VISION 2035
for
Management of Disaster due to Tropical Cyclones and Associated Hazards
in
WMO/ESCAP Panel Member Countries

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Panel on Tropical Cyclones Secretariat

India Meteorological Department

Chapter-1: Introduction

Among the various hydrometeorological hazards, the tropical cyclones (TCs) over the North Indian Ocean (NIO) pose a potential threat to coastal population as well as marine community of the region. Historically, in terms of losses of human life, the Bay of Bengal (BoB) TCs accounted for deaths exceeding thousands and caused huge losses to property. Till the beginning of 2000, 75% of the TCs which caused death of 5000 or more in the world had been over North Indian Ocean (NIO) especially over the Bay of Bengal (BoB). BoB has a notorious history of 300,000 deaths in Bangladesh in 1970 due to “Bhola” cyclone and about 10000 deaths due to super cyclone which hit Odisha coast in Paradip in 1999.

Recognizing these facts, the World Meteorological Organization (WMO) and the Economic and Social Commission for Asia and the Pacific (ESCAP) jointly established the Panel on Tropical Cyclones (PTC) in 1972 as an intergovernmental body. Its membership comprised six countries affected by tropical cyclones in the Bay of Bengal and the Arabian Sea. Originally, its member countries were Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Thailand. Later Maldives joined this Panel in 1982 followed by Sultanate of Oman in 1997, Yemen in 2016 and Iran, Qatar, Saudi Arabia & United Arab Emirates in 2018. Today the PTC has 13 members.

The PTC plays a critical role in reducing the risk & impact of tropical cyclones and associated hazards, such as storm surges, tsunamis, and heavy rainfall events, on the vulnerable coastal and island communities of the Bay of Bengal and Arabian Sea. As the region faces increasing climate change challenges, rapid urbanization, and growing populations in disaster-prone areas, it is crucial to strengthen disaster risk reduction (DRR) frameworks to minimise losses to life and property in the region.

The PTC Secretariat has developed the V**ision-2035 for the next 10 years** which aims to achieve zero death toll and minimisation of losses to property due to TCs in the region through an effective early warning system and comprehensive disaster management strategies. The vision 2035 aims to integrate technological advancements, community engagement, regional cooperation, and sustainable financing to reduce the vulnerability of the region's populations and ecosystems. The Vision 2035, is aligned with WMO’s policies and strategy of Early Warning and early Action for All, aiming to safeguard every life and strengthen the capabilities of the under-privileged nations in the region. It also sets goal to develop impact-based forecast and risk-based warnings for all sectors in the region, to minimise losses to property.

Chapter 2: Challenges and Gap Areas

TCs are multi-hazard weather phenomena that bring with them hazards like heavy rain, strong winds, storm surge and secondary hazards like landslides, mudslides, landslips and mud slips etc. The **vulnerability of an area to TCs** depends on a combination of **geographical, environmental, social, and economic factors** that influence how severely an area may be impacted by a TCs. Major factors that contribute to the vulnerability of an area to cyclones include:

Coastal areas, particularly those near tropical oceans are more vulnerable to cyclones. The **tropical regions** are the most cyclone-prone because the warm sea temperatures in these regions provide the necessary energy for the development of cyclones. Areas along these latitudes are particularly vulnerable to storms. Coastal areas, especially those with low-lying land, peninsulas, and islands, are more vulnerable to storm surges and flooding. Cyclones can bring substantial coastal damage, especially in areas with large populations living near the coast. Areas with coastal plains or river deltas are often more vulnerable to flooding and storm surges caused by cyclones. Conversely, areas that are inland or mountainous may be less vulnerable to storm surges but could still experience heavy rainfall and landslides.

Further, NIO is a data sparse region. Accurate prediction depends upon the monitoring capabilities. Thus, there is need to share data as far as possible with the members. Further, the data shared should be standardized and compatible with other countries. This includes accuracy, instrument response times and other characteristics of instruments, frequency of observations, exposure, network densities and other related matters. The existing gaps in the observational data coverage of the Panel region is mainly due to the deficiencies in the operations of both land, Ocean & atmosphere observing systems and telecommunication networks, high cost and lack of consumables and spare parts.

