BULLETIN

WEATHER CLIMATE WATER

Early Warning and Anticipatory Action

WMO Bulletin

The journal of the World Meteorological Organization

Volume 71 (1) – 2022

Contents

Foreword

Dear Colleagues,

It is my pleasure to present this issue of the *WMO Bulletin* as a complement to the theme of World Meteorological Day "Early Warning and Early Action Hydrometeorological and Climate Information for Disaster Risk Reduction".

The Bulletin focusses on "Early warning and anticipatory action" with articles on harnessing technology and services, risk to resilience, the Global Multi-hazard Alert System, the WMO-UNDRR Centre of Excellence and on gender equality in the context of disaster risk reduction.

Over the past 50 years (1970–2019), a weather, climate or water-related disaster has occurred on average almost every day – taking the lives 115 people and causing US$ 202 million in losses daily. The number of recorded disasters increased by a factor of five over that 50-year period, driven by human-induced climate change, more extreme weather events and improved reporting. Thanks to better warnings, the number of lives lost decreased almost three-fold over the same period because of better weather forecasts and proactive and coordinated disaster management.

Early Warning Systems provide more than a tenfold return on investment, a 24-hour warning of a coming storm or heatwave can cut the ensuing damage by 30%. Spending US$ 800 million on such systems in developing countries would avoid losses of US$ 3–US$ 16 billion per year. And yet, despite these known great benefits, one in three people globally is still not covered by early warning services – that proportion is almost twice as high in Africa. Vulnerable people are disproportionately affected.

As part of global efforts on adaptation, the United Nations Secretary-General will announce on World Meteorological Day that the United Nations will spearhead new action to ensure every person on Earth is protected by early warning systems within five years. Secretary-General António Guterres has asked the WMO to lead this effort and to present an action plan at the next Conference of Parties (COP 27) to the United Nations Framework Convention on Climate Change (UNFCCC) to be held later this year in Egypt. WMO will lead the effort to achieve universal coverage of early warning services in close collaboration with key partners as a collective contribution towards global adaptation efforts. It will seek to close observation gaps, to expand the capacity for all countries to issue warnings ahead of a disaster while simultaneously also improving their capacity to act on those warnings and to respond in a manner that is people-centred, inclusive and accessible. Closing the early warning gap will require inputs from actors throughout the entire early warning to early action value chain. The new plan seeks to build on existing WMO activities and partnerships.

I would like to thank all contributors to this issue of the *WMO Bulletin* and hope that it provides a critical focus on enhancing observations, systems and services for early warning for the global population to protect, lives livelihood and mitigate economic damage.

Prof. Petteri Taalas
Secretary-General
World Meteorological Organization

Harnessing Earth System Science, Technology and Services to reduce Disaster Risk – WMO contributions

By Laura Paterson, Dominic Berod, Estelle de Coning, John Harding, Kenneth Holmlund, Yuki Honda, Jürg Luterbacher, Mike Sparrow and Bapon Fakhruddin, WMO Secretariat

Common Goals of the Hydrometeorological and Disaster Risk Reduction Communities

Sendai Framework

The Sendai Framework for Disaster Risk Reduction 2015–2030 provides a roadmap for making communities safer and more resilient to disasters. Its seven targets and four priorities outline a structure for preventing and reducing hazard exposure and vulnerability to disasters, increasing preparedness for response and recovery, and thus strengthening resilience.

WMO Vision

By 2030, we see a world where all nations, especially the most vulnerable, are more resilient to the socioeconomic consequences of extreme weather, climate, water and other environmental events; and underpin their sustainable development through the best possible services, whether over land, at sea or in the air. While the overarching WMO strategic priority is to enhance preparedness in order to reduce the loss of life, critical infrastructure and livelihoods from hydrometeorological extremes.

Strengthened connections between the two communities are critical at all stages of the climate risk cycle to achieve these shared goals. The communities need to continue to work together to understand the complexities and trade-offs of risks, to better predict compound and, at times, cascading hazards, and, critically, to enable effective action to reduce the impacts of natural hazards and, thus, mitigate impending disasters. WMO and the United Nations Office for Disaster Risk Reduction (UNDRR) have strengthened their relationship in several areas of work, including the creation of a joint Centre of Excellence for Climate and Disaster Resilience. Collaboration between WMO and the Disaster Risk Management communities is becoming ubiquitous across WMO activities.

Over the past 50 years, (1970-2019), a weather, climate or water-related disaster has occurred on average every day – taking the lives of 115 people and causing US$ 202 million in losses daily. The number of recorded disasters increased by a factor of five over that 50-year period, driven by anthropogenic climate change, more extreme weather events and improved reporting. But thanks to improved early warnings and disaster management, the number of deaths decreased almost three-fold over the same period. The benefits to society of the long-standing cooperation between the hydrometeorological and disaster risk management communities is undeniable.

The hydrometeorological sciences that provide user-oriented early warning services for disaster risk reduction (DRR) are underpinned by infrastructure, data exchange, tremendous computer power and expert professional capacity across many fields. These are important pre-requisites for understanding disaster risks, providing useful warnings ahead of disasters and strengthening resilience. In 2015, 187 countries adopted the Sendai Framework for Disaster Risk Reduction 2015–2030, which aims, as per its Target G, to "Substantially increase the availability of and access to multi-hazard early warning systems" and as per its Priority 1 to gain a better "Understanding Disaster Risk." Likewise,

DRR has become an even bigger priority for the hydrometeorological community.

Complex disaster risks and the Earth system

Hydrometeorological hazards and disaster risks do not follow straight paths. Great opportunities and complex risks arise as populations grow, move and adapt to economic changes, such as globalization, and environmental challenges such as climate change. The global financial system, supply and demand chains, energy sector and digital economy have become more complex and inter-connected. And with it, the very nature and scale of risk has changed to such a degree that it surpasses established risk management approaches (GAR 2019). Within this "system-of-systems," the impacts of natural hazards and other shocks have the potential to propagate, extending beyond the initial hazard footprint and resulting in cascading disasters. In addition, the impacts of hazardous events are being compounded by expanding urbanization, socioeconomic disparities and other factors. It is, therefore, essential that the WMO community consider a system-wide approach for DRR and resilience. Strengthening resilience requires collective actions through cooperation and partnerships with all levels of government, academia, business and civil society.

The WMO community's priority is to ensure cooperation and coordination of activities across

its focus areas – weather, water, environment and climate – to reduce disaster risks. Joint efforts are needed throughout the hydrometeorological community – science, technology, services and capacity development – and an integrated Earth system approach that looks at the physical planetary system as a whole (Figure 1). This approach is inclusive of the atmosphere, the ocean and hydrosphere, the terrestrial realm, the cryosphere and biosphere, breaking barriers and building comprehensive interdisciplinary teams with physical, behavioural, economic and social sciences. Such integration has been a priority for WMO for many years and one of the drivers of the recent WMO Reform. In 2019, the World Meteorological Congress endorsed a shift to an "Earth system approach" in parallel with its approval of the WMO Reform package.

Interdisciplinary Earth system efforts are improving our understanding of complex risks and unlocking new opportunities to enhance hydrometeorological forecasts and prediction, allowing previously unforecastable hazards to be better understood and anticipated. For example, the improved integration of ocean observing data into numerical weather prediction models has brought better resolution of slowly evolving ocean circulations, leading to enhanced longer-term sub-seasonal and seasonal predictability and improved potential for downstream climate services.

