

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

2023 edition

WEATHER CLIMATE WATER



WORLD
METEOROLOGICAL
ORGANIZATION

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EDITORIAL NOTE

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FOREWORD

The *WMO Guide for National Meteorological and Hydrological Services in Support of National Multi-hazard Early Warning Systems, Procedures, Coordination Mechanisms and Services* was approved for publication and implementation by the Executive Council at its seventy-sixth session (Resolution 11/EC-76). Guide No. 1 is on tropical cyclones.

WMO established a dedicated Tropical Cyclone Programme (TCP) in 1980 to specifically tackle this disastrous phenomenon around the world. One of the long-term objectives of TCP is to promote the establishment of regionally and nationally coordinated early warning systems (EWSs) for tropical cyclones, with multi-hazard configuration to support national disaster risk management and reduction mechanisms, warn people early and respond in a timely manner.

TCP has been implemented systematically at three levels – global, regional and national – as well as across the four areas of meteorology, hydrology, disaster risk reduction and capacity development. All three levels include governance to establish and improve coordination mechanisms, and systems to support services.

The global coordination mechanism cross-cuts Organization-wide technical programmes so all Members prone to tropical cyclones have equal access to the same quality of global observation data and forecasting guidance products. Regional coordination mechanisms, operating through regional tropical cyclone bodies, ensure region-specific Members prone to tropical cyclones have equal access to the same quality of operational tropical cyclone forecasting advisories from tropical cyclone Regional Specialized Meteorological Centres (RSMCs). Regional coordination mechanisms are enabled by regional tropical cyclone operational plans and manuals in each of the tropical cyclone basins.

The aim of this guide is to encourage Members to establish national coordination mechanisms and procedures through multiagency and multisectoral coordination and collaboration. The establishment of national coordination mechanisms will enable all Members to respond in a timely manner to early warnings of tropical cyclone disasters.

The global and regional coordination mechanisms covering all Members prone to tropical cyclones have been well established by TCP. Successful implementation of Multi-hazard Early Warning Systems (MHEWS) will fill the gaps in national/territorial coordination mechanisms and procedures, and all three-level coordination mechanisms and procedures will finally be in place, thus enabling Members to respond to tropical cyclone disasters with synergized actions and outreach to the last mile.

I trust that successful implementation of MHEWS will significantly contribute to national/territorial disaster risk management and reduction and the United Nations-wide “Early Warnings for All” initiative.

Lastly, I wish to express my sincere appreciation to all members of the Expert Team on Multi-hazard Early Warning Services Technical Guidance (ET-MTG), the Standing Committee on Disaster Risk Reduction and Public Services (SC-DRR) and SERCOM, and the expert reviewers, all of whom contributed to the successful development of this important guide.



(Petteri Taalas)
Secretary-General

PREFACE

The World Meteorological Organization (WMO) Guides for National Meteorological and Hydrological Services (NMHS) in Support of National Multi-Hazard Early Warning Systems (MHEWSs), Procedures, Coordination Mechanisms, and Services (referred to as the Guides) are being developed in response to the [Resolution 16](#) of the eighteenth session of WMO Congress (Cg-18, 2019). The WMO technical commissions, in collaboration with the regional associations have been tasked with developing a set of Guides to enable WMO Members to establish national procedures and coordination mechanisms that are necessary to support the delivery of more effective multi-hazard early warning services. The first of these guides focusses on tropical cyclones.

The Expert Team on Multi-Hazard Early Warning Technical Guidance (ET-MTG) was established with specific terms of reference to develop the Guides under the direction of the Standing Committee for Disaster Risk Reduction and Public Services (SC-DRR) which sits within the Commission for Weather, Climate, Hydrological, Marine and Related Environmental Services and Applications (SERCOM) of WMO.

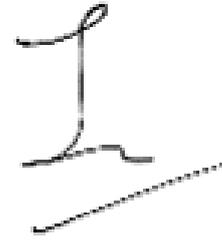
Based on the outcome of the questionnaire survey to those WMO Members prone to tropical cyclones, it was determined that whilst Members receive the same quality of tropical cyclone forecasting advisory information under regional coordination mechanisms, the delivery of early warnings and resultant early actions can differ dramatically at the national level. These differences are largely the result of issues with the lack of effective coordination mechanisms and procedures in response to tropical cyclone events at the national level.

The Guides will include descriptions on many areas, aspects and requirements related to national Multi-hazard Early Warning System (MHEWS) coordination procedures and mechanisms, such as hazards, impacts, knowledge, and challenges for MHEWS. Strategies for hazard awareness, warning, coordination, service delivery and emergency response, and procedures that need to be followed in multi-hazard early warnings will also be covered. Within this tropical cyclone Guide, good practices and national experiences from around the world are also summarized based on the outcomes of a survey of those Members prone to tropical cyclones.

The SERCOM ET-MTG as the authors of this Guide, all have extensive experience and expertise in operational tropical cyclone forecasting within their respective NMHS and responsibilities for the coordination of related services at the national/territorial level with their disaster management authorities. This Guide is therefore a reflection of their combined experience and knowledge. The Guide has also been reviewed by many experts from Members of the five regional tropical cyclone bodies.

Although this first Guide was developed with a focus on tropical cyclones, it may also be used as a basis for developing warning and advisories for other hazards given that it is structured on the basis of: 1) risk knowledge to support IBF and risk-informed warnings; 2) detecting, monitoring, analysing and forecasting the hazards and assessing their possible consequences; 3) coordination procedures on dissemination of warning information to communities, and communication with partners and; 4) preparedness and response capabilities at all levels, including support for national response and recovery strategies and planning. It is worth highlighting that these four principles are aligned with the four pillars of the United Nations “Early Warnings for All” Initiative (EW4All) Executive Action Plan for EW4ALL Initiative. This Guide can therefore be seen as a significant WMO contribution to ultimate aim of the EW4ALL Initiative, “*To ensure that everyone on earth is protected by an Early Warning System by the end of 2027*”.

I am very grateful for the work done in developing this Guide by the experts of the SERCOM ET-MTG. I also wish to express my sincere appreciation to the experts who carefully reviewed the Guide and thereby contributed to the completion of this important WMO Guide and approval for publication by the Executive Council at its 76th session (Resolution 11/EC-76).

A handwritten signature in black ink, appearing to read 'I Lisk', with a horizontal line underneath.

(Ian Lisk)
President of the Services Commission

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This guide was developed by the Expert Team on Multi-hazard Early Warning Services Technical Guidance (ET-MTG). ET-MTG members include:

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ET-MTG is one of the expert teams within the Standing Committee on Disaster Risk Reduction and Public Services (SC-DRR) in SERCOM.

EXECUTIVE SUMMARY

The successful implementation of Multi-hazard Early Warning Systems (MHEWS) will improve our ability to prepare communities for hazardous weather- and climate-related events and mitigate the impacts.

The eighteenth session of the World Meteorological Congress (Cg-18, 2019) approved [resolution 16 \(Cg-18\)](#) tasking technical commissions in collaboration with regional associations to develop a guide for Members to establish procedures/mechanisms for more effective MHEWS.

The aim of this guide is to enable (a) the early warnings of responsible warning authorities to be transformed into government-level warnings, the government in turn initiating early response actions for all partners and members of the public under its jurisdiction; and (b) outreach to the last mile to support early response actions.

This guide will serve to encourage Members to establish and develop national abiding procedures and mechanisms through legislation or administrative protocols specifying the transformation of National Meteorological and Hydrological Services (NMHSs) early warnings into government-level warnings, and strategies/actions in response to government warnings. This guide will further encourage Members to define accountabilities in the event of a failure to respond. These procedures and mechanisms should be supplemented with hazard monitoring and assessment systems to enable early warnings based on impacts and risks, including hazard observation, monitoring and modelling.

Published in 2021, the [WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services. Part II: Putting Multi-hazard IBFWS into Practice](#) (WMO-No. 1150) has helped countries to apply the concepts of impact-based forecast and warning services (IBFWS). However, there are still gaps between these concepts and actual implementation in both the developed and the developing worlds.

[Resolution 16 \(Cg-18\)](#) identified the need for a full guide to aid NMHSs to support the early alerting of governmental and non-governmental decision makers, thus permitting preparatory steps to be taken through MHEWS well ahead of the occurrence of hazards.

This guide is designed to provide practical guidance for MHEWS operations to help NMHSs to provide effective and institutional support in respect of national disaster risk management mandates. In the present context, MHEWS operations cover procedures, coordination mechanisms, services, legislation and policymaking. This includes leveraging existing guidance material and good practices related to the four elements of MHEWS from within WMO and also from its partners, with the following emphases:

- Risk knowledge – institutional coordination in the areas of risk information and assessment for impact-based forecasting and risk-based warning;
- Hazard awareness and warning – detection, monitoring, analysis and forecasting of hazards, and assessment of possible consequences;
- Service delivery – procedures and dissemination of advisory and warning information, including service delivery to communities and communication with partners;
- Preparedness – preparedness and response capabilities at all levels, including support for national response and recovery planning.

[Chapter 1](#) introduces hazards, impacts, knowledge and challenges for MHEWS. Strategies for hazard awareness, warning, coordination, service delivery and emergency response are

addressed in [Chapter 2](#). Procedures followed in multi-hazard early warnings are depicted in [Chapter 3](#). Good practices from around the world are reviewed in [Chapter 4](#). includes case studies submitted for this guide. Further references and resources are summarized in [References](#).

This is the first guide prepared by the Expert Team on Multi-hazard Early Warning Services Technical Guidance (ET-MTG). It is hoped that, given the multi-hazard nature of tropical cyclones, this first guide will shed light on other similar hazard clusters and be generalized to other early warnings.

CHAPTER 1. AN INTRODUCTION TO MULTI-HAZARD EARLY WARNING SYSTEMS AND THE CHALLENGES

1.1 DEFINITIONS, ESSENTIALS AND BENEFITS

To build capacity and strengthen resiliency, a few definitions, provided by the United Nations Office for Disaster Risk Reduction (UNDRR) (<https://www.undrr.org/terminology>), are essential: preparedness, prevention, recovery, resilience and response.

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

Prevention: Activities and measures to avoid existing and new disaster risks. While certain disaster risks cannot be eliminated, prevention aims at reducing vulnerability and exposure in such contexts where, as a result, the risk of disaster is removed. Examples include dams or embankments that eliminate flood risks, land-use regulations that do not permit any settlement in high-risk zones and so forth. Prevention measures can also be taken during or after a hazardous event or disaster to prevent secondary hazards or their consequences.

Preparedness: The knowledge and capacities developed by governments, response and recovery organizations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disasters. Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems (EWSs), and includes such activities as contingency planning. A preparedness plan establishes arrangements in advance to enable timely, effective and appropriate responses to specific potential hazardous events or emerging disaster situations that might threaten society or the environment.

Response: Actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected. Effective, efficient and timely response relies on disaster risk-informed preparedness measures.

Recovery: The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and “build back better”, to avoid or reduce future disaster risk.

Strengthening resilience depends on building capacity through prevention and preparedness, leading to effective response and recovery. The UNDRR Making Cities Resilient: *My City is Getting Ready!* campaign kit provides a ten-point checklist for making cities resilient:

- Put in place organization and coordination to understand and reduce disaster risk, based on participation of citizen groups and civil society. Build local alliances. Ensure that all departments understand their role in disaster risk reduction and preparedness.
- Assign a budget for disaster risk reduction and provide incentives for homeowners, low-income families, communities, businesses and the public sector to invest in reducing the risks they face.
- Maintain up-to-date data on hazards and vulnerabilities, prepare risk assessments and use these as the basis for urban development plans and decisions. Ensure that this information and the plans for your city’s resilience are readily available to the public and fully discussed with them.

- Invest in and maintain critical infrastructure that reduces risk, such as flood drainage, adjusted where needed to cope with climate change.
- Assess the safety of all schools and health facilities and upgrade them as necessary.
- Apply and enforce realistic, risk-compliant building regulations and land-use planning principles. Identify safe land for low-income citizens and develop upgrading of informal settlements, wherever feasible.
- Ensure that education programmes and training on disaster risk reduction are in place in schools and local communities.
- Protect ecosystems and natural buffers to mitigate floods, storm surges and other hazards to which your city may be vulnerable. Adapt to climate change by building on good risk reduction practices.
- Install EWSs and emergency management capacities in your city and hold regular public preparedness drills.
- After any disaster, ensure that the needs of the survivors are placed at the centre of reconstruction with support for them and their community organizations to design and help to implement responses, including rebuilding homes and livelihoods.

The publication then lists the ways in which cities that proactively seek to reduce disaster risk, as part of their sustainable urbanization efforts, can benefit greatly:

- Saved lives and property in case of disaster with dramatic reduction in fatalities and serious injuries;
- Protected development gains and less diversion of city resources to disaster response and recovery;
- Active citizen participation and local democracy;
- Increased investment in houses, buildings and other properties, in anticipation of fewer disaster losses;
- Increased capital investments in infrastructure, including retrofitting, renovation and renewal;
- Business opportunities, economic growth and employment as safer, better-governed cities attract more investment;
- Balanced ecosystems, which foster provisioning and cultural ecosystem services such as fresh water and recreation;
- Overall better health and well-being;
- Improved education in safer schools.

Building capacity leading to strengthened resiliency is a calculated, consistent, deliberate, laborious and ongoing process bringing great benefits to the local community and those governing the country. Investing in local communities' resiliency allows the government to put greater emphasis on social equity and inclusion and addresses actions needed in underserved or neglected populations, which typically live in disaster-prone areas. It truly is more cost-effective to prepare a community for hazardous events than to pay for the injuries, death and damages following a disaster.

1.2 HAZARDS AND IMPACTS

In accordance with [WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services. Part II: Putting Multi-hazard IBFWS into Practice](#) (WMO-No. 1150), a “hazard” is defined as a hydrometeorological-based, geophysical or human-induced element that poses a level of threat to life, property or the environment.

This guide will focus on the hazards associated with tropical cyclones, which include high winds, rainstorms, storm surges and flooding. High winds are when windspeed exceeds a certain threshold, defined for a given location, for a specific period of time. A rainstorm is a marked precipitation event occurring for 1 h, with a total precipitation exceeding a certain threshold defined for a given location. A storm surge is an abnormal rise in water above normal tide levels, caused by atmospheric weather systems. Flooding is an overflow of water that covers or submerges land that is normally dry.

Multi-hazard or cascading events can have a more significant impact on human society and the Earth system than a single hazard. A tropical cyclone is one of the strongest atmospheric hazards and can create cascading events. Tropical cyclones produce high winds, heavy rainfall and storm surges, which combine to produce more significant flooding than a single hazard. They can also produce tornadoes and cause wildfires. Flooding and high winds disrupt transportation networks, energy supplies and other critical infrastructure, causing loss of life or physical harm, social isolation, interruption to employment and livelihood activities and psychological distress. To solve the problems of tropical cyclone multi-hazards effectively with effective Multi-hazard Early Warning Systems (MHEWS), a thorough understanding of the multi-hazards is crucial. For a comprehensive review, including hazard classification, interested readers are referred to [Comprehensive Risk Assessment for Natural Hazards](#) (WMO/TD-No. 955).

To make effective assessment and prediction possible, hazards need to be quantified in terms of magnitude, duration, severity and extent (see Table 1 for a summary). Impact is quantified in terms of levels of magnitude or severity, and it is defined as either the effect or influence of a hazard or weather event, including changes in knowledge, skills, behaviour, health or living conditions. Impact can therefore be economic, sociocultural and environmental.

Different magnitudes and duration can have different impacts on the environment. For example, different types of trees may break at different wind speed thresholds. Wind damage extent or severity may also be affected by orography or manufactured structures around trees. As such, predicting the impact of a known hazard is typically difficult, if not impossible. With this

Table 1. Factors that determine the extremity of a hazard

<i>Factor</i>	<i>Definition</i>
Magnitude	Based on an index or a set of indices of condition(s) exceeding certain threshold(s), which can be as simple as one meteorological element (for example, maximum sustained windspeed) or as complicated as a combined index of multiple variables (such as windspeed, storm surge and so forth). The magnitude of impacts is often categorized into four categories: <ul style="list-style-type: none"> – Low-impact – minor inconvenience, small and local economic losses – Moderate impact – minor damage, some social disruption – High-impact – damage, risks to health, broad economic impact – Extreme-impact – catastrophic losses, deaths, injuries, major social disruption. Indices, criteria and thresholds should be defined by National Meteorological and Hydrological Services (NMHSs) at the national and subnational level according to climate conditions and applications.
Duration	The computation of the persistence of a weather event (for example, duration of strong winds). It should be based on recording the start and end time of the event.
Severity	A measure that integrates the magnitude and duration of a weather event.
Extent	The geographical area affected by and the widespread aspect of a weather event.

limitation in mind, WMO has promulgated the adoption of impact-based forecasting. If the relationship between a hazard and the associated impact is known, we are able to estimate the resulting impact.

1.3 RISK KNOWLEDGE

Risk is the probability and magnitude of harm possible to humans and their livelihoods and assets because of exposure and vulnerability to a hazard, sensitivity or susceptibility to harm and lack of capacity to cope and adapt. It is thoroughly discussed in previous WMO publications, such as *Comprehensive Risk Assessment for Natural Hazards* (WMO/TD-No. 955), *WMO Risk Management Framework* (WMO-No. 1111) and *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150).

Exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected.

Vulnerability is the susceptibility of exposed human beings and their livelihoods and assets to negative effects when impacted by a hazard.

Risks arise from the combination of hazards, exposure of people and assets to hazards, and vulnerabilities and coping capacities in a particular location. Assessments of these risks require the systematic collection and analysis of data and should consider the dynamics and compounding impacts of hazards coupled with vulnerabilities resulting from unplanned urbanization, changes in rural land use, environmental degradation and climate change.

Communicating the risk in a given area requires clearly conveying the likelihood of an event occurring coupled with its potential impact (see Figure 1 for an example of a risk analysis matrix).

1.4 HAZARD DETECTION, MONITORING, ANALYSIS AND FORECASTING

All MHEWS are founded on the detection, monitoring, analysis and forecasting of hazards. Typical monitoring tools for tropical cyclones include satellite and radar imageries, surface and upper air observations from weather stations, oil rigs, buoys and ships, satellite wind data and data from aircraft. When a tropical cyclone is close to a landmass, Doppler radar, if available, is essential for monitoring both the location and intensity. In some tropical cyclone basins, aircraft reconnaissance is also used to make measurements in and around the centre of a

			IMPACT				
			Very low	Low	Medium	High	Very High
			1	2	3	4	5
LIKELIHOOD	Very Low	1	1	2	3	4	5
	Low	2	2	4	6	8	10
	Medium	3	3	6	9	12	15
	High	4	4	8	12	16	20
	Very High	5	5	10	15	20	25
			1	2	3	4	5
			Very Low	Low	Medium	High	Very High

Figure 1. An example of a risk analysis matrix

Source: *WMO Risk Management Framework* (WMO-No. 1111)

tropical cyclone and collect flight-level and surface wind data, central pressure, profiles of wind, temperature and moisture from dropsondes, and radar data. The Dvorak technique is applied automatically or manually by forecasters to satellite imagery to assess tropical cyclone intensity; it is supplemented with surface observations, in particular winds and pressure, to confirm the formation of a tropical cyclone.

Good quality observation data and analysis of the actual meteorological situation are not only the key to hazard detection by National Meteorological and Hydrological Services (NMHSs); they are also a major input to numerical weather prediction (NWP) models. The accurate prediction of tropical cyclone evolution by a NWP model determines how well the associated multi-hazard event can be forecast, which in turn influences potential impacts on the affected locations and the local communities. No NWP model can be 100% accurate, which means that the predicted potential impacts are subject to varying degrees of uncertainty. To quantitatively calculate the likelihood of different hazards, major NWP centres operate their own Ensemble Prediction System (EPS) to simulate the possible hazard scenarios as exhaustively as possible. Together with the known relationships between hazards and risks, the magnitudes of the impacts can all be assessed. Given the known exposure and vulnerabilities of people and property, risk assessment plays an essential role in preparedness activities to protect lives and livelihoods.

NMHSs have developed considerable expertise in and capacity for providing hydrometeorological forecast and warning services; however, they are often not familiar with either the concepts of vulnerability and exposure or the workings of emergency and disaster management. Partnerships and collaboration with a wide range of partners can include governments, international bodies, scientific institutions, disaster management authorities, the insurance industry and local communities as needed.

1.5 **EFFECTIVE MULTI-HAZARD EARLY WARNING SYSTEM PARTNERSHIPS**

Effective MHEWS is based on partnerships at various levels. This ensures actionable warnings, including potential impacts and related information, are provided to the public in a timely and effective manner. Clearly defined roles and responsibilities of partners are important. Coordination mechanisms should be documented in national and local legislation, policies, strategies and plans. Arrangements should be made among partners well ahead of the tropical cyclone season in respect of the necessary actions when a tropical cyclone is detected.

Partners and decision makers usually need to act before warnings are issued and may ask for longer lead times from NMHSs before warning decisions can be confirmed. Given the uncertainties involved in tropical cyclone forecasting, likelihood- or risk-based communication terminology is recommended.

To provide key information to the public in a timely and effective manner, NMHSs should start with a non-technical weather note on potential weather changes and impacts when the lead time is a few days. The dissemination of tropical cyclone information can gradually be stepped up through social media, as well as short messages on a website/app, followed by formal news and press conferences, all leading up to the issuance of a tropical cyclone warning.

1.6 **RISK-BASED WARNING AND DECISION-MAKING AUTHORITIES**

NMHSs have national mandates to establish and develop the full sequence of national systems for observing, data acquisition, data processing, forecasting, and delivery of forecasting and warning services. One step further could be forecast and warning information provided with a multi-hazard approach and based on impacts and risks. The positive effects of forecasting and warning information can only be realized if the information reaches all people in the warning area(s) and if they respond accordingly. To realize this, NMHSs must collaborate with other government agencies, the private sector and academic institutions to take joint and well synergized actions to support the mitigation and reduction of hydrometeorological hazards.

With hazard monitoring, impact-based forecasting and risk assessment tools in place, warning decisions can be made by either NMHSs or other decision-making authorities, based on calculated risks. To ensure warnings can be delivered to potentially impacted areas, it is important to establish programme management roles and responsibilities for development, implementation and delivery, and standard operating procedures (SOPs); develop a communication strategy that explains what the expected services are, the respective roles of partners and outreach activities; develop a plan for the quality management (*Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers* (WMO-No. 1100)) and assurance of products and services; and ensure technical information is communicated in a way that communities and authorities outside NMHSs can understand.

1.7 **IMPORTANCE OF LEGISLATION**

Legislation is a key tool to help mobilize and coordinate the efforts of the whole society and to prevent and control the risks of and mitigate the damages caused by a major hazard. It helps to safeguard people's lives and property.

One agency cannot do it all! Therefore, there is a need for effective coordination arrangements to be articulated and set within a legislative and public policy framework. The arrangements must reflect the role of all agencies in the EWS within the context of community safety and sustainability. Without the backing, through legislation, of the government, the EWS is bound to fail. Agencies need designated authority from lawmakers to include roles and responsibilities; agencies involved, including non-governmental organizations (NGOs); operational mechanisms; funding and technical support; resources available; the designated agency to initiate warnings; the agency leading coordination activities; maintenance of the mechanisms; and so forth. With a legal framework, agencies' SOPs can be synergized with memorandums of understanding and agency directives to produce the most comprehensive, collaborative and united EWS, leading to the best chance of success.

Some countries have enforced laws and regulations that support and validate the work of NMHSs in providing timely forecasts, watches and warnings for the protection of the public and the economy. For example, the Meteorology Law of the People's Republic of China and the Philippine Disaster Risk Reduction and Management Act of 2010. Japan and the Republic of Korea regulate their work through the Meteorological Service Act and the Weather Act, respectively. More examples are available in [Chapter 4](#) and [Annex 1](#).

1.8 **GLOBAL POLICIES SUPPORTING MULTI-HAZARD EARLY WARNING SYSTEMS**

The WMO Convention reaffirms the vital importance of the mission of NMHSs in observing and understanding weather and climate and in providing meteorological, hydrological and related services in support of relevant national needs, including the protection of life and property and safeguarding the environment.

The *PPE (Public-Private Engagement Publication) No. 2. Geneva Declaration – 2019: Building Community for Weather, Climate and Water Actions* called on governments to safeguard and strengthen the authoritative voice of NMHSs for the issuance of warnings and relevant information to support critical decisions related to natural hazards and disaster risks, in collaboration with national disaster management authorities. This calls for governments to take the lead role in national disaster mitigation and reduction mechanisms.

The *Sendai Framework for Disaster Risk Reduction 2015–2030* established seven global targets to support the reduction of disaster risk. Target G, for example, requires a substantial increase in the availability of and access to MHEWS and disaster risk information and assessments to people by 2030.

Lastly, in March 2022, the Secretary-General of the United Nations, Dr António Guterres, announced that [the United Nations will spearhead new action to ensure every person on Earth is protected by EWSs within five years.](#)

Combined, these policies require more Members to establish national MHEWS and associated operating mechanisms.

1.9 ADDRESSING THE CHALLENGES FOR STRENGTHENING MULTI-HAZARD EARLY WARNING SYSTEMS

The large and expensive impacts of disasters, including tropical cyclones, on society are a significant concern for all countries. Despite technological advancement, there are challenges that continue to be faced when implementing MHEWS. To identify and assess the gaps in effective MHEWS, it is best to identify and address the major challenges, which concern warning procedures and coordination mechanisms.

1.9.1 Warning procedures

If risks are either not known or inaccurate, they create a challenge for MHEWS. Risks arise from both the hazards and the vulnerabilities that are present in a community. We need to understand whether the hazards and vulnerabilities are well known. Risk analysis and hazard assessment should be based on experience and traditional knowledge, as well as human, social, economic and environmental vulnerabilities. Risk analysis and hazard assessment must be properly implemented.

The major concern here is the availability of data and development of appropriate tools in respect of the superimposition of exposure data and vulnerability information on different georeferenced hazard maps. Updating exposure databases to include damage to infrastructures caused by meteorological hazards is a challenge on account of rapid urbanization. A further challenge is educating people on the interpretation and use of hazard and risk maps and other tools. An understanding of hazard and risk information will guide the public in proper preparedness actions and measures prior to the approach of a natural hazard. Hazard and risk mapping must therefore be a priority for disaster risk reduction management.

In recent years, there has been great technological advancement in monitoring and forecasting tropical cyclones. Many systems that can issue warnings for multi-hazard events are in place and forecast accuracy has improved greatly over recent decades. However, further studies must be done on the estimation and forecasting of quantitative rainfall and wind structure, sudden changes in intensity, and tropical cyclone tracks, erratic tracks and rapid intensification leading to shorter lead times for warnings. Furthermore, the interaction between tropical cyclones and the sea is not well understood scientifically.

The big challenge for communicating early warnings is that forecasts cannot be 100% accurate. Forecast errors and uncertainties are inevitable in actual operational forecasts, for which reason early warnings and the related response(s) must have sufficient tolerance for false alarms. Additionally, there needs to be continued work on how to communicate uncertainty to the public. To address this challenge, the co-design and co-development of forecast-warning value cycles at the national level should be enhanced for the accurate interpretation of forecast guidance and uncertainties. Regional and global capabilities can be used to enhance the application of Earth system modelling and prediction data products available from the [WMO Global Data-processing and Forecasting System \(GDPFS\)](#) and to advance the co-development process through regional/global coordinated activities, such as demonstration programmes and pilot projects.

