Celebrating 150 Years of IMD: Frontiers for Early Warning

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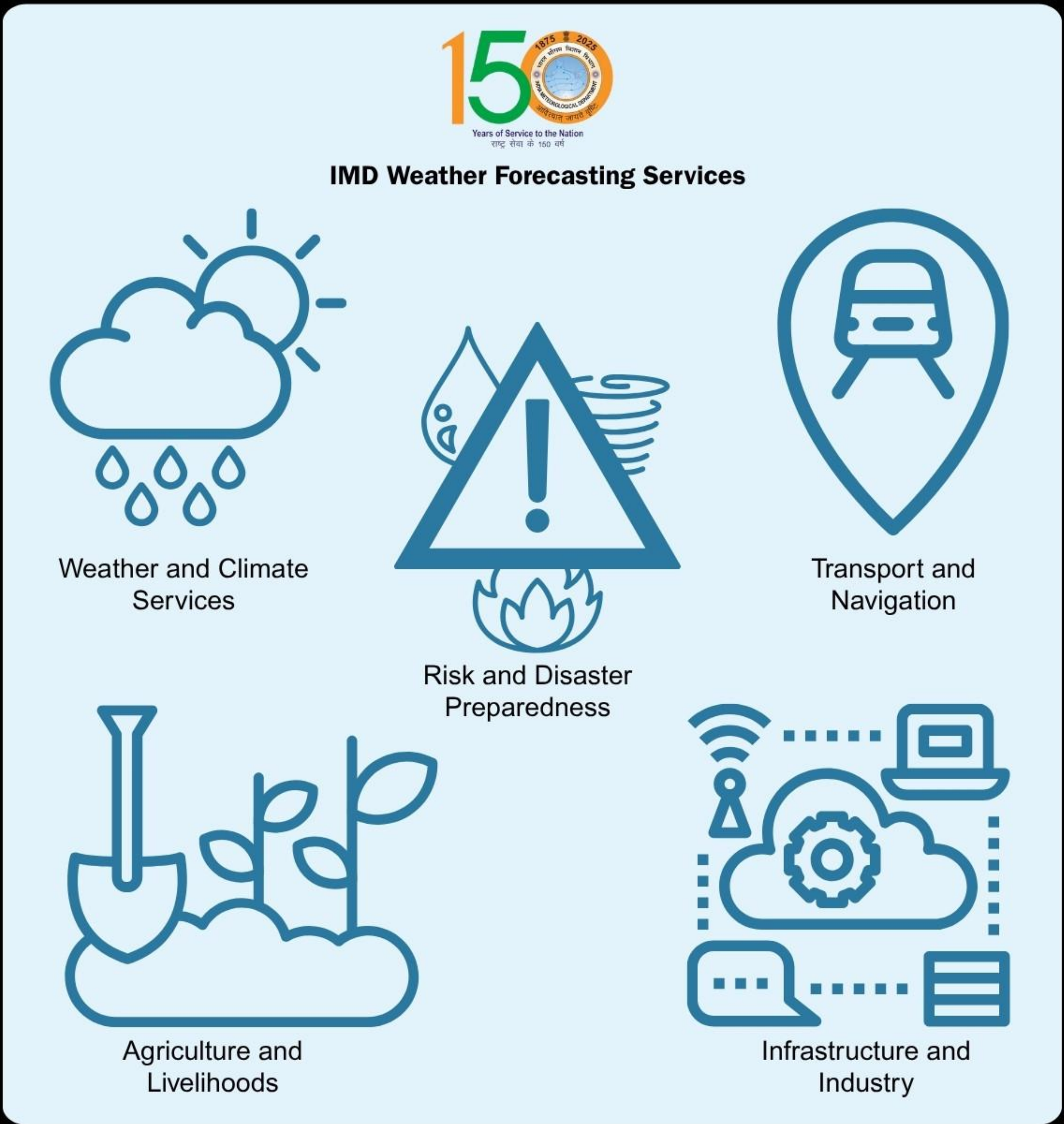

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Promoting Disaster Risk and Climate Resilience Awareness Across South Asia Since 2005.

Introduction

*By **Dr. M. Mohapatra,** Director General of Meteorology, India Meteorological Department, Ministry of Earth Sciences, Government of India*

It is with great pride and immense satisfaction that I extend my heartiest greetings to all readers, colleagues, stakeholders, and citizens of India on the occasion of a historic milestone—the completion of **150 years of the India Meteorological Department (IMD)**. This sesquicentennial celebration marks a remarkable journey of scientific progress, dedicated public service and enduring commitment to safeguarding life, property, and the environment. This milestone is not just a reflection of IMD's longevity but a celebration of its evolution as a national institution committed to weather and climate resilience, disaster preparedness, and public welfare

Established in 1875, the India Meteorological Department was born out of the need to monitor and understand the complex weather systems affecting the Indian subcontinent. Over the past century and a half, IMD has grown from a modest weather observation service into one of the world's leading meteorological organisations, with a robust network of observatories, advanced satellite & radar systems, numerical modelling, and artificial intelligence integration. Our progress reflects the transformation of India itself—from colonial administration to a modern republic embracing science and technology in every facet of national development. With a mandate to serve sectors as diverse as agriculture, aviation, energy, health, and disaster management, IMD has been at the forefront of supporting India's development while minimising the risks posed by extreme weather events

Throughout this journey, IMD has played a vital role in disaster risk reduction, providing early warnings for cyclones, heavy rainfall, heatwaves, thunderstorms, and other extreme weather events. Our services have saved countless lives and protected critical infrastructure, making IMD an indispensable pillar of national resilience and have guided both short-term responses and long-term planning. Particularly in recent decades, we have witnessed a significant improvement in the accuracy, lead time, and dissemination of forecasts, driven by advancements in high-performance computing, real-time data collection, and integration with national and international agencies.

IMD's contributions go far beyond weather prediction. With the shift from traditional weather forecasting to impact-based forecasting services, IMD has empowered farmers through agrometeorological advisories, supported aviation and maritime sectors with precision forecasts, and guided urban planning and energy management through climate assessments. Our partnership with disaster management authorities, state governments, local administrations and civil society organisations like AIDMI has ensured that critical information reaches the last mile, especially during life-threatening weather events.

As we celebrate this extraordinary milestone, we also recognise the challenges that lie ahead. Climate change, urbanisation, and increasing frequency of extreme weather demand continuous innovation and enhanced collaboration. In this context, IMD is deepening its investment in science, technology, and partnerships to ensure that our weather and climate services are increasingly user-centric, location-specific, and inclusive. Our goal is to ensure that no community is left behind in accessing actionable weather information—particularly the most vulnerable groups who bear the brunt of climate risk. IMD is fully committed to expanding its capabilities in line with the vision of "Weather and Climate Services for All", ensuring inclusivity, accessibility, and scientific rigor in every service we deliver.

This commemorative edition of the *Southasiadisasters.net* is a tribute to the legacy of IMD and the collective effort of scientists, meteorologists, engineers, forecasters, and administrative personnel who have shaped its journey. It showcases the evolution of weather services in India, celebrates key milestones, and reflects on the path forward. I extend my sincere appreciation to AIDMI for its ongoing work in the field of disaster risk reduction and for highlighting IMD's contributions in this special edition. On behalf of the India Meteorological Department, I hope we will move ahead with renewed energy and resolve, working together to build a weather-resilient and climate-smart India, rooted in knowledge, powered by innovation, and dedicated to the service of the people. ■

CYCLONE PREPAREDNESS

India Meteorological Department and Tropical Cyclones: Key Achievements and Agenda

*By **Cyrille Honoré**, Director of Disaster Risk Reduction and Public Services Branch, WMO, Geneva, Switzerland*

The India Meteorological Department (IMD) has been a leader in tropical cyclone monitoring and early warning services since its establishment in 1875. Recognising the severe impact of tropical cyclones on the coastal areas surrounding the North Indian Ocean, the World Meteorological Organization (WMO) and the Economic and Social Commission for Asia and the Pacific (ESCAP) jointly established the Panel on Tropical Cyclones (WMO/ESCAP PTC) in 1972 as an intergovernmental body. Since 1988, IMD has served as a WMO Regional Specialised Meteorological Centre (RSMC) for Tropical Cyclones, providing forecasts and advisories to the 13 member countries of the PTC. Over the years, it has strengthened its capabilities through cutting-edge technology, global collaborations, and innovative forecasting techniques, enhancing early warning systems and reducing the impacts of cyclones.

