) and 03 Met. sub-division recorded no rainfall (-100%).
- **Pre- Monsoon (March-May) 2023:-** During Pre- monsoon, the country as a whole received 13% less rainfall of its LPA (130.6mm). Out of 36 met sub-divisions, 17 sub-divisions recorded large excess rainfall, 04 recorded excess rainfall, 07 recorded normal rainfall, 06 Met sub-divisions recorded deficient rainfall, 02 Met sub-divisions recorded deficient rainfall and no met subdivision has in 'NO RAIN' category.
- **SW Monsoon (June-Sept.) 2023:-** During the SW-monsoon season, the country as a whole received 6% less rainfall of its LPA (868.6mm). NW India, Central India, East & NE India and Southern peninsula, received 101%, 100%, 82% and 92% of its LPA respectively. Out of 36 Met sub-divisions, 0 subdivisions recorded large excess rainfall, 03 met sub-divisions recorded excess rainfall, 26 recorded normal rainfall and 07 Met sub-divisions recorded deficient rainfall and not any Met. Sub-divisions in LARGE EXCESS, LARGE DEFICIENT, NO RAIN category of rainfall.
- **Post Monsoon Season (Oct-Dec) 2023:-** During the post-monsoon season, the country as a whole received 9% less rainfall of its LPA. Out of 36 Met subdivisions, 03 Met sub-divisions recorded large excess rainfall, 04 recorded excess rainfall, 18 recorded normal rainfall, 10 recorded deficient rainfall, 01 sub-divisions recorded large deficient rainfall and not any met. Sub-divisions recorded no rainfall category.

Design Storm Studies are being conducted to evaluate design storm estimates (average areal rainfall magnitude and time distribution) for various project catchments under some river sub-basins in the country, for use as main input for design engineers in estimating design flood for hydraulic structures, irrigation projects, dams etc. on various rivers. This estimation of design values is required for safe and optimum design of storage and spillway capacity. On the request of Central Govt./ State Govt., Private Agencies, design storm values (Standard Project Storm (SPS), Probable Maximum Precipitation (PMP) along with Time Distribution) and Return Period

Values (RPV) are being provided for users as main input on payment basis.

The design storm studies of Three (03) projects have been completed during 2023-24 (April, 2023 to March, 2024) and Design Storm Values and Project Reports were provided to the concerned project authorities and a revenue of Rs.19,39,290/- was generated.
A Technical Report on 'Design Storm Studies undertaken during 2023' is published in IMD website.

(b) 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 Folld 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.

(c) 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.

1.4 DISASTER RISK REDUCTION ACTIVITIES

1.4.1. India

1.4.1.1 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.

1.4.1.2 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.

1.4.1.3. 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.

1.4.1.4. 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.

1.4.1.5 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.

1.4.1.6. 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

1.4.1.7 Current Status

1.4.1.7.1 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.
1.4.1.7.2 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).

1.4.1.7.3 (**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.

1.4.1.8 National Disaster Response Force (NDRF)

1.4.1.8.1 Vision

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

1.4.1.8.2. 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.

1.4.1.8.3. 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.

1.4.1.8.4 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.

1.4.1.8.5 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.

1.4.1.8.6 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, 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.

1.4.1.8.7 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.

1.4.1.8.8. 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.

1.4.1.8.9. 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

1.4.1.8.10. 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

1.4.1.8.11. 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

1.4.1.8.12. 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

1.4.1.8.13. 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.

1.4.1.9. 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.

1.5 TRAINING

1.5.1. Training Component

The Human Resource Development has always been one of the prime thrust areas of the India Meteorological Department for capacity building and keeping pace with the latest trends in various activities in the department. Meteorological Training Institute (MTI) IMD Pune component of RTC India is the main center 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 2022. 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 2022-23, MTI has organized 9 regular long term (2-12 months duration) certificate training courses (5 BIP-M & 3 BIP-MT), with approximately 430 national participants and 1 overseas participant from Cameroon Island and during 2023-24 (till November 2023), 6 regular long term (2-12 months duration) certificate training courses (4 BIP-M & 1 BIP-MT), with approximately 152 national participants and 2 overseas participants from Mauritius Met. Services. 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. A Short-term Refresher course on "Aviation Meteorology" conducted in virtual mode & A Joint IMD-WMO group fellowship training on "Hands on practical aspects of Numerical Weather Prediction (NWP) conducted in Physical mode in 2022-2023. Customized training course on Aviation Meteorology for Meteorological Personnel of Bhutan is going on for the period 20.11.2023 to 15.12.2023 in physical mode.