An interconnected and interdependent early warning system (EWS) value chain must be adopted to better understand how Earth system
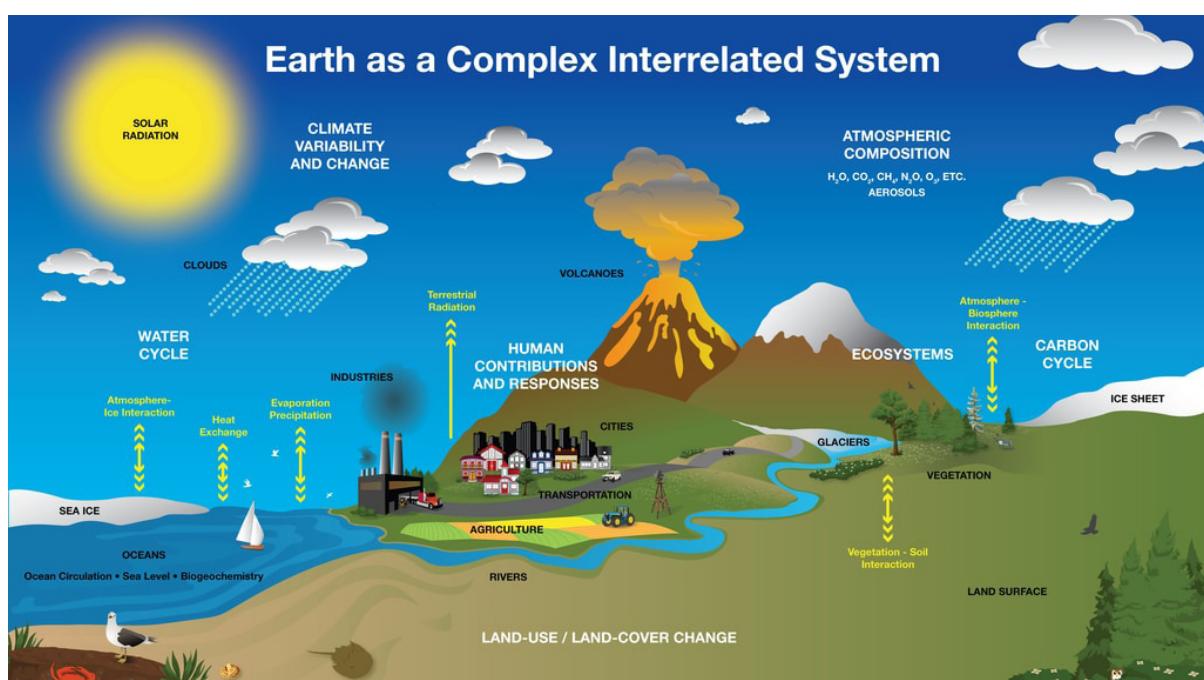
Figure 1. Schematic showing physical aspects of the Earth System (NASA)
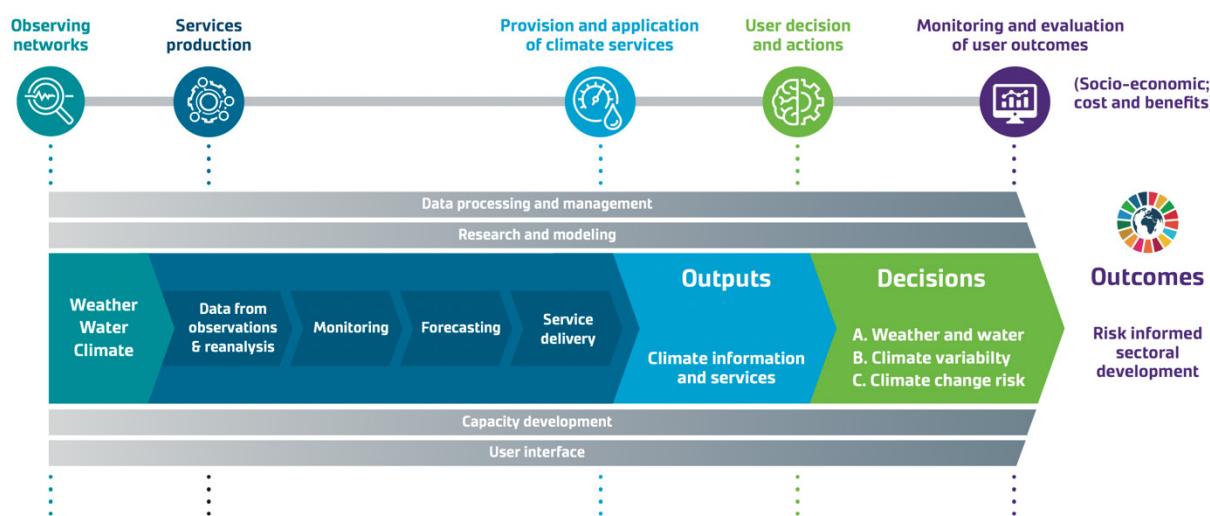
Figure 2. Hydrometeorological value chain (Fakhruddin, 2021)

data, science, technology and services can best support risk reduction (Figure 2). The WMO *Multi-Hazard Early Warning System Checklist* advocates for individual EWS elements to be addressed as interacting components and considers the different relationships, processes, inputs, contributions, outcomes and operational contexts of each stakeholder in the chain. Warnings can and frequently do fail in both developing and developed countries if all elements of the value chain are not equally strong. From understanding disaster risks and detecting, monitoring and forecasting hazards to the dissemination of warning information and the ability to respond; each step must connect to ensure that value is realized. The overall system is only as strong as the weakest link, and the failure of any one element will lead to the overall failure of the entire EWS, increasing risks to lives and infrastructure. National Meteorological and Hydrological Services (NMHSs) must function as well-oiled machines to deliver valuable, timely early warnings and must fully integrate national DRR and climate change plans and processes to be effective. The role of WMO is to create an enabling environment within the Earth system community and across the hydrometeorological value chain to support resilience and DRR.
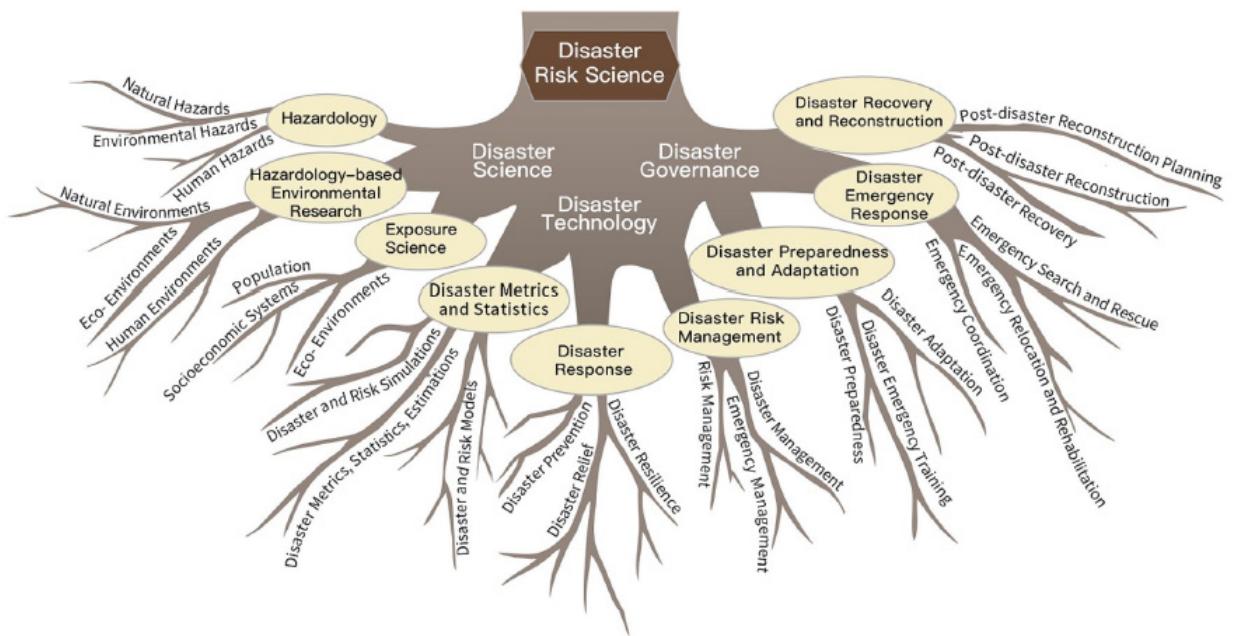
Earth system scientific research for reducing disaster risk