Key Achievements

IMD's cyclone warning services date back to 1875, making it one of the world's oldest systems. The establishment of RSMC in 1988 strengthened IMD's role in issuing tropical weather outlooks, track forecasts, and storm surge warnings. Advances in Numerical Weather Prediction (NWP), including Hurricane Weather Research and Forecast (HWRF) and Ensemble Prediction Systems (EPS), have improved cyclone track, intensity, and landfall forecasts. The lead time for cyclogenesis forecasts has extended to seven days, while landfall prediction errors have been reduced to less than 20 km in 24-hour forecasts.

IMD employs INSAT, HIMAWARI, and GOES satellites for real-time cyclone monitoring, rainfall estimation, and cloud motion analysis. The deployment of Doppler Weather Radars along the coastline enhances cyclone tracking, particularly for rapid intensification and recurvature.

Since Cyclone Phailin (2013), IMD has implemented impact-based forecasting, integrating hazard exposure and vulnerability assessments. Tools like Geographic Information Systems (GIS) and Decision Support Systems (DSS) visualise storm impacts, aiding disaster preparedness. IMD has also developed a Multi-Hazard Early Warning System (MHEWS), incorporating storm surge guidance, extreme rainfall alerts, and marine warnings for coastal cities.

Through training workshops and technology transfers, it enhances forecasting capacity across WMO/ESCAP Panel on Tropical Cyclones (PTC) member countries, ensuring a coordinated regional response. IMD and the WMO Regional Centre New Delhi are actively engaged in the WMO Coordination Mechanism aiming at providing Humanitarian Agencies with fit-to-purpose meteorological information.

Agenda for the Future

IMD aims to expand its Doppler Weather Radar system, deploy Unmanned Aerial Vehicles for direct cyclone observations, and strengthen ocean-based monitoring with additional buoys and satellites to improve tracking accuracy.

To further enhance forecasts, IMD is integrating AI and machine learning into prediction models, improving the detection of rapid intensification and recurvature scenarios. The introduction of probabilistic forecasting will better represent uncertainties, aiding disaster management decisions.

Strengthening last-mile connectivity is a priority. IMD is expanding multi-language, impact-based warning dissemination, ensuring communities receive timely, actionable information via mobile

The India Meteorological Department (IMD), a pioneer in cyclone forecasting since 1875, plays a vital role as a WMO Regional Centre for Tropical Cyclones. With advancements in satellite monitoring, Doppler radars, numerical models, and impact-based forecasting, IMD has significantly reduced casualties in the North Indian Ocean. Looking ahead, IMD aims to integrate AI, expand ocean and radar observations, and enhance last-mile warning systems to achieve its Vision 2035: zero loss of life and climate-resilient communities.

networks, social media, and GIS-based platforms. Community-based resilience programmes will support vulnerable populations with localised preparedness strategies.

IMD also plans to establish a Tropical Cyclone Research Test Bed in India, advancing research on cyclone dynamics and refining forecasting techniques. Regional capacity-building initiatives will continue, strengthening cooperation for cyclone risk reduction.

Recognising climate change's impact on cyclone intensity and frequency, IMD is developing climate-resilient forecasting systems and integrating coastal vulnerability assessments into disaster management planning. The department is also promoting nature-based solutions, such as mangrove restoration, to mitigate cyclone impacts.

Conclusion

IMD's leadership in tropical cyclone forecasting has significantly reduced casualties and economic losses in the North Indian Ocean. Its Vision 2035 aims for zero loss of life and minimal property damage through technological advancements, regional cooperation, and enhanced community engagement. By leveraging next-generation forecasting techniques and strengthening disaster preparedness, IMD remains committed to a weather-ready and climate-resilient future for India and the region. ■

DISASTER PREPAREDNESS

Indian Early Warning System: A Model for the World

*By **Sanjay Agrawal,** Dy Director General, Disaster Management, Ministry of Communications, Government of India, New Delhi, India*

As climate change intensifies the frequency and severity of natural disasters, effective early warning systems are crucial to minimising loss of life and damage. India, with its vast and diverse population, has developed one of the world's most advanced and cost-effective Common Alerting Protocol (CAP)-based Integrated Alert System, setting a global example. Since its inception, India has delivered over 45 billion location-based SMS alerts, covering various disasters.

Key Features of India's Early Warning System

Integrated and Fully Automated: All stakeholders, including government agencies and local authorities, are connected through the system, and states have dedicated dashboards for monitoring. The system is fully automated, eliminating the need for manual intervention, ensuring timely and efficient dissemination of alerts.

Global Standards: Indian Early Warning system globally the largest to disseminate alerts to more than 1.40 billion population and it is designed on global standards of Common Alerting Protocol (CAP) i.e. ITU-T X.1303.

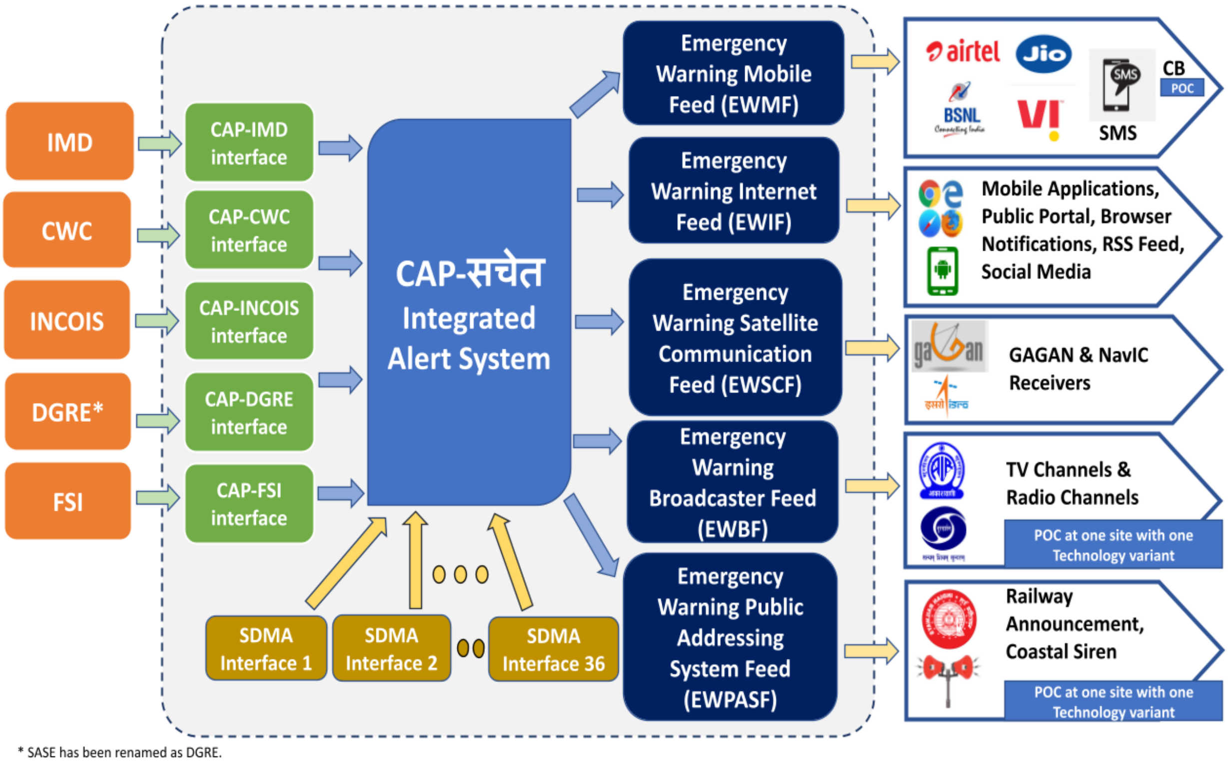
Geo-Targeted Alerts: Precision in disaster communication is essential. India's geo-targeting capability ensures that alerts reach only those in affected regions, preventing unnecessary panic.

Multi-Mode Communication: India employs a multi-channel approach—SMS, mobile apps, radio, TV, satellite communication, and public address systems—to ensure no one is left out. The Sachet mobile app provides real-time alerts, while satellite-based systems like GAGAN and NavIC reach remote areas.

Timely Dissemination of Alerts: A successful early warning system depends on timely alerts. The system provides valuable lead time for individuals to evacuate or take preventive actions.

Multi-lingual support: Alerts are delivered in over 19 Indian languages, ensuring accessibility for diverse linguistic groups. This localised approach enhances disaster preparedness, facilitating better

"We learned about the Sachet app during the training on extreme heat. I have installed it, and now I can plan my small business better to protect it from climate risks," said a small business owner from Ahmedabad, Gujarat, India. Photo: AIDMI.