E-learning method in training program has been introduced 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.

Various training conducted during the period from 2022-23 and 2023-24. Many meteorologists from various organisations are trained. Advanced Meteorological Training Course (AMTC) conducted for Indian Navy, Coast Guard and also trainee from Cameroon as part of the Forecasters Training Course (FTC). Other training programmes like Integrated Meteorological Training Course (IMTC), Direct Recruited Scientists Training Course (DRSTC) and Basic/Modular Training Course are also conducted during the period.

1.5.1.2. Trainings conducted by Regional Specialised Metyeorological Centre, New Delhi

India Meteorological Department (IMD) is one of six Regional Specialized Meteorological Centre's (RSMCs) in the world recognized 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, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, 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 Centre's (ACWCs) and Cyclone Warning Centre's (CWCs) were also included. In 2015, International Training on Workshop on Tropical Cyclones Forecasting was organized with participants from WMO/ESCAP Panel countries, Australia, Switzerland, Cambodia, Lao PDR and Philippines.

This year, the WMO's Tropical Cyclones Forecasters Training 2023 was conducted by Regional Specialized Meteorological Centre (RSMC), New Delhi during 03-13 April through Web-Ex. This was the 19th 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, Sri Lanka, Maldives, Pakistan, Iran, Oman, United Arab Emirate & Saudi Arabia, and 80 participants from various sub-offices of IMD. The training was 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.

1.5.1.3 Other training:

a) Attachment training at RSMC New Delhi during February, 2023

b) User specific training for users

c) Refresher courses on

(i) Satellite

(ii) Radar

(iii) NWP applications

1.5.1.4 Regular Courses on General Meteorology

S.No.	Departmental/Non Departmental courses	Duration	Training centres	Eligibility Criteria
1.	Advanced Met. Course (Departmental Training	1 Year	Pune	B.Sc* (with Physics or Maths as main subject) /M.Sc./B.E./ B.Tech.
2.	Forecasters Training course	6 Months	Pune	B.Sc. (with Physics or Math as main subject) and after successful completion of Intermediate Met. Training course
3.	Intermediate Training course including one month on the Job training.	3 Months	Pune, Delhi, Kolkata & Chennai centres.	B.Sc. (with Physics or Maths as main subject) after successful completion of Basic Met. Training course.
4.	Integrated Meteorological Training course.	4 Months	Pune, Delhi, Chennai a Kolkata	Fresh recruited Scientific Asst. with B.Sc. (Phy., Math/ BE/B. Tech. qualification
5	LA's Modular Course	2 Months	Delhi Kolkata.	Departmental Met. Attendant who have passed SSC and working in same cadre for 5 years

1.6 RESEARCH and publication

1.6.1 India

India Meteorological Department remained involved in extensive research activities. The major achievements during 2023 were:

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

1.6.1.1. Panel News

- Panel News letter of PTC is a bi-annual document, which is issued after every six months. However, due to COVID Pandemic it got discontinued.
- THE PTC news letter is revived and the 2023 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.

1.6.1.2. 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 has been completed and published. The same is also available on RSMC, New Delhi website under the heading, publications.

1.6.1.3. Journal publications (MAUSAM, 2023)

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1.7. REVIEW OF THE TROPICAL CYCLONE OPERATIONAL PLAN (2023)

Coordination within WMO Tropical Cyclone Programme

In its 50th session of PTC, the Panel was presented about activities under, and those requiring coordination through, TCP and WMO regional offices. It appreciated the comprehensive presentation, and thanked WMO support to the Panel.

The Panel was informed that that all activities in relation to TCP under WMO Annual Operating Plan under LTG 1 (better serve the society) and 4 were very well implemented without delay. There was no impact by Covid-19 during implementing TCP activities. WMO expressed sincere appreciation to Members and their experts to have made all possible efforts to work closely to enable to carry out those TCP activities with success.

The Panel was also informed of the Resolutions/Decisions/Recommendations of EC-75 (June 2022), EC-76 (27 Feb. – Mar. 2023) and Cg-19, respectively, which are highly relevant to implementation of TCP.

The Panel was further informed about global activities of TCP in relation to global coordination and technical developments under the Advisory Group on Tropical Cyclones (AG-TC). Those activities included, among others:

- WMO GDPFS centers' compliance review.
- WMO Coordination Mechanism (WCM) and the Weather4UN project.