Effective responses are heavily reliant on multi-hazard impact-based forecast and warning services (IBFWS), which need to know “what the weather will do” instead of the traditional forecasting system stating “what the weather will be”. People expect forecasts to be exact in

terms of the intensity, location and time of a given occurrence. With impact-based forecasting, the numerical values of weather parameters are not needed; the focus is instead on the severity of impacts and likelihood of occurrence at a projected time. Impact-based forecasting systems require weather data to be translated into hazards and then impact estimation using risk information. The current challenge is that impact-based forecasting either cannot be done by NMHSs alone or is inconsistent with existing responsibilities. Good partnerships and protocols must be in place to address this challenge, for which the cooperation of Civil Defence and emergency management agencies and other service institutions is necessary.

In some countries, the availability of qualified technical staff is still a concern. Having an adequate number of competent meteorologists and hydrologists to ensure that there is a smooth operation to analyse, compose appropriate messages and communicate with national emergency operations centres, the media and public is essential. Staff development programmes on EWS should be enhanced within NMHSs, taking into consideration [competency-based capacity-building and succession planning](#).

To address the challenges of multi-hazard IBFWS, [WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services. Part II: Putting Multi-hazard IBFWS into Practice](#) (WMO-No. 1150) will be of great help. (WMO-No. 1150) will be of great help.

1.9.2 **Coordination mechanisms**

People should be reminded of the responsibility that comes with the release of forecasts and other information. To address this and to help to educate people, policymakers should develop legislation to improve and strengthen the mechanisms around forecasting, warnings, information-sharing and risk communication.

Another challenge is that reference forecast information issued by global and regional operational centres and NWP models, which was originally used by professional forecasters for internal communication, is being shared with communities through the Internet, causing information confusion in the community. As a result, NMHSs struggle to explain not only the uncertainty of the forecast itself but also the inconsistency with international NWP model forecasts. If the international forecast proves to be more accurate, it will have a negative impact on the authority and credibility of national and local forecast services.

The forecasts and warnings issued on the Internet by unauthoritative entities pose a particular problem, especially when there are discrepancies between these forecasts and warnings and the official forecasts and warnings issued by mandated NMHSs. This results in confusion and could reduce trust and confidence in NMHSs.

A successful warning needs the effective delivery of information, and the execution of proper preparatory actions depends on the application of social and behavioural sciences. For MHEWS to be considered effective, forecasts and warnings must be disseminated and communicated to the maximum extent possible and well understood. Based on the information communicated, appropriate preparedness actions can be taken by different types of users, such as disaster managers, media practitioners, responders and the public. To attain this, NMHSs need the full cooperation of different partners, other service institutions and users. Success lies in how the message is written by the sender and perceived by the receiver that commands action. In communicating, one of the challenges that forecasters face is how to express forecasts and warnings using terms and statements that are clear and easily understood by all people in society. More often than not, warning messages are said to be so highly technical that ordinary citizens cannot understand them. The messages should include information about the uncertainties associated with tropical cyclone hazards. Communication experts and social scientists are of great help in this regard.

The timely delivery of warning messages to communities in remote areas affected by tropical cyclones is also one of the major challenges for NMHSs. Isolated areas not yet covered by advanced communication access and technology have no access to weather forecasts and warning advisories shared on social media platforms. In these cases, traditional communication

practices, such as the ringing of church bells, the rhythmic beating of drums and so forth, are utilized. Public awareness campaigns, drills and simulations must be carried out regularly. Annual exercises are critical to ensuring that the various agencies and communities know exactly what they must do to reach a high level of effective response.

The mode of transmission of warning messages is another area to be monitored and evaluated. In addition to conventional newsprint, telefax, television and radio broadcasts, NMHSs maintain their own websites and use social media platforms and apps. Website content should be regularly updated to ensure that accurate information is communicated to the public in a timely manner. Messages must be monitored to ensure that official information is captured, especially in dealing with social media platforms.

To increase the value of weather-related warnings, a value cycle approach is necessary, with the continuous evaluation and updating of communication strategies through post-event analysis, user engagement, user testing and awareness of design principles. Whereas false alarms or missed events are remembered by people, accurate forecasts are not. One false alarm to 10 accurate forecasts has a substantial impact on people's trust.

The management of communication among NMHSs and disaster management organizations, other agencies and partners, including the media, is critical to ensure a proper response to any hazard. It is important to note that, during the passage of a storm, it is critical for NMHSs to have either a liaison with national emergency operational centres or direct, uninterrupted communication with weather services.

Tropical cyclone mitigation is a complex, systematic endeavour, and its success or failure depends not only on the timely and accurate forecasts and early warnings of NMHSs but also on the effective response actions of various government entities and society. Multiagency cooperation mechanisms for disaster management must be established at the national, regional and local levels. The challenge here is for NMHSs to maintain strong partnerships and coordination with the other government agencies, private organizations and institutions involved in disaster management activities. The establishment of an integrated tropical cyclone preparedness and mitigation system with the cooperation of government-led entities and extensive social participation defining the responsibilities of each partner and the coordination mechanisms is crucial. This includes the development of an agreed SOP. Legislation or national administrative measures are another method that can be used to compel relevant parties to do their part to respond to the warnings. In some countries, there are legal documents or policies that clearly state the roles and responsibilities of the entities involved.

Not all countries and regions have preparedness plans to support response mechanisms, and in some instances plans are either outdated or just not utilized. Abundant and applicable preparedness plans guarantee the effectiveness of linkage coordination mechanism. When NMHSs issue tropical cyclone warnings, all relevant departments and social forces should take corresponding coordinated actions.

CHAPTER 2. RECOMMENDED STRATEGY FOR MULTI-HAZARD EARLY WARNING SYSTEMS

As Pat played on the beach, a village elder approached with word of an approaching storm. Pat, just being a child, hurried home with the news. The family gathered to discuss their options. Evacuation was out of the question because their island was too far away to get to a safer island with their boats. Finding a hardened structure to withstand the onslaught of wind, rain and coastal inundation was useless since the strongest structure was too small for all the villagers to squeeze into, although the most vulnerable among them would request this option from the elders. Their only effective option was to move their canoes to the highest point on the island, which was only 3 m above high tide, and prepare for the storm surge to wash over the area. This meant tying their boats to palm trees and protecting themselves from blowing debris and heavy rain. As the family prepared for the approaching cyclone, they sent Pat to the village centre to gather the latest information, which came through the only communication device available to the villagers – a shortwave radio. Pat learned that the cyclone was increasing in strength, with the storm surge expected to rise above 3 m. Pat hurried home to let the family know about the dire situation. Preparations continued. The island council gathered to finalize preparations, including working together to protect the most vulnerable folks and those who needed extra help. It also needed to arrange for immediate recovery needs, such as medical attention, food, shelter, transportation and potable water, which was a struggle since many island communities would require this response after the passage of the storm.

Having the ability to plan, knowing where to get authoritative information, being ready to act and identifying how to recover from an event makes all the difference. Before one begins to plan for a hazardous event, there needs to be recognition and acceptance that disasters can and do happen. Although having a written plan starts one on the path to success, the plan needs to be widely distributed, practised, reviewed and updated. In this chapter, we will explore recommendations for good practices and successes and failures of “the system” through describing technical guidelines and regulations developed for national multi-hazard early warning procedures, coordination mechanisms, system protocols and services.

2.1 OVERARCHING PRINCIPLES

2.1.1 Keep it Aligned for REsults

The Keep it Aligned for REsults (KARE) principle will help tremendously in getting the desired end results, including keeping people safe and decreasing property damage. While developing an early warning system (EWS), keeping the goals in mind throughout the process is paramount for the outcome to be robust, successfully oriented and interconnected. As partners, a shared and aligned vision can bring, and keep, everyone together to create and sustain an effective set of plans. For example, having an initial gathering with disaster risk reduction managers, meteorological, hydrological, and climatological forecasters, politicians, faith-based community organizers, village elders, representatives of the International Federation of Red Cross and Red Crescent Societies (IFRC), first responders, disaster recovery experts and other community leaders that is focused on the participants meeting, greeting and getting to know one another while brainstorming a vision puts everyone on the road to success. A modest vision is all that is needed, such as “everyone in harm’s way receives timely warnings, reacts to save lives and livelihoods and obtains the necessary supplies for recovery”.

2.1.2 Keep It Simple for Success

The Keep It Simple for Success (KISS) principle will help tremendously in bringing about the necessary actions to keep people safe and decrease property damage. The more complex a set of plans, the greater the chance of failure. If plans are kept simple, it will be easier for people to understand and apply the procedures quickly and effectively. Procedures tend to

expand as post-storm reviews are applied without considering the set of plans as a whole. Therefore, applying the KISS principle each time the procedures are amended will lead to a successful outcome.

2.1.3 **Lives Over Economy**

The Lives Over Economy (LOVE) principle will help tremendously in keeping the focus on humane choices to prioritize the safety of people over protecting property. The more developed an economy and society, the greater the potential loss of property caused by a tropical cyclone with the same intensity. However, the overprotection of property can sometimes lead to unnecessary injuries, and even loss of life and wealth. Where there is life, there is hope and wealth. Therefore, applying the LOVE principle in the absence of sufficient response time will lead to a successful outcome for those who are in harm's way.

2.2 **PREPAREDNESS**

A perfect warning with plenty of lead time is worthless unless those in harm's way receive the warning and respond appropriately, which is why preparation is of the utmost importance for protecting lives and property. A simple, people-centric preparedness approach will ensure the actions are coordinated and seamless, and disorder during an event is reduced, leading to the improved efficiency of tropical cyclone response and reduction of disaster impacts. This includes establishing standard operating procedures (SOPs) to ensure consistent operations; data and information exchange; clear roles and responsibilities; and the provision of information in an understandable and timely manner. Preparedness needs to incorporate tropical cyclone exercises that include communities and partners. A strong exercise programme will produce an effective tropical cyclone early warning and response system.

2.2.1 **Standard operating procedures**

SOPs are a standard set of steps to be followed to ensure tasks are performed in the same way and to the same standard each time. At a high level, they often specify the "who" (responsible agency) and "what" (roles and responsibilities), and many times they further specify the "when" and "why" of agencies' roles and responsibilities in respect of an EWS. There are two effective levels of procedures. High-level procedures that can be developed into synergized SOPs specify the "who", "what", "when", "where", "why" and "how" of tasks or activities associated with disasters to support national-level policy documents. Lower-level procedures, sometimes referred to as "operational directives" or "checklists", specify the more detailed "how to" and are internal to a particular workplace or agency, for which reason they are not shared or synergized.

Protocols must be established to activate and mobilize emergency operators (for example, emergency managers, local police, firefighters and health services) who disseminate warnings to the public and decide what measures to take, including issuing orders for evacuation or sheltering in place. This way, the public and other partners are aware of which authorities issue the warnings, resulting in greater trust in the message. The standard procedure is to create synergy through a multi-hazard and multiagency cooperative development, sharing, review, analysis and documentation process so the whole is greater than the sum of its parts. Through this process, EWSs will be improved, and overall efficiency will be increased. SOPs should be updated, as needed, after every event based on the after-action review.

SOPs may refer to memorandums of understanding (MoU). MoUs help to ensure different agencies and organizations understand each other's roles and responsibilities and how they can perform in an integrated manner as partners. MoUs can be either bilateral (between two agencies) or multilateral (among multiple agencies). A MoU identifies the parties involved, defines the subject matter and objectives and establishes agreed-upon roles and responsibilities.

2.2.2 Integration

Disaster preparedness measures, including response plans, need to be fully developed, disseminated to the community, practised and underpinned by legislation where appropriate. To protect lives, it is essential that SOPs account for the needs of people with different degrees of vulnerability (urban and rural, women and men, older and younger, people with disabilities, special needs individuals and so forth). It is among vulnerable populations that the greatest number of casualties are likely to occur. Incorporating traditional knowledge and redundancy into SOPs will help to build a robust and complete set of plans. Another important aspect of early action and response options across time and geographical scales is linked to the provision of funding to support them. In order to keep SOPs fresh and up-to-date, regular exercises need to be undertaken to test and optimize the effectiveness of early [warning dissemination and communication](#) processes, and preparedness for and response to warnings.

Integration incorporates concepts of synergy through multi-hazards, multiagencies and integration methods. To avoid conflicting information, different agencies' interrelated roles and responsibilities must be incorporated into their respective SOPs. This can be accomplished through a systematic review of the roles and responsibilities assigned to all agencies within a country involved in the EWS. All levels of government, from the national to the subnational and local levels, that are involved in the warning processes must be included in the development, execution and revision of SOPs.

Preparation includes reaching out to the most vulnerable communities to train, educate, practise and develop individual plans for when disaster strikes. By implementing the KARE, KISS and LOVE principles, one can design a successful outreach campaign. Keeping your campaign aligned with the vision of protecting lives and property, arranging a simple process and prioritizing saving lives over protecting property will allow you to achieve the greatest chance of success in the face of a hazardous event. Having a variety of formats for disseminating and communicating information provides the best chance of reaching more people in a style they will understand. In today's society, it seems visuals and less text are preferred, leading to easily interpretable information. Therefore, one may consider integrating social science into programmes to consider risk perception and to understand how the public consumes and processes tropical cyclone information.

A tropical cyclone preparedness system should be composed of:

- General provisions, including purpose, basis, scope of application and a review, update and maintenance schedule;
- General hazard and vulnerability information, including physical geography, socioeconomic factors and critical infrastructure;
- An organizational system, including leading, emergency liaison and working agencies;
- Emergency preparedness, including communication and information, search and rescue, professional guarantee, security, and medical, material, financial and social mobilization;
- Supervision and management, including public information exchange, training, exercises, rewards and application of lessons learned;
- EWS information, including warning information, warning level classification, warning operations and main defence protocols;
- Emergency response measures, including general requirements, organization, response grading and action, and transitioning to recovery procedures;
- Disaster assistance, supply of emergency response materials, repair of damaged properties, reconstruction, insurance and compensation, investigation and lessons captured.

To begin your preparedness campaign, a knowledge of hazards and where safety exists during each hazard is necessary to design a successful operating plan. Each community has its own history with hazardous events and can provide local knowledge that may not be widely known. For example, a stream may become a raging river when moderate rain falls over a basin for only a few hours owing to the steepness of the terrain, or a harbour might be very sensitive to tsunami waves as compared to the surrounding beaches, thereby intensifying storm surges. Reaching out to vulnerable communities can bring this local knowledge to the surface and help National Meteorological and Hydrological Services (NMHSs) to provide impact-based warnings, in turn leading to a response with a greater chance of success. Other parts of preparedness campaigns include education, training and exercises. Several visits will need to take place to build trust, inclusion, understanding and awareness.

To develop and improve Multi-hazard Early Warning Systems (MHEWS), one must know and anticipate the potential hazards, including downstream and after-hazard dangers. The best way to understand the impacts of hazards is to understand the history of a community and talk to those who have been in harm's way. Gaining local knowledge is imperative to build robust, impact-based MHEWS.

Once the typical hazards have been noted and planned for, looking into a complex situation will be the next step in honing your SOPs. For example, a flood followed closely by a tropical cyclone may require moving those already evacuated from the flood to a different location because of the predicted fierce winds.

A national survey conducted by the Citizens Corps of the United States of America in 2009 found that 67% of respondents agreed that preparing in advance would help them to handle a disaster; however, only 35% considered themselves to be prepared. This is a big gap, not to mention that just over 1 in 10 of those surveyed said preparing for a disaster was not at all useful. Therefore, trying to motivate people to prepare will require a concerted and consistent effort. Elsewhere in the survey a question about barriers was presented. The most commonly mentioned primary reason for not preparing was the belief that emergency responders, such as fire, police or emergency personnel, would help (29%). Other primary reasons included a lack of knowledge (24%) and time (26%).

Looking at what motivates people to take training and prepare for a potential disaster, the survey found:

[m]ost individuals taking preparedness classes or emergency training attributed their motivation to a mandatory function of their job or school (48%). The second most common response was for the concern and safety of family or others (21%). Some respondents (14%) also reported taking preparedness training because family or friends did.

This is a big obstacle to overcome! Basically, only one third of those surveyed participated in preparedness classes or emergency training through their own motivation, presenting a conundrum about making training mandatory and providing incentives.

Mandatory training for the public is not realistic; consequently, providing incentives may be the only tool available to reach those who need to prepare. What do incentives look like? Simple things, such as safety fairs where displays of emergency vehicles and demonstrations of emergency procedures draw large crowds. During safety fairs, educational material can be handed out and short training sessions conducted. A full-scale exercise where the community actively participates, especially children or older people, can be a fun and an educational experience. However, it can also be very expensive. Another motivator for attendance is sustenance. When a community or organization gathers for an event or meeting, providing an inexpensive treat can attract people and, in some communities, it is either culturally appropriate or expected. Remember, when community leaders support preparedness, those around them will have that mindset too. The IFRC guide on [Community Early Warning Systems: Guiding Principles](#) provides copious information on how to engage at a community level, including good practices and lessons learned. Getting specific preparedness training and education into the hands of those who need it is vital for successful MHEWS.

According to the [Sendai Framework for Disaster Risk Reduction 2015–2030](#), children have a vital role in strengthening community resilience. In recognition of the need to promote disaster risk reduction education among children, the [COPE disaster book series](#) was created in 2018. The books cover natural hazards ranging from floods and earthquakes to wildfires and cyclones, providing coping tools, preparedness and relatable stories in an imaginative way that is easy to understand. COPE uses a creative, narrative, collaborative and contextually sensitive educational approach to disasters that highlights key disaster risk reduction messages that are easy to remember, such as “EVACUATE!” for floods and “DROP, COVER & HOLD!” for earthquakes. WMO has served as scientific adviser to COPE since 2020, advising so far on wildfires, storm surges, droughts and volcanoes. COPE messages are being disseminated globally. In 2022, the disaster book series was uploaded to the United Nations Children’s Fund (UNICEF) Learning Passport Global Digital Library and the East Asia and Pacific Library as supplemental content, which means key disaster risk reduction messages will be spread to millions of children far and wide.

Getting authoritative information into the hands of those who can make a difference is vital for saving lives. Having recurring outreach campaigns will assist in bringing about the desired reaction. For any warning system, the first step is to make sure those in harm’s way recognize they are in danger. This comes through education and training even before the disaster occurs. An awareness of potential hazards in respect of where one works, lives and plays goes a long way to knowing how to remain safe. The second step is knowing how to get warning information. Although this usually comes through a multitude of sources, sometimes it comes through only one. Mobile phones are found in many communities and can be the fastest way to get warning information into the hands of those who can react appropriately and inspire others to do the same. Other popular means of communication include social media, Internet sites, television, radio, satellite connections and community warning sounds, such as sirens, gongs, bells, horns, loudspeakers and so forth. Once people receive a warning, they are likely to attempt to verify it through electronic sources and even through family members and neighbours. If conflicting information is received, the likelihood of proper action being initiated decreases rapidly, demonstrating the importance of partners and stakeholders providing collaborative and enhanced information. Also, having a mature authoritative source, such as a National Meteorological Service (NMS), National Hydrological Service (NHS) or National Disaster Management Agency (NDMA) will lend credence to any warning(s) issued.

Once people have received preparedness education and training, the next step is to develop a response plan. IFRC provides a family safety plan checklist and a template for family safety plans (see [References](#) for links). When individuals have a plan, they will be confident in their decisions to keep themselves and their loved ones safe and may even be able to help those in need.

2.3 EXERCISING THE PLAN

The effectiveness of any warning system is based on it achieving the expected results. Therefore, implementing a warning system not only provides the greatest chance of success but also a means of evaluating and improving it. When conducting exercises, it is important to be inclusive, encompassing all those involved in responding and reacting to a hazard.

According to the [Integrated Flood Management Tools Series No. 11. Flood Emergency Planning](#):

[c]oordination is required between government agencies, including disaster management committees at different levels, line departments, public works, health, armed forces and police, economic and finance, planning, education, rural development, transport, communication, environmental and natural resources, where disaster management committees can take the lead and coordinate the planning process. Active NGOs may play an important role in interacting with government agencies and in undertaking emergency measures at the local level within an overall flood emergency plan.

To take this one step further, those in harm's way need to know how to react, which means bringing national-level plans into the community so neighbourhoods, families and even individuals can participate in functional drills. The practice will give all involved confidence in the system and the planning and it will reinforce what is necessary for a successful outcome. The publication continues:

[i]n many vulnerable communities, experience shows that flood issues are not always given a high priority compared with daily survival issues, such as livelihood, lack of water and sanitation facilities, law and order, and so forth. This often makes communities behave passively towards flood risks, as they are seen as a remote occurrence without a perceived chance to control events (otherwise described as a fatalistic behaviour). This renders communities more vulnerable and sometimes more exposed to floods. To avoid this situation, motivation for initiating community participation, such as socio-economic incentives and systematic training, are indispensable.

Although the document is focused on flood planning, its concepts can be applied to all hazards.

Exercising an emergency response plan comes in many different forms and under many different names. Other names commonly used are "practice", "drill" and "play". For our purposes, we will use the term "exercise". Common forms of exercise start with basic knowledge and understanding risk and include tabletop exercises, during which participants talk through a scenario, functional exercises, during which those involved perform their duties in a simulated operational environment, and full-scale exercises, during which everyone on location simulates "the real thing" as closely as possible. Pre-season campaigns to remind vulnerable populations to prepare themselves include press conferences, tropical cyclone activity forecasts, communications about SOPs and tropical cyclone alert systems, exercises and information about where to find out more. The Ready website of the United States of America (<https://www.ready.gov/exercises>) provides the basics and resources for developing and conducting exercises.

2.4 **BUILDING CAPACITY AND RESILIENCY LEADING TO EFFECTIVE RESPONSE AND RECOVERY**

After preparing, developing plans and exercising procedures, capacity-building continues as the ability to respond grows through investing in people, infrastructure and emergency management. Since governments are responsible for preparing their citizens and visitors for hazardous conditions, these matters need to be resourced through legislation or administrative directives. As stated in I World Bank publication *Ready2Respond: A Framework for Emergency Preparedness and Response*, when the capacity to respond to an impending hazard is robust, it:

reduces felt consequence and enables rapid recovery, reducing cumulative impacts to public safety and the economy. Therefore, ensuring capacity for emergency response protects WBG investment across development sectors and the development gains that have resulted from those investments.

Thus, the return on investment in building a robust response capacity is well worth it. The publication provides the results of studies reviewing how investing in a response-ready community before a hazardous event occurs saves both time and money. Out of the 49 investments considered in the study:

64% saved both time and money. The investments saved a total of USD 12 million toward future response costs for a net savings of USD 6.4 million and an average ROI of 2.1. However, certain investments, such as those that focused on personnel development, produced a much higher ROI of 18.7. Perhaps more importantly, 93% of preparedness investments saved time for emergency response operations and no investment slowed operations down.

The more resilient a community is, the more quickly those within the community can get back to living normal lives and restoring livelihoods once the hazardous conditions have passed. Obtaining funding to invest in capacity-building and resilience is generally the key to enriching MHEWS. The aforementioned publication provides a short list of financial instruments that were available as of 2017:

- Program-for-Results (PforR) Financing
- Caribbean Catastrophe Risk Insurance Facility (CCRIF)
- Climate Risks and EWSs (CREWS) Initiative
- Catastrophe Deferred Drawdown Option (CAT-DDO)
- Global Facility for Disaster Reduction and Recovery (GFDRR).

The Systematic Observations Financing Facility (SOFF) is a WMO-specific finance mechanism.

2.4.1 **Becoming weather-ready**

Preparing is built on a long history of lessons learned and adjusted based on evolving circumstances, such as climate change. One can see in the following example of success versus an example of dissolve how important having a plan can be. The neighbouring islands of Saint Barthélemy and Saint Martin displayed vastly different preparation techniques when provided with the same resources. The Government of Saint Barthélemy used the resources to bolster construction and resilience, while the Government of Saint Martin floundered. Investigation found that there were major differences between institutional and administrative organization and level of economic development, exhibiting that a one-size-fits-all approach is inadequate. Therefore, each plan must be tailored to the needs of the people, and every government must look at equity of services to serve the most vulnerable.

Citizens and visitors want the best chance to live their lives in a safe environment and generally rely on the government to make that happen. Therefore, making your nation, region, county, prefecture, community and family weather-ready contributes significantly to this safety effort. WMO has developed a programme to do this called “Weather-ready Nations”, which focuses on strengthening capacity at NMHSs and NDMAAs towards better and augmented use of weather, water and climate information to save lives, reduce human suffering and lessen the economic impacts of hydrometeorological hazards.

Prepare your communities by developing impact-based forecasting, including the use of technology and communication tools, and developing, maintaining, practising and improving synergized SOPs; and by all means provide education, training and outreach to those who could be in harm’s way.

2.5 **RESPONSE**

When a disaster occurs, relying on preparedness, training and SOPs during the response will provide the best chance of success in keeping people safe along with decreasing damage to infrastructure and property. Being ready to respond is key to achieving the collective goals established at meetings leading up to the disaster. Keeping a people-centred, goal-oriented frame of mind as the response gets under way will help to build cooperation, leading to the best results possible. As stated in *Ready2Respond: A Framework for Emergency Preparedness and Response*:

[t]o achieve preparedness ..., response systems, and the early warning systems that enable response, need to work horizontally across government ministries and departments and also vertically through national, regional and local levels of government. Inclusive in these systems is the role of NGO response partners

for the delivery of assistance and aid regardless of the event's scale and impact intensity. An effective preparedness system enables local level preparedness as a priority while in parallel creating supportive and aligned coordinating capacity and specialized resources at the national and sub-national levels for larger scale events.

The publication provides a description of the five primary elements that enable a high-functioning capacity; namely personnel, facilities, information, equipment, and legal and institutional framework.

Personnel: A highly skilled and experienced workforce is the most valuable resource in any disaster preparedness and response system. To achieve this, a culture of preparedness must be established that places the trust of the public and political body in the agencies tasked with ensuring public safety and minimizing economic disruptions. This requires intensive and extensive training of those involved in emergency preparedness and response to acquire knowledge, develop skills and gain practical experience. This development of personnel must take advantage of the best available plans and information, facilities and equipment to ensure an interoperable systems approach is broadly understood. It must enable deep capability in focused areas of expertise to ensure investment in personnel development transitions from the individual to the team, and from the team to the agency culture.

Facilities: Coordination of effort for emergency preparedness and response activities requires a structural presence, be it for command and control, movement of emergency aid or the staging of response teams and their equipment. These facilities act as a core element in establishing a culture of preparedness, ensuring a dependable common operating picture and resilient services when most other critical infrastructure and government service is disrupted. This component ensures that there is a nexus for information, personnel and equipment as an emergency preparedness and response system matures through focused investment.