The schematic diagram shows that all Alert Generating Agencies (IMD, CWC etc), all Alert Authorising Agencies (SDMAs) and all Alert Dissemination Agencies (Radio, TV, Mobile etc) are connected to an integrated system eliminating the need of manual intervention.

resource allocation and evacuation planning.

Overcoming Implementation Challenges: Regulatory and Policy Interventions

Implementing an effective early warning system in a vast and diverse country like India presents numerous challenges requiring regulatory and policy intervention by the Government challenges. Key interventions include:

Cost-Free Disaster Alerts: To remove financial barriers, the Government mandated zero tariffs for SMS and Cell Broadcast alerts, ensuring widespread use without budget constraints.

Enhancing Public Trust: A fixed SMS header was introduced for disaster alerts, increasing authenticity and reducing resistance from telecom providers.

Mandatory Cell Broadcast System: Initially absent in most networks, Cell Broadcast faced resistance from Telecom Service Providers (TSPs) due to security concerns. Following extensive consultations, the Government issued policy directives mandating its implementation across all networks.

Standardising Handset Compatibility: Mobile devices in India lacked uniform support for Cell Broadcast alerts. Policy directives, issued via Gazette Notification, ensured standardisation, enabling consistent alert reception.

Indigenous Technology Development: To reduce costs and dependency on foreign OEMs, C-DOT developed an indigenous Cell Broadcast system, now covering 60% of India's telecom network. This scalable solution enhances resilience and national autonomy.

India's Leadership in Global Early Warning Systems

By integrating indigenous technology, strategic policies, and global collaboration, India has set a global standard in disaster preparedness. Disseminating over 45 billion alerts, the system exemplifies scalability and efficiency, reinforcing India's role as a leader in early warning systems. The United Nations (UN) and the World Meteorological Organization (WMO) aim for "Early Warning for All" by 2027, a goal India is well-equipped to help achieve. India can support other nations through capacity-building, regulatory guidance, and international collaborations. By sharing technology and expertise, India can facilitate the development of early warning systems tailored to other countries' needs. ■

Local Action, Global Reach: Forging a Resilient Future Against the Silent Scourge of Extreme Heat

*By **Jagan Chapagain,** Chief Executive Officer and Secretary General of the IFRC, Geneva, Switzerland*

On behalf of the International Federation of Red Cross and Red Crescent Societies (IFRC), I congratulate the India Meteorological Department (IMD) on its 150th anniversary. IMD has been a cornerstone of India's safety, leveraging weather science to protect lives. This milestone underscores the critical importance of robust scientific institutions in our collective efforts towards "Local Action, Global Reach of Early Warnings for All."

While cyclones and floods often capture headlines, extreme heat operates with a stealth that belies its devastating impact. It is the "silent assassin of climate change." 2024 was the hottest year on record; 2023 only briefly held the record. Annually, an estimated 489,000 people die from heat-related causes, 45% in Asia. The IFRC's Climate Centre estimated that in a single year, over 60% of the world's population suffers under extreme heat, at least for a few days.

And these figures, though alarming, are likely underestimates, as many heat-related deaths are attributed to other conditions. The economic toll is also immense, with losses up to 6.7% of GDP in developing nations.

The escalating climate crisis dramatically increases the probability of mass fatality heat disasters, a challenge not confined by season or hemisphere. From record summers in South America and Australia to unprecedented March 2024 school closures in South Sudan due to temperatures exceeding 42°C, human-induced climate change is making heatwaves more frequent and intense.

At IFRC, we witness this daily. Our commitment to the "Early Warnings for All" (EW4All) initiative is steadfast; we co-lead its crucial pillar on "Preparedness to Respond," aiming to protect everyone by 2027. But warnings must catalyse early, anticipatory action - translating forecasts into accessible, empowering information.

This is where "local action" becomes paramount. The IFRC network, with 191 National Societies, is deeply embedded in communities. In the Asia Pacific, this work expands: active Early Action Protocols (EAPs) for heatwaves are operational in Bangladesh, Myanmar, and Vietnam. Last year, the Bangladeshi EAP activation targeted 123,000 vulnerable people. Additional simplified Early Action Protocols (sEAPs) are developing in Thailand (heat-pollution) and Pakistan, while nations like the Maldives and Sri Lanka advance sEAPs for climate-health issues like dengue. IFRC is also active in the Southeast Asia Heat Health Forum.

Our work in Nepal provides a concrete example. To protect its communities, the Nepal Red Cross Society, with IFRC and Red Cross Red Crescent Climate Centre support, scientifically identified a 38°C 'heat threshold' for the city of Nepalgunj. This specific temperature was pinpointed by analysing 24 years of local climate data as the point at which heat transitions to an extreme level, triggering alerts and protective measures. Such localised thresholds are vital because they form the scientific basis for early actions.

Shining a light on this pervasive threat is vital. City heat action plans, like Nepalgunj's and those in Ahmedabad and Karachi, are crucial. They identify vulnerable groups, establish action triggers and champion simple solutions like market shades and local tree planting.

Accessible science and forecasts save lives. This includes media broadcasts, direct outreach like Australia's Telecross REDi programme, and anticipatory actions such as Vietnam Red Cross's mobile cooling centres or Spain's proactive lifeguard rostering. Local volunteers, like those in Bangladesh teaching heat first-aid, are trusted community messengers.

As IMD embarks on its next 150 years, its role is ever more critical. The journey requires intensified collaboration between meteorological services, humanitarians, governments, academia, and communities. Though the future seems daunting, with anticipation, local investment, and global commitment to early warnings, we can mitigate extreme heat's worst impacts. ■

FLOOD RESILIENCE

Flood Forecasting in India: Journey from 1958

By ***Sharad Chandra***, *Commissioner (Flood Management) and* ***Rajesh Kumar,*** *Sr. Joint Commissioner (Flood Management), Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, New Delhi, India*

Introduction

Disastrous floods of 1954 necessitated a paradigm shift from using only structural measures for flood control to the starting of non-structural measures for mitigating floods. One of the important recommendations of the "High Level Committee on Floods" constituted by the Government of India in April 1957 was "Absolute or permanent immunity from flood damage is not physically attainable by known methods of flood control. Flood Plain Zoning and Flood Forecasting & Warning and like measures should therefore be given due importance, particularly, as they don't require large capital investments".

Flood Forecasting & warning service as the most important, reliable and cost-effective non-structural measures for flood mitigation, was initiated by erstwhile Central Water & Power Commission in India in November 1958 by setting one forecasting station at Old Delhi Railway Bridge, for the national capital, on the river Yamuna.

Floods of 1968 in many parts of the country causing considerable loss of life hastened the process of flood forecasting. In 1969, Central Water Commission (CWC) was charged with the responsibility of issuing flood forecasting services in flood-prone basins of Ganga, Brahmaputra, Narmada, Teesta, Mahanadi and Coastal rivers of Orissa.

Recommendations made by 5th Conference of State Minister's of Irrigation and Power held at Ooty in

September 1970, mention for "Extension of flood forecasting activities to other flood prone rivers; Modernisation of flood forecasting techniques; importance of meteorological organisation for assisting in flood forecasting by establishing Flood Meteorological Offices (FMO) at various flood forecasting centres under India Meteorological Department (IMD)"

In 1974, the flood forecasting activity was extended to Godavari and in 1978 to Krishna River systems. After the disastrous floods of 2001, the activity was extended to Pennar basin in South India. At the end of XI Plan, CWC had 175 flood forecasting stations in different basins of the country.

State Governments were also requested to identify the locations for expanding the network of Flood Forecasting Stations. Presently, the total number of flood forecasting stations are 340, consisting of 200 Level and 140 Inflow Forecast Stations and covering all major flood-prone river basins and States.

The CWC's comprehensive strategy effectively aligns with the WMO's guidelines by focusing on the timely delivery of useful information, engaging stakeholders, regularly evaluating its network and embracing technological advancements. This approach not only enhances the CWC's flood forecasting capabilities but also significantly contributes to better flood management and community resilience in India.