- Tropical Cyclone - Probabilistic Forecast Products (TC-PFP) Project.
- Review of the GDPFS Manual related to appendices on TC matters.
- International Workshop on Tropical Cyclones – 10th session (IWTC-10) – recommendations.
- Tropical Cyclone Forecaster Competency.
- Development of Tropical Cyclone Impact-based Forecasting products – Implementation Decision 10 (EC-68).
- WMO Guide for National Meteorological and Hydrological Services in Support of National MHEWS Procedures, Coordination Mechanisms, Systems and Services – Tropical Cyclones.

The Panel was informed that the "WMO Guide for National Meteorological and Hydrological Services in Support of National Multi-Hazard Early Warning Systems, Procedures, Coordination Mechanisms, and Services, Guide No. 1 – Tropical Cyclones" (**WMO No. 1339**) was published. This Guide emphases:

(a) Risk knowledge — Institutional coordination in the areas of risk information and assessment for IBF and risk-based warning;
(b) Hazards awareness and warning — Detection, monitoring, analysis and forecasting of the hazards and assessment of possible consequences;
(c) Service delivery — Procedures and dissemination of advisory and warning information including the service delivery to communities and communication with partners;
(d) Preparedness — Preparedness and response capabilities at all levels, including support for national response and recovery planning.

The Guide is in high alignment with the four pillars of the United Nations Early Warning for All Initiative (EW4ALL). It is considered as a goog source and reference and intended to promote Members to establish their national/territorial synergized coordination mechanism and procedures through multi-agency and multi-sectorial coordination and collaboration, thus to enable each Member to have timely responses to early warnings of tropical cyclone disasters to the last mile

The Panel noted with appreciation that many training activities on tropical cyclones were organized during the inter-sessional period to support capacity development of the Members to meet competencies and skills that are required for tropical cyclone forecasting and warning services. The Panel appreciated RSMC New Delhi to have organized annual training for the Panel Members to enhance their tropical cyclone forecasting and warning competencies o better serve their people.

The Panel was informed that the regional activities on tropical cyclone regional bodies were well organized in the past year. Those meetings updated regional arrangements for tropical cyclone circumstances and strengthened regional collaboration and coordination with concerted approaches toward tropical cyclones.

The Panel was informed that the 10th International Workshop on Tropical Cyclones (IWTC-X) took place in Bali, Indonesia, face-to-face, supplemented with simultaneous online mode for its plenary sessions, from 5 to 9 December 2022. The IWTC-X was hosted by the Agency for Meteorology, Climatology, and Geophysics of the Republic of Indonesia (BMKG). It was attended by more than120 in-person participants and over 300 registered online. reports, presentations, and recordings available on the IWTC-10 website. The workshop produced, based on detailed discussion, in total 22 recommendations. It is a quadrennial event jointly organized by WGTMR/WWRP and TCP.

1.8. PTC SECRETARIAT

Decision regarding the PTC Secretariat hosting took place during the PTC-50 session in Baharin from 19-23 Dec 2023.

Based on the decision taken during last session (PTC-49), Chairman PTC sent the invitation to PTC member countries calling for hosting PTC Secretariat for the period from 2024 to 2027 (4 years). Responding to this letter, PR of Thailand expressed that they are not ready to host the PTC secretariat. The PR of Myanmar informed that they don't have expertise to host the secretariat. The PR of Pakistan informed that they are hosting the PTC Secretariat since 2004 and if given the opportunity can rehost the PTC secretariat providing all the required facilities. The PR of India informed that they agreed in principle to host the secretariat and all facilities as required can be provided. WMO representative presented the status to the PTC. The PTC discussed in details about the terms of references for hosting the PTC secretariat and agreed upon the TOR.

The PTC requested all the representatives to all the member countries about their willingness to host the PTC secretariat. The members were asked to give their choice to elect one from India and Pakistan. The majority of the members elected India for the new Secretariat of the WMO/ESCAP Panel on Tropical Cyclones (PTC) over the Bay of Bengal and the Arabian Sea for next 4 years from 2024-2027.

The PTC appreciated Government of Pakistan for having hosted the Secretariat since 2004 and provided support to the PTC. The PTC congratulated Govt. of India for hosting the PTC Secretariat during 2024-27. In this regard, a formal letter followed by host agreement from the Chair of PTC will be addressed to the PR of India to take the charge of the PTC Secretariat for the period of 2024-2027. The host agreement will be signed by the Host Country (India) and the Chairman of the PTC.