Information: The collection, analysis and swift dissemination of information enables better decision-making in advance of emergencies, during response operations and through the transition to early recovery. Impacts of emergencies are felt locally, and so community engagement is vital to a well-developed state of preparedness. The information used for preparedness and response includes the information generated from EWSs to provide residents, and the response teams that support them, with advance notice of emerging hazardous events. The coordination of emergency information from responding agencies and social media ensures horizontal and vertical situational awareness that enables efficient, coordinated and prioritized response operations. Lastly, the development of hazard and vulnerability maps along with other georeferenced emergency information, captured digitally and shared electronically, provides decision makers with a key resource for planning across timescales to reduce risk. For high-quality information to have an impact, it must be utilized by well-trained, committed personnel that have the appropriate equipment to respond safely and effectively.

Equipment: The appropriate acquisition, use and maintenance of preparedness and response equipment ensures timely information-sharing and safe, effective rescue operations. It further ensures the ability to effectively communicate despite the harshest possible conditions. These investments assist governments to overcome the capital requirements to ensure access to life-saving technologies and resources. Combined with established parts and the service supply chain, it enables governments to ensure their core preparedness and response agencies have the tools to deliver their services safely and effectively.

Legal and institutional framework: Clarity about the role of various public and private agencies is critical during disaster and emergency response. Where ambiguity exists, so do inefficiency and jurisdictional overlap. When lives and economic loss are threatened during an event, this ambiguity can increase both potential and actual losses. To address this challenge, improvements regarding preparedness and response roles can be a potent means to improve resilience at various levels of government. Ideally, accountabilities are clearly enshrined in legislation with directive regulations. Wherever possible, de-conflicted policy instruments identify the operational expectations of those agencies that are assigned a preparedness and

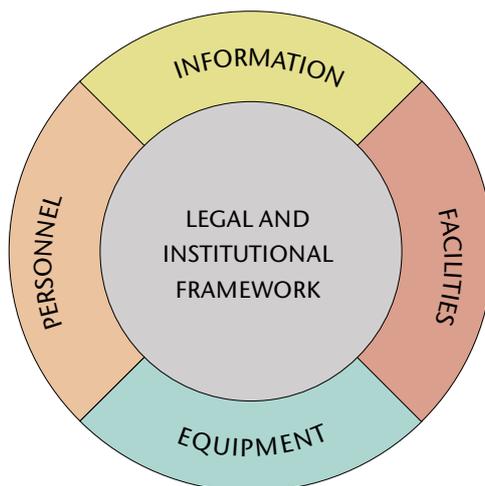


Figure 2. Emergency preparedness and response system key elements

Source: *Ready2Respond: A Framework for Emergency Preparedness and Response*

response mandate. However, even in the absence of complete organizational clarity, investment in preparedness and response can often improve a jurisdiction’s ability to mitigate impacts and limit disaster- and emergency-related losses.

As Figure 2 illustrates, the legal and institutional framework is at the core and enables the functioning of the other elements. To be successful, SOPs must address all these elements.

In the end, through a plethora of preparedness practices and through effective writing, executing, training and exercising SOPs, responding to a pending disaster should be a relatively smooth process. However, there will be things that are not expected, leading to new lessons learned, as well as things that went quite well, which turn into good practices. The result of incorporating these new ideas in SOPs will be a more robust plan.

2.6 RECOVERY

Once again, planning is key for effective recovery after disaster strikes, and codifying recovery efforts into policy is required to procure resources and direction in a timely manner. Ideally, this should be done before an event as part of preparedness. After the policy has been established, a lead agency can be assigned to develop a framework for recovery. According to the [Guide to Developing Disaster Recovery Frameworks](#), “[i]t is the role of the lead agency to establish and oversee the coordination mechanisms that guarantee coherent policy application and effective implementation at the regional and local levels”. The publication also states “[p]utting the recovery framework in place prior to a disaster increases the likelihood that the gains from the recovery process will carry over into sustainable development”. Therefore, policy will not only establish roles and responsibilities but also increase resiliency after the hazard passes.

The GFDRR publication [Building Back Better: Achieving Resilience through Stronger, Faster, and More Inclusive Post-Disaster Reconstruction](#) describes the need to have:

the appropriate policies and tools ... made available to affected households, firms, and local and national authorities *before the disaster hits*. These are usually incorporated into a *disaster recovery framework* that include[s] contingency plans and institutional arrangements with a clear allocation of responsibility in the recovery period, access to practical knowledge and information, and strong and inclusive financial protection provided by a combination of disaster-response social safety nets, insurance mechanisms, and access to borrowing to finance the reconstruction.

Plans to build increasing resilience into inclusive recovery, especially for the poorest and most vulnerable populations, must start with access to reconstructive support, including financial assistance. According to *Building Back Better: Achieving Resilience through Stronger, Faster, and More Inclusive Post-Disaster Reconstruction*, rebuilding more inclusively, stronger and faster “could generate major benefits, totaling US\$ 173 billion per year, or 31 percent of current well-being losses due to natural disasters”.

Building back more inclusively ensures that post-disaster support reaches all affected population groups. This emphasizes the importance of providing reconstruction support to low-income households, which are typically more exposed, more vulnerable and less comprehensively supported. If all countries had the ability to provide the poorest people with the post-disaster support found in developed countries, global well-being losses due to disasters could be reduced by 9%, equivalent to a 52 billion US dollar (USD) increase in annual global consumption. The effect is particularly pronounced in countries with high inequality, and where poor people have little access to social protection and financial instruments. According to available estimates, in those countries, building back more inclusively could reduce disaster losses by 27% or more.

Building back stronger reduces well-being losses by ensuring that reconstructed infrastructure can resist more intense events in the future. If all countries were to “build back stronger” in the next 20 years – ensuring that rebuilt assets could resist hazards with a 50-year return period – global well-being losses due to natural disasters would be reduced by 12%, a gain equivalent to USD 65 billion annually. Stronger reconstruction would reduce overall well-being losses due to natural disasters by more than 40% in 10 countries in particular: Antigua and Barbuda, Dominica, Fiji, Guatemala, Lao People’s Democratic Republic, Myanmar, Peru, Tonga, Trinidad and Tobago and Vanuatu.

Building back faster reduces disaster impacts by accelerating reconstruction through measures, such as contingent reconstruction plans, pre-approved contracts and financial arrangements. Estimates show that if average reconstruction time were reduced by two thirds (without compromising the quality of reconstruction), global well-being losses could be reduced by 14% – equivalent to increasing global consumption by over USD 75 billion per year. These gains would be especially pronounced in countries with frequent events, such as small island or sub-Saharan countries.

Having a plan to build resilience into recovery will provide those in future harm’s way with the confidence for protection during and a quicker recovery after disasters. In addition, recovery provides an opportunity to train and educate those in previously underserved communities, further building capacity and resilience.

Another vital element for recovery is communication, both among agencies as well as with those rebuilding their lives. To communicate effectively, there must be multiple methods of getting messages to and from those involved and affected. Having numerous means of two-way communication is essential and requires planning, deliberate effort and resources. Relying on a single point of failure, even if it is robust, can leave a country without vital means of receiving data or getting crucial information to others in the field. Having a communication plan with built-in redundancy should allow the reliable transmission of critical information during hazardous events.

2.7 SUMMARY

The story of Pat’s village provides a great example of how a people-centric, simple and aligned EWS can provide those in harm’s way with the ability to take appropriate action to save lives, reduce property damage and be ready to recover from a hazardous situation, including tropical cyclones. Pat’s village was prepared, knew exactly how to receive the warning, took appropriate action without hesitation, assisted those who needed help and was prepared for recovery. The last step, which was not part of the story, is to review the process and update the plan as necessary (more on this in [Chapter 3](#)). The story shows how a simple plan can make the difference for quick action. Also, working together made a difference to those who needed

assistance as well as to the smooth execution of the plan. Ensuring correct action is taken starts with outreach, education, training and exercise well before a disaster is pending. Make sure you know your partners and local leaders by name through exercises and training – the time to meet them for the first time is not when a disaster is pending. Therefore, to prepare your citizens well, plan, communicate, collaborate, educate, reach out at the local level, practise and always aim to improve.

CHAPTER 3. RECOMMENDED MULTI-HAZARD EARLY WARNING PROCEDURES

3.1 THE PROCESS

With the ability to forecast disasters comes the capability to provide early warnings.

Being able to detect an impending disaster is necessary for an early warning system (EWS) to be effective. Creating and improving monitoring systems is essential to detect an upcoming event. Table 2 details worst-case scenarios for which EWSs should be developed.

Once monitoring and detection systems are in place, accurately forecasting a hazard is necessary to provide early warnings. Tolerance for false alarms and the inability to detect the severity of impacts needs to be taken into consideration. For example, a community living along a riverbank may accept several false alarms for flooding because the time it takes to evacuate the village only allows low confidence in forecasts. This example shows the importance of outreach and education, which enhance EWSs by working with communities to understand their needs and so communities understand the government’s limitations.

The following sections assist in developing and enhancing processes to reach those in harm’s way, ultimately saving lives and reducing property damage (for more details, see the references in [References](#)).

3.1.1 Monitoring

Detecting threatening situations is vital for providing early warnings. Knowing what is typical, what is possible and what an extreme event produces are necessary to start the process. The systematic monitoring of environmental parameters and meteorological elements forms the basis for accurate prediction. These parameters are used for the preparation of meteorological analysis and to diagnose the current scenario. The same analysis field serves as the initial basis for numerical models to generate forecast fields. This emphasizes the importance of establishing a standardized (as prescribed by WMO), quality controlled and optimal network of meteorological observatories.

Table 2. Generalized “worst-case” scenarios for early warning lead times

Real-time “now-casting”	Short-term forecasting	Medium-term forecasting	Long-term forecasting
Seconds-minutes	Hours-days	Weeks-months-season	Years or more
Earthquakes Industrial threat Dust devils Tornados Flash floods	Severe storms Wildfire Tropical cyclones Landslides Floods Tsunamis Volcanoes Heatwaves Epidemics	Drought ENSO Extreme temperatures Conflict	Sea level rise Deforestation Desertification Dry spells Extreme rainfall Soil degradation Environmental pollution

Since weather does not recognize political boundaries, sharing data is vital for understanding the larger scale of the atmosphere. WMO encourages and even provides ways to share data.

Space-based monitoring and aircraft observations of cloud patterns and other derived parameters – such as vertical wind shear, low-level convergence, upper-level divergence, mid tropospheric humidity and upper tropospheric humidity (UTH) and warming, and sea surface temperature (STT) – form an integral part of basic diagnostic inputs in respect of the data-sparse oceanic regions, where tropical cyclones originate.

The resources provided in [References](#) provide a way forward, including a way to finance your observing system.

3.1.2 **Forecasting**

The ability to provide relevant, effective and actionable forecasting starts with an understanding of how atmosphere and water movement across the Earth, both over land and in the seas, affects those in harm's way.

An accurate prediction of tropical cyclones determines how accurately the multi-hazard event can be forecast, which in turn influences potential impacts on the affected communities.

Questions should include:

- How much uncertainty is there in the forecast as to the tropical cyclone track and likely landfall area?
- How much uncertainty is there in the forecast as to the wind speed, intensity and wind field structure of the tropical cyclone?
- How much uncertainty is there in the forecast as to wind speed, precipitation and storm surge, both in terms of the temporal period (that is, when they are likely to affect people) and spatial domain (that is, the areal extent of associated hazards)?
- How well understood are the single and multidirectional interactions among different tropical cyclone variables and are they captured by the models?
- Which models or combinations of models offer the best skill for different components of the tropical cyclone multi-hazard event and best capture the situational forecast uncertainty?
- What role do observations play in improving multi-hazard forecasting for both simultaneous and cascading hazards?
- How do uncertainties influence the forecasting of simultaneous and cascading hazards, and how do these uncertainties influence risk and impact scenarios?

Empirical, statistical and numerical methods, and new emerging techniques, such as artificial intelligence (AI) and machine learning, are in vogue for predicting tropical cyclone track, intensity, landfall, structure and multi-hazards (storm surges, high winds and heavy rainfall).

A lot of research has focused on understanding the interactions and relationships between tropical cyclones and their associated hazards (that is, high winds, heavy rainfall and storm surges). For example, Lianshou Chen, Ying Li and Zhengquan Cheng (2010) considered the physical mechanisms of rainfall associated with landfalling tropical cyclones and found that rain rates are not only related to tropical cyclone intensity but are also influenced by moisture transport and latent heat release. Links have been established between sea surface temperature and tropical cyclone rainfall area and wind size in the tropics (Yanluan Lin, Ming Zhao and Minghua Zhang (2015)). There are several drivers of tropical cyclone-related storm surges, including maximum wind speed, central pressure and storm size (Jennifer L. Irish, Donald T. Resio and Jay J. Ratcliff (2008)), speed of movement (João Lima Rego and Chunyan Li (2009)), angle of approach and the surrounding geography (for example, the shape of the shoreline,

coastal features and offshore morphology), which can influence storm surge height and extent. In terms of real-time forecasting, John A. Knaff et al (2016) illustrate the importance of correctly estimating tropical cyclone wind radii to inform warnings and provide initial conditions for downstream applications, including wind speed probabilities and wave forecasting. It is well recognized that the inputs (that is, tropical cyclone track, surface winds and pressure) used to drive storm surge warning models (for example, P.L.N. Murty et al (2017)) and other downstream hazard models will have a direct impact on forecasts and therefore on the accuracy of warnings. Understanding which parts of the forecasting chain influence the predictability of various simultaneous and cascading hazards to the greatest extent is essential for improving multi-hazard communication and subsequent decision-making.

Proper education and application are necessary for the successful development and enhancement of National Meteorological and Hydrological Services (NMHSs). A wealth of reference links is provided in [References](#).

3.1.3 Early warning methodologies

For those in harm's way to prepare for an event, obtaining timely and relevant information about impending hazards is necessary. To this end, one can follow the guidance of the Coastal Inundation Forecasting Initiative (CIFI). CIFI guidance facilitates the development and implementation of warning services for tropical cyclones, with the goal of operating and maintaining a reliable forecasting system that informs national decision-making by:

- Identifying national and regional requirements, particularly end user needs;
- Encouraging full engagement of all partners;
- Implementing coastal inundation end-to-end operational forecasting and warning systems;
- Developing cross-cutting cooperation among different scientific disciplines and user communities;
- Building communication platforms among the researchers, forecasters and disaster managers involved in coastal inundation management;
- Transferring technology to participating countries;
- Providing specialized training for operators, forecasters and disaster managers.

The WMO Typhoon Committee [Manual on Synergized Standard Operating Procedures \(SSOPs\) for Coastal Multi-hazards Early Warning System](#) describes an effective EWS as requiring:

- Involvement and commitment of high-level government policymakers
- Legal and legislative framework
- National plan or policy identifying roles and responsibilities
- EWS as an integral part at all levels of government
- Coordination across many/all agencies at national to local levels
- Operational mechanism defined
- Identification of budgetary and technical support
- Designation of an agency for coordination activities
- A comprehensive national hazard risk assessment.

In addition, the International Federation of Red Cross and Red Crescent Societies (IFRC) publication [Community Early Warning Systems: Guiding Principles](#) provides guiding principles for community EWSs:

- Integrate within disaster risk reduction – EWS is not stand-alone
- Aim for synergy across levels: community, national and regional/global
- Insist on multi-hazard EWS
- Systematically include vulnerability
- Design EWS components with multiple functions
- Accommodate multiple timescales
- Embrace multiple knowledge systems
- Account for evolving risk and rising uncertainty
- EWS without borders: target the full vulnerability and hazard-scape
- Demand appropriate technology
- Require redundancy in indicators and communication channels
- Target and reach disadvantaged and vulnerable groups
- Build partnerships and individual engagement.

These frameworks for developing a people-centred, effective, efficient, well-understood and practised EWS for all partners can make processes seem routine even during hectic and frenzied times pre-event. Synergy, cooperation and confidence are essential for quick action. When those in harm's way receive early warnings from authoritative sources, they have confidence in the warnings and know how to react on account of the education, training and outreach that occurred prior to the event, hopefully leading to the number of casualties being significantly or completely reduced. Plans for communication, dissemination, response, recovery and after-action reviews (AARs) are components of the basic needs of any EWS.

In developing or improving an effective EWS, the WMO [Multi-hazard Early Warning Systems: A Checklist](#), the [Quick Reference Guide on Synergized Standard Operating Procedures \(SSOPs\) for Coastal Multi-hazards Early Warning System](#) and IFRC guidance should be utilized. Also, keep in mind the Keep it Aligned for Results (KARE), Keep It Simple for Success (KISS) and Lives Over Economy (LOVE) principles introduced in [Chapter 2](#).

3.1.4 **National Meteorological and Hydrological Services standard early warning protocols**

Another important factor for a successful EWS is the role of NMHSs. The ability of NMHSs to not only detect and forecast a pending event but also effectively communicate the impacts is vital to the success of executing a plan. Having a standard operating procedure (SOP) saves lives and reduces property damage. To develop or improve NMHS protocols for an effective EWS, we turn once again to [Multi-hazard Early Warning Systems: A Checklist](#) and the [Quick Reference Guide on Synergized Standard Operating Procedures \(SSOPs\) for Coastal Multi-hazards Early Warning System](#). These publications recommend developing and maintaining good working relationships between NMHSs and disaster management agencies for coordination and effective and consistent communication. Identify risk by monitoring hydrometeorological hazards; providing high-quality archived and real-time data; conducting multi-hazards and vulnerability analysis and mapping; and publishing forecasts with potential impacts. Reduce risk through the

provision of short-term hazard forecasts and warnings related to specific impacts (for example, a flood or storm surge) to support emergency preparedness planning and response, and medium- and long-range forecasts (probabilistic information on hazards and their changing patterns) to support sectoral planning. Lead or actively participate in the development and improvement of effective EWSs. It should be noted that observation systems operated by NMHSs and an efficient communications system form the backbone of NMHS warning services and play a crucial role in respect of the effectiveness of the entire EWS.

Building partnerships and involving partners leads to greater success. This includes agreement on warning standards, procedures and systems for consistent warning and education information; ways of getting vulnerable populations to take effective action; sharing experience, knowledge and lessons learned from a wide range of people; accomplishment of tasks that cannot be done by a single agency or organization; and better use of financial resources and cost sharing through a commitment by all to a common goal.

NMHSs can tailor the warning information and decision support services they provide to the specific needs of partners by understanding different aspects of national economies, cultures, vulnerabilities, economic statuses, community capabilities, decision-making processes and impact on partners' operations. Care should be taken to ensure the warning is neither too long nor too complicated (KISS principle). NMHSs are responsible for creating warning content and distributing warning messages. NMHSs may consider using warning tones, colour codes and/or graphical warnings. A standard format and plain language are essential to spark action. A good early warning message must contain the following elements:

- **Timing:** When is the hazard expected to begin?
- **Location:** Which areas are potentially going to be affected?
- **Scale:** What is the potential magnitude of the hazard (for example, level of water, wind speed, likely area of inundation and so forth)?
- **Impact:** What will the potential impacts of the hazard on communities and the environment be?
- **Probability:** What are the chances of the hazard happening?
- **Response:** What should at-risk populations do to protect themselves?
- **Uncertainties:** alternative hazard scenarios and the anticipated potential impacts on society.

3.2 PRODUCE PROCEDURES

As part of emergency response management procedures at the national level, the government should set out a contingency plan for disasters. The plan should be multi-hazard, clearly delineating the administrative strategy, organizational framework and warning and alerting systems for responding to all possible types of events for the geography and climate. The contingency plan should stipulate the functions and responsibilities of, as well as coordination/ collaboration among, all key partners, including government bureaux/departments, public utilities companies, transport operators and non-governmental organizations (NGOs).

When developing procedures to deliver early warnings for a multitude of hazards, one must keep in mind the goal: save lives and livelihoods and, when possible, protect property. People-centred, impact-based, easy-to-understand and simple-to-use procedures are a must

for getting the desired response from those in harm's way. The *Manual on Synergized Standard Operating Procedures (SSOPs) for Coastal Multi-hazards Early Warning System* states, for procedures to be effective:

coordination, collaboration, support, and assistance are needed not only horizontally with other agencies at the same level of government, but also vertically, to involve all levels of government, citizens, and media. An effective EWS must provide the required information to the people at risk so they in turn can perform the correct actions to save their lives and property regardless of whether they live in a large city or a rural, coastal location.

From the national government to the individual in harm's way, a knowledge of written procedures for how to react when disasters are pending is essential for success. Developing, maintaining, practising and improving SOPs will lead to the best possible outcome, as presented in [Chapter 2](#). Synergizing SOPs across all levels to, in the words of the *Quick Reference Guide on Synergized Standard Operating Procedures (SSOPs) for Coastal Multi-hazards Early Warning System*, "create SOPs through a cooperative development, review, analysis, and documentation process in a [m]ulti-hazards and multi-agency way so the whole is greater than the sum of its parts" will lead to the smoothest, most collaborative method available. the purpose of having synergized SOPs is fivefold:

[e]nsure tasks are performed in the same way and to the same standard each time; [m]aintain high quality and consistent service in hazard situations; [d]iscuss, determine, and approve the most efficient and effective method to perform tasks before an emergency occurs; [i]mprove cooperation and integration of different tasks among agencies involved in EWS; and ... reduce training time.

To this end, all levels can be prepared to have the most robust, people-centric, impact-based response possible.

Success requires thorough and close collaboration and coordination with partners and those vulnerable to pending disasters. The *Multi-hazard Early Warning Systems: A Checklist* provides a structure:

[t]he checklist, which is structured around the four key elements of early warning systems, aims to be a simple list of the main components and actions to which national governments, community organizations and partners within and across all sectors can refer when developing or evaluating early warning systems. It is not intended to be a comprehensive design manual, but instead a practical, non-technical reference tool to ensure that the major elements of an effective early warning system are in place.

The *Manual on Synergized Standard Operating Procedures (SSOPs) for Coastal Multi-hazards Early Warning System* is:

designed to provide flexible approaches, operational guidance, and recommendations based upon best practices and available resources to prepare SSOPs for coastal multi-hazards early warning systems. It includes key concepts, basic principles, and basic standards for SSOPs.

Combining these two resources as a country or region develops or refines its procedures will assist in delivering an effective set of processes based on a holistic and well-rounded approach.

3.3 **DISSEMINATION AND UPDATE OF ALERT AND WARNING MESSAGES**

Before a tropical cyclone approaches or during the quiet season, early alert messages, public education and outreach activities should be practised, as mentioned in [Chapter 2](#), as resources allow.

During the cyclone season, depending on the context and available communication means, publishing an extended weather outlook article on potential weather and impacts should be adequate to alert people. To ensure wide coverage and sufficient reach, all available media platforms should be utilized to push or promote the article – for example, websites, social media, weather blogs and mobile apps. If cooperative, long-term working relationships can be built with the mass media, there is a good chance weather stories from the weather authority will be covered by newspapers and television channels. Nowadays, video content is predominantly much more popular than text with an average audience. If affordable or already available, educational video materials on tropical cyclones and other natural hazards could be extracted or replayed to alert the public of the characteristics of an approaching tropical cyclone. As longer-range tropical cyclone forecasts become more available from major numerical weather prediction (NWP) centres, briefings on the tropical cyclone outlook up to four weeks in advance may be organized for special users or even the public on a regular basis. These briefings include information about possible tropical cyclone formation areas and subsequent movements and are based on a large number of NWP model runs.

Both wind speed and direction may change rapidly, likewise the associated impacts – for example, storm surge. It is of paramount importance to ensure warning signals and messages are up to date and reflect the potential impacts. While the update frequency of televisions/radios may not be controlled by the weather authority, bulletins on websites and push notifications on mobile phones can be synchronized quickly and frequently. For the effective cross-border exchange of information concerning hazards, a common alerting protocol (CAP) is highly recommended for packaging warning messages.

Closer to but still before the time warranted for tropical cyclone warning signals, some form of weather advisory or actionable weather advice could be formulated and disseminated through all channels available. To raise public awareness to the highest level, media briefings or press conferences will be needed. Within the expected lead time for a tropical cyclone to exert influence on or impact the location of concern, the appropriate warning signal, among other weather warnings, should be disseminated by all available means without delay.

In places where television remains the primary channel of warning dissemination, meteorologists from weather authorities are recommended to conduct televised briefings or even take part in the production process before and during tropical cyclone signals. This can reinforce the weather service authority. During media briefings on tropical cyclones, the potential impacts of cascading hazards should be communicated to the public, together with precautionary actions to be taken.

3.3.1 **Communication, collaboration and coordination among partners**

When a tropical cyclone warning signal is issued by the weather authority, other government departments are expected to make corresponding arrangements – for example, the education department, about school closures, and the transportation department, about road closures – in accordance with the prescribed procedures and coordination mechanisms in the contingency plan. By law or by agreed practices, relevant government authorities should publish and maintain guidelines for hazard preparedness so employers and employees and schools and parents can develop arrangements for the suspension and resumption of work and school, based on the level of warnings.

Key partners usually need to take actions before the public do once the warning has been issued. They will typically ask for longer lead times from the weather authority before the warning decision can be confirmed. Under such scenarios, communication protocols between the two sides will be important to exchange information in a clear, easily understandable and unambiguous manner. Given the uncertainty involved in tropical cyclone forecasting, likelihood-

or risk-based communication terminology is recommended: for example, “high chance of raising tropical cyclone signal from X to Y UTC” instead of “tropical cyclone signal will be issued at X UTC”, or “high risk of shoulder-level storm flooding” instead of “storm surge will reach X m above mCD”.

To ensure all members of the public, including partners, can understand tropical cyclone signals and warning messages to take appropriate actions, short videos, radio programmes, public talks, government seminars as well as site visits to key partners should happen as a means of public education. They should be conducted on a regular basis throughout the year, especially during the quiet season. Physical and virtual NMHS open days can be organized to introduce the work of weather authorities and boost public understanding and awareness of severe weather, including tropical cyclones. Through such interactive engagements, trust may also be built up between weather authorities and the public.

3.4 AFTER-ACTION REVIEW

Assessing performance after a disaster is an important step to improve response during the next disaster, update SOPs, build resilience, increase capacity and determine where training and education are needed. During the process, good practices can be identified, suggestions on how to incorporate lessons learned can be voiced, accountability can be addressed, means to address vulnerable and underserved communities can be considered and the execution of the response can be assessed.