Over the past decades, enormous scientific progress has been made in Earth system sciences leading to the delivery of more responsive user services and significant inputs to various United Nations DRR initiatives. This has been achieved through integrated and systematic research efforts addressing local, regional, national and global societal and community needs. Earth science research has advanced towards a better understanding of disaster risks, of disaster risk governance, of where further investments are needed for resilience, and of the enhancements required to improve disaster preparedness for effective response and to build back better (Alcántara-Ayala et al. 2021).

One of the Long-Term Goals of the WMO Strategic Plan 2020–2023 is to "advance targeted research by leveraging leadership in science to improve understanding of the Earth system for enhanced services." Application of the best science in each component of the EWS value chain will improve the forecasts and warnings of all WMO Members. The full value chain includes disaster risk research, which provides systemic and multi-risk perspectives to manage and reduce risks, losses and damages due to natural hazards, then progresses to disaster risk management, improving decision-making, while also implementing effective, science-based disaster risk practices and policies (e.g. Shi et al. 2020) (Figure 3). The value chain also goes "the last mile" to effective communication and application of understandable and actionable knowledge by end users so that they take the necessary action to save lives.

Towards the Perfect Warning: Bridging disciplinary gaps through partnership and communication, which will be published by Springer later this year in the context of the WMO World Weather Research Programme's (WWRP) High Impact Weather project, offers fine examples of how the Earth system approach can be engaged throughout the early warning value chain. The publication, aimed at professionals from one end to the other of the early warning value chain, includes a specific chapter on early warning systems and their role in DRR.

Figure 3. A framework of disaster risk science research – a root system diagram of the three-layered disciplinary structure (from Shi et al. 2020)

The World Climate Research Programme (WCRP) links across to DRR on several timescales and in various study areas such as sea-level rise, droughts and flooding related to a changing climate. For example, its new "Lighthouse" activities on "Safe Landing Climates" look at understanding high risk events, including sea-level rise and water resources on multi-decadal and longer timescales. Another example is its "Explaining and Predicting Earth System Change" activity which is developing an integrated capability for quantitative observation, explanation, early warning and prediction of Earth system changes on global and regional scales, focusing on multi-annual to decadal timescales.

Earth system data, observations and infrastructure for reducing disaster risk

At the heart of the global weather enterprise, sits the machinery that allows the collection and exchange of observations, numerical prediction modelling and global product dissemination, without which anticipating weather, climate and water-related hazards that may lead to disasters would be impossible.

Observations from all over the world are fed into global numerical prediction models operated by WMO Members, including ten Members that operate as WMO-designated World Meteorological Centres. These highly advanced models use the laws of physics to build a global three-dimensional picture of the atmosphere, oceans, cryosphere, biosphere and land, and to simulate its evolution from minutes to decades. The advances in weather forecasts in the last decades have been tremendous thanks to more and better assimilated observations, higher computing power and scientific progress in the understanding of dynamics and physics.

The WMO Global Data-processing and Forecasting System (GDPFS) facilitates the development, operation and enhancement of worldwide systems for the generation and dissemination of analyses and forecast products over all timescales and for the dissemination severe weather advisories and warnings. Given the importance of this infrastructure, WMO works continuously to advance and improve all its aspects. WMO is currently establishing a new GDPFS activity for sub-seasonal predictions to enable a seamless approach from nowcasting through to decadal prediction and to develop GDPFS activities for hydrological services.

Data policy and exchange

Global numerical predictions of hydrometeorological events cannot be reliable without global Earth system data and effective exchange and use of that data. Even beyond improving the accuracy of severe event forecasts, data providers have the greatest interest in exchanging data as previously inaccessible data from other sources will make them more effective and sustainable – they can only sample a small portion of the Earth on their

own. Numerical prediction requires a combination of data from all possible data sources – from standard in situ to satellite and new technological measurements as well as from a rapidly growing number of private and academic data providers – while there is a constant pressure to reduce data production costs. The best way to leverage these challenges and increase the benefit/cost ratio is to share more data: greater use also increases the value of the data.

The sharing of Earth system data requires policies, standards, regulatory materials and technology to allow assimilation of different data types and technical solutions for data management, discovery and sharing. In October 2021, the World Meteorological Congress took three historical decisions to that effect:

1. The establishment of the Global Basic Observing Network (GBON) as part of the WMO Integrated Global Observing System (WIGOS): GBON will implement a new set of standards that will enhance the global real-time observing system thanks to an approach that will address major observational data gaps and allow data accessibility to all stakeholders. The initial priority for GBON is numerical weather prediction, but an extension to ocean, cryosphere and hydrology will follow.

2. As institutional support to GBON, Congress adopted the WMO Unified Data Policy, which enables the sharing of all Earth system data in a transparent and consistent manner (WMO, 2021).

3. The Systematic Observations Financing Facility (SOFF) (WMO, 2020b) was set-up together with major funding partners: SOFF aims at supporting Least Developed Countries (LDCs) and Small Island Developing States (SIDSs) in developing and operating their monitoring networks.

Congress further adopted an action plan for hydrology and established the Water and Climate Coalition, enabling the concretization of the Earth system approach in a new collaborative framework to support the reduction of climate, weather and water risks.

Supporting disaster risk management with satellite data
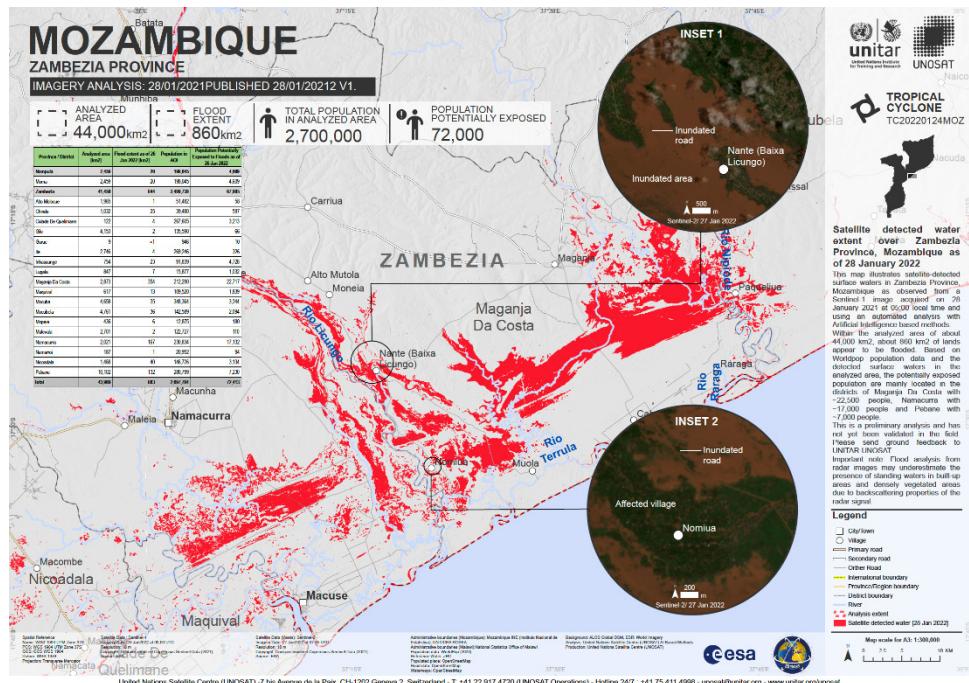
As noted in the United Nations Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5): Climate Change 2014 and emphasized in AR6 Climate Change 2021: The Physical Science Basis, "the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season)." However, there is a need for near-real time monitoring of pre-conditions and emerging and ongoing extreme events at the global level. The operational use of the satellite data and products, in conjunction with surface-based observations, are essential for successful DRR. A unique advantage of satellite observations is their larger scale spatial coverage, which complements potentially more accurate but spatially sparse surface-based observations.