Dr. Mrutyunjay Mohapatra, Director General of Meteorology, IMD thanked all the 13 members of PTC, for electing India to host the PTC Secretariat during 2024-27.

Documents related to the past activities, correspondence etc. of the PTC secretariat and the TOR will be communicated to New PTC Secretariat (Appendix-I).

- **<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>**

To commemorate 50 years of PTC, it was decided in PTC 49 Session followed by the meeting of the organizing committee constituted thereof to invite the proposed logo from the PTC members. RSMC New Delhi circulated the Action Points to members. The sample logos were received from the members and circulated to the PTC members by RSMC. The proposed logos were presented by RSMC in the 50^{th} Session of PTC. A dedicated Logo to commemorate 50 years of PTC was finalized and approved by the PTC and is given below. This Logo will be used for next one year (till December 2024).

The PTC Secretariat will propose a permanent logo based on wide circulation to the members of PTC and their inputs and suggestions. That will be presented in the 51st Session of PTC for consideration. (Action: WMO/PTC Secretariat).

1.9 SUPPORT FOR THE PANEL'S PROGRAMME

1.9.1. PTC Trust Fund

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

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PANEL ON TROPICAL CYCLONE TRUST FUND
Trust Fund 421313
Final Statement of Income and Expenditure
For the period 1 January to 31 December 2022
Amounts in US dollars

1.	Balance of fund at 1 January 2022				166,880
2.	Income:				
	2.1 Contributions				
	2.1.1 India (25 March 2022)		2,980		
	2.1.2 United Arab Emirates (8 April 2022)		3,000		
	2.1.3 Thailand (19 April 2022)		3,000		
	2.1.4 Oman (28 April 2022)		3,000		
	2.1.5 Myanmar (17 May 2022)		3,000		
	2.1.6 Bangladesh (28 June 2022)		3,030		
	2.1.7 Sri Lanka (5 July 2022)		3,000		
	2.1.8 Maldives (7 September 2022)		3,000		
	2.1.9 Oman (21 December 2022		3,000		
	2.1.10 Total contributions			27,010	
	2.2 Interest			110	
	2.3 Total income				27,120
3.	Total available funds during reporting period				194,000
4.	Expenditure:				
	4.1 Direct project costs			-	
	4.2 Indirect project costs				
	4.2.1 Unrealized loss on currency exchange	a/	650		
	4.2.2 Bank charges		70		
	4.2.3 Total indirect project costs			719	
	4.3 Total project expenditure				719
5.	**Balance of fund at 31 December 2022**				**193,281**

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 (UNORE) in force on the day of the transaction. Project account balances (in CHF) are translated to applicable donor reporting currencies based on UNOREs 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
Date: 2023.02.21 16:53:44 +01'00'
Brian Cover
Chief, Finance Division
20 February 2023

Certified Correct:
Taoyong Peng
Senior Scientific Officer, Tropical Cyclone Programme
20 February 2023

1. Final Statements of Incomes and Expenditure for the Period 1 January to 31 December 2022

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

   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 2022, 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 2023

The salient features of the cyclonic disturbances (CDs) over the north Indian Ocean (NIO) during the year 2023, 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 2023:

- Depression over southeast & adjoining southwest Bay of Bengal (30th January – 02nd February 2023)
- Extremely Severe Cyclonic Storm "MOCHA" over the Bay of Bengal (9th-15th May,2023)
- Extremely Severe Cyclonic Storm "BIPARJOY" over the ARABIAN Sea (6th - 19th June, 2023)
- Deep Depression over the Northeast Bay of Bengal (1st – 3rd August, 2023)
- Depression (30th Sept – 1st October)
- Extremely Severe cyclonic Storm TEJ over southwest Arabian Sea (20-24 October, 2023)
- Very Severe Cyclonic Storm HAMOON over westcentral Bay of Bengal (21-25 October, 2023)
- Cyclonic Storm "MIDHILI" over Bay of Bengal during 15th – 18th November, 2023
- Severe Cyclonic Storm "MICHAUNG" over Bay of Bengal during 1st – 6th December