According to the World Health Organization (WHO) [Guidance for After Action Review \(AAR\)](#):

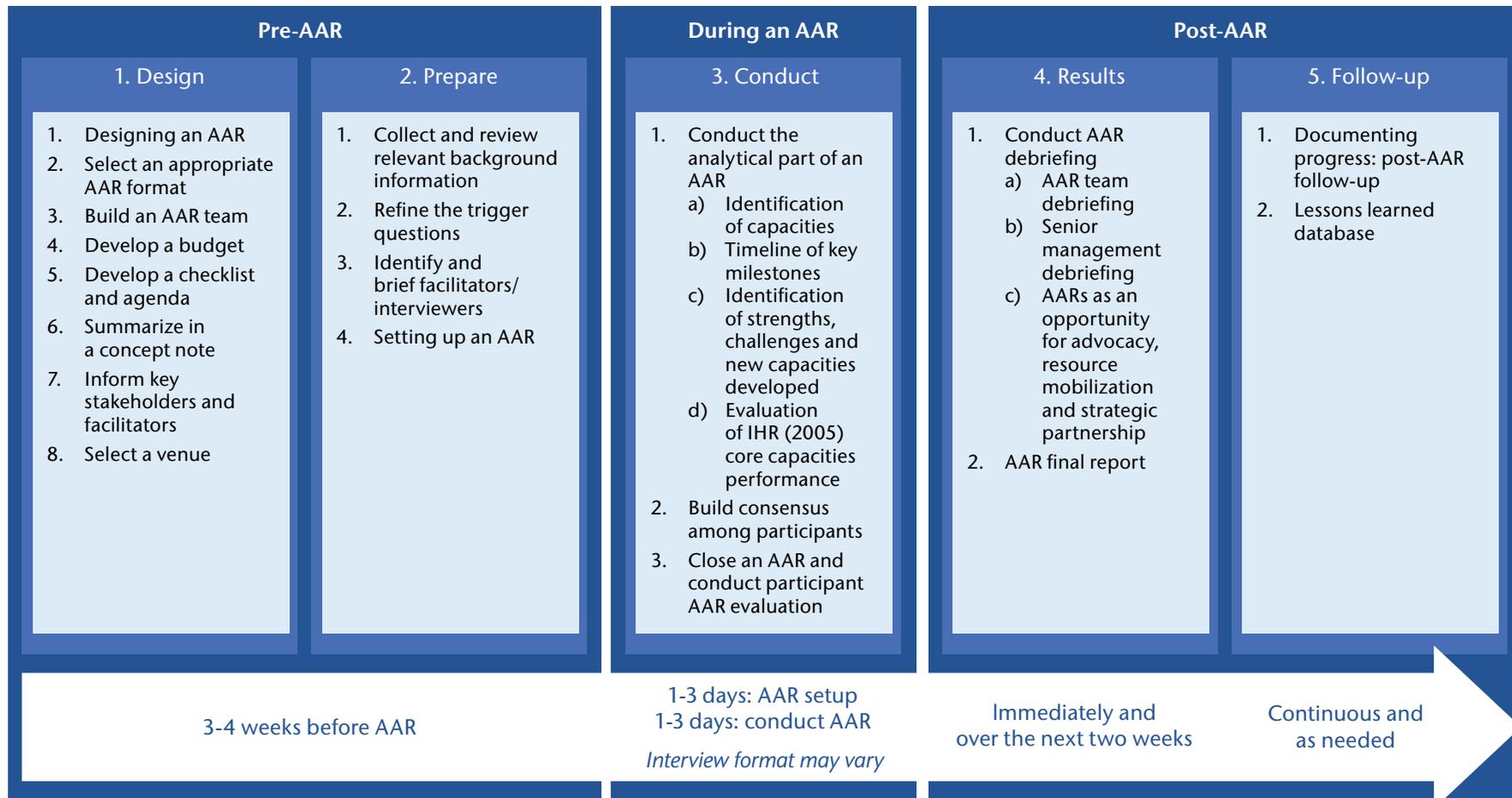
[a]n AAR is a review of all actions taken during the response to an event. The review aims to identify capacities in place before the response, any challenges that came to light during it, the lessons identified, and any best practices observed during the response, including the development of new capacities.

Refer to Figure 3 for an AAR planning road map.

The benefits of an AAR are that it:

- Ensures critical thinking around the event to determine underlying factors that may have led to any failures and successes encountered during the response;
- Builds consensus on issues for follow-up, as it involves all those that were engaged in the response;
- Allows the identification and documentation of lessons learned for immediate application.
- Allows cross-sectoral learning, as it involves more stakeholders than just those in the weather sector. This helps to bring new perspectives and strengthen relationships and coordination across sectors;
- Allows advocacy for support, as an AAR report can be used as an advocacy tool for domestic financing for all involved;
- Builds capacity for preparedness and response, as gaps and best practices identified in the AAR can be respectively addressed for improvement, and documented and institutionalized.

During the AAR, calculating a few statistics can help to verify the information disseminated by the authorities. For example, the NMHS may issue flood warnings. Verifying whether the event occurred (genuine or false alarm) and warning was issued (probability of detection), and the lead time, can provide important data for the NMHS to improve its warning capability.



IHR (2005): International Health Regulations (2005)

Figure 3. AAR planning road map

Source: Guidance for After Action Review (AAR)

NMHSs determine the level of tolerance a community has for false alarms, which may already be ingrained in the local culture or even woven into the government's fabric. If one is to increase lead time, normally one must expect a greater number of false alarms. This is where education, training and outreach in local communities can improve understanding of the limitations of EWSs and gain the support of local communities in respect of contributing to future efforts.

3.5 **CONCLUSION**

Developing and refining a set of procedures is not an easy task. It takes dedication, hard work, significant relationship building, multidiscipline partner interaction, flexibility, intimate knowledge of disasters and recognition of how vulnerable communities react to impending hazards. In addition, motivating people to prepare for possible disasters can be a daunting endeavour. However, the effort applied to prepare people and produce procedures and practise and then implement plans will save lives and livelihoods and decrease property damage.

The ultimate goal is to save lives and livelihoods and, when possible, protect property. To accomplish our goal, planning, building capacity, fostering resiliency and communicating appropriately will lead to an effective response and quicker recovery. Also, codifying through legislation and policy the roles and responsibilities; agencies involved; operational mechanisms; funding; and resources available will set those in harm's way up for success. Preparing those vulnerable to hazards through education and training will begin the process of changing behaviour, leading to coordinated and proper responses when warnings are issued. The plans already in place will be executed, protecting lives and safeguarding property. By helping to build a weather-ready nation, communities can increase capacity and improve resilience, thereby increasing confidence in responses to and recovery following hazardous conditions and decreasing the chance of a disaster. As a world community, we must, and we will, take up this challenge, working together to foster resilience.

CHAPTER 4. PRACTICES AND APPROACHES TO MULTI-HAZARD EARLY WARNING SYSTEMS

4.1 INTRODUCTION

The governments of all countries affected by tropical cyclones give great importance to disaster prevention, mitigation and relief work, and establish their own tropical cyclone and related Multi-hazard Early Warning Systems (MHEWS). Years of tropical cyclone response practice has proven that these systems ensure the safety of people's lives and property and the sustainable development of national economies to the maximum extent, and mitigate disaster losses related to tropical cyclones.

This chapter presents some of the responses to the [questionnaire](#) distributed through the WMO Tropical Cyclone Programme (TCP). The responses are examples of different Member practices in respect of national tropical cyclone and related multi-hazard early warning and response procedures, coordination mechanisms, systems and services. Although it is nearly impossible to show all the work that is being done in all geographical areas where tropical cyclones are a threat, the responses included give a sense of what is being done. Some countries are presented here, while others and further responses are presented in [Annex 1](#) in their entirety.

Some conclusions will follow at the end to highlight the most interesting aspects and to point out the gaps that still exist, showing the ways in which MHEWS could be improved.

4.2 LEGAL BASIS FOR TROPICAL CYCLONE EARLY WARNING SYSTEMS

Most of the casualties and financial losses occasioned by disasters in coastal areas are related to tropical cyclones. Risk- and disaster-related tropical cyclone management has always been a major issue for the governments in high-risk areas. To mobilize and coordinate the efforts of the whole society to prevent and control the risk of and mitigate the damages caused by tropical cyclones to safeguard people's lives and property, laws have been enacted in most countries located in tropical cyclone-prone areas.

Laws and regulations have paved the way for a paradigm shift in those countries' national disaster management systems, from ones primarily focused on response and preparedness for response to ones focused on reducing and managing disaster risks. A comprehensive national disaster management system is usually established based on national laws and a people-centred philosophy. It has become clear that, for disaster risk reduction and management to succeed, effective early warning systems (EWSs) must be established.

All the countries that responded to the questionnaire have laws and regulations in force for issuing tropical cyclone warnings, though these might vary according to different cultures.

In the Cayman Islands, provisions have been made in the Disaster Preparedness and Hazard Management Law, Section 7 of which states "[t]here shall be established a National Emergency Notification System for the Islands", while the Official Hurricane Plan provides the framework for preparedness, response and recovery.

China has formulated and improved its laws and regulations, including the Meteorology Law and the Flood Control Law of the People's Republic of China. A prevention-oriented, holistic and integrated approach has been adopted. Efforts have been made to take scientifically sound measures during the entire process from early warning to response, including monitoring, forecasting, prevention, resistance, rescue and assistance, and to leave no regrets.

Cuba has a wide legal basis regulating the functioning of EWSs at all levels. Law No. 75/94 (21 December 1994) (National Defence Act) establishes the main missions and measures of the Civil Defence System and the principles for its territorial and institutional organization. In May 2022, the National Assembly of People's Power passed a law on the environment and natural resources that updates and englobes within Law No. 81/97 (11 July 1997) on the environment the principles and processes of EWS in Cuba, considering best practices and lessons learned. Several legal bodies on the issue will be updated in the coming months.

In Hong Kong, China, the Hong Kong Special Administrative Region Government has the Contingency Plan for Natural Disasters, which is the Government's strategy, organizational framework and alerting system for responding to natural disasters. The Plan also stipulates the functions and responsibilities of government bureaux/departments, utilities companies and non-governmental organizations (NGOs) in the event of natural disasters. A tropical cyclone warning system is an integral part of the Plan.

In Japan, the Meteorological Service Act defines the duties of the Japan Meteorological Agency (JMA), such as observation, forecasting and warning. The Act stipulates that JMA shall give warnings for concerning meteorological phenomena caused by tropical cyclones (Article 13 and so forth). In addition, restrictions are imposed on the issuance of warnings by those other than JMA (Article 23), ensuring it is the single national authoritative voice for warnings. The Disaster Countermeasures Basic Act stipulates the disaster management system for the entire Government, including local governments and municipalities. JMA plays a major role in providing up-to-date weather information, including warnings, in the system. The EWS for tropical cyclones in Japan is based on the above acts and related regulations.

In Oman, the National Multi-hazard Early Warning Centre, which is located in the Civil Aviation Authority, is the base of all tropical cyclone forecasts and multi-hazard warning systems related to weather. However, the Centre follows the legislation and procedures of Regional Specialized Meteorological Centres (RSMCs) and WMO regulations on tropical cyclones.

In the United States of America, the legal basis upon which the EWS for tropical cyclones is based is comprised of the National Weather Service Organic Act of 1890; the Weather Research and Forecasting Innovation Act of 2017; the Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988; and annual budget appropriations and associated congressional language. The National Hurricane Center is the source of all tropical cyclone forecasts and warnings, and the Central Pacific Hurricane Center is responsible for forecasts and warnings in the central Pacific and Hawaiian Islands.

4.3 GOVERNANCE AND INSTITUTIONAL ARRANGEMENTS

A complete and collaborative partnership for EWS is an important foundation for tropical cyclone disaster response. In all the countries that responded to the questionnaire, this partnership is present one way or another.

The China Meteorological Administration (CMA) has a major responsibility for tropical cyclone early warning, monitoring and forecasting. CMA analyses and predicts floods and disasters, issues forecasts and warnings in a timely manner and participates in emergency response. To form a joint prevention and response effort for an integrated tropical cyclone response at the national level, the State Flood Control and Drought Relief Headquarters and a collaborative partnership system were established. Under the leadership of the State Council of the People's Republic of China, the Headquarters is responsible for leading and organizing national tropical cyclone early warnings and response efforts. A Vice Premier of the State Council is the General Commander of the Headquarters, the Deputy Administrator of the CMA is one of the two Deputy Secretaries-General and several members are senior officials from member agencies. The member agencies of the Headquarters, as the partners of CMA, work closely and collaboratively to perform their duties in respect of tropical cyclone response. The major partners of CMA

include the Ministry of Emergency Management; the Ministry of Natural Resources; the Ministry of Water Resources; the Ministry of Transport; the National Radio and Television Administration; the Ministry of Civil Affairs; and the General Staff Department of the People's Liberation Army.

In India, disaster management has started to address the issues of EWSs, forecasting and monitoring set-up for various weather-related hazards. A structure for the flow of information in the form of warnings, alerts and updates about ensuing hazards has been established within this framework. A multi-stakeholder, high-powered group has been set up with representatives from different ministries and departments; some of these ministries were also designated as the nodal authorities for specific disasters. Following a report by the High-Powered Committee on Disaster Management on the establishment of a separate institutional structure for addressing disasters and enactment of a suitable law for institutionalizing disaster management in the country, multilevel links between these ministries and the disaster management framework have emerged. In the present structure, there is a National Disaster Management Agency (NDMA) at the centre, and State Disaster Management Authority at state and district levels. In addition to this, there is the National Crisis Management Committee.

In Oman, the exchange of information between the Directorate General of Meteorology (National Multi-hazard Early Warning Centre) and the National Emergency Management Committee is regulated by a memorandum of understanding (MoU) that provides for the monitoring of tropical cyclones. The National Multi-hazard Early Warning Centre standard operating procedure (SOP) includes all the technical procedures for guaranteeing the implementation of the MoU, and the frequency and content of reports.

In the Philippines, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), as the National Meteorological and Hydrological Service (NMHS), is involved in the first three elements of the country's EWS, with a particular focus on monitoring and forecasting and disseminating warnings. As for response capabilities, responsibility falls to members of the National Disaster Risk Reduction and Management Council and the local government units.

In the United States, tropical cyclone operational forecast and warning responsibility is met through a combination of national centres and local forecast offices. The National Hurricane Center and the Central Pacific Hurricane Center are responsible for all meteorological and storm surge decisions concerning the analysis and forecasting of ongoing and potential tropical cyclones within their respective United States areas of responsibility. The two centres also operate as tropical cyclone RSMCs in their respective basins. While the hurricane centres issue tropical wind and storm surge warnings along the United States coast, local weather forecast offices issue tropical wind warnings inland that are consistent with their respective hurricane centre's forecast.

4.4 **USE OF RISK INFORMATION IN TROPICAL CYCLONE WARNINGS**

Risk information has been introduced in most meteorological centres that forecast tropical cyclones. Although the way to do it may differ somewhat, the intention is the same; namely to assess vulnerability and exposure to better guide people to mitigate risk. An overview on how it is used follows in the coming paragraphs.

In Cuba, the local office of the Ministry of Science, Technology and Environment in each province coordinates with the rest of the organizations in the territory to obtain the necessary data to determine the risk. The organizations involved include the territorial divisions of the National Housing Institute, the Institute of Physical Planning, the National Statistics Office, the National Institute of Water Resources, and the Ministries of Public Health and Education. The findings are all stored in a database supported by a system of geographical information, which is updated as actions are implemented to reduce vulnerabilities. The methodology allows the local governments to periodically determine risk so that reduction is monitored. This requires specialists from each organization to update the information related to each indicator of vulnerability.

In Hong Kong, China, tropical cyclone warnings are primarily designed with reference to territory-wide sustained wind strength near sea level. Risk information is conveyed to the public through the warning bulletins and precautionary statements associated with different levels of tropical cyclone warnings. For example, the tropical cyclone warning bulletin issued by the Hong Kong Observatory (HKO) will include the flood risk for low-lying and flood-prone areas when storm surge is predicted to exceed warning/alert levels. For tropical cyclones coming into the proximity of Hong Kong, China, accompanied by high winds coming from changing directions, people will be warned of sudden changes in wind direction. Even before local winds pick up and when the weather may still look calm, HKO will alert the public to the risk and impact of the swells and waves generated from afar by an approaching tropical cyclone.

In India, a web-based Geographical Information System (GIS) hazard vulnerability atlas has been prepared by the India Meteorological Department (IMD), segregating each of the multi-hazards associated with cyclones, such as strong/gale-force winds, heavy rainfall, pluvial and fluvial floods and storm surges. The possible risks associated with secondary cyclone hazards, such as landslides, are handled and planned for by local administrations. Other non-structural measures include the introduction of objective analysis and a forecasting platform; the decision support system; a synergized SOP; the policies and guidelines of the Government; collaboration and partnership with various stakeholders, press and electronic media and disaster managers; and the introduction of user- and sector-specific impact-based warnings along with suggested actions.

In Japan, warnings for the hazards posed by tropical cyclones, including floods and landslides caused by heavy rainfall, are issued by using indices corresponding to the type of hazard instead of simply observed or predicted rainfall amount. Based on these indices, a 1 km mesh real-time risk map is provided with five different colours to indicate the current and predicted risk level at each location, depending on how close it is to the predetermined warning threshold in which past disasters and the vulnerability of the area are considered. Risk distribution is automatically created, announced and updated every 10 min as supplementary information to weather warnings. Meteorological warning criteria/thresholds are predefined based on various indices (for example, soil water index) or disaster statistics, vulnerabilities of the region and the status of infrastructure facilities, such as the height of levees prepared by local meteorological offices and relevant agencies, or the corresponding quantities of meteorological elements, such as wind speed and wave height. The criteria/thresholds are updated periodically based on the latest disaster statistics. It is the basic practice of JMA to improve warnings and weather information based on lessons learned from past disasters.

In Oman, risk information is conveyed to the public through the warning bulletins and precautionary statements associated with the different levels of tropical cyclone warning signals. The tropical cyclone warning bulletin issued will include wind (speed and direction), thunderstorm, wave height and flood risk for low-lying areas, all of which depend on the regions that are expected to be affected by a tropical cyclone and its associated hazards.

In the Philippines, on account of the lessons learned from past disasters (that is, Typhoon *Haiyan*), there is an urgent need to innovate from focusing on the accuracy of hazard-based forecasting to also outlining the potential impacts of a hazard – an evolution from “what the weather will be” to “what the weather will do”. A project is ongoing that will catalyse a paradigm shift from traditional weather forecasts to multi-hazard impact-based forecasting and early warning. Project innovation includes combining the best available science and local knowledge on probabilistic hazard mapping, modelling, forecasting and risk assessment. Probabilistic risk assessment, mapping and technologies will be developed to provide risk information that will inform development policies, investment programmes and resilience plans for the pilot areas of Metro Cebu and Manila (at the local level).

4.5 **MONITORING, FORECASTING AND MANDATES FOR WARNINGS**

All meteorological forecast offices or centres have activities on monitoring and forecasting, and mandates for warning development, although the names might differ.

In the Cayman Islands, the National Weather Service (NWS) is responsible for monitoring the region for possible threats. The warning process begins when the Chair of the National Hazard Management Council convenes a meeting, depending on the time and the characteristics of the approaching storm. The Director of the Government Information Service and/or the Chair of the Joint Communication Services Emergency Support Team liaise(s) with the Director General of the NWS, the Director of Hazards Management Cayman Islands (HMCI) and the Chair of the National Hazard Management Council to prepare advisory bulletins and ensure that copies are sent to the Governor, Premier, Ministers, Members of Parliament (MPs), members of the National Emergency Operations Centre, heads of government departments, Radio Cayman and other local media, cellular service providers and utility companies. Information must be posted on the HMCI website (www.caymanprepared.ky), as well as on Twitter, Facebook, gov.ky and weather.gov.ky. All advisories should also be posted on thehub.gov.ky and WebEOC.

In China, CMA has built up a comprehensive tropical cyclone monitoring and forecasting system covering the north-western Pacific and the South China Sea, with multiple observation resources, objective methods and numerical weather prediction (NWP) models. Five-day operational forecasts of tropical cyclone intensity, track and precipitation throughout a tropical cyclone's lifespan are issued to the public. For those tropical cyclones likely to make landfall over the mainland, potential impact and hazard pre-assessments are provided to the authorities.

In India, IMD maintains a 24 h watch over the north Indian Ocean to monitor any development of cyclonic disturbance and its further intensification, movement and impact. A well-defined SOP is followed to monitor and predict tropical cyclones, starting with the organization of pre-cyclone exercises prior to the beginning of the cyclone season and maintenance of round-the-clock watch. It is followed by extended-range, medium-range, short-range and nowcast predictions till landfall, and post-landfall forecasts and warnings till the system maintains its intensity of depression.

In Japan, the implementation of JMA operations is carried out in accordance with the Meteorological Service Act and related regulations, and various internal rules. The monitoring of tropical cyclones and the forecasting of their track and intensity are carried out at JMA headquarters and based on observations by meteorological satellites and other sources, as well as NWP. Forecasters at JMA headquarters and local meteorological observatories share information closely to prepare warnings and other related information, taking lead time into consideration. Weather warnings for each municipality are issued by local meteorological observatories, using a dedicated application, and based on track and intensity forecasts, various guidance products and indices based on observations and NWP, and predetermined criteria/thresholds.

In the United States, tropical cyclone monitoring is a multifaceted effort, with multiple government agencies and the private sector participating. Observational data is processed by the United States NWS into systems and displays used by forecasters whenever possible or provided via the Internet. Observational requirements for tropical cyclones are updated internally on a 10-year cycle and resource investment is determined accordingly. Every 6 h, the National Hurricane Center and the Central Pacific Hurricane Center issue updated text products and graphics that include track and intensity forecasts for the next 5 days. In the United States Atlantic basin, a potential storm surge flooding map and storm surge watch/warning graphic are included in this advisory package. Details on the products and services provided by these centres can be found in NWS Directive 10-607. The mandates to carry out these operations are listed in the Compact of Free Association Act of 1985 and come from the United States Congress.

4.6 DISSEMINATION MECHANISMS

In the Cayman Islands, the EWS process commences once the tropical cyclone/hurricane is expected to impact the area within 72 h. This is listed as the alert. The meteorologists' responsibility is to provide the most current storm location, intensity, track and expected impact timeline to local media sources. Storm information is initially provided via email but, as the system approaches the area, meteorologists may provide warnings to the public through television and radio broadcasts. Meteorologists therefore play a critical role in communication for preparedness. Once a tropical storm/hurricane watch is issued 48 h prior to impact, the NWS and HMCI work with the Government Information Service and/or the Joint Communication Services to tailor specific response messages to be broadcast by Radio Cayman, the weather station and other media houses.

In China, the EWS for tropical cyclones includes the current position/intensity of the tropical cyclone and future changes, winds, precipitation, waves and tides, as well as flash flooding, debris flow, river flooding, urban waterlogging and so forth caused by tropical cyclones. CMA uses a colour-based tropical cyclone warning system; namely red, orange, yellow and blue warnings, with the red warning as the top category. In the event of significant tropical cyclones, meteorologists or experts from national, provincial or municipal meteorological offices could present the warnings to the public through television and radio broadcasts.

In Cuba, early warning messages begin to be issued by the National Forecast Centre 120 h in advance of possible impact and are repeated every 24 h. When the hurricane enters the area of surveillance of the Caribbean Sea, warnings are issued every 12 h, and when the hurricane poses a potential threat to Cuban territory within 72 h, warnings begin to be issued every 6 h. When the hurricane is very near, warnings are issued continually every 3 h or less. The National Forecast Centre permanently monitors the formation and development of tropical cyclones and tropical waves from their formation off the coast of West Africa to their journey across the Atlantic towards the Caribbean. Any tropical cyclone that enters or is formed in the region, known as the Area of Reinforced Surveillance, is closely monitored, even if it is just a tropical wave with some likelihood to develop. The National Staff of the Civil Defence evaluates the warning and issues a notice for the governments of the threatened provinces and for the state organizations whose resources might be affected (the Ministries of Agriculture, Tourism and Information and Communications, among others.) Television channels and radio stations, both national and local, transmit 24 h/day interviews with specialists and authorities; reports related to the evolution of the hurricane; the protective measures being adopted in each place; and guidance on measures to be completed.

In Hong Kong, China, tropical cyclone forecasts and warning information are delivered to the public via the HKO website and MyObservatory mobile app, television/radio broadcasts and social media (including Facebook, Instagram, Twitter, WeChat and Weibo), with push notifications from MyObservatory being the most important means. HKO meteorologists comprise an internal media unit responsible for the production and broadcast of both regular television weather programmes and ad hoc television and radio media briefings when a tropical cyclone warning is in force.

In India, IMD organizes a pre-cyclone meeting to develop direct interaction with disaster managers and to create awareness of lessons learned and initiatives just prior to the start of the cyclone season. An extended-range outlook is issued every Thursday, giving the probability of cyclogenesis as low (1%–33%), moderate (34%–67%) or high (68%–100%) for the next two weeks. A daily watch is maintained over the north Indian Ocean, and a detailed bulletin discussing model guidance, prognostic and diagnostic features and the probability of cyclogenesis over the next 7 days is prepared as part of the Forecast Demonstration Project (FDP). The *Tropical Weather Outlook* bulletin is issued every day throughout the year, discussing convective cloud features over the Indian seas and the probability of cyclogenesis over the next 5 days as zero (0%), low (1%–25%), moderate (26%–50%), fair (51%–75%) or high (76%–100%).

In Japan, since the Meteorological Service Act imposes restrictions on warnings issued by those other than JMA, the Agency is basically the single national authoritative voice for

weather warnings in Japan and is widely recognized as such. The dissemination of weather warnings is conducted online through multiple channels. Some government agencies and telecommunication companies are obligated by the Meteorological Service Act to issue weather warnings or to endeavour to do so. In addition, private meteorological service providers and media organizations actively disseminate weather information through multiple media, such as broadcasting, newspapers, websites and social networking services. JMA has a press club, and it usually communicates well with reporters from major media organizations. When the impacts of a severe weather phenomenon are expected, forecasters from JMA headquarters and local meteorological observatories hold press briefings as necessary, and they appear in a variety of media, including broadcasting. Recently, when there has been a need to warn of severe river flooding, joint press conferences have been held with the government agency in charge of river management to share the sense of crisis with the public. In some regions, other related organizations, such as those connected with public transportation, participate in the joint press conferences. In preparation for an approaching tropical cyclone, the local meteorological observatory holds typhoon briefing session to provide detailed explanations of forecasts and meteorological information to prefectures, municipalities, river administrators and other front-line disaster management organizations. In addition, the local meteorological observatory dispatches the JMA Emergency Task Team to municipalities that are expected to be in significant danger and supports their disaster management efforts by providing explanations of weather information. To provide support to local disaster management officials, the local meteorological observatory has a team of forecasters called "Forecaster in Your Town" to strengthen cooperation with municipal officials. In addition, as part of this initiative, a short, remote weather briefing is provided daily to local governments during normal as well as in emergency times. Local governments are free to participate and can put questions to the forecaster after the briefing. The briefings are recorded so that local governments can watch them later if they are unable to participate in real time.

In the Philippines, PAGASA recognizes that the delivery of timely and reliable warning information is of the utmost importance to ensure the protection of people's lives, properties and livelihoods. As soon as warnings are generated, information is disseminated to the concerned agencies and public using various platforms and channels. When tropical cyclones occur, press conferences are conducted on a regular basis, during which warning information is directly reported by meteorologists and experts through television channels and social media platforms. Likewise, forecasters conduct daily weather updates aired through various social media platforms, such as Facebook and Twitter. Forecasters further live-stream the warnings on Facebook and YouTube. Before the coronavirus disease (COVID-19) pandemic, regular media briefings were held during the issuance of severe weather bulletins every 6 h, with radio and television personnel going to the PAGASA office for live coverage. During the COVID-19 pandemic, these briefings were live-streamed on Facebook and YouTube. PAGASA partnered with Google for the initial development of a common alerting principle (CAP) for tropical cyclone warnings in Google Public Alerts.