There is a need to better use and to improve the monitoring of weather and climate extremes from space. Satellite operators, WMO Regional Climate Centres (RCCs), NMHSs and other stakeholders are pursuing that objective. WMO has a pivotal role to play as is reflected in the Space-based Weather and Climate Extremes Monitoring (SWCEM) project approved by the Eighteenth World Meteorological Congress (Cg-18) in June 2019. SWCEM has already started to monitor drought and precipitation over relatively short periods from pentads (5-day) up to a month. Additionally, WMO is pursuing related initiatives such as the Satellite Analysis of Tropical Cyclones workshops that aim to increase the accuracy and reliability of satellite analysis of tropical cyclones through the sharing of knowledge and technologies between operational forecasters and researchers.

The WIGOS Vision for 2040 (WIGOS2040) provides a forward-looking view of the space-based capabilities required for Earth observation, including in support of DRR. Space agencies are responding to WIGOS2040 and coordinating their observations to provide critical data and products covering application areas like drought, flood, fire and air quality monitoring.

In order to link the needs of disaster and relief organizations with space technology solutions to help mitigate the effects of disasters, space agencies have adhered to The International Charter Space and Major Disasters. The Charter makes satellite data available for disaster management. By combining Earth observation assets from different space agencies, the Charter allows resources and expertise to be coordinated to create products which inform rapid response in major disaster situations; (Figure 4) thereby helping civil protection authorities

Figure 4. Example of a satellite detected water extent map product illustrating flooding extent in Mozambique following Tropical Storm Ana, published by the UN Satellite Centre (UNOSAT) on 28 January 2022. (https://www.unitar.org/maps/map/3454)

and the international humanitarian community. This unique initiative mobilizes agencies around the world and benefits from their know-how and satellites through a single access point that operates 24 hours a day, 7 days a week and at no cost to the user.

In addition to the space agencies that form the Charter, national and regional disaster monitoring organizations also support the Charter's efforts as co-operating bodies. Together, they provide support to those in need following major disasters, and benefit from the wide distribution of data that the Charter offers.

Earth system services for reducing disaster risk

An integrated system that considers the past, present and future and recognizes that all living and non-living things are interconnected and interrelated is necessary to build a resilient and sustainable future. The system would also have to acknowledge the importance of collective community voices to fashion workable solutions. Such transdisciplinary integrated engagement is critical to the success of EWS and early actions to support DRR.

WMO is dedicated to improving hydrometeorological services to support decision-making and disaster resilience. The currently in development WMO Global Multi-hazard Alert System (GMAS) will offer a framework for enhancing the availability of authoritative warnings and information related to extreme and/or potentially high-impact weather, water and climate events regionally and globally. (Full details on the activities which sit within the GMAS framework can be found in an article on page 19.)

The GMAS Framework and the aforementioned *Multi-Hazard Early Warning Systems Checklist* build on the outputs and activities of the WMO Disaster Risk Reduction Programme and other related programmes. The DRR Programme works to enhance cooperation and the cost-effectiveness of the EWS of NMHSs to make them more systematic and sustainable. WMO publishes and regularly updated technical standards and guidelines to help strengthen NMHSs capacities to support preparedness through EWS, to provide hazard information for understanding and mitigating risk, and to engage with disaster risk governance structures at all levels. Recent publications include the newly extended *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150), and the *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019)* (WMO-No. 1267). Meanwhile complementary initiatives, such as the Call to Action on Emergency Alerting issued

jointly with the International Federation of Red Cross and Red Crescent Societies (IFRC) and the International Telecommunications Unit (ITU), help to raise awareness and galvanize political support for critical technical requirements to reduce disaster risks.

The Global Framework for Climate Services (GFCS), a partnership of many governments and organizations, aims to develop and promote the use of climate information and services. It builds on existing initiatives and infrastructure to evolve the full climate services value chain from observations, research, development and delivery of products and services to the applications of these services in support of decision-making in climate sensitive sectors. The vision of GFCS is to "enable better management of risks of climate variability and change and adaptation to climate change, through development of science-based climate information and prediction and their integration into planning, policy and practice on global, regional and national scales." GFCS supports countries to design weather, water and climate services for multi-stakeholder structures – from agriculture, energy, health, water and DRR – to promote economic development and the delivery of such services at the country level.

GFCS also provides implementation support for the co-creation of operational products (Figure 5). Collaborative co-design and co-production are vital to address climate change and non-climatic hazards. It engages users and sectors for greater alignment and consistency of hazard definitions, which increases community resilience. This collaborative approach has proven effective in reducing loss of life and damage to property.

Regional Climate Outlook Forums (RCOFs), an initiative of WMO, NMHSs, regional institutions and other international organizations, serve as a platform for establishing links between NMHSs and WMO Global Producing Centres (GPCs) for long-range forecasting. National, regional and global level practitioners and decision-makers from various sectors – agriculture and food security, water resource management, energy production and distribution, public health, DRR and response, and outreach and communication – participate in RCOFS. Following RCOF reports, the Famine Early Warning Systems Network, for example, has released food security outlooks based on RCOF products, which have been critical in planning food-grain reserves and distribution (Figure 6). Similarly, based on the RCOFs products, seasonal river runoff have been predicted to reduce associated climate-related risks to water and hydroelectric resources in certain regions.
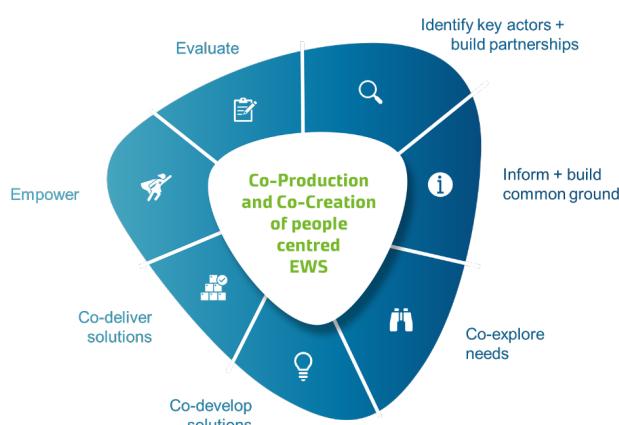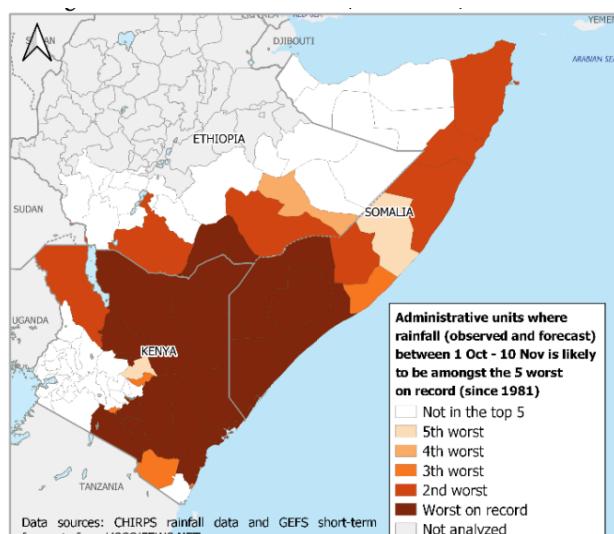
Climate Risk and Early Warnings Systems (CREWS) Initiative