Observed tracks of the CDs during 2023 are presented in **Fig. 2.1.**

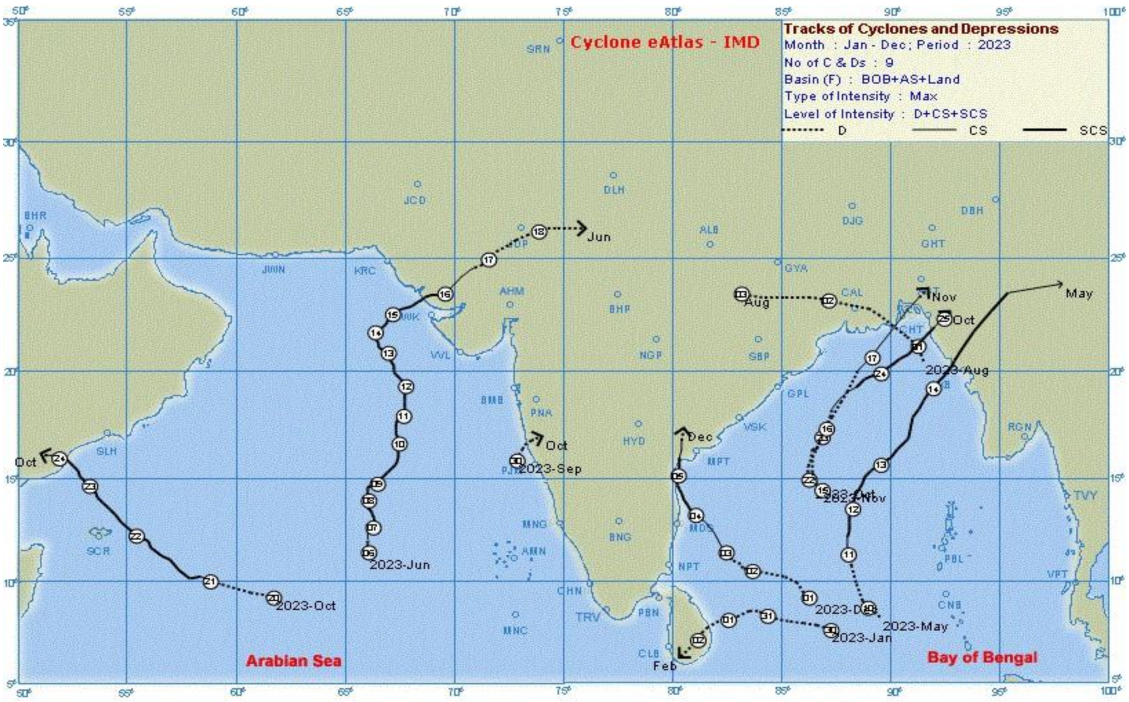

Fig 2.1: Observed Tracks of all cyclonic disturbances during 2023.

- Annual Frequency of CDs: During 2023, 9 CDs (maximum sustained wind speed (MSW) ≥ 17 knots) developed over the NIO against normal (during 1965-2021) of 11.2 per year. Thus, annual activity of formation of CD was below normal during the year 2023.
- Frequency of different categories of CDs: There were 2 depressions and 1 deep depressions (MSW: 17-33 knots) (Normal: 6.5 per year), 1 cyclonic storm (MSW: 34-47 knots) (Normal: 1.8 per year), 1 severe cyclonic storms (MSW: 48-63 knots) (Normal: 2.9 per year), 1 very severe cyclonic storms (MSW: 64-89 knots) (Normal: 2.9 per year) and 3 extremely severe cyclonic storms (MSW: 90-119 knots) (Normal: 2.9 per year) during the year 2023. A total of 6 cyclones (MSW≥ 34 knots) developed over the NIO during 2022 against normal of 4.7 per year. Overall, the frequency of formation of depressions over the region was less than normal and that of severe cyclones was above normal during 2023.
- Frequency of CDs over Bay of Bengal and Arabian Sea: There were 3 CDs over Arabian Sea (Normal: 2.3 per year), 6 over Bay of Bengal (Normal: 7.8 per year) and 0 over land (Normal: 1.1 per year) during 2023. Basin-wise activity wrt formation of CDs was above normal over Arabian Sea and below normal for Bay of Bengal and Land.
- Frequency of cyclones over Bay of Bengal (BoB) and Arabian Sea (AS): There were 3 CDs over Arabian Sea (Normal: 2.3 per year) (Above Normal), 6 over Bay of Bengal (Normal:7.8 per year) (Below Normal). Overall activity was above normal over Arabian Sea and below normal over Bay of Bengal.
- Unique features wrt lifetime of cyclones: During 2023, Biparjoy was the longest lifetime.
- Frequency of CDs in different seasons: There was 1 depression during Winter Season (Above Normal), 2 CDs during pre-monsoon season (Normal:1.4 per year) (Below Normal), 2 CDs during monsoon season (Normal: 4.9 per year) (Below Normal), 4 CDs during post-monsoon season (Normal: 4.8 per year) (Below Normal). Overall activity was above normal during the pre-monsoon and winter season. It was below normal during monsoon and post-monsoon season.
- Landfall: All the CDs were land falling systems (Normal: 3.2 per year). So the land falling activity was above normal this year.
- Tracks (Straight/recurving): All 6 cyclones had recurving tracks.
- Landfall of cyclones: All 6 cyclones crossed the coast as cyclones (Normal: 3.2 per year). Overall frequency of landfalling cyclones was above normal.
- The forecast performance of RSMC New Delhi during 2019-23 vis-a-vis 2014-18 is shared herewith:
- The average track forecast errors during 2019-23 have been 72 km, 112 km and 156 km respectively for 24, 48 and 72hrs against the average errors of 86, 132 and 178 km during 2014-18. The errors in track prediction registered an overall improvement of 20% upto 96 hours lead period during 2019-23 and comparable beyond that.
- The annual average errors in intensity forecast during 2019-23 have been 7.1 knots, 9.3 knots and 13.8 knots respectively for 24, 48 and 72hrs lead period of forecast against the average errors of 9.6, 14.1 and 14.3 knots during 2014-18. The errors in intensity prediction registered an overall improvement of 20-30% upto 60 hours lead period during 2019-23.
- The annual average landfall point forecast errors during 2019-23 have been 18 km, 42 km & 73 km for 24, 48 & 72hrs lead period against the average errors of 47 km, 70 & 104 km during 2014-18. The errors in landfall point prediction registered an overall improvement of 30-60% upto 72 hours lead period during 2019-23.
- The landfall time forecast errors during 2019-23 have been 2.8, 4.6 & 9.5hrs for 24, 48 &