In the United States, hurricane specialists at hurricane centres work on a 6 h cadence to deliver a standard set of products and services. When tropical cyclones affect land, the cadence can be shortened to provide information more frequently in accordance with NWS Directive 10-607. The National Hurricane Center and the Central Pacific Hurricane Center issue a standard set of text and graphical products with the same look and feel, making them recognizable to the user. They also disseminate tropical cyclone products through multiple channels, including www.hurricanes.gov, the Advanced Weather Interactive Processing System, the Satellite Broadcast Network and the National Oceanic and Atmospheric Administration (NOAA) Weather Wire Service, in addition to social media. Furthermore, weather forecast offices convey coastal hurricane centre warnings and their inland tropical warnings via a CAP on alerts.weather.gov, through the Emergency Alert System, and through Wireless Emergency Alerts sent to wireless devices via the Integrated Public Alert and Warning System of the Federal Emergency Management Agency (FEMA). NWS forecasters provide information through media interviews and generic broadcasts made available to television and radio stations. Official warnings are directly disseminated to the public through automated systems that broadcast warning messages over television and radio stations, in addition to mobile broadband networks. The National Hurricane Center provides a media spokesperson (typically the Director) who gives

dozens of national and local media interviews during tropical cyclone threats. In addition, the National Hurricane Center and weather forecast offices use social media to provide live and recorded briefings to make the public aware of tropical cyclone hazards.

4.7 **MULTI-HAZARD APPROACH AND THE CONCEPTS OF IMPACT-BASED FORECASTING IN TROPICAL CYCLONE EARLY WARNING SYSTEMS**

A multi-hazard approach and the concepts arising from impact-based forecasting are an important basis for the public to understand warning messages. Several, though not all, weather services make use of these important tools in the forecast of and warning process for tropical cyclones.

In the Cayman Islands, as part of ongoing efforts, the NWS produces relevant infographics with impact-based forecasting that are shared with the public.

In China, when CMA issues tropical cyclone warnings, a multi-hazard approach and impact-based forecasting are incorporated through the inclusion of the cyclone's current position/intensity and future changes, as well as winds, precipitation, waves and tides, and, if possible, flash flooding, debris flow, river flooding and urban waterlogging caused by tropical cyclones.

In Cuba, a multi-hazard framework is used by the National Forecast Centre and an impact-based forecasting concept is to be introduced in the information regarding tropical cyclones. However, further coordination is required with the Civil Defence System, which has the mandate for the protection of people and the economy.

In Hong Kong, China, tropical cyclone warning bulletins cover multi-hazards, including the potential impacts of high and changing winds, drowning risk owing to swells and waves, and squalls and flooding caused by either storm surges or heavy rain. In the boreal autumn, tropical cyclone hazards along the coastal areas of southern China can become very tricky and highly unpredictable owing to the interplay of a tropical cyclone with the north-east monsoon. In October 2021, Tropical Storm *Lionrock* brought record-breaking rainfall of over 300 mm to Hong Kong even though it was still located about 500 km away and the local winds did not yet warrant a higher tropical cyclone signal. As far as possible, the potential of multi-hazards is communicated to the public by televised weather programmes, press conferences, push notifications via the MyObservatory mobile app and so forth before a tropical cyclone arrives so that they can be better prepared.

In India, IMD follows a multi-hazard approach in providing early warnings. Warning graphics are assigned a specific colour based on the impact matrix. Impact-based forecasts, comprising a list of potential impacts in association with the forecasted weather event and suggested actions for reducing the impacts, are incorporated in the warning bulletins in a textual format. A web-based Dynamic Composite Risk Atlas – Decision Support Tool is being implemented for the use of disaster managers, enabling them to arrive at better risk-informed decision-making during cyclones.

In Japan, the various weather warnings that play a major role in the EWS for tropical cyclones and their announcement criteria are based on the concept of impact-based forecasting. JMA issues not only individual warnings for each hazard but also tropical cyclone information (text and graphic information) that comprehensively describes the hazards caused by tropical cyclones, such as wind, flooding, inundation, landslides, storm surges and high waves.

In the Philippines, the development of an impact-based forecasting and warning service is ongoing. PAGASA has, however, been utilizing a multi-hazard approach in its early warning information. For example, during a cyclone event, associated hazards are incorporated into a series of severe weather bulletins that are disseminated to the public and concerned disaster risk reduction agencies. At present, PAGASA is utilizing a proto-impact-based forecasting approach in which potential impacts are indicated in the warnings; however, no comprehensive risk

information is integrated into the analysis. As soon as the impact-based forecasting and warning service has been developed and the system is well verified, PAGASA will adopt and implement an impact-based approach in its early warning services.

In the United States, a multi-hazard approach is applied with extensive coordination from experts in each hazard seen in a tropical cyclone event, including wind, storm surge, coastal and inland flooding, rainfall and severe weather (that is, tornadoes and thunderstorms). Impact information is coordinated on the storm scale through the National Hurricane Center and the Central Pacific Hurricane Center, which provide impact-based decision support to national partners. In accordance with NWS Directive 10-601, weather forecast offices publish hurricane threat and impact graphics and text products (tropical cyclone/hurricane local statements and tropical cyclone watches/warnings) that provide local information on wind, storm surge, flooding, rain and tornado threats specific to their local area of responsibility. Weather forecast offices use these products and other routine NWS products to provide impact-based decision support services to local partners.

4.8 **ROLE OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES IN PUBLIC AWARENESS AND EDUCATION ACTIVITIES**

One of the most important activities in countries affected by cyclones should be that connected to public awareness and education because of the potential they have to decrease the number of fatalities caused by the hazards related to tropical cyclones.

In the Cayman Islands, at the start of the hurricane season, the NMHS and other government entities commence a public campaign and appropriate training programmes for all aspects of disaster preparedness, mitigation and management and loss reduction.

In China, CMA is devoted to increasing public awareness of the prevention and mitigation of meteorological disasters in various ways. It plans and organizes nationwide science activities on World Meteorological Day (WMD) and National Disaster Prevention and Reduction Day, during Meteorological Science and Technology Week and so forth. It carries out targeted science popularization for different groups of people, such as teenagers, farmers, community residents, policymakers and civil servants. It organizes the construction of meteorological popular science resources in various forms, such as books, illustrations, videos, Internet pages, courseware and exhibits, and it promotes the nationwide sharing of these resources. Through cooperation with the mainstream media, all kinds of popular science information are widely disseminated via television programmes, websites, social networks and other mass media.

In Cuba, citizen preparedness for disaster situations extends from the top authorities to workplaces, schools and communities. It is aimed at making everyone capable of organizing or carrying out the actions planned, according to their responsibilities, and aware of the risks they may be exposed to and the measures they must take to protect their lives and their property. A separate mention should be made of the yearly 2 day-long *Meteoro* national disaster risk reduction drill. Usually conducted during a weekend in May, it helps authorities and communities to prepare for disaster situations. It is used to test the warning, communication and information systems and check the logistics needed for different protection measures, such as the evacuation of people, goods and economic resources, as well as vulnerability mitigation actions. It receives ample coverage from all communication media (television, radio, newspapers and so forth) regarding aspects that the population ought to know for every province. The Cuban Meteorological Service plays an important role in the public's awareness and in educational activities. Hundreds of conferences and chats are offered every year in workplaces and factories, as well as in different types of social organizations.

In India, outreach activities are a part of the early warning services provided by IMD. Various programmes are conducted routinely to raise awareness about weather forecasting, early warnings and weather-related natural hazards, especially those caused by cyclonic storms over the seas and coastal areas. Twice every year, IMD headquarters and all its field forecasting offices hold open days during which weather experts explain to and educate the public about these

activities. Prior to the cyclone season, area cyclone warning centres and cyclone warning centres conduct a series of lectures, meetings and film showings to impart knowledge of the impending hazards associated with such systems. IMD takes part in the mock drills and training of the public and police organized every year by the National Disaster Response Force and State Disaster Response Force.

In Japan, since weather warnings and related information are referred to by residents when making evacuation decisions and by the mayor of a municipality when issuing evacuation orders to residents in accordance with the law, it is important to conduct activities to deepen understanding of weather warnings and other information among residents and municipal officials. Based on this understanding, local meteorological observatories are strategically working to promote understanding among municipalities and to disseminate knowledge to residents. Specifically, they are strengthening cooperation between municipalities and local meteorological observatories, conducting workshops with local disaster prevention leaders and promoting public awareness activities in cooperation with educational institutions. JMA headquarters and local meteorological observatories hold several open days for children during the boreal summer so that they can gain a better understanding of the services offered. In addition, JMA headquarters has a permanent Meteorological Science Museum where people can learn about meteorology, earthquakes, tsunamis and volcanoes through various exhibitions. The JMA website provides e-learning and supplementary materials for the public, as well as materials for local governments to use in workshops.

The United States NWS, including the National Hurricane Center, the Central Pacific Hurricane Center and weather forecasting offices, carries out an extensive hurricane outreach and educational programme. This includes providing training to core partners (such as emergency managers and the media) as well as to other NMHSs through the annual WMO RA IV Workshop on Hurricane Forecasting and Warning. In addition, hurricane awareness tours are conducted both in the United States and in the Caribbean to engage local communities and the public, increase awareness of hurricane hazards and encourage hurricane preparedness activities prior to the start of the hurricane season. Some of these activities occur during National Hurricane Preparedness Week, which is a time to emphasize the importance of individual preparedness.

4.9 **FINAL THOUGHTS**

All countries that responded to the questionnaire have, one way or the other, promulgated laws and regulations that support and validate the work of NMHSs in providing timely forecasts, watches and warnings for the protection of the public and the economy. The same could be said of the collaborative partnerships for EWSs, which usually collaborate closely with civil protection and disaster management agencies as well as with local governments.

The use of risk and vulnerability information has been introduced in most meteorological centres that forecast cyclones. Although there are different ways to use this information depending on local context, the intention is the same: namely to assess vulnerability and exposure to better guide people to protect themselves.

Timely, authoritative, recognizable and understandable warnings, as well as standard dissemination mechanisms, are present in all countries. In many countries, meteorologists and experts from NMHSs do not present the warnings to the public; instead, they do so either by means of journalists or special bulletins to be read on air by news anchors or any other means.

The use of a multi-hazard approach and the concepts of impact-based forecasting in EWSs for tropical cyclones have been implemented in only some countries, while others are beginning to look at the use of impact-based forecasting. There is an urgent need for a multi-hazard approach coupled with impact-based forecasting to be developed and implemented in all tropical cyclone basins. This is a gap that must be filled in the near future.

While several NMHSs play an important and leading role in public awareness and education activities, many of them have a very limited activity in this field owing to a lack of personnel or economic resources. Shared material needs to be available to help the countries that are less engaged in public awareness and education.

Taking previous events into consideration to improve emergency preparedness and prevention is the norm for countries located in tropical cyclone basins. It should be noted that though successful response efforts are important, those that were not an overall success and even those that resulted in a disaster are also important. This is where lessons can be captured, addressed and transformed into steps to improve EWSs for tropical cyclones and future preparedness, prevention and response efforts.

ANNEX. COUNTRY EXAMPLES

Annex 1 showcases examples of good practices from a number of Members who have already established Multi-hazard Early Warning Systems (MHEWS), procedures and coordination mechanisms for national weather services (NWSs) under tropical cyclone circumstances. Annex 1 is open to all Members who wish to share their good practices and success stories with others.

1.1 CAYMAN ISLANDS – CASE STUDY

The Cayman Islands tropical cyclone early warning system (EWS) includes numerous agencies to support Hazard Management Cayman Islands (HMCI) as the lead agency. The functions of HMCI are to facilitate and coordinate the development and implementation of comprehensive disaster management programmes. The Disaster Preparedness and Hazard Management Act (2019 amendment) provides the legal framework for HMCI to function. A collection of senior government managers chaired by the Deputy Governor serves as the Chair of the National Hazard Management Council, whose responsibility is to manage the response to any non-security threat to the Cayman Islands, including warnings for tropical systems. As an overseas territory of the United Kingdom of Great Britain and Northern Ireland, the National Hazard Management Executive, led by the Governor, communicates with the authorities of the United Kingdom, other overseas territories and jurisdictions and international organizations through the Governor's Office. HMCI and the Cayman Islands NWS operate very closely together as components of the EWS. The Meteorological Law of 2010 provides the legal framework for the Cayman Islands NWS to function.

The Cayman Islands NWS maintains a watch over a monitoring area that extends from South America to 25 °N and from Central America to 60 °W. As part of its monitoring and warning responsibilities, it creates and disseminates updates and warnings in both text and graphical formats to all media contacts, the public and members of the disaster management community. The Cayman Islands NWS releases statements and graphical images for the genesis of all systems and continues these updates depending on the location of the system. For systems outside of the monitoring area, no further updates are provided. For systems within the monitoring area, the number of graphical images is increased to include data for all bulletins released by the National Hurricane Centre, especially for systems on a path to threaten the Cayman Islands. To improve its services, the Cayman Islands NWS has started a process of developing an impact-based forecasting and warning system with its partners, beginning with the passage of Hurricane *Grace* in August 2021.

In terms of public education, the NWS works closely with HMCI to hold joint events to educate the public. Although there are numerous occasions when the two agencies work together, they also provide public education separately.

Annual hurricane exercises, post-storm reports and assessments are key methods for improving EWSs. A good example of this was in 2021 when reports and a post-storm assessment indicated that the Cayman Islands NWS website was not fit for purpose, leading to the Government approving funding for the creation of a new website. While improving the EWS is a key result of annual storm exercises and post-storm assessments, there remains no better test for an EWS than a live event. This hard lesson was learned when Hurricane *Ivan* passed through the islands in September 2004, leading to major changes in the EWS.

1.2 CHINA – TYPHOON EARLY WARNING AND RESPONSE SYSTEM

1.2.1 Introduction

To mobilize and coordinate the efforts of the whole society to prevent and control floods and droughts and mitigate the damages caused by subsequent disasters in order to safeguard people's lives and property, China has formulated and improved its laws and regulations, including the Meteorology Law, the Flood Control Law and the Drought Control Regulation of the People's Republic of China. There is also the law on response to emergencies, the national overall emergency plan for public emergencies, and measures for the release and dissemination of meteorological disaster early warning signals that have been promulgated by the State Council of the People's Republic of China.

A comprehensive typhoon and flood control system, led by the Government, has been established with joint forces from multiple departments, accountability assigned to different levels and extensive social participation. During practice, "be people-oriented" principles are followed to ensure the safety of people's lives and property, which are prioritized to prevent fatalities and minimize losses. Furthermore, a prevention-oriented, holistic and integrated approach is adopted. In response to typhoons and floods, all efforts are made to take scientifically sound measures during the entire process from early warning to response, including monitoring, forecasting, prevention, resistance, rescue and assistance, and to leave no regrets. A working system whereby the Administration head assumes full responsibility has been adopted to maximize the unique political and institutional strengths of China in terms of mobilizing social resources efficiently and to make sure that the responsibilities of flood control are assigned to all levels and to all people at the same level. Years of typhoon and flood control practice have proved that the system has been a successful and effective institutional arrangement.

1.2.2 Chain of command

1.2.2.1 Organizational structure

A complete organizational structure for typhoon EWSs is an important foundation for typhoon response. In accordance with laws and regulations, the principles of unified leadership, the assignment of responsibilities to different levels of government and the combination of vertical and horizontal levels of government functions, the national, provincial, municipal and county governments have all established typhoon early warning and response headquarters for which the Government assumes overall responsibility, with the participation of leaders from relevant departments. These headquarters are responsible for the organization, command, coordination, supervision and other daily work for typhoon early warning and response in their specific region. Each township (subdistrict), as well as the departments and units related to typhoon response tasks, has also established its headquarters or leadership group and is responsible for daily work, such as organization and coordination in the township (subdistrict), departments and units, according to the division of responsibilities. Thus, a joint prevention and response effort has been formed for an integrated typhoon early warning and response system at the national level.

Under the leadership of the State Council, the State Flood Control and Drought Relief Headquarters is responsible for leading and organizing the national typhoon response efforts, with one General Commander (Vice Premier of the State Council), two or three Deputy General Commanders, a Secretary-General (Vice Minister of Emergency Management), two Deputy Secretaries-General (Deputy Director General of the China Meteorological Administration (CMA) and an officer from the Central Military Commission (CMC)) and several other members (officers from member agencies).

1.2.2.2 **Division of responsibilities**

The State Flood Control and Drought Relief Headquarters has set up its office in the Ministry of Emergency Management, where it is responsible for organizing, coordinating, guiding and supervising national efforts in respect of typhoon early warning and response. The member agencies of the Headquarters, in accordance with their stipulated responsibilities, work closely and collaboratively under the leadership of the Headquarters to perform their duties with regard to typhoon early warning and response. The main member agencies of the Headquarters and their duties are:

- **The CMA:** Responsible for typhoon monitoring and forecasting. It analyses and predicts floods and disasters caused by typhoons, issues typhoon forecasts and warnings in a timely manner and participates in the emergency response to typhoon-induced disasters.
- **The Ministry of Emergency Management:** Responsible for organizing, coordinating, supervising and guiding the daily typhoon response work of the Headquarters. The Ministry organizes river water management during typhoon events, and water projects, and is further responsible for organizing and guiding the construction and management of national typhoon response projects and supervising local governments to complete the repair of water projects damaged by typhoon floods.
- **The Ministry of Industry and Information Technology:** Responsible for the security and emergency repair of public communication facilities to support communication during typhoons.
- **The Ministry of Transport:** Responsible for the safety of highways, railways, aviation and water transport facilities during typhoons, search and rescue at sea and the transport of personnel, materials and equipment during typhoons.
- **The National Radio and Television Administration:** Responsible for radio and television stations at all levels to publicize the typhoon response, and for the timely reporting of flood information issued by the Headquarters and important information on the typhoon response around the country.
- **The Ministry of Civil Affairs:** Responsible for disaster relief during typhoons. The Ministry coordinates efforts to verify the disaster, releases unified official disaster updates and provides information on major disasters to the Headquarters in a timely manner. The Ministry is responsible for organizing and coordinating disaster relief and livelihood assistance for affected people in typhoon-hit areas. It manages, distributes and supervises central relief funds for affected people. In addition, the Ministry organizes, guides and manages disaster relief donations and so forth.
- **The Ministry of Public Security:** Maintains social order in affected areas and combats disinformation, looting and theft of materials for typhoon response and criminal activities that damage typhoon response facilities. The Ministry assists in organizing the evacuation and relocation of people from hazardous areas.

1.2.2.3 **Work system**

In China, a system has been adopted whereby the Administration head assumes full responsibility for typhoon early warning and response. The administrative heads of local governments, departments and agencies at all levels are responsible for establishing local headquarters (or leading groups) for typhoon response under the leadership and guidance of higher headquarters, and they provide overall leadership and guidance to local headquarters carrying out typhoon response activities in their areas of responsibility. Under the unified leadership, command and coordination of the State Flood Control and Drought Relief Headquarters, the headquarters (or leading groups) at each level carry out the nationwide typhoon response. A work system has been established under the leadership of the State Flood Control and Drought Relief Headquarters to strengthen and standardize typhoon early warning

and response. In the event of emergencies, meteorological departments at all levels may send special reports on typhoon monitoring and forecasting directly to local governments, and the responses should be promptly organized and implemented by flood control and typhoon response headquarters. A “working guidance team” should be sent to the front line to guide the work for a typhoon response if necessary.

1.2.3 **Early warning and preparedness system**

To minimize the casualties and losses occasioned by typhoons, governments at all levels as well as relevant departments and agencies should take into account their responsibilities for typhoon response work and the practical conditions of defence projects and formulate protocols for typhoon response. The Regulation of the People’s Republic of China on Flood Control specifies the procedures for the preparation of typhoon response protocols and the responsibilities of departments and agencies undertaking typhoon response tasks during the preparation of typhoon response protocols. This regulation further stipulates the legal penalties for those who fail to prepare and implement plans as per the requirements.

A complete protocol should include an organizational system (leading, emergency liaison and working agencies); prevention and warning (signal, classification and main defence protocols); emergency response (grading and action, measures, information release and ending responses); post-disaster management (assistance, supply of materials, reconstruction, insurance and compensation, investigation and summary); emergency preparedness (communication and information, emergency and rescue, professional guarantee, security, and medical, material, financial and social mobilization); and supervision and management (public information exchange, training, exercises, rewards and penalties and protocol management). Some of the core elements of the protocol in China are summarized below.

1.2.3.1 **Early warning signals**

The National Meteorological Centre of the CMA identifies the 24 h and 48 h warning zone (typhoons located in this warning zone will make landfall or affect mainland China within 24 h to 48 h based on their climatic characteristics). In practice, CMA closely monitors and provides rolling forecasts for typhoons in the north-west Pacific Ocean (including the South China Sea). When a typhoon has entered or is predicted to enter the warning zone and has or is expected to have an imminent impact on mainland China (bringing strong winds, heavy rainfall, flooding, storm surges and so forth), CMA will use the national information release platform for emergency disasters to issue typhoon warnings and promptly report them to the State Flood Control and Drought Relief Headquarters.

The warnings are generally divided into four levels according to the potential hazard, urgency and activities of the typhoon: Level IV (general), Level III (serious), Level II (severe) and Level I (extremely severe), with corresponding colour labels (blue, yellow, orange and red, respectively), as indicated in Figure A1 and detailed below.

- **Blue warning – Level IV (general):** The typhoon is likely to or has affected the area within 24 h, with an average coastal or land wind force of 6 or above, or wind gusts of force 8 or above, which are likely to persist.
- **Yellow warning – Level III (serious):** The typhoon is likely to or has affected the area within 24 h, with an average coastal or land wind force of 8 or above, or wind gusts of force 10 or above, which are likely to persist.
- **Orange warning – Level II (severe):** The typhoon is likely to or has affected the area within 12 h, with an average coastal or land wind force of 10 or above, or wind gusts of force 12 or above, which are likely to persist.



Figure A1. Typhoon warning levels by colour

Source: China Meteorological Administration (CMA)

- **Red warning – Level I (extremely severe):** The typhoon is likely to or has affected the area within 6 h, with an average coastal or land wind force of 12 or above, or wind gusts of force 14 or above, which are likely to persist.

1.2.3.2 **Response actions**

The State Flood Control and Drought Relief Headquarters and its member agencies should analyse the possible impact(s) of typhoons based on the typhoon alert signals and the characteristics and responsibilities of their own sectors, jointly issue special alerts with the CMA, such as “flash floods and geological hazards”, and activate emergency responses accordingly. The emergency response status is divided into four levels (Levels IV, III, II and I, in ascending order), which usually correspond to the four-tier colour-coded warning levels, but the emergency response status may be inconsistent with the warning levels. In practice, by observing the principles of “be people-oriented” and “better to err on the side of overestimation than to miss a forecast”, the level of the emergency response status is usually slightly higher than the level of the warning (such as initiating a Level I response when receiving a Level II alert and so forth). In addition, when the flood stabilizes and the hazard is over or eliminated, the National Meteorological Centre and the State Flood Control and Drought Relief Headquarters will lift the typhoon alert and the emergency response status according to consultation results. Listed below are the emergency response actions for Level I.

- **State Flood Control and Drought Relief Headquarters:** The General Commander should preside over a national special meeting on the typhoon, which the heads of the headquarters should attend, and make emergency arrangements for the typhoon response. The guidance on the response should be enhanced. The principal leader of the State Council should broadcast a televised speech to mobilize the military and civilians to fight the disaster.
- **Headquarters at all levels:** The heads of the headquarters should take command and promptly implement all typhoon response and rescue measures. Possible hazardous conditions should be resolved in a timely manner and every effort should be made to protect people’s lives and property.
- **Member agencies of headquarters at all levels:** The principal leaders should take command to organize and require the system or the industry to work in top gear in typhoon response and rescue as well as to ensure that response measures are in place.
- **Typhoon response agencies at all levels and relevant emergency response agencies:** All response measures should be implemented as per the centralized deployment by the headquarters. The public should be reminded to check whether self-protective measures are implemented. Either classes should be suspended or other specific protective measures should be taken for primary and secondary schools (including high schools and vocational and technical schools), kindergartens and related institutions. Production, work and

business should be suspended as appropriate for companies and institutions other than government agencies, enterprises and public institutions that directly ensure social functioning.

- All professional rescue teams should declare a state of emergency, clear the drainage and roads and perform emergency repairs as soon as possible. All institutions responsible for emergency materials should provide a guarantee for a typhoon response.
- Troops and armed police should carry out rescue and relief tasks according to instructions from the headquarters.
- Media agencies and management institutions of large displays in public spaces should be prepared to put up typhoon-related alerts, safety tips and emergency notices at any time. Telecommunications carriers should assist in the dissemination of the above-mentioned information via Short Message Service (SMS).

1.2.4 **Information assurance system**

The information assurance system is composed of information collection, information release, decision support and command conferencing systems, which can collect and transmit real-time typhoon wind, rain and flood information. The system can perform functions, such as the digital management of seawalls, pump stations, embankment facilities, vulnerable projects and project sections, and provide flood and typhoon response materials, video monitoring of major flood and typhoon response locations and time periods, and remote conferencing and command attended by multiple departments. The system ensures real-time updates on the disaster and the immediate mass mailing of typhoon response information.

1.2.4.1 **Information collection system**

As well as integrating real-time information on typhoons and accompanying hazardous factors, such as wind, rain and tide, that may lead to disasters, the information collection system monitors changes in the flood control infrastructure (seawalls, embankments, pump gates and so forth) of the State Flood Control and Drought Relief Headquarters and its member agencies, the stockpiling of typhoon response materials and the dispatch of typhoon response personnel.

1.2.4.2 **Information release system**

Typhoon warning signals are issued through the National Emergency Warning Release System, which is organized and coordinated by government departments and constructed and operated by meteorological departments. This system serves as an authoritative platform for the collection and distribution of warnings for multiple types of hazards. It consists of 1 national-level release centre, 31 provincial-level release centres, 343 prefectural- and municipal-level release agencies and 2 015 county-level release agencies, which are responsible for the release of local typhoon warnings to all levels of government.

Once a typhoon warning signal has been issued, media agencies and facilities, such as broadcasts and large display screens in public spaces, should promptly insert (and/or scroll) relevant alerts, safety tips and emergency notices. Television stations should place the alert signal in a prominent position on screen. The web portals of each level of headquarters and its member agencies should provide the weather report, typhoon forecast, flood notices, flood bulletins, watergate monitoring, daily water level reports, disaster briefings, real-time tracking and other information related to the typhoon and the typhoon response. In recent years, a fax broadcasting platform and a SMS mass-sending platform have been set up to send warning signals and signals of upcoming actions, such as the upgrading/downgrading or cancellation of warning signals (pre-notification), via fax or SMS to all levels of headquarters and their member agencies. Telecommunications carriers should assist in the SMS release of the above information.