Modernisation in Data Collection and Transmission

Initially, CWC was using manual gauges for observation of rainfall and water level and High Frequency (HF) Wireless Sets for data communication from remote sites to divisional flood control rooms. During 1980s, for the first time 14 stations under Upper Yamuna Basin was converted to automatic sensor-based observation of water level and rainfall and transmission through Very High Frequency (VHF) communication towers to communicate the data automatically from a remote site to the control room in the Upper Yamuna Division, CWC, New Delhi. The first satellite-based system of communication with automated data acquisition started under the Dam Safety Assurance and Rehabilitation Project (DSARP) in 1999, when 35 stations in Mahanadi Basin and 20 stations under Chambal Basin were taken up for modernisation. Two Earth Receiving Stations were also established, one at Burla (Odisha) and the other at Jaipur (Rajasthan). CWC has presently 1121 Real Time Data Acquisition System (RTDAS) stations and 29 modelling centres in various river basins.

Modernisation in Flood Forecast formulation

Conventional flood forecasting models utilises Statistical correlation and regression equations to formulate flood forecast. During 1980s, the concept of mathematical models was introduced. Currently, CWC is issuing 7-day advisories for floods at all 340 flood forecasting stations utilising MIKE-11 modelling tools. This is in addition to short-range forecast (response time upto one day) being issued by CWC utilising a statistical model.

CWC is also working on a spatial flood warning system (Flood Inundation). Spatial flood warning system for Mahanadi, Godavari and Tapi has been developed and is ready for launch.

Modernisation of Meteorological Inputs

After the recommendation made by 5th Conference of State Ministers of Irrigation and Power held at Ooty in September 1970, IMD started FMOs in various locations to cater to the needs of Flood Forecasting. These FMOs provide Quantitative Precipitation Forecasts (QPF) to the concerned Flood Forecasting Divisions. Numerical Weather Prediction (NWP) model outputs are utilised for 7-day advisories by CWC. There are currently 15 FMOs established by IMD to provide QPF for over 160 river catchments.

Modernisation of Forecast Dissemination

Dissemination of flood forecast to the concerned first responders, who will in turn warn the general populace regarding the impending floods, started through wireless. With the advent of internet, e-mail is used for quick and reliable dissemination. Now, dedicated website for different products is available namely, http://ffs/india-water.gov.in/ for short range forecasts and http://aff/india-water.gov.in/ for 7-day advisories. These utilise Water Information Management System (WIMS) for a better data entry system, report generation and user-friendly web functions. 'Flood Watch India' mobile application is also available for flood-related information anytime and anywhere. CWC flood forecasting services are also integrated with 'Sachet-Common Alerting Protocol (CAP)' and National Disaster Emergency Management (NDEM). Various social media platforms are also being used for dissemination of flood-related information. ■

ENERGY FORECASTING

Weather Services for the Power Sector: Key Achievements and Opportunities

*By **Pankaj Agarwal,** Secretary, Ministry of Power, Government of India*

India's power grid, recognised as the world's largest synchronous national grid, is the backbone of the nation's economic progress. However, its complexity and increasing reliance on weather-dependent load and renewable energy sources make it highly vulnerable to meteorological extremes. In recent years, India has faced an extreme rise in temperatures, including March-April 2022, February 2023 and February 2024, each recording the highest maximum temperatures in 122 years. August 2023 also set a record for the highest average temperature over the same period. These heatwave or exceptionally high temperature conditions have increased electricity demand for cooling, pushing the grid to a peak demand of 250 GW and a daily usage high of 5466 million units (GWh).

These conditions tested the resilience of conventional power plants and transmission systems while also complicating the integration of renewable energy sources such as solar and wind, which are influenced by fluctuating weather patterns. Additionally, higher agricultural electricity demand, with farmers relying more on electric pumps and irrigation systems due to water scarcity, further increased stress on the power system.

The India Meteorological Department (IMD) has played a crucial role in addressing these challenges. By providing detailed forecasts on temperature, humidity, solar radiation and wind patterns, IMD has enabled utilities to anticipate and prepare for spikes in electricity demand. During the 2022 heatwave, IMD's timely forecasts helped utilities implement measures to prevent major power disruptions. In 2023 and 2024, advanced weather predictions supported more rigorous planning for resource adequacy before the peak summer period, ensuring stable grid operations and effective balancing of supply and demand. IMD's specialised forecasts for solar and wind energy generation have also helped utilities optimise power supply strategies during extreme weather conditions. IMD is now providing weather forecast data at a high grid resolution of 12x12 km, compared to the earlier 25x25 km grid size. IMD is also working to increase grid resolution to 6x6 km. The forecast frequency has been increased to four times a day instead of once daily as earlier, and IMD is working further to provide the weather updates on an hourly frequency. IMD's collaboration with power sector stakeholders has been transformative, delivering detailed weather insights such as temperature projections, wind patterns and solar radiation estimates that enhance decision-making.

Short-range (up to a week), medium-range (3-6 months), and long-range forecasts (beyond a year) have become essential for strategic and operational planning, particularly as renewable penetration grows in the country. Short range is important for unit commitment viz. keeping sufficient thermal units in service while medium range forecasts are crucial for maintenance planning of the coal fleet. The long-range forecasts are useful for capacity expansion exercises considering that each weather year is different. As the forecast errors increase for any time horizon beyond a week, it is important to see how we can use Artificial Intelligence (AI) tools for a better forecast.

India's diverse climatic conditions make it highly susceptible to extreme weather events such as severe heatwaves, cold waves, and cyclones, all of which significantly impact electricity demand and power system infrastructure. Accurate and precise weather forecasting, along with early warning systems, is essential to mitigate these challenges. IMD's continuous advancements in forecasting technologies and its efforts to enhance the dissemination of weather information to key stakeholders, including the power sector, are becoming increasingly critical. As India's energy demand grows alongside its economic expansion, further strengthening IMD's forecasting capabilities will play a vital role in ensuring a stable and resilient power supply while safeguarding the grid against the escalating risks posed by extreme weather conditions. ■

EXTREME HEAT PREPAREDNESS

How to Make Heatwave Early Warning More Effective? Key Action Areas

*By **K. S. Hosalikar,** Former Head, Surface Instrument Div, IMD Pune; **Rajib Chattopadhyay,** IITM Pune; and **Ananya Karmakar,** CRS, IMD Pune, India*

According to the AR6 of IPCC, human-caused climate change has increased the frequency and intensity of heatwaves since the 1950s and additional warming will further increase their frequency, duration and intensity. With every additional increment of global warming, changes in extremes continue to become larger. Heatwaves amplify the impact of drought, increase wildfire behavior, hazardous smoke, water insecurity, power shortages and agricultural losses, which cause significant damage to communities around the world.

As we all know now that globally the year 2024 was the warmest year in the 175-year observational records so far (*Ref: State of Climate Report 2024 by WMO*) and in same line for India; the annual mean surface air temperature averaged during 2024 was observed to be +0.65°C above the long-term average (Period 1991-2020), marking 2024 the warmest year since nationwide records began in 1901. (*Annual Climate Summary 2024, by IMD*). So, under these circumstances, to make the existing EWS for Heatwaves in India more effective, the following key areas need to be further focused. Of course, many of the things are already in process and available. May be requires further fine-tuning and shaping.

1. At present, in the country, IMD issues the HW alerts as and when needed as per its standard operating procedure (SoP) with sufficiently good lead time. Alongside it also issues other HW related products like Heat Index, Discomfort Index, Excess Heat Factor Index few more seamlessly using text, GIS graphics, Charts etc using all digital platforms like websites, SMN, Apps etc.
2. In addition to if AI is used for generation and dissemination in highly customised ways for various sectors like health, agricultural, power, water, disaster management, etc for more effective and quick decision-making process by these sectors for effective mitigation. This will add value to process.
3. The platforms like Chat-GPT can be brought in, which will enable the concern sectors/customer to raise the query about HW alerts that will be answered immediately in auto mode. Again, this will further improve the understanding and confidence-building among the users.
4. As mentioned above that HW are highly likely to increase in its frequency, duration and intensity; more surface meteorological observations would be required. May be in a city, it could be at every 3-5 km and other places 5-10kms especially in the HW prone areas. These observations would be real time and accessible to all stake holders on a digital platform.
5. New areas of HW are emerging in the country; needs to be overseen very carefully especially in absence of earlier such records. Response of local administration and people is also critical here.
6. R&D in HW science is a continuous process and new predictions tools, models are coming up. Integrated approach at global and regional levels in terms of technology, hand-holdings, infra support, would be great.
7. Other than the land-based HW, we are also experiencing the marine HWs, that again will require more observations over the seas. A better understanding of it will help in minimising the impacts on coastal communities, fishing, severe weather, and global ocean circulation patterns.
8. HW's severity is socio-economically biassed, as seen earlier. HWs often target poor and vulnerable unorganised sectors like people without proper infrastructure, hawkers,

> "Heatwaves do not fetch as much public attention as more dramatic disasters such as earthquakes and floods, but until more recently they were taking a substantial toll of lives in India".
>
> *(Ref: Beating the Heat; Report by NDMA)*

construction workers, and women. The HW Alert system must address these sectors and other layers below in the society using some out of box ideas. Like we can have extension workers, NGOs, a battery of trained students, flyers at construction sites, coastal areas with effective local PA systems, provision of temporary shelters, drinking water points in the city, etc.