72hrs lead period against the average errors of 2.9, 5.1 & 5.8hrs respectively during 2014-18. The errors in landfall time prediction registered an overall improvement of 10% upto 48 hours lead period during 2019-23.

Statistics of bulletins issued during 2023:

- National Bulletin for national disaster managers, media and general public: 280
- RSMC Bulletin including daily Tropical Weather Outlook for WMO, ESCAP, 13 PTC member countries: 584
- Tropical Cyclone Advisory Centre Bulletin for Civil Aviation (TCAC Bulletin): 116
- Bulletin under Global Maritime Distress and Safety System: 577

Table 2.1.1 Some Characteristic features of cyclonic disturbances formed over north Indian Ocean and adjoining region during 2023

S No.	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. Attain ed
1.	Depression over southeast & adjoining southwest Bayof Bengal (30th January – 02nd February 2023)	30th January, 2023 over southeast and adjoining southwest BoB (7.7N/87.2E)	Crossed Sri Lanka coast between Batticaloa and Trincomalee near latitude 7.8°N and longitude 81.6°E during 0330 to 0430 hours IST of the 2nd February as a depression with the estimated maximum sustained wind speed of 25 knots gusting to 35 knots (45-55kmph gusting to 65 kmph).	1004 hPa at 0300 UTC on 30th January 2023 near (7.7N/87.2E)	25 knots at 0300 UTC on 30th January 2023 near (7.7N/87.2E)	T 1.5

2.	Extremely Severe Cyclonic Storm "MOCHA" over the BoB (9th-15th May, 2023)	9th May, 2023 over southeast BoB and adjoining south Andaman Sea (8.3N/89.5E)	Crossed North Myanmar – Southeast Bangladesh coasts between KYAUKPYU (Myanmar) and Cox's Bazar (Bangladesh) close to North of Sittwe (Myanmar) near latitude 20.3 and longitude 92.8 with maximum sustained wind speed of 180- 190 Kmph gusting to 210 kmph during 0700-0900 UTC (1230-1430 hrs IST).	938 hPa at 1800 UTC on 13th May, 2023 near (17.9N/91E)	115 knots at 1800 UTC on 13th May, 2023 near (17.9N/91E)	T 6.0
3.	Extremely Severe Cyclonic Storm "BIPARJOY" Over the ARABIAN Sea (6th - 19th June, 2023)	6th June, 2023 over southeast AS (11.3N/66.0E)	Crossed Saurashtra & Kutch and adjoining Pakistan coasts between Mandvi (Gujarat) and Karachi (Pakistan) close to Jakhau Port (Gujarat) near latitude 23.28°N and longitude 68.56°E during 1700 hours IST and 1800 hours IST.	958 hpa at 0300 UTC on 11th June, 2023. (18N/67.6E)	90 knots at 0300 UTC on 11th June, 2023. (18N/67.6E)	T 5.0
4.	Deep Depression over the Northeast Bay of Bengal (1st– 3rd August, 2023)	1st August, 2023 over central parts of North BoB (20.5N/91.5E)	Crossed Bangladesh coast near latitude 21.9°N and longitude 90.3°E close to east of Khepupara, during 1530 to 1630 hours IST on 1st Aug 2023, as a deep depression, with maximum sustained wind speed of 55-65 kmph gusting to 75 kmph.	988 hpa at 1200 UTC on 1st August, 2023. (22.5N/89.5E)	30 knots at 0600 UTC On 1 st August 2023 near (21.2N/91.2E)	T 2.0