Even though there have been tremendous progress with respect to cyclone warning system, still there are gaps in observations, understanding TC processes, modelling, landfall aspects and last mile connectivity. Gaps in observations primarily include lack of direct observations from the cyclone field as over the NIO, as we do not have dropsonde, aircraft/UAV reconnaissance, limited scatterometer, no ground based mobile observing platforms. There is lack of complete coverage of NIO with sea surface wind observations at least once a day. There is need to augment the ground observing systems with mobile observing platforms (mobile wind profilers) around the expected area of landfall; and also install temporary observing equipments in the coastal areas near the expected landfall point (meso-network) at the premises of individuals & private agencies interested in weather monitoring and remove the equipments after the event. In the absence of direct observations in the cyclone field, characteristics like wind & temperature distribution along the vertical and horizontal structure of eye and eye wall etc. over the NIO are still highly subjective. In order to better understand TC processes more research is required. There is need to carry out more diagnostic studies on past cyclones to understand the influences of land interactions & synoptic scale eddy interactions, develop conceptual models specific to NIO basin and also need to undertake more studies on asymmetry in precipitation structures under the influence of topography, cyclone movement, vertical wind shear, diurnal cycle & convective bursts. While the TC environment is largely understood, the TC inner core structure is least understood. Hence Research Test Bed on cyclone should be established with all observations and computing infrastructure facility in a coastal state.

Though there has been significant improvement in TC forecast accuracy over the region, **forecasting the track and intensity of TCs** remains challenging in certain situations. Predicting rapid intensification or weakening, as well as the timing and location of recurvature, continues to pose difficulties. Track forecast errors are particularly problematic when there are significant changes near landfall. This is especially true for (i) recurving TCs and (ii) TCs with rapid or slow movement during landfall. Studies show that forecast errors for TCs with rapid track changes are approximately 5 to 20% higher for lead times ranging from 12 to 72 hours, compared to the mean track forecast errors observed between 2003 and 2013.

Currently, probabilistic forecast products have not been implemented, and there is a need to introduce probabilistic information for landfall predictions, heavy rainfall, winds, and storm surges. Presently, a static cone of uncertainty, based on the past five years of average errors, is used to overlay the forecast track. However, a probabilistic cone of uncertainty should be introduced for greater accuracy. Intensity prediction also remains a significant challenge. Further research is needed to enhance our understanding of the conditions, precursors, and processes that lead to intensity changes throughout a TC's lifecycle, from pre-formation to decay. Special attention should be given to rapid intensification and near-coast formation, including the onset, duration, and potential rate of intensification.

Since cyclones develop through the interaction of the ocean, atmosphere, and land, there is a clear need for coupled ocean-atmosphere-land interaction models to more accurately forecast track and intensity. Landfall characteristics are heavily influenced by atmospheric and sea conditions, as well as the region's topography, bathymetry, and physiography. As such, improving the accuracy of adverse weather forecasts for landfalling cyclones—such as track, intensity, landfall timing, and associated weather conditions like heavy rainfall, strong winds, and storm surges—is essential. Additionally, there is a need to enhance the accuracy of location-specific quantitative precipitation forecasts for extreme rainfall events and gale wind warnings.

While the accuracy of extended-range forecasts for the first week is reasonable, further improvement is needed in terms of both accuracy and lead time. Additionally, there is a significant gap in the availability of seasonal TC forecasts, which should be addressed to align with practices in other regions.

The vulnerability of an area also depends upon various **meteorological factors** including the frequency & intensity of landfalling cyclones, probable maximum precipitation, probable maximum storm surge and probable maximum sustained winds over the region. Cyclones are often accompanied by heavy rainfall, which can lead to widespread flooding. Areas with poor drainage systems, or those already prone to flooding, will be more vulnerable to the impacts of cyclones. Prolonged rainfall can further increase the flood risks, especially in river basins and urban areas with inadequate infrastructure. The land use and urbanisation also play a key role in increasing the risk from TCs. Poorly constructed buildings, lack of proper infrastructure, and unregulated development can all contribute to greater vulnerability. Areas that lack adequate evacuation routes or storm shelters are particularly at risk. Further the degradation of natural barriers such as mangroves, coral reefs, and sand dunes in recent years have also contributed to increased vulnerability to storm surges and coastal flooding. Deforestation or loss of vegetation, has also resulted in increased vulnerability of regions to landslides, soil erosion, and flooding during cyclonic events.