9. The Summer Outlook provided by IMD along with HW related information needs to be more intensely brainstormed sector-wise for improved understanding from both the sides.
10. Effective EWS also include response of the community and the stake holders and so make it more effective, the HW related inputs must go into both long-term and short-term planning by the administration / stake holders for the given place in advance.
11. IMD has recently launched the National Framework for Climate Services (NFCS) -India. It's a programme to further establish a structured multi-point interaction and exchange of climate information among the various central, state ministries, agencies, academia, industries, media, and other stakeholders. HW in the country are many times widespread and for a longer duration and under such circumstances like during cyclones, NFCS will be especially useful framework. NFCS will also address the climate/weather hazards in the country.
12. New initiatives in HW programme can be brought in through R&D in observation techniques, predictions with impact, dissemination, and feedback from the general public and stakeholders.
13. Since HW can also trigger the Forest Fires, causing threats to wildlife, affecting the ecosystems. So, the concerned agencies need this critical inf.
14. To create more awareness, all the central, state government agencies, and other industries/organisations can port IMD's HW and other severe weather warnings over their official websites for their employees to see regularly. This will further create understanding and mitigation sensitivity. Involve maximum NGOs.
15. Innovative technologies can come to the rescue, like, mobile embedded with temperature sensors will be taking auto observations continuously and sending it to central servers. Industries participation would be needed.
16. Awareness is key and so we need more effective graphics, slogans, flyers, workshops, seminars, and awards too. Innovation has a big opportunity here. ■

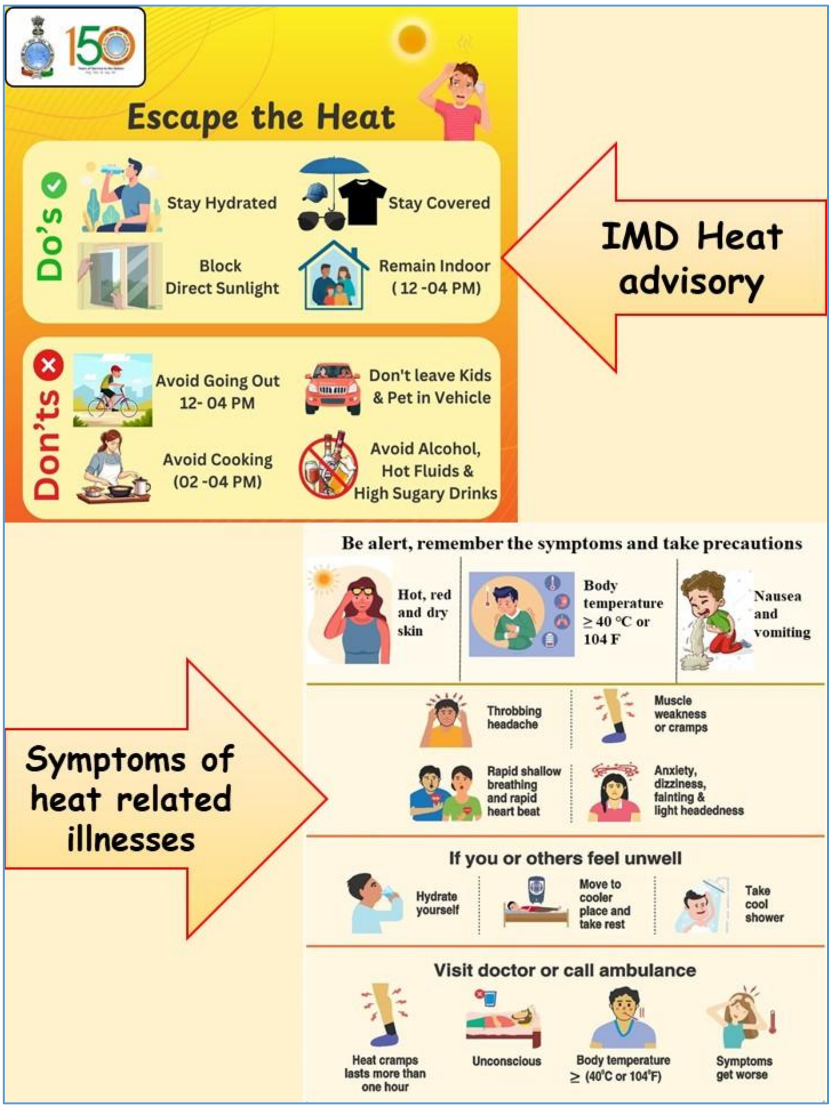


Figure 1: Heatwave preparedness and health advisory issued by the IMD.

CLIMATE SERVICES

Evolution of Meteorological Services in India and Future Scenario

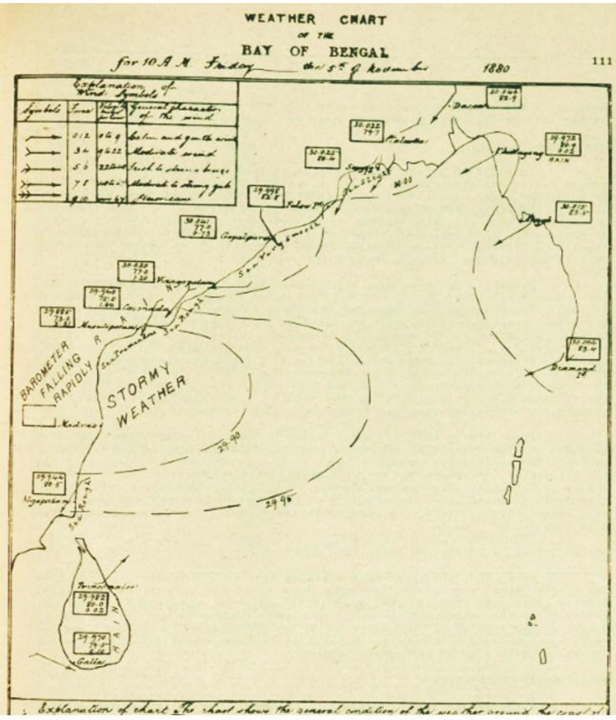
By ***Dr. Ranjan Kelkar,*** *Former Director General, India Meteorological Department, Pune, India*

When the India Meteorological Department (IMD) was established in 1875, its two priority areas were shipping and agriculture. In the early years, ships were warned of impending storms only through visual signals hoisted at ports. Much later, around 1912, IMD began sending warnings to ships at sea by wireless messages. Captains of ships docking at ports would also brief IMD meteorologists about the weather they had encountered at sea. IMD could thus compile atlases of storm tracks over the Bay of Bengal and Arabian Sea. Over the years, IMD's cyclone warning system has undergone a sea change.

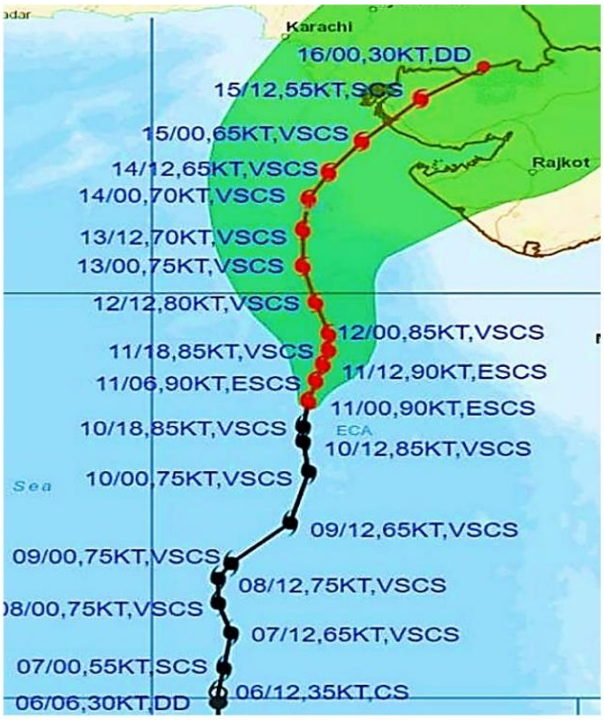
When India was under British rule, it suffered from chronic droughts and famines in which thousands would perish. In 1932, IMD established a Division of Agricultural Meteorology at Pune dedicated to improving agricultural productivity in the country. IMD worked in close collaboration with agricultural institutions and set up a network of cooperating agromet observatories in the country besides its own. Crop-weather calendars were compiled that farmers could consult for timing their field operations. Crop-weather relationships were arrived at for predicting crop yields. IMD started issuing farmers' weather bulletins over All India Radio in the 1950s and an Agromet Advisory Service for farmers was started in the 1970s which is now functional in all agroclimatic zones.