As mentioned in the outset of this article, over the last 50 years, there has been a downward mortality trend though the recorder number of weather, climate and water-related disasters has increased fivefold. Yet, casualty risks are increasing in LDCs and SIDSs. Studies have shown that most of the countries in question have limited capacity to access and process global and regional forecasts and predictions

Source: FAO, Data: USGS/FEWS NET

Figure 6. Administrative units where rainfall (observed and forecast) between 1 October–10 November 2021 is likely to be amongst the five worst on record (since 1981) (Source: Extract from the IGAD Climate Prediction and Applications Centre (ICPAC) Food Security Network Working Group (FSNWG) Food Security Alert, November 2021)

Figure 5. Co-production and co-creation of people centred EWS (Fakhruddin, 2021)

and to issue timely warnings that are understood and acted upon by populations at risk (*UNDRR Global Assessment Report 2015*, *UNDP Human Development Report 2020*, *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)* (WMO-No. 1267)). Closing the capacity gap also requires financing mechanisms that address specific needs, recognize the full value chain approach, and are sufficiently flexible to address the weakest links in national systems. In 2015, the Climate Risk Early Warning System (CREWS) initiative, with WMO, UNDRR and the World Bank as its three implementing partners, was established by several countries for this purpose.

The timing and accuracy of weather, water and climate forecasts has increased substantially over the last decades. In the Indian Ocean, for example, the current average 3-days official forecasts errors are below 200 km. This is lower than the average 2-day track forecast errors of previous seasons up to 2010 (Figure 7). As a result, decisions leading to early action can now be taken 24 hours earlier than previously. More accurate forecasts imply more effective warnings. For example, more precise tracking of tropical cyclones results in clearer indications of the coastal areas requiring evacuation

(Review for the Forty Years of WMO Tropical Cyclone Programme (1980–2020)).

NMHSs require sustained capacity to support the value chain from monitoring weather, water and climate parameters through to forecasting extreme events and providing related services. The WMO Strategic Plan 2020-2023 states the Organization's clear ambitions to "close the capacity gap of NMHSs in developing countries and enhance their service delivery capacity." However, accountability for the loss of life and livelihoods to extreme events does not rest exclusively with NMHSs. As already mentioned, the effectiveness of NMHS services depend on their integration in broader national strategies and systems to manage disaster risk and adapt to climate change.

CREWS aims to support LDCs and SIDS by strengthening their capacity to access the most advanced forecasts and predictions and to develop the institutional ties and standard procedures required to communicate warnings to the people who require them the most. Through CREWS, the ambition of WMO is to reduce the number of lives lost to disasters in LDCs and SIDS by 2030.
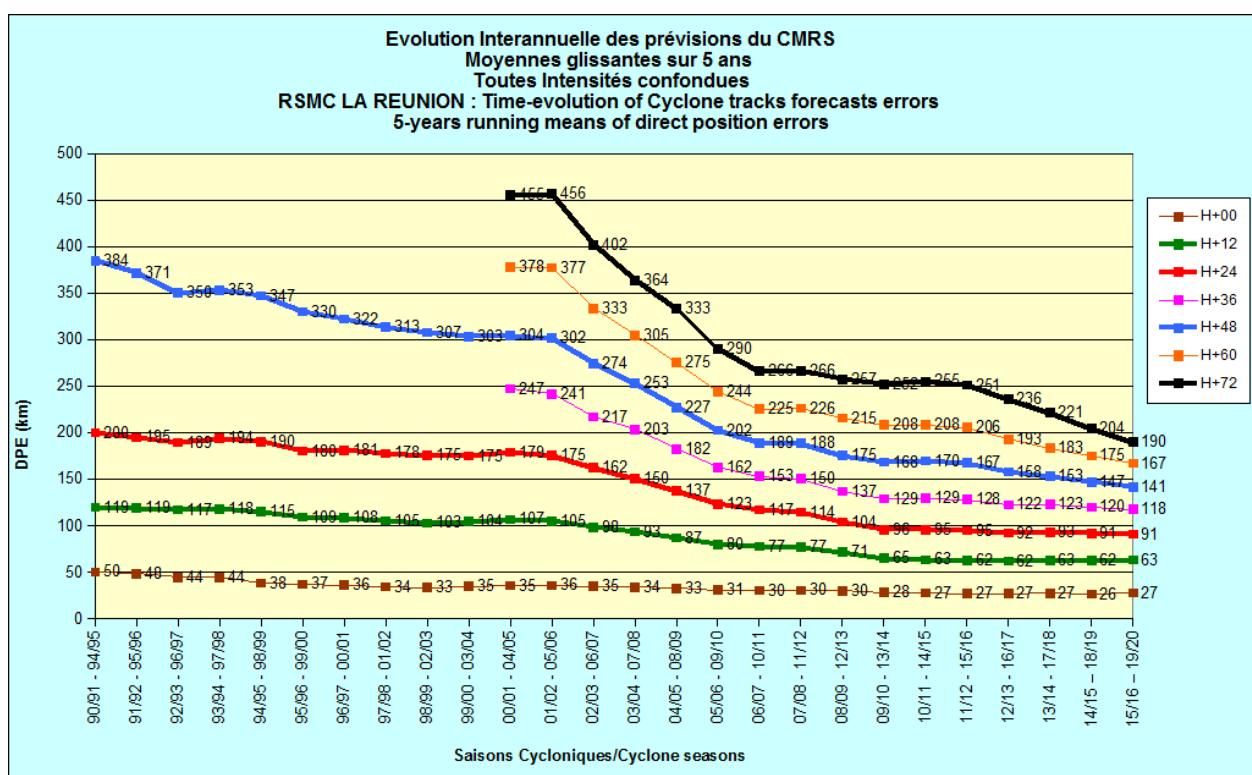
Figure 7. Time-evolution of Southwest Indian Ocean five-year rolling cyclone mean track forecast errors (km) (Meteo-France La Réunion, 2022).

First requirement: recognizing need to improve

Accepted principles, such as the need for impact-based forecasts, predictions and warnings drive the work carried out by WMO and its partners. However, certain principles of what constitute effective climate services and EWS, while well established and generally understood, are difficult to operationalize in LDCs and SIDS. Building long term capacity and resilience is a challenging endeavor, requiring continuous learning and adapting by all the actors involved and a backing of solid science and research. The building of systems and capacity to ensure that forecasts and warnings inform those at risk of the potential impacts of an event is can only be achieved by working together with a wider set of institutions that are responsible for monitoring loss and damages and carrying out risk analysis for extreme events.

A central aspect of efforts to close the capacity gap and to better integrate hydrometeorological products and services into DRR is the recognition that progress needs to be measured against the national targets set by the Sendai Framework, agreements under the United Nations Framework Convention on Climate Change, and the United Nations Sustainable Development Goals (SDGs).

References

WMO, 2021: *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)* (WMO-No. 1267).