Moreover**,** most of the population in this region has **poor socio-economic** background. Areas with high population density, especially those with a large proportion of vulnerable groups (e.g., the elderly, children, people with disabilities, and women), are more likely to suffer extensive damage and loss of life during cyclones. Poorer regions with limited resources may lack the means to build resilient infrastructure, implement early warning systems, or effectively evacuate and shelter communities in the face of a storm. Poor communities, especially those reliant on agriculture or informal livelihoods, face more vulnerability in the event of a cyclone because they may not have the financial means to rebuild homes or restore livelihoods after a disaster. Cyclones can devastate agriculture, fisheries, and infrastructure, leading to long-term economic losses to the vulnerable populations. Additionally, rapid urbanization, high population increase rates, and high population densities without reducing the poverty levels has further increased the vulnerability to disasters, resulting in heavy losses of life and property damage.

Climate change has led to increased vulnerabilities in the North Indian Ocean (NIO) region, particularly due to the intensification and changing patterns of tropical cyclones (TCs). These vulnerabilities affect various socio-economic, environmental, and infrastructural aspects, amplifying the region's exposure to the impacts of cyclones. The key factors contributing to these vulnerabilities include rising sea surface temperatures leading to more intense and longer lasting cyclones, heavier rainfall, larger inundation, coastal erosion, threat to critical infrastructure, health risks, loss of biodiversity and ecosystems etc.

All these challenges can be addressed through targeted actions involving improvements in all components of early warning system mainly observations, modelling, data & advisories dissemination, communication and customised impact based forecasts and risk based warnings.

Chapter 3: Vision 2035

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

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**.

Vision 2035:

- ❖ To achieve Zero loss of life and minimal loss to property through Impact Based Forecast and Risk Based Warnings
- ❖ For the above expected outcome, each panel member to improve observational, communication, modeling, decision making and forecasting system. The detection of TC centre and intensity should improve by 20 percent and similar improvement should be aimed for the associated TC hazards like rainfall, wind and storm surge.
- ❖ To improve the numerical modeling system and decision support system to improve forecast accuracy of TC track, intensity and associated hazards by 20 percent.
- ❖ To encourage cooperation and trust among members to share observational data so that no cyclonic disturbance goes undetected & unpredicted 20 days in advance
- ❖ Development of a cyclone forecasting system which can combat impact of climate change through accurate forecast, at desired spatio-temporal scales and implementation of various adaptation & mitigation measures.

- ❖ During the next decade, the Panel aims to focus on regional collaboration, technological advancements, community preparedness, research, and sustainable financing. The Panel envisions to lead all measures intended to reducing the impact of tropical cyclones and associated meteorological, hydrological, and ocean hazards. This comprehensive vision will pave the way for a more resilient and disaster-resistant future for the Bay of Bengal and Arabian Sea regions.

Chapter 4: Strategy

The Bay of Bengal and Arabian Sea regions are home to numerous countries with varying capacities to handle tropical cyclones and other natural hazards. The key to effective disaster risk management is regional cooperation.

Focused plan and strategy need to be implemented to achieve a disaster free region as discussed below:

1. Enhancement of observational network including surface upper air, boys, satellite and radar observation network
2. Improvement in modeling system, development of Decision support system, impact based forecasting and risk based warning system in each member country.
3. **Enhancement of the collaboration and cooperation** among the Members and RSMC New Delhi by exchange of information and knowledge and research studies related to tropical cyclones including numerical modeling and climate change impacts. Member countries to encourage and promote research on Multi hazards associated with tropical cyclones.
4. The Panel's vision is to foster **collaborative emergency response systems** that allows seamless, cross-border coordination. This could involve establishing a unified regional disaster response protocol, training programs and enhancing joint simulations.
5. The Panel's leadership in **facilitating dialogues between countries** will be crucial for establishing these cooperative mechanisms. Multinational exercises, including joint evacuations, disaster recovery simulations, and the use of shared resources, will contribute to greater preparedness
6. **Technological advancements**, such as advanced satellite systems, machine learning, and artificial intelligence (AI), can significantly enhance forecasting models. In the coming years, the Panel aims to enhance its forecasting capabilities for better data integration, cross-border sharing of information, and capacity-building programs focused on emerging technologies. This can lead to improvements in the accuracy and timeliness of warnings.
7. **Artificial intelligence (AI) and machine learning (ML)** offer immense potential to revolutionize forecasting and early warning systems. Over the next decade, the Panel will advocate for the integration of AI and ML into meteorological models, enabling faster and more precise predictions.
8. AI can be used to analyze vast amounts of data from satellite imagery, ocean buoys, and atmospheric sensors, while machine learning algorithms can detect patterns that would be difficult for humans to identify. This will not only improve forecasting but also help **predict the socio-economic impacts of tropical cyclones**.

9. **Enhancement of capacity building and technology transfer** for early warning dissemination and response at the national and community levels to bridge the gap between the Members through bilateral and multilateral arrangements;
10. The effectiveness of disaster risk management hinges on the expertise of professionals in the field, including meteorologists, hydrologists, and disaster management specialists. Over the next 10 years, the Panel to implement a **comprehensive training program** to develop these skills in all member countries.
11. This may include **specialized training** on the use of new technologies in forecasting, simulation models for storm surge predictions, impact-based forecasting and risk based warning, common alert protocol and best practices in evacuation planning. Moreover, the Panel may support the **exchange of knowledge and expertise among countries** to ensure that best practices are shared region-wide.
12. **Effective communication** is the backbone of any early warning system. The Panel will work on improving the accessibility and reliability of communication channels, ensuring that communities receive timely, actionable warnings. This will include integrating technologies such as mobile phones, social media, and local radio broadcasts.
13. **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;
14. This may involve **public education campaigns**, interactive platforms for people to ask questions and receive accurate information, and partnerships with non-governmental organizations (NGOs) to facilitate grassroots engagement.
15. Incorporating **climate change projections** into disaster risk management is a critical focus for Panel. Research will be directed toward understanding how changes in sea surface temperatures, atmospheric pressure, and other factors associated with climate change are likely to affect frequency and intensity of TCs.
16. The Panel will also work on developing **climate adaptation strategies** to address the long-term risks posed by changing cyclone patterns. This includes identifying vulnerable populations and regions that are most at risk and designing specific intervention measures to increase resilience.
17. The Panel to encourage **establishment of regional and global knowledge-sharing platforms** where scientists, disaster management professionals, and policy-makers can collaborate. These platforms will provide access to real-time data, research papers, case studies, and post-event analyses to enhance understanding of tropical cyclone dynamics and their impacts.
18. The future of disaster risk reduction lies in cutting-edge research. Over the next decade, the Panel will prioritize funding and collaboration in **research** on tropical cyclone genesis, intensification, recurvature etc and their impacts. Panel may encourage collaboration with universities, research institutes, and international organizations leading to develop a disaster resilience region.

5. Outcome

- ❖ Improvement in forecast accuracy of genesis, track intensity, landfall point and time and associated adverse weather including heavy rainfall, wind and storm surge leading to almost zero (less than 15 km) landfall point forecast error upto 3 days lead period.
- ❖ To enable public and disaster managers to realize zero death and drastic reduction in loss of property due to any cyclone over the region.
- ❖ Development of a region, which is well familiar with actions prior to, during and post every cyclone, thereby enabling a disaster resilient society.
- ❖ Enhancement of regional collaboration, technological advancements, community preparedness, research, and sustainable financing.
- ❖ The Panel envisions to lead all measures intended to reduce the impact of tropical cyclones and associated meteorological, hydrological, and ocean hazards.
- ❖ This comprehensive vision will pave the way for a more resilient and disaster-resistant future for the Bay of Bengal and Arabian Sea regions.

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