1.2.5 **Rescue and relief system**

A typhoon rescue and relief system mainly consists of rescue materials as well as rescue and relief teams. There are more than thirty varieties of rescue materials – for example, straw bales, woven bags, timber, steel, blocks and stones – that are stockpiled by headquarters at all levels and their member agencies, departments, institutions with typhoon response tasks and professional organizations (including non-governmental organizations (NGOs)). Rescue and relief teams include highly specialized rescue experts, such as meteorological, water, electric power, greening, gas, transportation, fire, communications, environmental protection and biochemical teams. The teams also include mobile rescue experts, such as from the construction and industrial field, troops, armed police and public security, as a rescue task force. The satellite, civil affairs and insurance departments should also set up professional teams for medical rescue, disease control, civil assistance and insurance claims in order to protect people's lives and property to the maximum extent possible.

1.2.5.1 **Material stockpiling**

The necessary typhoon response materials are stockpiled and allocated according to levels. A certain amount of emergency materials should be stocked in key typhoon response areas in case of emergencies. A detailed description of the storage location, transportation protocol, contact information and responsible personnel must be stated in the typhoon response protocol.

1.2.5.2 **Emergency response teams**

According to the principle of combining professional and civilian teams, a joint response task force of the military (police) and civilians is formed during typhoon responses at all levels. Emergency response teams generally consist of professional rescue teams, which are made up of the member agencies of the headquarters, and resident troops, armed police, the fire department and public security officers. The teams are required to be well organized, flexible, obedient and prompt in their actions in order to be readily available and able to fight and succeed.

1.2.5.3 **Disaster relief**

Upon the occurrence of disasters, such as typhoons or major hazards to typhoon response engineering projects, the local typhoon response headquarters should monitor and track the incident promptly according to the nature of the incident; contact the relevant departments immediately; propose emergency disposal measures immediately according to protocols; report to the headquarters at the next level up; and mobilize the typhoon response resources and personnel task forces under its jurisdiction promptly to conduct an on-site response or rescue.

When dealing with typhoons and other related disasters as well as major engineering hazards, all member agencies are subject to the centralized command of the headquarters, perform their individual tasks according to the division of responsibilities and work in solidarity in order to respond quickly and efficiently. On-site security and order as well as local social stability should be maintained to prevent triggering secondary and subsequent disasters and to minimize losses.

1.2.5.4 **Drills and inspections**

Based on the principles of "safety first", "always ready", "prevention first" and "do the best in emergency rescue" in respect of typhoon response, inspections of the implementation of ideas, institutional arrangements and response measures are carried out. The purpose of the inspections is to identify and eliminate the hidden dangers of typhoon response activities to ensure safety during the typhoon season. Inspections should highlight uninspected spaces, hidden or weak components, unclear causes of hidden or weak components, improvement measures that have not been implemented, unclear responsible persons and instances where

the persons responsible for incidents caused by human errors are not held accountable. The inspections should follow the above principles and be carried out in a targeted and uninterrupted manner so as to supervise the implementation of various flood control measures and avoid hidden hazards and accidents. Typhoon response inspections include self-inspection of the agencies responsible, inspections of professional agencies and random inspections of management departments. They further include pre-typhoon inspections, special inspections during the typhoon and reviews after the rectification of hidden dangers.

Drills are an effective means to test the quality and implementation of typhoon response protocols and to publicize typhoon responses. Typhoon response headquarters at all levels should conduct different types of emergency drills regularly as per the protocol to test, improve and enhance emergency preparedness and response capabilities and to ensure the relevance and operability of the protocols. Professional emergency response teams must conduct targeted typhoon response drills annually for various types of local hazards related to typhoons that are prone to occur. Professional drills conducted jointly by multiple departments are generally held once every two to three years and are organized and implemented by typhoon response headquarters at all levels.

1.2.6 **Concluding remarks**

On the one hand, with socioeconomic development, the technical means of typhoon response activities have been improved and response capability has been enhanced. On the other hand, exposure to typhoons and vulnerability to disasters have increased, especially in the context of the climate-change induced increase in the intensity of typhoons and the extremity of disaster-causing factors, such as storm surges. Meanwhile, along with socioeconomic development, the latest and higher requirements for typhoon response work have been proposed. Therefore, typhoon response protocols and work systems should be improved in practice over the coming years.

At present, there are still uncertainties in refined typhoon forecasts. It is well known that, although the forecasting of typhoon tracks has improved significantly in recent years, typhoon intensity forecasts have progressed slowly over the past few decades and the capability of quantitative forecasts of wind and rain as well as distribution remains low. Therefore, there is considerable uncertainty in the timing, intensity and area of typhoon alerts. Such uncertainty should be considered in the preparation of typhoon response protocols and in the design and construction of the working system, especially when dealing with issues, such as the standardization of protocols and the adaptability of warnings with uncertainties.

In respect of the six components of typhoon response work (namely monitoring, forecasting, prevention, resistance, rescue and assistance), monitoring and forecasting serve as the basis for prevention. If prevention is successful, there will either be no or only a small disaster. If prevention fails, resistance, rescue and assistance must be carried out. Good resistance leads to easier rescue and assistance with lower costs, for which reason it is the key to rescue and assistance. The most effective means of resistance to a typhoon is the enhancement of typhoon response engineering projects. In the future, when faced with changes in exposure and vulnerability to typhoon hazards in the context of climate change and socioeconomic development, it will be necessary to conduct a scientifically sound assessment of the effectiveness (safety) and construction cost of these engineering projects, update engineering standards and improve engineering facilities as well as the intelligent work mode (adaptive typhoon warning signals).

1.3 **CUBA – TROPICAL CYCLONE EARLY WARNING SYSTEM**

1.3.1 **Introduction**

The island condition and geographical location of Cuba in the path of most tropical cyclones that develop in the Atlantic basin and the Caribbean Sea make these hydrometeorological events the greatest hazard for the nation. Yet, official reports by agencies of the United Nations indicate that Cuba is one of the less vulnerable countries with regard to these weather events.

This is possible, to a large extent, owing to the EWS that Cuba has had in place for several years, supported by numerous institutions including an efficient meteorological service with an extensive monitoring network of meteorological and hydrological stations and weather radars. The EWS ensures permanent monitoring, timely warning and effective communication links between the monitoring systems and branches of the Civil Defence, from the national to the local level.

The dissemination of forecasts and warnings is underpinned by a secure system of communication and the involvement of all mass media, including radio, television and newspapers, alternative resources and the people. Plans have been designed for different situations on the basis of the most likely disaster scenarios.

All resources are made available during these contingencies, ensuring that people are effectively protected against the different hazards they might face where they live.

The Cuban Government has been investing material resources and human capital in the creation and improvement of its EWS for tropical cyclones and other systems of alert for more than 40 years. As a consequence, the resolution of meteorological and hydrological monitoring systems has been strengthened through the acquisition of new equipment, the training of specialists and the development of working tools that improve understanding of the hazards. Plans have been refined and structures have been perfected to ensure their implementation along with the population's preparation, at national to local levels. An extensive network of radio and television stations, as well as newspapers and other facilities, has been created to ensure the quick dissemination of alert messages, including the transmission of information from person to person. Local access and distribution points for early warnings have also been created in communities at greater risk. Associated with local administration centres, these outlets contribute to ensuring the timely transmission of information for the reduction of municipal risk.

1.3.2 **Legal basis**

The Cuban EWS for tropical cyclones has the following key components (a) the technological capabilities of the Meteorological Service to predict the occurrence of hazardous events and issue specialized warnings for the Civil Defence as well as a clear explanation of the current and future situation to the people, and (b) the existence of plans elaborated from modelled risk scenarios to advance preparations by institutions trained for their implementation and reinforced by a prepared population with an appropriate perception of the hazard, all facilitating quick mobilization.

A set of institutions is entrusted with the monitoring of all events that threaten the country. They ensure surveillance against hydrometeorological events, drought, forest fires, floods, earthquakes, epidemics and animal and plant diseases, and keep the relevant state authorities systematically informed, with the reporting frequency ranging from daily to monthly depending on the variables and phenomena involved.

These institutions have branches in all provinces, and some have municipal representation, and supply data on the variables they measure to both the national and the territorial authorities. This surveillance network provides the basis for the country's EWS and is part of its Civil Defence System.

Cuba has a broad legal framework that regulates the functioning of EWSs at all levels. Only those laws and directives that provide guidance in this area are mentioned below.

Law No. 75/94 (21 December 1994) (National Defence Act) establishes the main missions and measures of the Civil Defence System and the principles for its territorial and institutional organization.

Decree-law No. 170/97 (8 May 1997) on the Civil Defence system of measures, as a complementary document to Law 75, regulates the role and position of state agencies and organizations, economic entities and social institutions in the disaster reduction process; the organization and implementation of these measures to protect people and the economy; the establishment of phases during the response; and the funding for disaster reduction plans.

Guideline No. 01/05 (20 June 1995) of the Vice-President of the National Defence Council¹ on the planning, organizing and preparing by the country for disaster situations establishes the regulations for the disaster reduction process and the guidelines to organize response and recovery at all levels. This document provides for the supply of updated information by surveillance and EWSs, and its contribution to the actions implemented during the response is one of the most important elements within disaster reduction plans. It stipulates that, in the event of tropical storms, "Early warning notices will be issued prior to the establishment of the response phases, so that the necessary measures are taken in advance". According to this guideline, the National Staff of the Civil Defence is the agency in charge of ensuring the implementation of the Civil Defence measures and the observance of international standards and agreements regarding the civilian population signed by Cuba. It is responsible for coordinating with the Ministry of Foreign Investment and Economic Cooperation concerning international cooperation and aid programmes in cases of disasters caused by natural hazards or other types of catastrophes. In addition, its powers and functions include organizing, coordinating and controlling the work of state agencies and organizations, economic entities and social institutions, with a view to protecting people and the economy, as well as acting as a national organizing platform for the system.

Resolution No. 43/06 (8 August 2006) of the Ministry of Science, Technology and the Environment establishes that the Environment Agency is the body that has the mandate to organize, lead and conduct hazard, vulnerability and disaster risk studies. There are other legal texts that complement this guiding document at all levels. These include Law No. 81/97 (11 July 1997) on the environment; Law No. 41/83 (13 July 1993) on public health care; Law No. 77/95 (5 September 1995) on foreign investment; and Law No. 85/98 (21 July 1998) on forestry, as well as ministerial and local resolutions that address specific aspects regarding the functioning of the EWS for tropical cyclones and other hydrometeorological events.

Resolution 106/99 (6 December 1999) of the Ministry of Science, Technology and the Environment establishes the Institute of Meteorology (INSMET) as the authorized agency to give meteorological and climatic information. Section 11 of the document sets down that one of the functions of the Cuban Meteorological Service is to improve meteorological and climatic prediction, especially of phenomena that constitute hazards for human life, as well as for material goods and the national economy. This resolution assigns to INSMET nationwide responsibilities to issue through the media, as the only authorized institution, meteorological and climatic information that may be required, especially warnings and forecasts of variables, processes and meteorological phenomena that constitute a hazard for human life, material goods, the economy and the development of the country. A similar role is set down for provincial meteorological centres as the only institutions authorized to disseminate and to issue through the provincial media meteorological and climatic information that may be required, especially the warnings and forecasts of processes and meteorological phenomena that could constitute a hazard for human life, the loss of material goods, the economy and the development of the country.

The Executive Committee of the Council of Ministers issued Ordinance Law No. 279/07 (19 March 2007) "On General Principles, Organization, Preparation and Provisions of the Hydrometeorological System of Cuba for Exceptional Situations". This document sets down

¹ The National Defence Council is the highest level in the response structure of the country.

that the Hydrometeorological System for Exceptional Situations is the group of hydrological and meteorological entities deployed in the territory of the country that has as its main mission to obtain, to analyse, to evaluate, to process and to issue the necessary hydrological and meteorological information for the execution of protective measures directed at the mitigation of the effects of disasters caused by natural hazards. This process is repeated every year and it serves to improve the system by considering the experiences of the previous year.

In May 2022, the National Assembly of People's Power passed a new law on the environment and natural resources that updates and englobes within Law No. 81/97 (11 July 1997) on the environment the principles and processes of EWS in Cuba, considering best practices and lessons learnt. Several legal bodies on the issue will be updated in the coming months.

1.3.3 **Structure and division of responsibilities**

The Cuban Meteorological Service is an active participant in the preparation and planning procedures of the EWS. Its fundamental function is to raise awareness among the people, as well as the institutions of the country, by providing information on what a hurricane is; the various hazardous phenomena associated with it; the different risks to be faced and how to avoid them; how the system of warnings is organized; and how to interpret warning messages. The Meteorological Service also participates in the preparation phase of the nationwide exercise *Meteoro*, which is organized every year by the Civil Defence before the start of the hurricane season. Meteorologists also participate through the frequent delivery of talks to provincial and local governments, Civil Defence bodies and journalists on hurricanes and the predicted behaviour of the next hurricane season. These activities are covered by radio and television and serve to prepare the population for the next hurricane season.

Coordination plans and communications links between the Meteorological Service and the Civil Defence are updated in order to place the EWS in a state of complete readiness before the start of the hurricane season.

The Cuban Civil Defence is organized throughout the national territory based on the country's political-administrative divisions and State structure. Its activity is supported by the use of the human and material resources available in government agencies and organizations, economic entities and social institutions; that is, the organized forces of society.

The President of the Council of State heads the Civil Defence System through the Ministry of the Revolutionary Armed Forces. In this capacity, the Ministry is supported by the National Staff of the Civil Defence, which is the leading agency in the Civil Defence System.

The presidents of local governments are the heads of Civil Defence in their territories. To carry out this work, they have the support of the local professional Civil Defence entities that, along with State organizations at all levels, coordinate, organize and plan the periodic assessment of risks associated with each event, disaster reduction measures, people's preparedness, the dissemination of information regarding actions to take and the behaviour to be observed during different situations. They also control the implementation of the protective measures for different segments of the population, their property and the economy.

Likewise, the top authorities of the Central State Administration and those of social institutions and entities are the heads of Civil Defence for these bodies and are responsible for the implementation in their respective areas of the measures contained in the approved disaster reduction plans.

Those individuals at the head of ministries, industries, companies, education centres, hospitals, banks, cooperatives, stores, workshops and other production, service or research centres are also the heads of Civil Defence in their respective institutions. They are in charge of planning, organizing and implementing Civil Defence measures, which are mandatory for all institutions.

Political and mass organizations at all levels play an important role in the implementation of Civil Defence measures because of their autonomy and characteristics. These organizations have always actively participated in evacuation, rescue operations and citizen's orientation and information in the event of disasters.

Disaster reduction plans are drafted for every territory and for all economic entities. These plans include an assessment of the risks at every location and are updated yearly using the data provided by the entities regarding the vulnerability parameters established by the methodology. The plans include measures to mitigate vulnerability, and preparedness, response and recovery actions. They are prepared following the instructions provided by the entities' higher government level and the decisions adopted by local governments.

Disaster reduction plans that are prepared at each territorial level as well as within each organization and ministry start from an updated assessment of the risk difference of each location, which is defined on the basis of the magnitude of the hazards associated with each meteorological event and the vulnerabilities identified at that level. Starting from the update and appropriate zoning of risk, actions for the mitigation of vulnerabilities are established for that year, taking into account the available material and financial resources and prioritizing the most at-risk areas. Further taking into account the level of risk at each location, measures for the protection of the population and economic resources are refined and appropriate response actions are planned to address each event, including measures needed to guarantee a quick and efficient recovery. National organizations and ministries update the guidance for their entities, which refine their plans accordingly.

The Cuban Meteorological Service is engaged from the very beginning in the process of planning an early warning. It issues the first early warning signal by means of a document entitled *Early Warning Message*, which is sent to the Civil Defence and the central Government when a meteorological situation is seen as being potentially dangerous for the country over the next 120 h period. The message is issued in clear language that is understandable to non-meteorological personnel, enabling them to appreciate the uncertainties associated with a meteorological process that may or could happen and affect the country within a relatively long time frame of 120 h. This type of information is transmitted to the population through the media in order to increase the level of concern without causing immediate alarm.

The precise purpose of early warning messages is to inform the Civil Defence and the high authorities of the country, as well as the public, in a timely manner, that it is necessary to monitor the meteorological situation over the coming days so that, if a hazardous meteorological system develops, they will be ready to take the required preventive measures.

1.3.4 **Work system**

The Cuban EWS takes advantage of the existing socioeconomic structure, the strength of institutions and the levels of organization and education of both the authorities and the general population, among other aspects that help its functioning.

In general terms, the main elements of the Cuban EWS are:

- The central surveillance entities in charge of monitoring hazards and their territorial branches in charge of this work at the regional and local level. The central surveillance entity for meteorological systems is the INSMET National Forecast Centre (National Meteorological Service (NMS)).
- The authorities at different levels entrusted with the provision and dissemination of disaster-related information and with implementing the relevant protective measures, advised by officials and experts of the Civil Defence. These authorities are the top officials at provincial and municipal levels (governors or presidents of provincial governments; mayors or presidents of municipal government).

- The media and mass and social organizations at the local level, which help to disseminate information. These include local media, newspapers, radio and television stations that exist in all the provinces and most of the municipalities in the country. The mass and social organizations that participate in the dissemination of the information in urban and rural areas are, respectively, the associations of neighbours known as the Committees for the Defence of the Revolution, which bring together residents and exist in all neighbourhoods of the country, and the National Association of Small Farmers.
- The public, who are well organized and prepared. They are, fundamentally, people of the mass and social organizations that have been trained to disseminate messages of alert in communities far from the main cities and towns. They include the people in charge of the operational sites for early warning located in key places with difficult access, who are prepared to measure rainfall and the level and flow of rivers. These latter individuals have means of communication enabling them to rapidly inform their respective centre of risk management located at the municipal government site.

1.3.5 **Early warning system for tropical cyclones**

The EWS for tropical cyclones is a well-structured, coherent, nationwide system that works closely with the INSMET National Forecast Centre and the National Staff of the Civil Defence. These two organizations exchange and analyse information, allowing authorities to take the necessary measures and establish the relevant phases or “calls for action”.

The EWS for tropical cyclones includes the following elements:

- An effective meteorological and hydrologic surveillance system with the appropriate human and material resources to ensure permanent monitoring and timely warning, both at the national and local level.
- Effective communication between meteorological and hydrologic surveillance systems and Civil Defence institutions, both at the national and local level.
- A network for transmitting information, supported by secure communication systems.
- The use of all mass media to disseminate warning notices, including radio, television, newspapers, alternative means and people, both at the national and local level.
- Plans designed for different situations on the basis of likely disaster scenarios and supported by all resources available in each territory, in order to ensure the effective protection of the people under different levels of risk.

In the context of risk management and the handling of disaster hazards, the EWS plays an important role in reducing human and material losses. In Cuba, the EWS is considered a major Civil Defence asset and is systematically used and strengthened.

The nationwide *Meteoro* exercise is held once a year over a weekend in May, prior to the beginning of the hurricane season. The first day of this drill (Saturday), at all levels of the country (nation, province, municipality, people’s council, community and entities), general preparation as well as all measures planned for response and the recovery are reviewed and exercised. On the second day (Sunday), practical activities, such as evacuation and protective measures, are carried out with the population and the forces that participate in the response. The Meteorological Service prepares a set of simulated warnings to be disseminated by all communications links that also serve to test the system. In addition, the Meteorological Service plays a role in increasing public awareness by reviewing the main characteristics of hurricanes, the warning service and the correct interpretation of warnings, as well as by providing an overview of the coming hurricane season. These talks are presented at the commencement of the exercise at provincial and municipal levels, and this activity is covered by national, provincial and municipal media.

1.3.6 Response actions

The exchange of information between the INSMET National Forecast Centre and the National Staff of the Civil Defence at the national level facilitates decisions on the phasing of the response for threatened territories, which presupposes a certain time frame for the adoption of measures in those places. The more effectively the EWS works, the greater the opportunity it provides for provinces and municipalities to react and so be able to protect the lives of people and economic resources exposed to different risk levels.

Whenever a province receives an early warning message or notice of the establishment of one of the phases of the response, the authorities begin immediately to undertake the measures for that phase outlined in the plan for disaster reduction, taking into account the characteristics of the threatening event, the level of risk to people and the exposed economic resources. In this decision-making process, a similar exchange to that at the national level takes place between provincial authorities and meteorological centres to determine the magnitude of the impact of winds, rains and storm surge in the territory, building on the guidance that is received from the NMS. Once this assessment has been carried out, the planned measures for protection developed during the preparations for each possible scenario begin to be implemented, making this a fast and efficient process.

Starting from the information provided by the INSMET National Forecast Centre, the National Staff of the Civil Defence analyses the initial situation, and a note from the Civil Defence can be sent to provide an early warning to the governments of the threatened territories. The exchange of information between the National Forecast Centre and the National Staff of the Civil Defence continues while the hazard threat remains over any portion of the country. Response action in Cuba is organized into three phases or stages – the “Informative”, “Alert” and “Alarm” phases. For each phase, and for each event, protection measures are planned. The EWS functions according to the phase that has been established, taking into account the fact that, as the hurricane approaches the territory, the ways to disseminate the messages change. The establishment of each phase is approved by the central Government, having been proposed by the National Staff of the Civil Defence following consideration of, among other factors, the recommendations provided by the NMS.

Likewise, the meteorological and hydrological services in each province interact with the authorities and are responsible for keeping them and the provincial population informed through all available communication means.

There are three levels of local government in Cuba; namely province, municipality and people’s council. These three instances of government each have a president and a structure that facilitates the organization of the Government’s administration. The National Forecast Centre interacts with the Government at national level, while the provincial meteorological centres interact with the Government at provincial, municipal and people’s council levels, offering information and advice during the different Civil Defence phases.

INSMET, through the National Forecast Centre, interacts directly with the central Government, the National Staff of the Civil Defence, the national media, provincial meteorological centres and the National Institute of Hydraulic Resources.

Provincial meteorological centres provide information on their territory to the provincial and municipal governments, to the Civil Defence at that level and to the provincial and municipal media, as well as to the provincial delegations of the National Institute of Hydraulic Resources.

Provincial meteorological centres fulfil a similar role to the National Forecast Centre, except that they relate to provincial and municipal governments, Civil Defence and local users, including people’s councils. In practice, the provincial meteorological centres represent INSMET at the provincial level. However, only the National Forecast Centre can issue early warnings and warnings in the event of a large-scale weather system, such as a hurricane. In such circumstances, provincial meteorological centres serve as advisers to assess the local impact that a hurricane

may have in a certain province. In the event of severe local storms or other rapidly developing local weather features, a provincial meteorological centre can issue its own local warning to local authorities, while merely informing, and receiving advice from, the National Forecast Centre.

The role of the National Staff of the Civil Defence in relation to drafting early warning reports, the operation of the mass media and the activities undertaken by local authorities to ensure that warning messages reach the entire population and that the necessary measures are taken, are defined in additional documents, which are issued at each level and are included in the disaster reduction plan.

Local authorities also issue guidance and directions to subordinate levels, specifying the functions to be carried out by these different structures in relation to, for example, the transmission of alert messages down to the level of people's councils, reports that should be provided by early warning access and distribution points and the maintenance of the flow of information. A great number of additional documents on this topic exist but they are not detailed here.

In accordance with what is established in Guideline No. 01 of the Vice-President of the National Defence Council, the heads of all state organisms and local authorities issue resolutions and instructions to regulate the functions assigned to their respective agencies and entities within the general framework of the EWS, and for the execution of other activities within the disaster reduction process. The Chief of the National Staff of the Civil Defence, the Minister of the Institute of Hydraulic Resources and the Minister of Radio and Television have issued corresponding instructions in this regard.

Following the response to an event, an analysis is made of how effective the EWS worked, and measures are taken to strengthen the system based on the experience gained in dealing with the event, thereby ensuring the refinement of procedures. The operation of the EWS is also assessed during the yearly *Meteoro* drill. In addition, before the beginning of each hurricane season, the system is reviewed to ensure that everything is in place.

1.4 **FRANCE/LA RÉUNION – TROPICAL CYCLONE BATSIRAI**

The French EWS for tropical cyclones has proved its effectiveness for decades in La Réunion. However, improvements are still regularly made in order to increase anticipatory actions, better describe the potential impacts of tropical cyclones, improve messaging and deliver an improved representation of uncertainty. Tropical Cyclone *Batsirai* (January 2022–February 2022) is a good example to highlight key recommendations and progress.

1.4.1 **Meteorological context**

First advisories were issued by Regional Specialized Meteorological Centre (RSMC) La Réunion on 26 January 2022 when the nascent system was a mere tropical disturbance. The budding storm was already considered a potential threat since long-term numerical weather prediction (NWP) was predicting a track in close vicinity of the sister islands of La Réunion and Mauritius. The cyclone warning system was activated on 30 January 2022 by the Prefect of La Réunion following the advice of the French NMS, Météo-France, with the cyclone pre-alert stage being declared. Weather conditions were expected to deteriorate over the next few days (beyond 48 h).

Figure A2 shows the track of Tropical Cyclone *Batsirai*, the centre of which eventually passed no closer than 190 km to the north of La Réunion on 3 February 2022. This was a fortunate scenario for the two islands since *Batsirai* had undergone a third round of intensification, leading to a peak in its intensity just after it had passed Mauritius, while it had in parallel undergone a large expansion in terms of size.

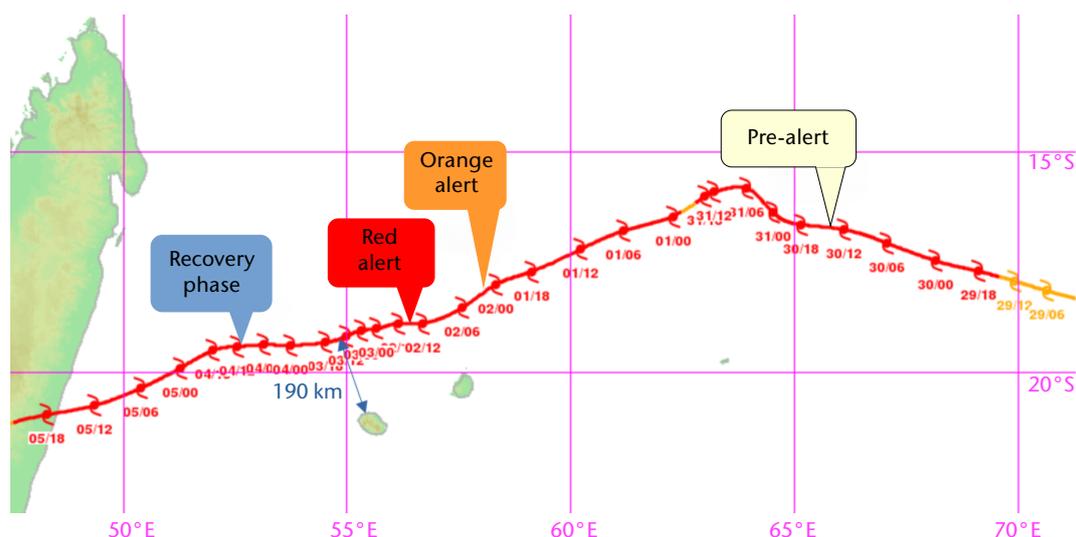


Figure A2. Track of Tropical Cyclone *Batsirai* and timing of alerts for La Réunion

Source: Regional Specialized Meteorological Centre (RSMC) La Réunion

Tropical Cyclone *Batsirai* had a strong influence on the weather conditions in La Réunion. Despite the dangerous inner core of the cyclone missing the island, La Réunion was shocked by strong winds (in line with the initial forecasts and messages delivered 4 days earlier, with strong winds gusting more than 150 km/h in mountainous areas), drenched by heavy rain pouring down on the inland mountains and affected by severe flooding. The volcano area hit the 2 000 mm threshold in 4 days owing to the large size of the cloudy and rainy envelope of the cyclone and the slowing down of the storm's motion on 3 February 2022. Despite the combination of exceptional rainfall and very strong winds on the reliefs, no casualties were occasioned by the cyclone. A state of disaster was declared in almost all the municipalities of the island. For the agricultural sector alone, the damage was estimated at 47 million euros (EUR).