UNDRR, 2015: *Chart of the Sendai Framework for Disaster Risk Reduction 2015-2030*.

WMO, 2019: *WMO Strategic Plan 202–2023*.

WMO, 2018: *Multi-Hazard Early Warning Systems: A Checklist*.

UNDRR, 2019: 2019 Global Assessment Report. https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019

Alcántara-Ayala, I. et al. 2021: Integrated Disaster Risk Management: From Earth Sciences to Policy Making. Front. Earth Sci.

Shi, P., Ye, T., Wang, Y. et al. 2020: Disaster Risk Science: A Geographical Perspective and a Research Framework. Int. J. Disaster Risk Sci. 11, 426–440. https://doi.org/10.1007/s13753-020-00296-5

WMO, 2021: *Bulletin Vol. 70 (2)*, WMO Unified Data Policy.

WMO, 2020b: Establishing the Systematic Observations Financing Facility: a new way of financing basic observations.

SWCEM: https://public.wmo.int/en/programmes/wmo-space-programme/swcem)

Fakhruddin, B. (SHM), P. Gluckman, A. Bardsley, G. Griffiths, A. McElroy, (2021): Creating resilient communities with medium-range hazard warning systems, Progress in Disaster Science, Volume 12, 2021,100203, ISSN 2590-0617, https://doi.org/10.1016/j.pdisas.2021.100203.

WMO, 2021: *Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150), Part II: Putting Multi-Hazard IBFWS into Practice

WMO, 2020: Review for the Forty Years of WMO Tropical Cyclone Programme (1980–2020)).

UNDP, 2020: Human Development Report 2020. http://www.hdr.undp.org/en/2020-report

Risk to Resilience: Climate change, disasters and the WMO-UNDRR Centre of Excellence

By Roger Pulwarty, US National Oceanic and Atmospheric Administration (NOAA), Loretta Hiebert-Girardet and Ricardo Mena Speck, United Nations Office for Disaster Risk Reduction (UNDRR), and Erica Allis, Cyrille Honoré and Johan Stander, WMO Secretariat

Climate change is increasing the frequency, intensity, spatial extent, duration and timing of adverse weather and climate events in all areas of the world. Interconnected and globally-networked energy, water, health, trade and finance sectors, along with technological interdependencies and the daily lives of people living in poverty are expanding vulnerabilities to unfamiliar and unprecedented levels. Interactions and impacts propagate across communities, the economy and then beyond administrative or national borders. Risk can no longer be considered in isolation as they cascade and compound along entire systems with impacts that are multi-pronged, long-lasting and non-linear.

Cascading risks and resulting impacts were evident in Puerto Rico in 2017 when Hurricanes *Irma* and *Maria* caused critical system failures, loss of or reduced services in various sectors, internal displacements and, in some cases, migration. In January, when an underwater volcanic eruption in the South Pacific sent a tsunami racing towards Tonga, the population – already reeling from the tropical cyclone season – confronted physical devastation and health threats from volcanic ash and gases.

Cascading impacts often extend beyond national borders. In the Tonga example above, the pressure and tidal waves from the volcano travelled around the globe, stacking up impacts, including an oil spill off the Peruvian coast. Other examples further illustrate the globally-networked nature of risks:

- the 2011 floods in Bangkok, Thailand affected the car industry in Japan as its suppliers were in the flood areas
- the 2010 Russian droughts affected food imports in different parts of the world
- the 2020/2021 drought in Taiwan, China is currently affecting semiconductor chip production and supply in the global marketplace (Forbes 2021).

The rapidly changing risk landscape presents both challenges and opportunities for communities and governments that are implementing the Sendai Framework for Disaster Risk Reduction 2015-2030, the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Sustainable Development Goals (SDGs). Currently, few disaster risk methods consider the spatial or temporal correlation and dynamic consistency between global to local drivers of extreme events. As a result, there is considerable uncertainty about triggering events, shock propagation and remotely linked or indirect impacts (Palmer and Stevens, 2019; Lloyd and Shepherd, 2020). Superficial treatment of these elements could limit the benefits of, or lead to ineffective, adaptation efforts. In the worst cases, this could lead to maladaptation and the further exclusion of socially marginalized people in resilience efforts.

To respond to these issues, the WMO and United Nations Office for Disaster Risk Reduction (UNDRR) launched a Centre of Excellence for Disaster and Climate Resilience (hereafter referred to as "the Centre of Excellence") on the 2021 International Day for Disaster Risk Reduction. In the Centre of Excellence, WMO and the UNDRR will work together with partner agencies to strengthen efforts to transform scientific knowledge and tools into action supporting climate change mitigation, adaptation and DRR. At the 2021 International Day, WMO and UNDRR leadership both offered complementary and compelling visions for the Centre of Excellence:

"This new Centre of Excellence for Climate and Disaster Resilience will act as an information hub about the escalating impacts of climate change and extreme weather and how we can manage and mitigate these risks." – Prof. Petteri Taalas, WMO Secretary-General

"This new Centre of Excellence will concentrate minds on what extreme weather and other hazards mean for daily life on planet Earth for the foreseeable future and spur efforts to adapt and cope with that reality." – Mami Mizutori, the UN Secretary-General's Special Representative for Disaster Risk Reduction

Three initial activity areas have been proposed for the Centre of Excellence and are being discussed and validated with partners. These are introduced below.

1. *Strengthened climate and disaster risk governance*

The UNDRR, together with the UNFCCC, noted that "the coherence between climate change adaptation and disaster risk reduction is a defining issue for risk governance in the 21st Century." (UNDRR-CRED 2020). In keeping with this statement, management across the Disaster Risk Reduction (DRR) – Climate Change Adaptation (CCA) continuum is hereafter referred to as comprehensive disaster and climate risk management or "CRM".

Three major challenges have been identified for CRM:

• creation of synergies between DRR and CCA implementing agencies at the local, national, regional and international levels

• enhancement of risk management capabilities by bridging the gap between science and policy at the local and national levels

• facilitation of more efficient and effective management of globally-networked and transboundary risks. (Casajus Valles et al 2021; UNDRR 2021)

While hazards and triggers are more easily identified today, gaps exist in understanding and addressing the underlying factors that make people vulnerable. The root causes of vulnerability can include social and economic inequalities, ecosystem degradation, poorly designed urban infrastructure, access to and capacity to use information, conflict and displacement (IPCC 2012; 2022; Oliver-Smith et al 2016; UNDRR 2021). Understanding the multiple dimensions and dynamics of vulnerability will provide a more comprehensive picture of systemic risk and accelerate transitions towards systems based and prospective approaches to risk management.

Managing the complexity of systemic risk requires transformation across the dimensions of risk governance. Effective governance includes the actions, processes, traditions and institutions – formal and informal – by which collective decisions are reached and implemented.

The recent Central American case study (see box on page 14) highlights the need for strengthened risk governance in the context of tropical storms, droughts and the COVID-19 pandemic. Successes in aligning regional capabilities to help meet national and local risk identification and management are illustrated. Several challenges remain for developing effective governance and enabling capabilities, however, immense opportunities for developing research, information and learning to overcome these challenges exist within and across regions.

The dimensions of effective governance include but are not limited to (UNDRR 2021):

• Coordinated sectoral and cross-sectoral policies that align and leverage collaborative multi-stakeholder partnerships

• A diversity of actors from national and sub-national governments, the private sector, research bodies, and civil society, including community-based organizations offering a broader portfolio of opportunities and equitable solutions

• Strengthened global-to-local financial architectures that enables greater access to resources and that views resilience as an investment in present and future economic, social and environmental sustainability.