5.	Depression (30th Sept – 1st October)	30th September, 2023 over eastcentral Arabian Sea off south Konkan-Goa Coast (15.9N/ 72.8E)	Crossed South Konkan coast between Panjim and Ratnagiri during 1500-1700 UTC	1000 hpa at 1200 UTC on 30th September (16.6N/73.2E)	25 knots at 0300 UTC on 30th Sept (15.9N/72.8E)	T 1.5
6.	Extremely Severe cyclonic Storm TEJ over southwest Arabian Sea during 20 - 24th October	20th October, 2023 over southwest AS (9.3N/61.7E)	Crossed Yemen coast close to south of Al Ghaidah between 2100 UTC and 2200 UTC near (15.90N/52.15E)	964 hpa at 0300 UTC on 22nd October, 2023. (12.3N/55.4E)	95 knots at 0300 UTC on 22nd October, 2023. (12.3N/55.4E)	T 5.0
7.	Very Severe Cyclonic Storm HAMOON over westcentral Bay of Bengal during 21-25th October	21st October 2023 over westcentral BoB (14.7N/86.4E)	Crossed Bangladesh Coast to the south of Chittagong near (21.90^0N/91.90^0E) between 1900 UTC and 2000 UTC	984 hpa at 0300 UTC on 24th October, 2023. (20.0N/89.5E)	65 knots at 0300 UTC On 24th October, 2023. (20.0N/89.5E)	T 4.0
8.	Cyclonic Storm "MIDHILI" over Bay of Bengal during 15th – 18th November, 2023	15th November, 2023 over westcentral BoB (14.5N/86.8E)	Crossed Bangladesh coast near Khepupara during 0900-1000 UTC of 17th November as a Cyclonic Storm with the maximum sustained wind speed of 35 knots (65-75 kmph gusting to 85 kmph)	998 hpa at 1200 UTC on 17th November, 2023. (22.8N/90.8E)	40 knots at 0600 UTC On 17th November, 2023. (21.2N/89.5E)	T 2.5

9.	Severe Cyclonic Storm MICHAUNG over Bay of Bengal during 1st – 5th December	1st December, 2023 over southwest BoB (9.1N/86.4E)	Crossed South Andhra Pradesh coast close to south of Bapatla during 0700-0900 UTC of 05th December (near Lat 15.7 and Lon 80.3 as a severe Cyclonic Storm with the maximum sustained wind speed of 50 knots (90-100 kmph gusting to 110 kmph)	992 hpa at 1800 UTC on 3rd December, 2023 12.8N/81.6E)	55 knots at 1200 UTC on 3rd December, 2023 (14N/80.5E)	T 3.5

Table 2.1.2 Statistical data relating to cyclonic disturbances over the north Indian Ocean during 2023

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	↔								↔			
2.	DD								↔				
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 2023 at different stages of intensity

i. For NIO Region

S.No.	Type	Life Time in (Days)
1	D	11 days 21 hours
2.	DD	7 days 15 hours
3.	CS	4 days 21 hours
4.	SCS	4 days
5.	VSCS	9 days 9 hours
6.	ESCS	4 days 12 hours
	Total Life Time in (Days)	42 days 6 hours
	Average	04 days 17 hours

ii. For Bay of Bengal Region

S.No.	Type	Life Time in (Days)
1	D	8 days 12 hours
2.	DD	6 days
3.	CS	3 days 9 hours
4.	SCS	2 days 18 hours
5.	VSCS	1 days 6 hours
6.	ESCS	1 days 18 hours
	Total Life Time in(Days)	23 days 15 hours

iii. For Arabian Sea Region

S.No.	Type	Life Time in (Days)
1	D	3 days 9 hours
2.	DD	1 days 15 hours
3.	CS	1 days 12 hours
4.	SCS	1 days 6 hours
5.	VSCS	8 days 3 hours
6.	ESCS	2 days 18 hours
	Total Life Time in(Days)	18 days 15 hours

iv. For Land Region

S.No.	Type	Life Time in (Days)
1	D	0 days
	Total Life Time in(Days)	0 days

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	9	7	6	6	5	4	4	3	3	0

D) Basin-wise distribution of cyclonic distribution

Basin	**Number of cyclonic disturbances**
Bay of Bengal	6
Arabian Sea	3
Land depression	0