1.4.2 Lessons learned and key progress

1.4.2.1 Increasing anticipation and dealing with uncertainties

The tropical cyclone warning system was activated when the centre of *Batsirai* was about 1 150 km to the east-northeast of the island. The pre-alert stage was declared more than 73 h before cyclonic conditions affected La Réunion. Providing early warnings with a considerable lead time contributed to improving emergency preparedness and pre-positioned stock capacity and to increasing and improving anticipatory action.

The EWS for tropical cyclones in French overseas territories falls under the leading authority of the main local administrative authority. The regulatory framework governing the system is defined in a standard operating procedure (SOP) that describes all the procedures and protocols ruling the warning system and that provides guidelines and action sheets for all the different departments and partners involved in crisis and emergency management. Actions taken by emergency management in respect of Tropical Cyclone *Batsirai* included preparation of emergency shelters; cancellation of school attendance; preventive evacuation of people requiring medical care at home; closure of roads exposed to landslides and coastal inundation; and preparation of a lockdown during the red alert stage.

The tropical cyclone warning system is based on a chronological countdown; the warning level shifts and increases when a threat is confirmed and the estimated time for a potential impact from the storm approaches. With regard to Tropical Cyclone *Batsirai*, the different stages of the tropical cyclone warning system ("Pre-alert", "Orange alert" and "Red alert") were

well anticipated, resulting in the efficient preparedness of all partners involved in emergency management. The orange alert stage was declared 24 h before cyclonic conditions were expected to affect the island. The red alert stage was declared by the Prefect with 5 h notice in order to give everyone enough time to either go back home or to a safe place. When a red alert is issued, all activities stop, and everyone is compelled to stay either at home or in a shelter, unjustified movement being liable to a fine.

Uncertainty plays a vital role in respect of what actions are to be taken. Uncertainties with regard to tropical cyclone track and intensity and wind extension forecasts lead to major uncertainties regarding impacts, especially for small islands. In order to improve communication regarding uncertainties, Météo-France provides local authorities with a specific timeline for “worst-case” and “average” scenarios. It integrates predictions of alert level changes and expected impacts for each parameter (wind, rainfall amounts and coastal inundation) at the local scale and includes local vulnerabilities. This timeline has become a key product for emergency management coordination briefings. Providing alternative scenarios for decision-making processes is crucial to be prepared for different scenarios (including the direct impact of the dangerous inner core of a tropical cyclone, such as *Batsirai*).

1.4.2.2 ***Maintaining close cooperation between National Meteorological and Hydrological Service partners and stakeholders***

Governance in La Réunion is under the leading authority of the Prefect, who is assisted by subprefects based in the different subregions (of which there are three). In terms of emergency management, the armed wing of the Prefect is the Civil Defence Administration. Météo-France is the official institution that is recognized as the unique technical adviser to the Prefect and to the local authorities. At the local level, mayors are in charge of protecting the citizens of their municipalities and as such have the authority to take all the necessary measures that a given meteorological situation might require.

In respect of Tropical Cyclone *Batsirai*, once the warnings went into effect, two tropical cyclone forecasters from RSMC La Réunion were dispatched to the Emergency Operations Centre to provide direct contact impact-based decision support services. The Director of RSMC La Réunion directly assisted the Prefect during the entirety of the red alert stage.

The response to Tropical Cyclone *Batsirai* showcases the importance of close collaboration between partners and stakeholders in providing the most relevant information for an evolving hazardous event, resulting in the NMHS, disaster management organizations, NGOs and broadcast and print media work together, with one voice, through an authoritative source. Pre-season training sessions and exercises are crucial in this context to build trust, understanding and awareness. One of the recommendations of the post-evaluation report carried out by the Civil Defence was to increase the number of participants (up to 250) in the pre-tropical cyclone season seminar in La Réunion.

1.4.2.3 ***Efficient and consistent communication***

The warnings are announced by the Prefect, who is in charge of disseminating official communications about warning levels and related recommendations in terms of preventive measures and behaviour guidelines to the population. Météo-France is in charge of technical communications about a meteorological situation and forecast, including the expected consequences for the island in terms of winds, rains, swell and so forth, linked to the approach of a storm. Perfectly consistent information is needed.

All the main messages – with a strong emphasis on easily understandable key messages – are delivered via the Météo-France website and Facebook account, while live radio and television interviews are regularly given either by specialist cyclone forecasters (radio) or by chief forecasters (television). Warnings are also disseminated at the national level (mainland France), including by the Directorate General for Civil Protection and Crisis Management and the Crisis Management Operational Centre.

Thanks to the coordination of the emergency management community, when Tropical Cyclone *Batsirai* struck, information flowed through all dissemination sources, including Météo-France social media accounts, its website and mobile app, Facebook, broadcast and print media. During the red alert stage, four press conferences were held by the Prefect, who systematically involved the Director of Météo-France. Several journalists from broadcast and print media were accommodated in the premises of the Emergency Operations Centre.

1.4.2.4 **The importance of impact-based forecasts**

Track and intensity forecasts are not very relevant to the description of impacts at the local level. This is why tropical cyclone products should focus on associated hazards (violent winds, torrential rainfall, storm surges, coastal inundation, floods and landslides). During Tropical Cyclone *Batsirai*, specific attention was paid to delivering impact-based forecasts, including predicted rainfall amounts and flash floods and coastal inundation forecasts, including tropical cyclone products based on new methods merging forecasters' expertise, and to spreading the information included in NWP ensemble models.

In order to better take into account the potential impacts of tropical cyclones, the EWS for La Réunion is based on a two-dimensional approach mixing winds and rains. Formerly, the criteria defining cyclonic conditions were solely based on winds (cyclonic winds corresponding to peak gusts exceeding 150 km/h). Since December 2018, the system has been based on a matrix of decisions combining forecasted maximum winds and expected rain return period (see Figure A3). Hydrological background is also considered (if heavy rains were observed before the event, the warning level will be raised to take into account the potential impact of soil saturation on water run-off or overflow).

1.4.2.5 **The importance of teaming up with third parties**

In terms of impacts, the hydrological aspects are not dealt with by Météo-France but by another specialized administration, the Directorate General for Planning, Housing and Nature, which is in charge of its own specific warning system for the different river catchments on the island (Vigicrues). This impact-based flash flood warning system is operated in close collaboration between the Directorate General and Météo-France. High-resolution rainfall forecasts are integrated as an input to the flood warning system, which integrates local people's experience, direct information from the Directorate General for Civil Protection, the altitude of roads, urbanized areas and so forth. During a tropical cyclone event, hydrological forecasters are accommodated in Météo-France premises in order to guarantee the consistency of meteorological forecasts and hydrological predictions.

		"Wind" effects (gusts)				
		< 100 km/h	From 100 to 130 km/h	From 130 to 150 km/h	From 150 to 200 km/h	> 200 km/h
Rain effects	Return period < 2 y.					
	Return period < 5 y.					
	Return period < 10 y.					
	Return period < 10 y.					

Figure A3. A matrix of decisions combining forecasted maximum winds and expected rain return period

As regards coastal impacts, the high swell warnings formerly disseminated have been replaced by warnings of coastal inundation and high waves. Probabilistic forecasts of cyclone-induced coastal inundation now routinely produced by Météo-France are an input to the warning system.

1.5 HONG KONG, CHINA – SOME TIPS ON MULTI-HAZARD EARLY WARNING SYSTEMS AND DISASTER RISK REDUCTION IN THE FACE OF A TYPHOON

Typhoon *Mangkhut* (September 2018) offers an excellent example of how zero casualties can still be achieved in a highly developed and densely populated city when exposed to extremely high winds, heavy rain and record-breaking storm surge impacts. One week before Typhoon *Mangkhut* hit, the Hong Kong Observatory (HKO), the official weather service in Hong Kong, China, started various communication approaches to raise the awareness of not only the public but also the Hong Kong Special Administrative Region Government and other stakeholders, such as the mass media. Closer to the warning time, strategic social media posts with short videos on multi-hazards and potential impacts were sent to mobile devices in order to escalate public awareness and call for preparedness.

A Government-wide joint press conference on Typhoon *Mangkhut* (see Figure A4) was held 2 days before its closest approach in order to forewarn the public on the one hand and guarantee the Government's readiness on the other. One day later, several government bureaux/ departments, including HKO, appeared on radio programmes to urge the public to prepare for *Mangkhut*. Together with the emergency response and rescue actions laid down in the Contingency Plan for Natural Disasters, the people of Hong Kong, China, knew exactly what to do. Owing to years of education and rehearsals on a yearly basis, Hong Kong, China, survived the devastating impacts of *Mangkhut*. Post-*Mangkhut*, HKO initiated and sustained an ongoing effort to crowdsource photos and videos of tropical cyclone impacts, including a dedicated web page ([Interactive Map of Storm Damage by Mangkhut](#), Figure A5) and a new mobile app feature ([My Weather Observation](#)). Subsequently, research studies on *Mangkhut* continued covering not only the scientific but also the [economic](#) impacts. According to a joint study by HKO and the Hong Kong Federation of Insurers, the estimated direct economic loss occasioned by *Mangkhut* in Hong Kong, China, was about 4.60 billion Hong Kong dollars (HKD) (0.6 billion US dollars (USD))!

Some key lessons can be learned here in respect of successful disaster risk reduction. First, a legislative or executive foundation, such as the Contingency Plan for Natural Disasters, is crucial for all kinds of EWSs to achieve the last mile because it sets out the government's strategy, organizational framework, alerting system and emergency action plans for responding to natural disasters. The Contingency Plan stipulates the functions and responsibilities of government bureaux/departments, utilities companies and NGOs in the event of natural disasters, including tropical cyclones. The tropical cyclone warning system operated by HKO is an integral part of the Contingency Plan.



Figure A4. A Government-wide press conference (left) and HKO *Cool Met Stuff* videos (right) to alert the public to the multi-hazards and potential threats of *Mangkhut*

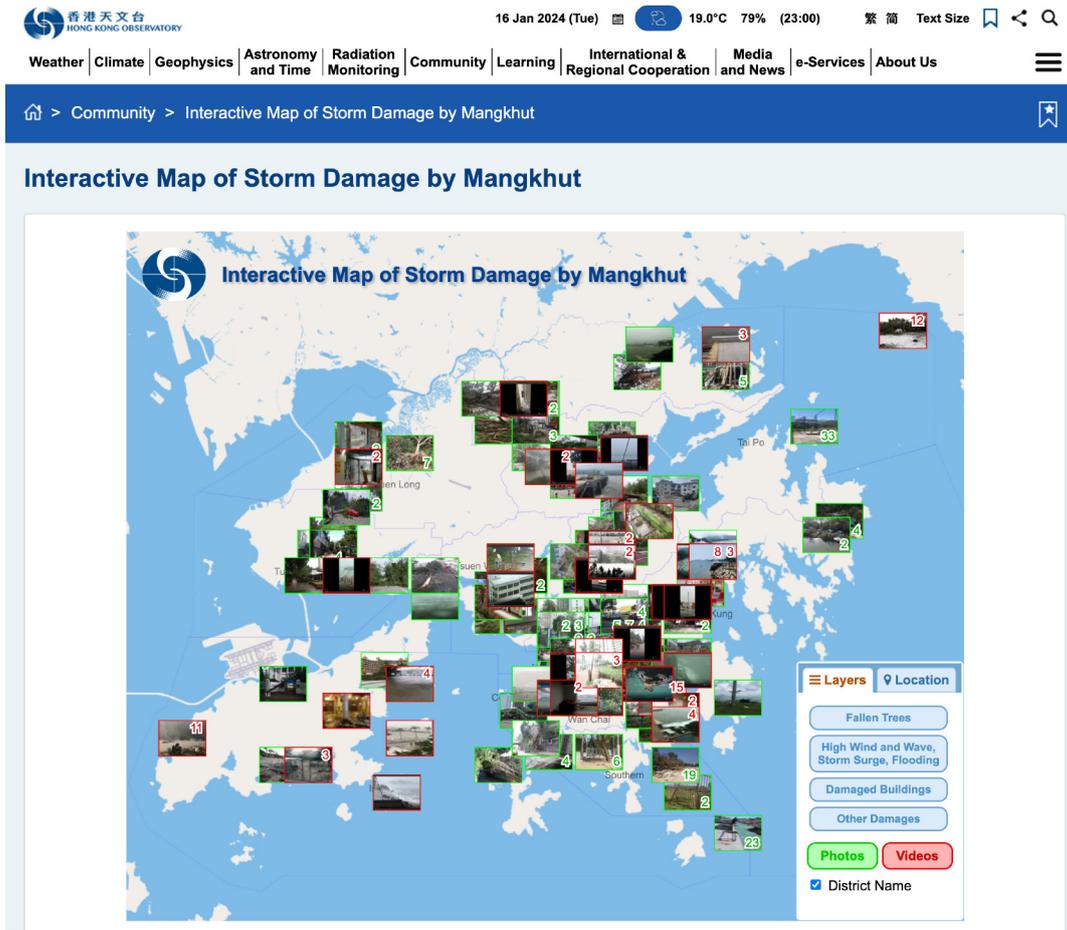


Figure A5. Interactive Map of Storm Damage by *Mangkhut*, web page

Effective and efficient coordination is the second key element. When a tropical cyclone warning signal is issued by HKO, other government bureaux/departments make corresponding arrangements – for example, announcements about school closures, installation of demountable flood barriers in flood-prone areas, evacuation of residents from flood-prone areas and so forth – in accordance with the procedures prescribed in the Contingency Plan. The Labour Department of the Hong Kong Special Administrative Region has published a [Code of Practice in Times of Typhoons and Rainstorms](#), in accordance with which employers and employees develop mutually agreed arrangements for the suspension and resumption of work, depending on the level of tropical cyclone warning signals.

The third key element is effective and efficient information dissemination. Tropical cyclone forecasts and warning information are delivered directly to the public via the HKO website and mobile app, MyObservatory, television/radio broadcasts and social media (including Facebook, Instagram, Twitter, WeChat and Weibo), with push notifications from MyObservatory being the most important means. HKO meteorologists comprise an internal media unit responsible for the production and broadcast of both regular television weather programmes and ad hoc television and radio media briefings when a tropical cyclone warning is in force.

With the system and information at hand, the fourth key element is an all-round communication strategy. What differentiates a tropical cyclone from other natural hazards is its potential for multi-hazards. Such an important aspect cannot be overlooked and is communicated to the public of Hong Kong, China, by all means possible, including television weather programmes, press conferences, push notifications via the MyObservatory mobile app and so forth, before a tropical cyclone makes landfall so that the public can be better prepared beforehand. Sometimes, an infographic or even a cartoon can help to project complicated information in a way that is clear for people. Typically, to raise public awareness and preparedness, HKO will publish a blog

article on potential weather changes and impacts on the mobile app and website, based on the latest tropical cyclone forecasts. Depending on the context, readily available video content from the popular educational television series *Cool Met Stuff* is extracted or replayed to alert the public to the characteristics of the approaching tropical cyclone. Closer to the time for tropical cyclone warning signals, a *Special Weather Tips* message will be disseminated, followed by media briefings by HKO meteorologists. During the quiet season, short videos, radio programmes, public talks and governmental seminars, as well as site visits to key partners, are adopted as a means for public education. Physical and/or virtual open days are organized every year to introduce the work of HKO to boost public understanding and awareness about severe weather, including tropical cyclones. Starting from the 2021 tropical cyclone season, online briefings on the tropical cyclone outlook up to four weeks in advance have been organized for government and special users twice per week.

The fifth key element is the tropical cyclone warning operated by the National Meteorological and Hydrological Service (NMHS)/RSMC that often plays a pivotal role throughout the disaster risk reduction process. While the majority of people may not know much about weather and meteorology, most have experience of risks, and a risk-based warning is therefore more effective in general. Tropical cyclone warning signals in Hong Kong, China, are primarily designed with reference to territory-wide sustained wind strength near sea level. Risk information is conveyed to the public through the warning bulletin and precautionary statements associated with each level of tropical cyclone warning signals. For example, the tropical cyclone warning bulletin issued by HKO will include the flood risk for low-lying and flood-prone areas when storm surge is predicted to exceed warning/alert levels. For tropical cyclones coming into the proximity of Hong Kong, China, accompanied by high winds coming from changing directions, people will be warned of sudden changes in wind direction. Even before local winds pick up and when the weather may still look calm, HKO will alert the public to the risk and impact of the swells and waves generated from afar by an approaching tropical cyclone.

As a concluding remark, knowledge of the key elements of successful disaster risk reduction is not enough. A sustainable capacity-building strategy should also be in place. As technology and science continue to advance, NMHSs need to synchronize with research and development in respect of global/regional/local in situ and remote-sensing observations; automatic algorithms based on artificial intelligence (AI); and objective guidance from multiple NWP models, Ensemble Prediction Systems (EPSs) and post-processing products, just to name a few based on HKO practices. Meanwhile, traditional wisdom and local knowledge still form an important part of HKO operational procedures. To cater for the changing needs of society, public feedback and special user survey results, as well as liaison group meetings for key sectors, are being adopted to collect inputs for the continuous improvement of the HKO tropical cyclone warning system, which is operated under an ISO-9001-certified quality management system.

1.6 **INDIA – GOOD PRACTICES FOLLOWED IN INDIA AND BY REGIONAL SPECIALIZED METEOROLOGICAL CENTRE NEW DELHI FOR THE MEMBER COUNTRIES OF THE WMO/ECONOMIC COMMISSION FOR ASIA AND THE PACIFIC PANEL ON TROPICAL CYCLONES**

1.6.1 **Introduction**

Following the establishment of the WMO Tropical Cyclone Programme (TCP) in 1980 to assist vulnerable countries to minimize the loss of life and property caused by tropical cyclones, RSMC New Delhi took over the responsibility for providing cyclone early warning advisories to the countries bordering the north Indian Ocean, under the purview of the WMO/Economic and Social Commission for Asia and the Pacific (ESCAP) Panel on Tropical Cyclones (one of the five regional bodies designated to look after the regional components of the TCP). Based on the tropical cyclone operational plan for the region, RSMC New Delhi issues a daily *Tropical Weather Outlook* at 0600 UTC and special tropical weather outlooks/cyclone advisory bulletins at 6 h–3 h intervals to member countries whenever a cyclonic storm develops in the north Indian

Ocean. RSMC New Delhi is located at the headquarters of the India Meteorological Department (IMD), the national agency entrusted with the responsibility for providing early warnings for all weather- and climate-related natural hazards affecting India.

Nationally, IMD has a three-tier organizational structure for cyclone warnings with the Cyclone Warning Division at IMD headquarters, three area cyclone warning centres in Chennai, Kolkata and Mumbai and four cyclone warning centres in Ahmedabad, Bhubaneswar, Thiruvananthapuram and Visakhapatnam to cater for the country's requirements.

The Cyclone Warning Division is co-located with the RSMC for Tropical Cyclones and the Tropical Cyclone Aviation Centre. At the regional level, the IMD Director General of Meteorology leads all discussions with WMO and the permanent representatives of all 13 member countries of the WMO/ESCAP Panel on Tropical Cyclones. At the national level, the Director General of Meteorology is responsible for briefing the Prime Minister's Office, the National Crisis Management Committee, the Cabinet and Home Secretary and the chief secretaries of affected states. The Head of the Cyclone Warning Division liaises with central-level disaster managers, including the National Disaster Management Authority, the National Disaster Response Force, the Secretary of Railways, Road and Shipping, the chief secretaries of concerned states, national television and All India Radio. The area cyclone warning centres and cyclone warning centres are responsible for liaising with state- and district-level disaster managers. The ultimate responsibility for operational storm warning work for the respective areas rests with the concerned area cyclone warning centres and cyclone warning centres.

1.6.2 **A few examples of good practices**

1.6.2.1 ***Inclusion of the latest data in assessing exposure and vulnerabilities while communicating risk information in tropical cyclone early warnings***

Risk management of cyclones depends on several factors, including (a) hazard and vulnerability analysis, (b) preparedness and planning, (c) early warnings, and (d) prevention and mitigation. In recent years, there have been significant improvements in impact-based forecasting and risk-based warnings of cyclones reaching land in India owing to the introduction of an impact matrix based on historical damage data; augmented rain gauge and gauge-satellite merged data sets for real-time rainfall monitoring; ScatSat; Doppler Weather Radar; high wind speed recorders and Automatic Weather Stations (AWSs) for wind monitoring; the introduction of multi-model and single model EPSs and other dynamical statistical tools; cyclone-specific models, such as the Hurricane Weather Research and Forecasting model for rainfall and wind assessment; and storm surge and coastal inundation modelling by the Indian National Centre for Ocean Information Services (INCOIS) in collaboration with IMD.

A web-based Geographical Information System (GIS) hazard vulnerability atlas has been prepared by IMD, segregating each of the multi-hazards associated with cyclones, such as strong/gale-force winds, heavy rainfall, pluvial and fluvial floods and storm surges. The possible risks associated with secondary cyclone hazards, such as landslides, are handled and planned for by local administrations. Other non-structural measures include the introduction of objective analysis and a forecasting platform; the Decision Support System (DSS); a synergized SOP; the policies and guidelines of the Government; collaboration and partnership with various stakeholders, press and electronic media and disaster managers; and the introduction of user- and sector-specific impact-based warnings along with suggested actions. The hazard vulnerability atlas is further being fine-tuned with the implementation of a web-based dynamical cyclone risk assessment system by the National Disaster Management Authority in collaboration with IMD, state governments and other stakeholders.

1.6.2.2 ***A process for monitoring and forecasting tropical cyclones based on synergized standard operating procedures***

IMD maintains a 24 h watch over the north Indian Ocean to monitor any development of cyclonic disturbance and its further intensification, movement and impact. A well-defined SOP is followed to monitor and predict tropical cyclones, starting with the organization of pre-cyclone exercises prior to the beginning of each cyclone season and maintenance of round-the-clock watch. It is followed by extended-, medium- and short-range and nowcast predictions till landfall, and post-landfall forecasts and warnings till the system maintains its intensity of depression.

A systematic checklist is prepared for identifying and predicting the location, intensity and landfall of and adverse weather associated with tropical cyclones. In addition to all the observations and model guidance, IMD utilizes a digitized forecasting platform to compare, comprehend and analyse guidance from various sources to make a final decision and generate user-friendly warning products. DSS has the facility to plot and analyse different weather parameters and satellite, radar and NWP model products in the GIS platform and to generate warning graphics. Final consensus follows discussion among various forecasters countrywide via daily videoconferencing. Thus, the analysis and prediction of a tropical cyclone involves blending guidance from dynamic and statistical models, meteorological observations and technology with knowledge, experience and the expertise of forecasters.

To predict cyclogenesis, guidance from an array of models is used, including the IMD Genesis Potential Parameter index; the Multi-model Ensemble (MME) Climate Forecast System Version 2.0; the Global Forecast System; the Weather Research and Forecast model; the Global Ensemble Forecast System; the National Centre for Medium-range Weather Forecasting (NCMRWF) Unified Model and EPS; the National Center for Environmental Prediction (NCEP) Global Forecast System; the European Centre for Medium-range Weather Forecasts (ECMWF); the Japan Meteorological Agency (JMA); and the Météo-France model. In addition, planetary-level features, such as Madden–Julian Oscillation (MJO), La Niña and Indian Ocean Dipole (IOD), which influence tropical cyclone genesis, intensification and movement, are monitored.

To predict track, landfall, intensity and adverse weather, in addition to the models discussed above, IMD utilizes guidance from its MME system and a cyclone-specific hybrid ocean model, coupled with the Hurricane Weather and Research Forecast model, the Statistical Cyclone Intensity Prediction model and a rapid intensification/weakening model.

1.6.2.3 ***Significance of outreach and the concept of inclusivity for better mitigation via early action***

Outreach activities are an intrinsic part of the early warning services provided by IMD. Various programmes are conducted routinely to raise awareness about weather forecasting, early warnings and weather-related natural hazards, especially those caused by cyclonic storms over the seas and coastal areas. Twice every year, IMD headquarters and all its field forecasting offices hold open days during which weather experts explain to and educate the public about these activities.

Prior to the cyclone season, a pre-cyclone exercise meeting incorporating all stakeholders directly or indirectly involved in managing cyclone-associated disasters is conducted at the national level by the Cyclone Warning Division (see Figure A6) and at the local level by area cyclone warning centres and cyclone warning centres. Moreover, a series of lectures, meetings and film showings is organized to impart knowledge of the impending hazards associated with such systems.

IMD takes part in the mock drills and training of the public and police organized every year by the National Disaster Response Force and the State Disaster Response Force. Furthermore, IMD has published (a) a document on the damage potential of cyclones, (b) frequently asked questions (FAQs), (c) terms and terminology, (d) leaflets in local languages, (e) videos, (f) SOPs,



Figure A6. A pre-cyclone exercise meeting

and (g) “Do’s and don’ts” for cyclones. In addition, the National Disaster Management Authority and State Disaster Management Authorities have developed many Information, Education and Communication (IEC) materials on cyclones.

1.6.2.4 ***Utilization of all available warning dissemination mechanism redundancy***

Cyclone warnings are disseminated to users through all possible means, including telephone; fax; email; SMS; the Global Telecommunication System (GTS); the WMO Information System (WIS); All India Radio; frequency modulation (FM) and community radio; television and other print and electronic media; press conferences and releases; common alerting protocols (CAPs); mobile apps; and social media. Web-based GIS dissemination of a cyclone warning, crowdsourcing and a CAP are already in place.

These warnings/advisories are also published on the IMD websites. IMD sends cyclone alerts via SMS to disaster managers, the media, the public, fishers and farmers. A Global Maritime Distress and Safety System (GMDSS) message is published on the RSMC New Delhi website and transmitted through GTS. The WIS Portal is utilized for cyclone warning dissemination and IMD issues NAVTEX bulletins for the coastal regions in the east and west of India for the operation of lightships and fishers. Furthermore, IMD has installed specially designed receivers in coastal areas for the transmission of warnings in the regional language(s) to the officials and people concerned using the broadcast capacity of an Indian Geostationary Satellite (INSAT). IMD is collaborating with the Indian Space Research Organisation (ISRO) on the dissemination of SMS to fishers on the high seas through the GAMES and NavIC systems. During the cyclone season, all possible means of communication are utilized to reach last mile users by IMD headquarters, IMD sub-offices and various disaster management agencies individually and collectively.

In addition, during the cyclone season, pre-recorded video clips by the IMD Director General of Meteorology as well as operational forecasters are circulated among the public via all possible communication media, including social media platforms, and constant media briefings are carried out by duty forecasters and IMD experts.