After the Second World War, military aviation saw a decline, but civil aviation got a sudden boost and required major operational support from IMD. All phases of aircraft operations are influenced by weather and current weather information and forecasts are crucial for flight safety and viability of airlines. As a member of the International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO), India has to follow international regulations. Presently, IMD is providing aviation meteorological services at over 100 airports through four Meteorological Watch Offices (MWOs) and several supporting units at these airports. IMD has installed state of art observing systems at all major airports and it operates an Online Briefing System (OLBS) for pilots.

Methods and techniques of observation have changed



1880 - Storm Warning Chart



2023 - Biporjoy Track Forecast

immensely since 1975 and today, India has its own weather satellites and a countrywide radar network. IMD has developed mobile apps through which people, especially farmers, can quickly get timely weather information. In parallel with the advancement of technology, new branches of science like radar meteorology, satellite meteorology, and numerical weather prediction have evolved over the last few decades. IMD runs its own numerical models on supercomputers, and disseminates its products over the internet, social media and mobile apps. IMD issues nowcasts, medium and extended range predictions and long range forecasts. Their spatial domains range from the country as a whole to block and panchayat levels. Tracks of tropical cyclones are now being predicted several days in advance.

With the accelerated growth of the nation towards a trillion-dollar economy, the demand for meteorological services has been coming from many new quarters. IMD is now providing meteorological information and forecasts for irrigation, flood management, exploitation of solar and wind energy, offshore oil exploration, disaster mitigation, human health, air pollution, tourism and yatras. Many of these activities are multi-disciplinary and IMD has to coordinate with several other agencies to be effective. Heatwaves, landslides, urban flooding, forest fires, and lightning strikes are some of the areas in which there are high expectations from IMD. The future is challenging, but IMD is well prepared for it. ■

REMOTE SENSING

Space Technology for Weather Services: An Essential Component

*By **Dr. Prem Shankar Goel**, Former Secretary, Ministry of Earth Sciences, India*

Way back in 1975, when we were writing requirements for INSAT-1 satellite, Prof Yashpal, then Director Space Application Centre, said that Very High-Resolution Radiometer (VHRR) would be the essential component, in spite of the complexity it introduces to the configuration of the satellite, like one sided solar panel, and a solar pressure compensatory Sail and Boom. It also introduced the requirement of very high stability of the platform so that the cloud velocity could be computed to an accuracy of 3 meters per second. Since then, one or more VHRRs have always been in orbit inside INSAT satellites.

Today, meteorology is no more a synoptic view of a few weather parameters like clouds, wind velocity and temperatures at a few locations, but an outcome of high-resolution atmosphere and ocean coupled numerical models. This needs high-resolution (temporal and three-dimensional) data on land as well as the ocean. Weather is a chaotic system; hence, a small error in initial conditions leads to very quick divergence and hence inaccuracy in the weather forecast. The only way to collect this data worldwide, not limited by national boundaries, including over oceans, is via satellites. Further, it is not just the atmosphere data, but also the ocean data like surface winds, ocean temperature, etc. However, we need ground-based data primarily for the calibration of sensors in the satellite. Doppler Weather Radars play a very important role though, but they cannot be deployed in the ocean. WMO is one of the most cooperative frameworks in the world for sharing data, hence every country does not have to have satellite observations throughout the globe.

India has mastered the forecast methodology of cyclone intensity and its route, reducing the loss of life by three orders of magnitude. While thousands of people used to lose their lives, the number is now in the single digits. Further, we are able to map the floods in near real time and provide advisories to rescue teams.

India has a very comprehensive space segment for collecting weather and ocean data, like INSAT satellites, not only accommodating multichannel VHRRs but also wind profilers and microwave sounders, etc. We also have ocean observation satellites in Lower Earth Orbit (LEO). Indian scatterometry data is used worldwide for ocean state assessment. As we see a tremendous improvement in computing capability, already in petaflops, and the emergence of quantum computers in future, it would be possible to run global numerical models with a resolution of about a kilometre. Such high-resolution data for the whole globe can only be obtained through satellites. Needless to say, numerical weather modelling is one of the most intense computing problems. The more we improve the model, the more computing power will be needed.

Be it a short-term forecast, nowcast or long-term forecast of the Indian Monsoon, satellite data is an essential component of weather forecasts and weather services. ■

DISASTER PREPAREDNESS

IMD in South Asia: A View from Myanmar

*By **Dr. Kyaw Moe Oo,** Director General, Department of Meteorology and Hydrology, Myanmar*

The climate of Myanmar is influenced by tropical monsoon winds, which are the southwest monsoon and the northeast monsoon. Myanmar has three distinct season, the rainy season, the cold (or) winter season and the summer season. In the Union of the President of Myanmar the observations indicated that the climate change is taking place in the field of temperature, precipitation, extreme climate and severity of disasters and in the southwest monsoon features.

Regarding temperature, the mean maximum temperature is increasing. Extreme temperature events are increasing both frequency and intensity associated with intensity of El Nino. In Myanmar the temperature generally vary between 10°C and 32 °C with the average mean temperature of 21°C in the northern low lands, sinking sometime to -1 °C or 0 °C in the high lands and 32°C in the coastal area. During the hot season, temperature sometimes reach 40°C and over in central dry zone. The southwest monsoon onset into the country is becoming late and its withdrawal from the country is advancing earlier. The southwest monsoon duration is shortened by three weeks from the northern Myanmar and one week from other parts compared to normal.

Meteorological, Hydrological and Climatic Extremes events are becoming more frequent around the world, especially the small Island and developing countries, due to climate change. According to the statements of the World Meteorological Organization, 2024 was the warmest year in the 175-year observational record. It is recorded that rising temperatures are causing the oceans to warm, glaciers and ice sheets to melt, and global sea levels are set to reach a record high in 2024, according to records from 1955 to the present. Myanmar also experienced extreme heat in 2024, setting a new record for the highest temperature (78 times), with Chauk, Magway Region, reaching (reached to) 48.2C, the highest temperature in that city in 56 years. It was also the highest temperature in Myanmar's history, including the entire country, and was included in the list of the hottest countries in the world.

In Myanmar, rapid and coordinated responses to early warnings for natural disasters such as storms, floods or droughts can help in preventing the loss of lives and properties due to natural disasters. We are highly grateful to India Meteorological Department for its full support to Myanmar's endeavours in disaster risk reduction and Early Warning System. IMD played pivotal role in promoting coherence between various sectors, communities and forecasters for DRR by revising IMD's standard operating procedures (SOP) for cyclone warning, updating annual cyclone operational plan for WMO ESCAP Panel countries and developing synergised SOPs for multi-hazard early warning across India and North Indian Ocean region, which has been ground-breaking. IMD organised trainings for forecasters in South & Southeast Asia and Middle-East countries and stakeholders including fishermen, farmers, and disaster managers, to ensure coherent utilisation of cyclone warning for DRR. Disaster reduction activities of DMH was not accomplished without valuable support and close cooperation with WMO and its Regional office, RSMC (New Delhi), RTHs for the early warning, training and other support for Myanmar.

Not only to Local, the global climate has also changed in a very dramatic manner. The vulnerability to disasters are increasing more than ever. We can't prevent hazards from happening. We may need to more cooperation and collaboration national, regional and global for Early Warning and Disaster Risk Reduction activities. ■

Myanmar's climate is rapidly changing, with rising temperatures and shorter monsoon seasons. The India Meteorological Department (IMD) has been a vital partner in strengthening Myanmar's early warning systems through training, technical support, and regional coordination. This collaboration is crucial for building resilience across South Asia in the face of escalating climate risks.