With these opportunities and a sense of urgency due to the rapidly changing climate, the Centre of Excellence aims to improve the knowledge of systemic risks and informed governance to facilitate value creation in addressing structural and complex risks. These efforts will help to better sustain the critical interdependent and complex systems on which economies, ecosystems and communities depend.

2. *Increased understanding of the systemic nature of climate and disaster risks*

At present, there are few well-documented examples of national disaster risk management systems and associated risk management measures explicitly integrating knowledge of, and uncertainties in, projected changes in exposure, vulnerability, and climate extremes. As described in the Central American Case study, a coordinated information

Crafting a virtuous cycle between, research, policy and practice: A Central American Case study

The IPCC points to Central America as the tropical region most sensitive to climate change (IPCC 2014). Four of the fifteen countries facing the highest risk of disasters globally are in Central America: Costa Rica, Guatemala, El Salvador and Nicaragua. The number of disasters in the region more than quadrupled since the 1970s (UNISDR-CEPREDENAC 2014). In recent years, Central America has improved its disaster response capacity by developing strategies to address the root causes of risk and position DRR at the heart of the sustainable development agenda as further described below.

Tropical storms, droughts and other factors

The impacts of Hurricanes *Eta* and *Iota* in late 2020 evidenced the fragility of the Early Warning Systems (EWSs) and the diverse levels of response across the region. These late-season storms – both Category 4 – produced torrential rainfalls and catastrophic wind, flood and storm surge across Central America, affecting more than 7.5 million people and multiplying high economic, environmental and productive asset losses.

The events occurred on the heels of five consecutive years of drought. The region has become significantly hotter and drier in recent decades. Large portions of Guatemala, Honduras, Mexico, and Nicaragua received less than 80% of the average rainfall in the summer of 2020 and climate-induced lack of food was identified

as a driver of displacement and migration in the region (WFP, 2019).
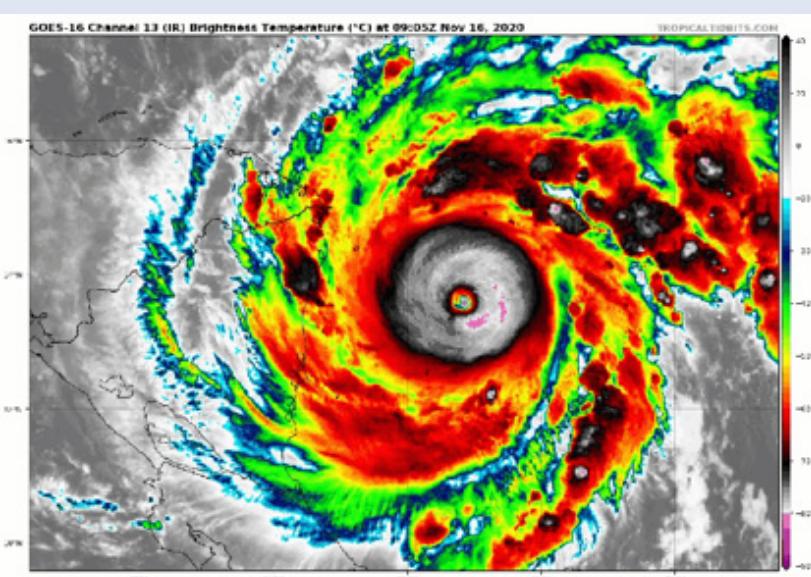
The COVID-19 crisis, which significantly affected the region both in terms of economic activity and employment (ECLAC-UNDRR 2021), played a large role in the context of historical and inherent risk drivers. These drivers include the informal economy, inequality, rapid urbanization, poverty and lack of political representation. This resulted in a disproportionate impact on the most vulnerable (ECLAC-UNDRR, 2021), as the opportunities to participate and design targeted interventions suitable to their contexts were reduced.

Better understanding of these cascading risks and how they propagate is necessary to develop ways to identify, manage or prevent them in the future. The need is urgent.

Governance and enabling capabilities

In 2020, the Coordination Centre for the Prevention of Disasters in Central America and the Dominican Republic (CEPREDENAC), developed the SICA COVID-19 Information and Coordination Platform, with assistance from NASA, World Bank and UNDRR. The platform was designed to support national pandemic strategies and used geographic information system mapping software alongside consultation services and digital materials to monitor, manage and report on the impact of the pandemic.

The platform also included weather, flood and landslide data, supported by regional partners

GOES-16 Channel 13 (IR) Brightness Temperature (°C) at 09:05Z Nov 16, 2020

The Category 4 Atlantic Hurricane Iota made landfall in Nicaragua on 17 November 2020 and went on to cause severe damages in areas of South America already devastated by Hurricane Eta less than two weeks earlier

CATHALAC regional workshop on Adaptation to climate change in the water sector: How does research respond to the needs of decision-makers? (Source: CATHALAC)

such as CATHALAC, the Central American Climate Forum and the Regional Hydraulic Resources Committee (CRRH). The platform successfully anticipated the potential impacts – the exposure of communities and infrastructure, hazard information, etc. – of Tropical Storm *Amanda*, and Hurricanes *Eta* and *Iota* in 2020. This experience shows the potential of cross-institutional collaborations and partnerships in the Central American Region.

WMO[1] and UNDRR[2] regional frameworks, private sector networks[3] and other regional counterparts mentioned above, provide spaces for cooperation to strengthen interaction. They offer innovative ways to work from regional to local scales to enhance the efficiency of MHEWS and risk management systems in the region. Most critical has been the creation of multi-stakeholder spaces at national and regional DRR platforms, which can be leveraged to improve climate data and DRR governance.

Addressing comprehensive disaster and climate risk management in the region

An intensified collaboration between WMO and UNDRR, extended to their network of partners,[4] would contribute fundamentally to bridging the gap between science, policy and action. It will strengthen regional integration and cooperation for more effective regional DRR governance. With its architecture of specialized institutions, Central America is a fertile ground for the guidance and coordination that can be facilitated by the Centre of Excellence.

---

1   Such as Regional Specialized Meteorological Centre in Miami, WMO Regional Climate Outlook Forum, Regional Climate Centres, Regional Training Centres

2   Such as UNDRR Regional Scientific & Technological Advisory Group

3   Such as Central American ARISE

4   Including the Regional Science and Technical Advisory Group, academia and the more than 15 national and 2 subregional members or the UNDRR-led Private Sector Network for Resilience Societies (ARISE).

platform can successfully anticipate potential impacts, including the exposure of communities and critical infrastructure, hazard variables and characteristics, but there is a need to scale theory into practice globally.

Systemic risks might be easy to mitigate early, yet failure to appreciate the role of underlying drivers of systemic risk will allow small, manageable risks to grow into major whole-of-society problems. Failed interventions and missed opportunities will increase both economic and human losses.

The Centre of Excellence will support interdisciplinary research to better understand how extreme weather and climate events interact with other drivers of risk to amplify disaster impacts in unprecedented ways. Multi-Hazard Early Warning Systems (MHEWSs) analysis is envisioned to support understanding on how hazards and/or impacts can co-evolve in contexts where hazardous events may occur alone, simultaneously, in a cascade or cumulatively over time and can result in interrelated effects. The integration of local knowledge with additional scientific and technical knowledge will be advanced to improve disaster risk reduction and climate change adaptation.

The enhanced risk analytics will be used to inform EWS design to avoid maladaptation. A global flagship report on risk with regionally, nationally and locally relevant good practice and technical guidance on data standards, leveraging hazard classification and cataloguing of disaster related statistics, is envisioned. This information will connect decision-makers to both incremental and transformational solutions to mitigate these risks and guide resource investments to the right areas at the right time to reduce levels of risk and mitigate and prevent future disasters.