1.6.2.5 ***The countdown approach being followed in early warning systems – Super Cyclonic Storm Amphan as an example of enhanced preparedness and response capabilities***

The following is an example of a success story in managing Super Cyclonic Storm *Amphan* in May 2020. Though the property damage associated with *Amphan* has made it one of the costliest cyclones in the recent past, the step-by-step countdown process as depicted below enabled disaster managers to limit the damages to a minimum.

1.6.2.5.1 ***Disaster management countdown and count up for Super Cyclonic Storm Amphan***

For the monitoring of Super Cyclonic Storm *Amphan*, preparedness commenced at the beginning of April 2020. At the onset of the cyclone season (April–June), a pre-cyclone exercise was held during the first week of April at IMD headquarters and various IMD sub-offices to take stock of preparedness for the coming cyclone season. Daily diagnosis and prognosis commenced on 25 April 2020, as per the SOP. The first alert about the possible development of a cyclone was sounded on 7 May 2020. The entire countdown process involved in monitoring Super Cyclonic Storm *Amphan* is described below.

Countdown stage eight (6 May 2020, 1330 IST):

The countdown process started on 6 May 2020 when IMD received the first signal about possible cyclogenesis over the Bay of Bengal, with the formation of upper air cyclonic circulation over the south Andaman Sea that had potential for intensification. Since then, continuous monitoring started with the issuing of four bulletins per day by the National Weather Forecasting Centre of IMD in respect of the cyclonic circulation meandering over the south Andaman Sea.

Countdown stage seven (7 May 2020, 1330 IST):

The extended-range outlook issued on 7 May 2020 (about 6 days prior to the formation of a low-pressure area on 13 May 2020, 9 days prior to the formation of a depression and 13 days prior to landfall on 20 May 2020) indicated cyclogenesis over the south Bay of Bengal with movement towards the north Bay of Bengal. IMD continued to monitor the cyclonic circulation and issue four bulletins per day from 7 to 12 May 2020.

Countdown stage six (13 May 2020, 1330 IST):

It began on 13 May 2020, the day of the formation of a low-pressure area over the south Andaman Sea (3 days prior to the formation of a depression on 16 May 2020 and 7 days prior to landfall). A special informatory message was sent to central and state-level disaster managers of east coast states and the Andaman and Nicobar Islands at 1330 IST, indicating the likely development of a cyclonic storm over the Bay of Bengal. IMD issued a press release and a special bulletin for the media and public indicating the formation of a low-pressure area and its possible intensification into a cyclone. It advised fishers not to venture into the identified sea region, which was expected to experience adverse weather. IMD continued to publish monitoring predictions in connection with this low-pressure area in its daily four bulletins until 16 May 2020.

Countdown stage five (pre-cyclone watch) (16 May 2020, 0845 IST):

It commenced with the intensification of the low-pressure area into a depression over the south-east Bay of Bengal on the morning of 16 May 2020. IMD started issuing structured bulletins with quantitative track and intensity forecast every 6 h, as well as adverse weather warnings. In the first bulletin in this series, released at 0845 IST on 16 May 2020 (104 h prior to landfall), a pre-cyclone watch for north Odisha and West Bengal coastal districts was issued,

indicating that the system would intensify into a cyclonic storm and cross the West Bengal coast with a maximum sustained wind speed of 155 km/h–165 km/h, gusting up to 180 km/h. It was further indicated that the system would cause heavy to very heavy rainfalls in a few places, with extremely heavy rainfalls in isolated places over Gangetic West Bengal on 20 May 2020. For coastal Odisha, heavy rainfalls in isolated places from the evening of 18 May 2020, heavy to very heavy rainfalls in a few places on 19 May 2020 and isolated heavy rainfalls over the north-east on 20 May 2020 were predicted.

The first meeting of the National Crisis Management Committee, chaired by the Cabinet Secretary on 16 May 2020 forenoon, was on preparedness measures, and similar meetings were conducted at the state level in Odisha and West Bengal. All partners and disaster management agencies at the national level and the Chief Secretaries of Odisha and West Bengal participated in this meeting. The IMD Director General of Meteorology delivered a presentation on the status of and forecasting of the cyclone; the expected adverse weather; the areas likely to be affected; the damage expected; and suggested actions. Accordingly, the actions were planned as per the instructions of the National Crisis Management Committee.

Countdown stage four (cyclone alert) (16 May 2020, 2030 IST):

It began with the intensification of the depression into Cyclonic Storm *Amphan* in the evening of 16 May 2020. The warnings were further upgraded, and a cyclone watch for north Odisha and West Bengal coastal districts was issued at 2030 IST on 16 May 2020 (92 h prior to landfall). Structured three-hourly bulletins commenced from 16 May 2020, with regular updates on all websites and social platforms. The pre-cyclone watch was upgraded to a cyclone alert (yellow message) for north Odisha and West Bengal coastal districts and was issued at 0840 IST on 17 May 2020 (80 h prior to landfall). It was indicated that squally winds of 40 km/h–50 km/h would commence along and off the Odisha coast from the morning of 19 May 2020, and along and off the West Bengal coast from the evening of 19 May 2020. The wind was predicted to gradually increase to a maximum speed of 100 km/h–110 km/h, gusting to 120 km/h, along and off the coastal districts of north Odisha during 20 May 2020 early morning to afternoon, and 155 km/h–165 km/h, gusting to 185 km/h, along and off the West Bengal coast during 20 May 2020 afternoon to night (during the time of landfall).

In the bulletin issued at 2030 IST on 17 May 2020, when the system lay as a very severe cyclonic storm over the south Bay of Bengal, extensive damage was expected, and action corresponding to an extremely severe cyclonic storm was suggested for north Odisha and West Bengal coastal districts. It was indicated that the system would cause extensive damage to all types of kutcha houses and some damage to old, badly managed concrete structures. Flying objects were potential threats and the extensive uprooting of communication and power poles was expected. The system was expected to disrupt rail and road links in several places, extensively damage standing crops, plantations and orchards, blow down palm and coconut trees and uproot large bushy trees. Large boats and ships were expected to be torn from their moorings. At this stage, the total suspension of fishing operations from 18 to 20 May 2020 and diversion or suspension of rail and road traffic was suggested. People in affected areas were advised to remain indoors, and disaster management authorities were advised to mobilize evacuation from low-lying areas.

Countdown stage three (cyclone warning) (18 May 2020, 0845 IST):

The cyclone alert was upgraded to a cyclone warning. It started with the intensification of *Amphan* into an extremely severe cyclonic storm on 18 May 2020, early morning. A cyclone warning (orange message) for north Odisha and West Bengal coastal districts was issued at 0845 IST on 18 May 2020 (56 h prior to landfall). In this bulletin, it was indicated that a storm surge of 4 m–5 m above astronomical tide would inundate low-lying areas of south and North Twenty Four Parganas, and a storm surge of 3 m–4 m above astronomical tide would inundate the east Medinipur districts of West Bengal around the time of landfall. Subsequently, *Amphan* intensified into a super cyclonic storm around noon on 18 May 2020. Continuous monitoring and prediction of its location, track intensity and associated adverse weather continued. Regular

three-hourly bulletins along with the organization of joint press conferences by IMD and the National Disaster Response Force commenced to raise awareness among the public about the impending disaster.

The second meeting of the National Crisis Management Committee, chaired by the Cabinet Secretary on 18 May 2020 forenoon, was on reviewing preparedness measures, and similar meetings were conducted at the state level in Odisha and West Bengal. A review meeting was also chaired by Hon'ble Home Minister on 18 May 2020 at noon. Another review meeting was chaired by Honourable Prime Minister on the afternoon of 18 May 2020, with the participation of concerned high-level disaster management authorities, and the IMD Director General of Meteorology presented the current status of and forecast for *Amphan*, the areas likely to be affected, the expected damages and suggested actions. Accordingly, the follow-up actions to the ongoing preparedness and mitigation measures were sharpened for necessary action. The IMD Director General of Meteorology and the Director General of the National Disaster Response Force addressed the joint press conferences organized by the Press Information Bureau on 18, 19, 20 and 21 May 2020 to brief the media and public about the impact of *Amphan*. The IMD Director General of Meteorology appeared live on Facebook on 18 May 2020 and facilitated frequent briefings to media persons from IMD headquarters and the cyclone warning centres in Bhubaneswar and Kolkata to raise awareness among the public about the expected adverse weather and damages associated with *Amphan* and actions to be taken by disaster managers and the public.

Countdown stage two (post-landfall outlook) (19 May 2020, 2330 IST):

It commenced at midnight of on 19 May 2020 (17 h prior to landfall) with the release of a post-landfall outlook (red message) for the interior districts of Assam, Gangetic West Bengal and Meghalaya after landfall, in addition to continued cyclone warnings for north Odisha and West Bengal coastal districts. The third meeting of the National Crisis Management Committee was chaired by the Cabinet Secretary on 19 May 2020 forenoon.

Countdown stage one (hourly updates) (20 May 2020, 0630 IST):

It commenced from 0630 IST on 20 May 2020 when the system lay about 155 km south of Paradip and 280 km south-southwest of Digha. IMD started issuing hourly updates on the current location, intensity and closest distance to different coastal cities/towns of Bangladesh, Odisha and West Bengal of *Amphan*, and current observations with regard to track, intensity, wind, rainfall and storm surge. This continued till the system crossed and thereafter maintained the intensity of a cyclonic storm. A total of 20 special hourly updates were issued in this regard.

Countdown stage zero (commencement of landfall process) (20 May 2020, 1430 IST):

It started with the commencement of the landfall process at 1430 IST on 20 May 2020 and continued for 2 h–3 h before the system crossed the West Bengal coast between Digha (West Bengal) and Hatiya Island (Bangladesh), and over Sundarbans, between 1530 IST and 1730 IST on 20 May 2020, with a wind speed of 155 km/h–165 km/h, gusting to 185 km/h, and a maximum storm surge of 4.6 m above astronomical tide, as predicted. Also in line with predictions, extremely heavy rainfall occurred over north Odisha and West Bengal coastal districts, including Kolkata.

Count up stage one (post-landfall follow-up) (20 May 2020, 1830 IST):

Hourly bulletins continued till the system maintained cyclonic storm intensity over the Indian region (that is, till 0230 IST on 21 May 2020). *Amphan* passed over Kolkata at around 2100 IST on 20 May 2020 as a very severe cyclonic storm, with a wind speed of 120 km/h–130 km/h, gusting to 145 km/h, as per predictions 3 days earlier. Regular three-hourly bulletins continued till the system maintained cyclonic storm intensity (morning of 21 May 2020). Six-hourly structured

bulletins issued by IMD during the weakening phase continued for various users till midnight on 21 May 2020. Thereafter, IMD maintained watch over the system till it became less marked and issued regular six-hourly bulletins.

Count up stage two (preparation of preliminary report) (21 May 2020, 0800 IST):

The preliminary report on the system was prepared and released in the form of a press release on 21 May 2020. A detailed report on Super Cyclonic Storm *Amphan* was issued on 13 June 2020. The fourth meeting of the National Crisis Management Committee, chaired by the Cabinet Secretary on 21 May 2020 forenoon, was on post-landfall follow-up actions.

IMD issued a total of 3 informatory messages prior to genesis, 45 national bulletins for national disaster managers, 45 bulletins for WMO/ESCAP member countries, including Bangladesh and Myanmar, 11 press releases and 19 hourly bulletins, in addition to other user-specific bulletins in association with Super Cyclonic Storm *Amphan*. All these bulletins and messages were sent by email and fax to central and state-level disaster managers and through GTS to WMO/ESCAP member countries. The messages were also published on various IMD websites, Facebook, Twitter and WhatsApp, and issued via mobile apps, the CAP, SMS and so forth.

In the case of Super Cyclonic Storm *Amphan*, forecasters faced multiple challenges with regard to the prediction of genesis, landfall point, landfall time and intensification. *Amphan* originated from the remains of a low-pressure area that persisted over the south Andaman Sea from 1 to 6 May 2020 and meandered over the south-east Bay of Bengal until 12 May 2020. It then reorganized as a low-pressure area on 13 May 2020 over the south-east Bay of Bengal, which in due course intensified into Super Cyclonic Storm *Amphan*. Considering model guidance, there was false alarm from 25 April 2020 about the genesis of a cyclone over the Bay of Bengal and its landfall over different coasts (such as the Andaman and Nicobar Islands, Bangladesh and Myanmar). It was a challenge to predict the place and occurrence of the low-pressure area and its possible intensification into a depression, its further intensification into a cyclone and its movement towards a particular coast. Also, the translational speed of *Amphan* varied greatly, for which reason the correct determination of landfall time was a difficult task. IMD usually examines about 12 global and regional models, including six models run by the Ministry of Earth Sciences and six international models. There was large spread in model guidance even 2 days before landfall. Even on 19 May 2020 (that is, 1 day before landfall), a few models were suggesting landfall over the Odisha-West Bengal border around noon on 20 May 2020. *Amphan* underwent rapid intensification from 17 May 2020 noon (1130 IST) to 19 May 2020 early morning (0230 IST), with an increase in wind speed 2.3 times during this period. However, with technological intervention and the utilization of knowledge, experience and expertise, IMD provided timely and accurate cyclone warnings to disaster managers, the media and public to manage Super Cyclonic Storm *Amphan* like many intense cyclones in recent years, including Extremely Severe Cyclonic Storm *Phailin* in 2013, Extremely Severe Cyclonic Storm *Hudhud* in 2014, Very Severe Cyclonic Storm *Titli* in 2018 and Extremely Severe Cyclonic Storm *Fani* in 2019.

Overall, the key lesson learned from the response to Super Cyclonic Storm *Amphan* is the importance of developing close relationships with partners to foster trust when communicating information about significant risks.

1.7 OMAN – NATIONAL MULTI-HAZARD EARLY WARNING CENTRE

The National Multi-hazard Early Warning Centre is the base of all tropical cyclone forecasts and multi-hazard warning systems related to weather in Oman, with an established SOP. Although the centre is located in the Civil Aviation Authority, it follows national legislation and the WMO [Manual on the Global Data-processing and Forecasting System](#) in respect of tropical cyclone forecasting, including marine-related hazards.

In Oman, the National Multi-hazard Early Warning Centre represents and leads the sectors of observation and early warning in the National Emergency Management Committee, which

is considered the main driver for national emergency management. The Committee includes several sectors, for example the Directorate General of Meteorology; the Civil Defence and Ambulance Authority; the national Government; different media; the National Institute of Hydraulic Resources; and different ministries. In the Committee, each sector is considered to be the leader in cases of emergencies that fall under its area of responsibility. As a result, the National Multi-hazard Early Warning Centre leads and directs activities by providing information to the rest of the Committee members.

The exchange of information between the Directorate General of Meteorology and the National Emergency Management Committee is regulated by a memorandum of understanding (MoU) that provides for the monitoring of tropical cyclones and different weather-related hazards. The National Multi-hazard Early Warning Centre SOP includes all the technical procedures for guaranteeing the implementation of the MoU. Once the National Multi-hazard Early Warning Centre SOP is activated, other sectors in the Committee activate their own SOPs accordingly.

The National Multi-hazard Early Warning Centre SOP describes how risk information is to be conveyed to the public through the warning bulletins and precautionary statements associated with the different levels of tropical cyclone warning signals and when dealing with other hazards. For example, the tropical cyclone warning bulletin issued will include wind (speed and direction), thunderstorm, wave height and flood risk for low-lying areas, all of which depend on the regions that are expected to be affected by a tropical cyclone.

The National Multi-hazard Early Warning Centre maintains round-the-clock watch over the Arabian Sea and north Indian Ocean to monitor any development of cyclonic disturbance and its further intensification, movement and impacts. A well-defined SOP is followed to monitor and predict tropical cyclones in the region.

After the observation of a tropical cyclone, a long process, starting with a systematic checklist, is prepared for identifying and predicting the location, intensity, landfall and adverse weather associated with tropical cyclones by the National Multi-hazard Early Warning Centre through its SOP. In order to forecast the different weather parameters of a tropical cyclone, several tools must be used, such as satellite, radar, NWP model products and so forth. The process of comparing, comprehending and analysing guidance from various sources is important for making a final decision and generating warning bulletins. The final discussion is usually held among various forecasters who participate in a weather briefing.

The National Multi-hazard Early Warning Centre disseminates weather bulletins based on its SOP through multiple channels, including recorded videos distributed via social media. Meteorological staff participate in many live television and radio interviews to deliver accurate information about and updates on a tropical cyclone. At the same time, the media plays a major role in delivering and clarifying situations to the public. Programmes, video clips and interviews include impact-based warnings that consider local vulnerabilities and exposure of areas to specific hazards.

The Civil Aviation Authority of Oman is the umbrella under which the Directorate General of Meteorology takes responsibility for observing and delivering warnings about different hazards. It plays a major role in public awareness and conducts activities and workshops for public education and preparedness. The Directorate General of Meteorology conducts many training workshops targeting the public, government ministries and even companies. It works with the Ministry of Education to prepare teaching materials regarding different hazards for different school grades and insert them in the curriculum. As part of preparedness, the Civil Aviation Authority conducts training for similar events, such as earthquakes and tsunami threats as well as storm surges and floods caused by tropical cyclones. These events target schools and sometimes entire small villages.

The last tropical cyclone that affected Oman was Severe Cyclonic Storm *Shaheen* in October 2021. *Shaheen* was an exceptional tropical cyclone in terms of its start point in the Bay of Bengal, at which point it had a different name. It then crossed the Indian subcontinent to the Arabian Sea where it intensified again before hitting an unusual area in northern Oman. The experience that

had been gained by the National Multi-hazard Early Warning Centre from previous tropical cyclone events allowed it to deal with the tropical cyclone in an efficient way that resulted in minimum destruction and loss of lives and properties.

The National Multi-hazard Early Warning Centre works according to a SOP developed from lessons learned. The lessons learned from Severe Cyclonic Storm *Shaheen* will be used to update the SOP.

Based on the experience of Oman in dealing with tropical cyclones, here are some thoughts and ideas that will enhance response actions by all sectors in respect of tropical cyclones and related hazards:

- Improving communication methods between the National Multi-hazard Early Warning Centre and other sectors with specific focal point(s) in each sector;
- Continuous meetings among sectors to develop/update proper SOPs to reach agreement in terms of who is responsible for doing what and when;
- Continuous evaluation of sectors' performance after each event;
- Internal training among sectors for a harmonized response during events;
- Joint technical development among sectors and sharing human resources and knowledge;
- Creating a single platform that brings together partners to share reports, warnings and needs.

1.8 PHILIPPINES – SOME GOOD PRACTICES OF THE END-TO-END WARNING SYSTEM

One of the good practices in the Philippines was the enactment of the Philippine Disaster Risk Reduction and Management Act of 2010 (Republic Act No. 10121), creating the National Disaster Risk Reduction and Management Council with four pillars, namely (a) Disaster Preparedness, (b) Disaster Prevention and Mitigation, (c) Disaster Response, and (d) Rehabilitation and Recovery (see Figure A7). The Department of Science and Technology is the Vice-Chair of Disaster Prevention and Mitigation, and the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), as the mandated warning agency for hydrometeorological hazards, particularly tropical cyclones, is a member of the Disaster Prevention and Mitigation pillar of the Council.

The enactment of the Philippine Disaster Risk Reduction and Management Act of 2010 paved the way for a paradigm shift in the country's disaster management system from a system primarily focused on response and preparedness for response to a system focused on reducing and managing disaster risks. Under the Act, regional- and local-level disaster risk reduction and management councils were created. Consequently, there are regional-, provincial-, city- and municipal-level disaster risk reduction and management councils, thereby delegating disaster risk reduction and management activities to local levels for faster actions.

Other good practices in the Philippines are as follows:

- A pre-disaster risk reduction assessment meeting with the members of the National Disaster Risk Reduction and Management Council when a tropical cyclone or a low-pressure system is projected to pose a threat to the country in the next 3 days–4 days. Possible scenarios and impacts are explained to disaster managers and decision makers for early preparations. Area-specific and time-bound hazards and risks are identified.
- Development of a community-based early flood warning system wherein local communities are involved in hazard mapping, observation, monitoring, warning and response. PAGASA

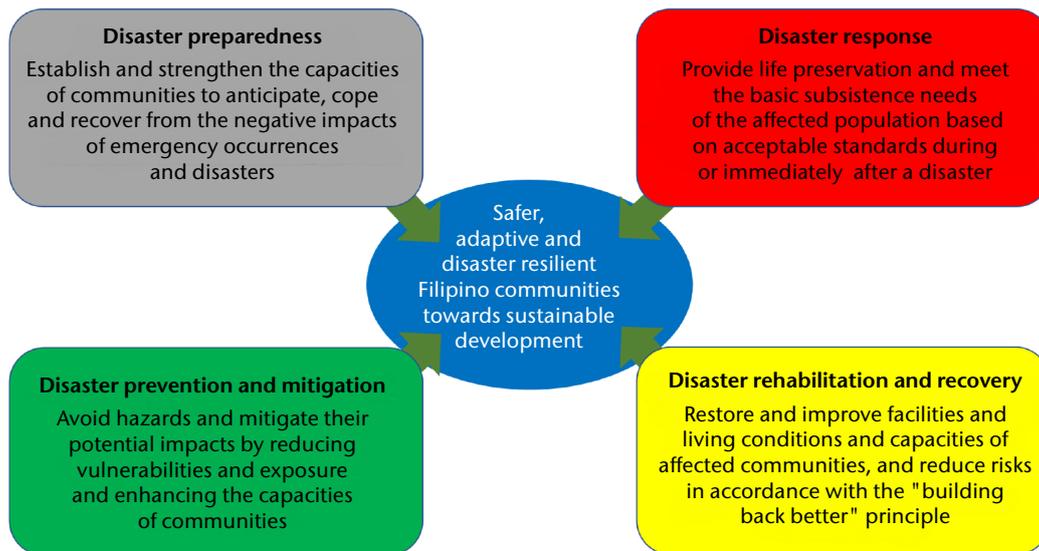


Figure A7. The four pillars of the National Disaster Reduction and Management Council

Source: National Disaster Reduction and Management Council

provides technical assistance and develops the standard methodology in respect of how the system is established. After the installation of rain and water level gauges in the area, local communities and government units are trained to operate the system, and drills are conducted regularly. It is the responsibility of local government units to ensure the sustainability of the system through government ordinances and policies. The system is people-centred; it fosters cooperation, ownership and responsibility on the part of the local community.

- PAGASA is starting to shift from a basic EWS to impact-based forecasting and warning. Through the assistance of the United Kingdom Met Office, it is now working on the development of an impact-based forecasting system for heavy rainfall and severe wind in Metro Cebu and Manila.
- With regard to warning communication, PAGASA registered its first CAP feed Uniform Resource Locator (URL) containing tropical cyclone alerts and warnings, in partnership with Google, in 2014. Right after, PAGASA developed a web application to generate CAP alerts for tropical cyclone warnings and general flood advisories and flood bulletins.

1.9 UNITED STATES OF AMERICA – A CLOSE CALL: EFFECTIVE MESSAGING WHEN A HURRICANE IS NOT QUITE GOING TO MAKE LANDFALL

The sustained wind speed of Hurricane *Lane* (August 2018) strengthened to 95 knots (177 km/h) 1 500 miles (2 400 km) west-southwest of Hawaii, United States of America. Hurricane *Lane* was moving at a moderate speed of 14 knots (26 km/h) towards the west, placing Hawaii 5 days away from possible impact. Although the forecast track had Hurricane *Lane* strengthening and then weakening and staying south of the Hawaiian Islands, the NWS, the United States NMHS, in Honolulu, Hawaii, sprang into action, sending early coordination information to dependent meteorological offices (DMOs), and referred to emergency management in the United States, partners and stakeholders. The following day, an official briefing commenced, linking emergency management from the village/town/city level to the county, state and even the national level. The briefing began with the Hawaii Weather Service providing the situation report for Hurricane *Lane* (at that point considered a major hurricane with sustained wind speeds of 115 knots (213 km/h)) in respect of forecast and uncertainty. With this information, emergency management was able

to coordinate among the varying levels and adopt a stand-ready posture. In the United States, local governments (village/town/city) are responsible for providing emergency services with support from county, state or national emergency management entities. Therefore, resources are provided based on need and availability. Prepositioning resources, such as generators, heavy equipment and personnel, are paramount in responding to and recovering quickly from pending hazards. In respect of Hurricane *Lane*, with the coordination of the emergency management community, information flowed through all dissemination sources, including social media. Preparations had begun.

Two days before the first possible impact of Hurricane *Lane*, the forecast track had it moving dangerously close to the Hawaiian Islands, with potential for damaging winds, life-threatening flash flooding and damaging surf. Emergency management coordination briefings continued with the broadcast media, camped out at the Honolulu Weather Forecast Office. Elected officials, from county mayors to the Governor and all the way up to the President, were briefed on the pending hazards to the Hawaiian Islands. With Hurricane *Lane* so close to the islands, meteorologists' confidence in the movement of Hurricane *Lane* became an important aspect for emergency management planners because, as always explained with regard to tropical cyclone forecasting, uncertainty plays a vital role in respect of what actions are to be taken. The focus turned towards the potential for heavy to extreme rain leading to flash flooding and landslides during the close passage of Hurricane *Lane*, as the forecast track brought the right front quadrant through all the Hawaiian Islands. Hurricane watches (a *Get Ready* bulletin with a goal of issuance 48 h in advance of impacts), which were eventually upgraded to hurricane warnings (a bulletin indicating hurricane conditions are imminent or occurring with a goal of issuance 36 h in advance of impacts), were issued for portions of the islands with an emphasis on heavy rainfall and high surf. Once the warnings went into effect, a meteorologist was dispatched to the Emergency Operations Centre to provide direct contact impact-based decision support services. The confidence of the meteorologist that Hurricane *Lane* would track south of the Hawaiian Islands continued to increase, allowing the main message to remain focused on the impacts of heavy rain, flooding and high surf. Actions taken by emergency management included preparing emergency shelters; cancelling school attendance; closing beaches and major parks; and even having buses displaying "Evacuation" provided to shelters on demand. Large-scale evacuations did not take place owing to emergency management trusting the NWS. This trust did not form overnight. Several years of building relationships, participating in exercises, conducting outreach and executing preparedness events together formed the trust that the NWS would provide the needed actionable information for emergency management to take appropriate measures.

Hurricane *Lane*, with a closest point of approach to Hawaii of about 115 miles (185 km), produced massive amounts of rainfall, with most islands experiencing at least 10 inches, several locations recording over 30 inches and a peak rainfall total of over 52 inches. The heavy rain caused severe flooding, mainly on the Island of Hawai'i (locally known as the Big Island), with more than one hundred structures affected and at least USD 22 million worth of damage caused to public infrastructure. One death was recorded when a man drowned after jumping into a rain-swollen stream in an attempt to save a dog.

This event showcases the importance of trust among partners and stakeholders in respect of providing the most relevant information for an evolving hazardous event. The terms "hurricane", "severe tropical cyclone" and "typhoon" bring pictures of destruction from wind to people's minds. However, when NMHSs, DMOs, NGOs and the broadcast and print media work together, with one voice, through an authoritative source, because of the relationships forged well before an event, those in harm's way can take the appropriate action to keep themselves and their loved ones safe and protect their property as best they can.

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