DATA-DRIVEN FORECASTING

Pathways on Numerical Weather Prediction for Weather Services in India

By **Dr. U.C. Mohanty,** *Distinguished Professor, Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar;* **Dr. R. Krishnan,** *Director IITM;* **Dr. V.S. Prasad,** *Director, NCMRWF; and* **Dr. D.R. Pattanaik,** *Head NWP Division, IMD, India*

Evolution of Numerical Weather Prediction (NWP)

The first successful numerical weather prediction (NWP) was made in 1950 by Jule Charney and John von Neumann, using simplified atmospheric models on a computer at Princeton University, USA. In India, pioneering work in NWP traces back to 1958, with a study led by Prof. P. K. Das that predicted Bay of Bengal monsoon depressions using a non-divergent barotropic model, published in the *Indian Journal of Meteorology and Geophysics* (Mausam). Later, very important findings published by P. K. Das (1964) on Baroclinic properties of waves behind a large circulation mountain got the 3rd Mausam Award. With this landmark effort, the early and mid-1970s witnessed significant developments in Objective Analysis of meteorological observations, which is a crucial component of numerical weather prediction (NWP). The severe tropical cyclones that struck the Bangladesh coast in 1970, resulting in the loss of over 300,000 human lives caused by a huge storm surge, led to efforts in India for the development of storm surge prediction models. The lead in this direction was taken by Das (1972).

Subsequently, an NWP group was formed at IMD and installed its first computer, an IBM 360/44, in 1973 at its headquarters in New Delhi and was maintained up to 1989 under the leadership of Prof. Das. This system facilitated objective analysis of observation data to provide initial conditions to a barotropic model that was operational in IMD to provide a one- to two-day forecast of the 500 hPa geopotential field and movement of atmospheric vertices such as monsoon depressions and western disturbances.

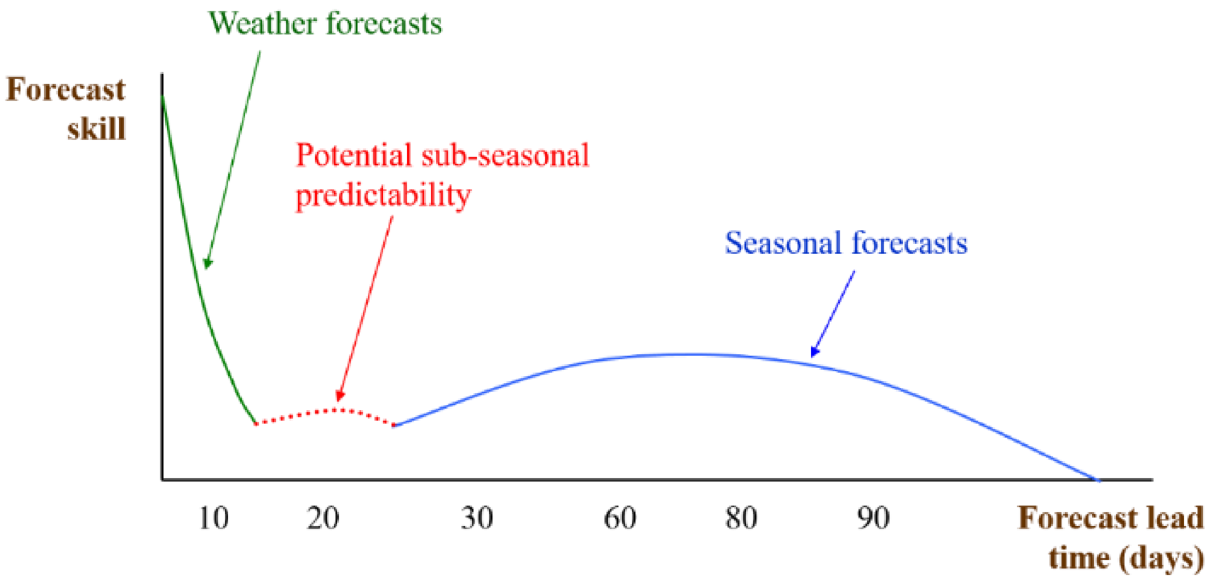
A new era in NWP began with the establishment of the National Centre for Medium-Range Weather Forecasting (NCMRWF) in 1988, equipped with the Cray-XMP/14 supercomputers. With the installation of a supercomputer, the NCMRWF significantly boosted NWP research and facilitated the development of a full-fledged NWP system to initiate work with global assimilation and prediction systems to provide medium-range forecasts for agrometeorological advisories in the country. The medium-range weather forecasting system was established in June 1994 after extensive experimentation, evaluation and adaptation through dedicated R&D efforts by NCMWF under the guidance of Prof. U. C. Mohanty, Head of the Research Division of the NCMRWF (on deputation from IIT Delhi). Subsequently, the NCMRWF global model provided lateral boundary conditions to the IMD multilevel regional model for short-range (1-3 days) prediction on an operational basis, marking a milestone in operational NWP in India. Subsequently, immense improvements were made in the NCMRWF through advanced data assimilation, sophisticated modelling systems and an ensemble prediction approach.

Advancements in Forecasting Systems

Over the decades, IMD and NCMRWF have made significant progress in improving short- and medium-range NWP systems and providing agrometeorological advisories to 127 agrometeorological zones across the country. These advancements are closely tied to the evolution of high-performance computing, from early machines capable of millions of operations (10^6 FLOPS) to today's supercomputers performing at petaflop (10^{15} FLOPS) levels.

IMD's operational forecasts have continuously strived to address severe weather events such as tropical cyclones, storm surges, heavy rainfall, severe thunderstorms, heatwaves, cold waves, and western disturbances over the entire country. In the course of time, coupled Atmosphere-ocean-land models with probable strike potential of tropical cyclones were developed and operationalised with impact-based warning systems to reduce the human casualties. In this regard, it is heartening to illustrate that the two severe cyclones in the recent days such as extremely severe cyclonic storm BIPARJOY (June 2023, in Arabian Sea) crossed Gujarat coast and severe cyclonic storm DANA (Oct 2024, in Bay of Bengal) crossed Odisha coast have resulted in zero human casualty, a dream of coastal dweller of both the basins.

A Schematic Diagram : Lead time and forecast skill



Source: Mohanty et al (2024). Climate risk management in agriculture: Monthly and Seasonal Forecast Application. Springer Nature.

Currently, IMD provides seamless weather and climate services across various time scales ranging from a few hours to a season using mathematical models as given below:

- Nowcast to Very Short Range: Up to 3–12 hours
- Short Range: Up to 3 days
- Medium Range: Up to 10 days
- Extended Range: Up to 4 weeks
- Seasonal Forecast: Up to one season

Each of the above forecast have different accuracy depending on the length of the forecast as given in the schematic diagram above. In addition, IMD also delivers agrometeorological advisories and city-specific forecasts for over 150 cities, including inputs for heatwaves, rainfall, and air quality. It is heartening to note that all these forecasts are objective in nature, using numerical models and high-performance computing systems of the MOES.

Contributions to Seasonal and Extended-Range Forecasts

Among the above forecasts, Seasonal and extended-range forecasts are spearheaded by the Indian Institute of Tropical Meteorology (IITM), Pune, under the Ministry of Earth Sciences (MoES), Govt of India. To enhance the accuracy of Indian summer monsoon rainfall forecasts, the Ministry of Earth Sciences (MoES), Government of India, launched the Monsoon Mission in 2012. Under this initiative, the Indian Institute of Tropical Meteorology (IITM), Pune, developed and implemented a state-of-the-art dynamical prediction system based on an atmosphere-ocean-land coupled model for:

(a) Seasonal forecasting of Indian summer monsoon rainfall, and
(b) Extended-range sub-seasonal prediction of monsoon active and break spells.

IMD's progress in numerical modelling has been bolstered by academic partnerships with leading academic institutions like IIT Delhi and IISc Bangalore and international collaborations primarily with the USA and UK. ■

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1. P. K. DAS, "Lee waves associated with a large circular mountain", MAUSAM, vol. 15, no. 4, pp. 547–554, Oct. 1964.
2. Das, P. K. (1972). Prediction model for storm surges in the Bay of Bengal. Nature, 239(5369), 211.

Extreme Heat Early Warning and Anticipatory Actions for Women-Led Small Businesses in Cities of India

*By **Pallavi Rathod, Vaishali Tiwari,** and **Grace George** of AIDMI, India*

As extreme heat events become more frequent and intense across India, their impact on health, livelihoods, and informal economies in cities is escalating. Among those most affected are small, women-led businesses that operate in high-risk urban and rural environments without adequate protection or preparedness support. AIDMI undertook an initiative in 2023 to support small businesses for anticipatory actions and adapting to extreme heat. One strong need is about understanding, accessing and using extreme heat early warning for protecting health, family and small businesses.