Table 2.1.3 Cyclonic disturbances formed over the north Indian Ocean and land areas of India during 1997-2023

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**

Table 2.1.4 Average translational speed of Tropical cyclones over the NIO during 2023

TC Name	Basin	Period	Average Translational Speed		
			6 Hr	12 Hr	24 Hr
MOCHA	BoB	09-15 May	14.6	14.4	14.4
BIPARJOY	AS	06-19 June	7.9	7.7	7.7
TEJ	AS	20-24 October	14.4	14.8	14.8
HAMOON	BoB	21-25 October	21.8	19.6	19.6
MIDHLI	BoB	15-18 November	18.6	19.1	19.1
MICHAUNG	BoB	20-24 December	10.1	9.6	9.6

Table 2.1.5 Velocity Flux of Tropical cyclones over the NIO during 2023

TC Name	**Velocity Flux (10^2 kt)**	**Accumulated Cyclone Energy (10^4 kt^2)**	**Power Dissipation Index (10^6 kt^3)**
MOCHA	10.6	7.72	6.11
BIPARJOY	30.03	22.94	18.05
TEJ	10.0	7.69	6.23
HAMOON	3.35	1.68	.88
MIDHLI	1.1	.41	.15
MICHAUNG	4.6	2.1	.99
Total	59.68	42.54	32.41

CHAPTER-III

Vision and mission of the Panel

3.1. 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 minimizingloss and damage caused by tropical cyclones and associated meteorological, hydrological and other ocean hazards in the Bay of Bengal and the Arabian Sea.

3.2. 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.*

3.3. 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 facilitiesfor better information sharing;
b. Natural disaster reduction, mitigation and prevention through the implementation of improved detection, prediction and warning systems of tropical cyclones, depressionsand 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 by 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 levelsto 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 cyclone 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 to minimize 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 of tropical cyclone risk awareness at the community level through awareness events, school education, trainings, 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 partnership including industries, non-governmental organisations (NGOs) etc. for awareness, feedback and information dissemination etc. aiming to disaster risk reduction (DRR);
n. Enhancement of resource mobilization activities for implementation of CTP.

3.4. Challenges and Opportunities

Panel is facing challenges and opportunities that have been raised in recent years in its implementation of the activities to fulfill 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.

Appendix-I

TERMS OF REFERENCE FOR THE PANEL ON TROPICAL CYCLONES SECRETARIAT

The Panel on Tropical Cyclones (PTC) Secretariat will coordinate the Panel's programme in close consultation with the WMO and ESCAP Secretariats. The PTC Secretariat will report to the Panel at regular intervals on the progress of the work so far undertaken. Specifically, to the extent that its available resources permit, the PTC Secretariat shall:

1) Assist the Members as administrative, documentary, and information centre of the Panel on Tropical Cyclones;

2) Implement the PTC decisions and coordinate and monitor the implementation of the PTC Annual Operating Plan;

3) Maintain close contact with the Panel Members and other relevant organization by correspondence and coordination to carry out all matters related to implementation of recommended programmes;

4) Follow up decisions of Panel meetings and related activities such as those concerning other regional tropical cyclone bodies, or the General Component of the WMO Tropical Cyclone Programme (TCP);

5) Manage the operation and promote the use of the PTC website;

6) Organize the annual session of the Panel by assisting in collection and preparation of material to be included in the documentation;

7) Process and take necessary action promptly on correspondence from Panel Members, WMO, and other sources;

8) Enhance visibility of the PTC in cooperation with Panel Members.
9) In consultation with WMO, plan and manage the utilization of PTCTF in support of TC programmes and activities. (PTCTF=Panel on Tropical Cyclone True Fund)

10) Identify emerging issues, including severe cyclone events, and propose actions in consultation with Member(s) concerned and AWG, for timely attention by TC Chair.