The programme implemented a series of field consultations and training sessions, reaching over 1200 women leaders owning small businesses across multiple Indian cities from five states of India. These conversations combined scientific guidance, practical examples, and locally relevant case studies. A significant component introduced to small businesses about India's efforts on extreme heat forecasting, particularly the early warning bulletins of the India Meteorological Department (IMD) and the digital alert platform SACHET developed by the National Disaster Management Authority (NDMA) with IMD.

Small businesses were introduced to the SACHET app, a centralised source of disaster-related alerts, including for extreme heat. While awareness of such platforms remains limited among grassroots users, such as small businesses or women, these efforts created a strong case for increasing outreach and usability. Small businesses appreciated how real-time alerts and advisories can support practical decisions to safeguard their health, manage household needs, and protect livelihoods.

A woman-led small business owner in Gujarat explores the SACHET app during a heatwave preparedness session. As a part of AIDMI's initiative, over 1200 women entrepreneurs across five Indian states were trained to access and act on IMD's early warnings—turning alerts into anticipatory action for health, family, and livelihood resilience. Photo: AIDMI.

Small businesses reflect that the six-day advance early warning information is really valuable. Small business owners highlighted that such lead time can be integrated into weekly planning—for example, adjusting stock purchases, securing shaded vending locations, or planning work shifts during cooler hours. This proactive approach can reduce spoilage of goods, mitigate income losses, protect health, reduce anxiety, and improve overall safety during extreme heat periods.

Equally important was the realisation that access to early warning is not sufficient unless accompanied by a proper understanding of its implications. Women business owners participants stressed the need for training not only on how to receive alerts but also on how to interpret them from the perspectives of health safety, family wellbeing, and income security. This understanding helps bridge the gap between information and action, transforming passive alerts into proactive decisions. Not only the last mile was reached, but also the last Indian before the disaster striked.

These field consultations revealed how important trust, format, and delivery methods are for early warning to be effective. Equally important are recognition of affected citizens' ability to take anticipatory action. About the future needs, these small businesses preferred receiving alerts through familiar and widely used platforms, especially mobile messaging services. They called for concise, colour-coded messages supported by audio or visual cues and local language options. Many even suggested integrations with local education institutions, and health centres, where children, teachers, and health workers could act as messengers to reach family members, and society —a method that proved effective during public health campaigns.

Who is warning and who is being warned, both are important. When both act in unity, as a team, early warning becomes anticipatory action.

Many community leaders expressed a strong interest in becoming peer educators themselves, recognising the potential for localised leadership in disseminating early warning information. This shift from recipient to trainer suggests a powerful pathway for scaling community-owned climate resilience.

Another major insight was the synergy between early warning, anticipatory action, and financial resilience tools like insurance. Many participants emphasised that while alerts are crucial, communities also need resources to act. Risk transfer through insurance and small grants was discussed as key enablers that would allow vulnerable households and businesses to prepare and respond more effectively.

Extreme heat affected population using early warning offers lucid, compelling, and e-learning insights into the frontiers of early warning experiences of millions of Indians across very different and diverse experiences.

Small businesses' reflections underscored the multifaceted impact of extreme heat. Women shared stories of vegetables spoiling, machines failing, children missing school, and market activities slowing down due to the heat. They emphasised that early warning information—when trusted and understood—can improve decisions that directly affect daily survival and long-term wellbeing with anticipatory actions.

Looking ahead, the initiative highlights the need to promote and integrate platforms like the SACHET app and IMD alerts into localised training and awareness efforts. This includes expanding training programs to new areas, conducting post-summer impact evaluations, and engaging decision-makers to institutionalise community-centric EWS and anticipatory action frameworks. Building capacity to not only receive but also understand and act must remain a top priority.

This IMD effort reaffirmed that effective early warning systems are not only about forecasts—they are about people and our planet. The efforts demonstrated that meaningful access, cultural relevance, and co-designed dissemination are what turn alerts into action. In the face of growing climate risks, this initiative offers a scalable model for empowering vulnerable communities through information they can trust, understand, and use.

The users of early warning, when affected population of India, invite us to a reflexive anticipatory action set to break down barriers and build new bridges between those who make the early warning come into being and those who use it to reduce or stop the impact of upcoming risk. Their grounded experience leads India into the boldly optimistic frontiers of early warning. ■

WAY AHEAD

Strengthening Early Warning Systems for the Next Generation

*By **Mihir R. Bhatt**, All India Disaster Mitigation Institute (AIDMI), India*

As the India Meteorological Department (IMD) celebrates 150 years of pioneering service worldwide, it stands at a critical juncture in its journey, warning from forecasting to enabling early action. The climate crisis is intensifying, and India faces growing risks from heatwaves, cyclones, floods, and droughts, to list a few. These risks are becoming more frequent, severe, interconnected, and cascading, being co-located in terms of origin to impact. IMD's future lies in making its services not only more accurate but also more accessible, useful, usable, people-centric, and anticipatory.

In the face of a fast-changing climate, early warning is not a privilege—it is a right. India's leadership through IMD shows that science, when guided by equity, can protect every life, in every corner, before disaster strikes.

Ten Priority Actions for the Way Ahead:

1. **Accelerated Regional and Global Cooperation**: Deepen robust collaboration with South Asian neighbours and Indian Ocean countries for shared data systems, capacity-building, and coordinated early warning dissemination to address

transboundary climate risks to start with.

2. **Sustained Last-Mile Connectivity and Local Action**: Ensure early warnings reach vulnerable communities in local languages through mobile phones, community radios, social media, and trusted local networks. Engage NGOs, youth, and volunteers in outreach and response in a sustained manner, beyond events, to between events.
3. **Transform Climate Resilience into Forecasting**: Embed climate projections and risk scenarios into forecasting models at all levels and for all sectors to better anticipate long-term shifts in monsoon behaviour, extreme heat, and urban flooding.
4. **Leverage Technology, AI, and Citizen Science**: Use artificial intelligence, machine learning, and mobile-based data collection to enhance accuracy, engagement, and personalisation of forecasts, especially in underserved and data-scarce areas, at par and in synergy with science that citizens hold and use for centuries.
5. **Universalise Multi-Hazard Early Warning Systems (MHEWS)**: Strengthen integrated systems that provide alerts for combined hazards (e.g., cyclone-induced flooding and heatwaves), supported by synchronised operating procedures across sectors and levels of governance for all citizens for all times and at all locations.
6. **Upscale Sector-Specific and Urban Forecasting**: Tailor warnings for agriculture, health, energy, and city systems in favour of affected people and assets, both. Integrate forecasts into urban resilience strategies and infrastructure planning, especially in climate-vulnerable towns and cities.

A field trainer guides a woman entrepreneur in rural Anand, Gujarat, on accessing climate alerts via mobile platforms. As IMD advances into its next era, people-centric and anticipatory early warning systems—like this local engagement—are vital to ensure no one is left behind in the path of rising climate risks. Photo: AIDMI.

7. **Simultaneously Invest in Observational Infrastructure and Indigenous Innovation**: Scale up weather stations, radar, satellite, and ocean buoys. Promote public-private partnerships and indigenous technology for cost-effective, scalable, and localised monitoring. Achieve such innovations with investments that are timely, substantial, and sustained.
8. **Link Early Warning with Risk Financing and Early Action**: Expand forecast-based financing tools and Early Action Protocols (EAPs) to enable humanitarian agencies and state actors to act before a disaster strikes to slow down, reduce, and, where possible, remove the negative impact.
9. **Make Nature-Based Solutions Central**: Connect forecasts to action by promoting green infrastructure, such as mangroves, urban tree canopies, and watershed restoration, as buffers that reduce disaster impacts and enhance community resilience, which in the end lead to re-naturing our own homes and our planet.
10. **Institutionalise Learning Dialogues and Capacity Building**: Establish national and regional platforms for co-creating people-centred early warning systems. Regularly and effectively engage civil society, media, academia, and local governments in learning and planning our joint future.

The next 5 years of progress must be defined by one goal: no one is left behind in the path of storms, floods, or heat. Let early warning be the bridge from science to survival, from data to dignity for loss to resilience.

From village to megacity, from ocean coasts to mountain ranges, early warnings must reach all. India's example reminds the world that resilience begins not with reaction, but with readiness.

Conclusion:

The IMD of the future must do more than predict—it must empower. Its strength will lie not only in technological advances but in its ability to deliver accessible, timely, and actionable information to those who need it most. With inclusive partnerships, policy innovation, and bold investment, India can help the world in building anticipatory, climate-smart, and resilient early warning systems for all. ■

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