3. *Risk-informed development and humanitarian action*

Stronger efforts at the international level alone will not necessarily lead to substantive and rapid results at the local level. And while the threats, hazards, risks and their implications are intertwined, the systems to prepare for, prevent and deal with them are not. The current landscape is fragmented across a multiplicity of disconnected climate, development, humanitarian, disaster risk and environment stakeholders, often working and in parallel towards the same goals, but with different approaches. The lack of coherence across these sectors hampers the overall effectiveness.

Moving forward with shared goals and objectives and on knowledge co-development requires driving positive feedbacks between science, policy and actions to manage and reduce risks. The Centre of Excellence will support these links. On a practical level, the Global Multi-Hazard Alert System (GMAS, see article on page 19) Framework will enhance Member alerting capabilities to close the EWS coverage gaps and strengthen connections between EWSs and decision-making processes. Furthermore, the WMO Coordination Mechanism (WMI, see article on page 46) will enhance WMO support to the United Nations and other humanitarian agencies to improve access to authoritative products made available by WMO Members, complemented with added-value advice. These efforts are targeted to support disaster risk reduction, preparedness and response – to save lives and livelihoods, and thus protect development gains in regions repeatedly battered by high-impact events and/or the cumulative impacts of sequences of multiple events.

The Centre of Excellence will focus attention on highly vulnerable and fragile contexts where needs are greatest, but obstacles make resilience building especially challenging. Where vulnerability is high and adaptive capacity low, changes in climate extremes can make it difficult for systems to adapt sustainably without transformational changes. Transformations that address future climate related resilience as a systemic challenge will require profound shifts in institutions, technologies, consumption patterns and personnel, as well as in the ecological, economic and social processes they influence. The Centre of Excellence will serve to identify and and guide testing of transformative solutions in fragile contexts, building on the understanding that transformation is facilitated through increased emphasis on adaptive management and learning (White et al 2001; Nissinen et al 2015; UNDRR 2021).

The path forward: the Centre of Excellence for Disaster ad Climate Risk Management

Following the first meeting of the Steering Committee of the Centre of Excellence in December 2021, WMO and UNDRR launched a series of bilateral consultations with partner agencies to refine the Centre of Excellence's theory of change and to prioritize activities for the annual work plan. Partners were unanimous that initial activities should be based on the core competencies of the agencies involved to enable quick action and wins to build momentum in delivering tangible results to countries and communities most at risk.

While consultations are ongoing, the discussions have already yielded tremendous insight into the modalities to achieve the Centre of Excellence's principal aspirations:

- Amplifier – A platform to elevate the work of individual agencies through coordinated action, to enhance the impact and reach of what each can achieve alone (foster connections between agencies that have expertise in data and science, policy, economic agenda setting and those with boots on the ground to develop the science, policy and practice interface)
- Connector – A space that provides the "glue" between the various activities across the fragmented sets of actors, identifying not only areas of intersection, but gaps and entry points where a coherent approach is needed
- Accelerator – A space for learning where ideas can be tested, brought to acceptability and scaled-up faster through joint action and collaboration
- Agent for transformational change – Actions that range from incremental steps to transformational changes are essential to reduce risks – the Centre of Excellence will serve as an incubator to cultivate transformational change.

Following the conclusion of the partner consultations, the annual work plan will be drafted for Steering Committee review and then public consultation at the Global Platform for Disaster Risk Reduction in May 2022.

The WMO, UNDRR and the Centre of Excellence's partners are committed to working across disciplines and institutions. The principal aim will be to develop products, services and processes to guide science, policy and practice to accelerate achievement of the Sendai Framework, the Paris Agreement and the 2030 Agenda for Sustainable Development.

A major aspiration for the Centre of Excellence will be to foster behavioral change. The Centre of Excellence aims for improved use of integrated knowledge and approaches by international, national and local partners in demand-side management to significantly reduce pressures on resources and adaptive buffers, thus substantially limiting reliance on externally driven interventions and humanitarian relief.

Efforts will be made to identify and leverage existing capabilities that may have been overlooked to protect and enhance the sustainability and capacity of the systems as a whole (IPCC 2012; Casajus Valle et al 2021; UNDRR 2021). In addition, training and capacity development with Centre of Excellence partners will engage more systematic science/policy and science/practitioner interfaces to enhance coherence and ensure results to the end of the last mile.

Acknowledgements

References

Casajus Valles, A. Marin Ferrer, M. Poljanšek, K. Clark, I. (eds.), 2020: *Science for Disaster Risk Management 2020: acting today, protecting tomorrow*, EUR 30183 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-18182-8, doi:10.2760/571085, JRC114026.

Economic Commission for Latin America and the Caribbean (ECLAC)/United Nations Office for Disaster Risk Reduction (UNDRR), 2021: *The coronavirus disease (COVID-19) pandemic: an opportunity for a systemic approach to disaster risk for the Caribbean*.

Forbes, 2021: *No Water No Microchips: What Is Happening In Taiwan?*

Intergovernmental Panel on Climate Change (IPCC), 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Special Report, Cambridge University Press 594 pp.

IPCC, 2014: *Climate Change 2014: IPCC Working Group II Impacts, Adaptation and Vulnerability*. IPCC Fifth Assessment Report (AR5), Cambridge University Press.

IPCC, 2022: AR6 *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge University.

Lloyd, E., and T. Shepherd, 2020: *Environmental catastrophes, climate change, and attribution*. Annals of the New York Academy of Sciences 1469, 105-124.

Nissinen, A., et al, 2015: *Combinations of policy instruments to decrease the climate impacts of housing, passenger transport and food in Finland*. *Journal of Cleaner Production*, vol. 107, pp. 455–466.

Oliver-Smith, A., Lavell, Burton, I, and I. Alcantara-Ayala, 2016: *Forensic Investigations of Disasters*

(FORIN): a conceptual framework and guide to research. IRDR FORIN Publication No. 2 57 pp.

Palmer, T., and B. Stevens, 2019: The scientific challenge of understanding and estimating climate change. *Proceedings of the National Academy of Sciences* 116 (49) 24390-24395.

Spiekermann, R., S. Norton, J. Weichselgartner, 2015: *The Disaster-Knowledge Matrix – Reframing and evaluating the knowledge challenges in disaster risk reduction. International Journal of Disaster Risk Reduction*. 13:96-108.

UNISDR-CEPREDENAC, 2014: Regional Report on the State of Vulnerability and Disaster Risk in Central America.

UNDRR, 2019: *Global Assessment Report (GAR) on Disaster Risk Reduction* 2019, 210 pp.

UNDRR, 2020: *The human cost of disasters: an overview of the last 20 years (2000-2019)*.

UNDRR, 2021: *GAR Special Report on Drought*. ISBN: 9789212320274.

White, G.F., R. Kates and I. Burton, 2001: Knowing better and losing even more: The use of knowledge in hazards management. *Global Environmental Change B: Environmental Hazards*, vol. 3, pp. 81–92.

The Global Multi-Hazard Alert System Framework – Supporting alerting capacities of Members in the climate crisis

By Fred Branski, National Oceanic and Atmospheric Administration (NOAA, USA); Armstrong Cheng, Hong Kong Observatory (HKO, Hong Kong SAR China); Rahul Sengupta, Animesh Kumar and Sandra Amlang, United Nations Office for Disaster Risk Reduction (UNDRRR), and Erica Allis, Samuel Muchemi, Adanna Robertson-Quimby, Cyrille Honoré, Johan Stander, Hwirin Kim, Misaeli Mavoa Funaki and Anne-Claire Fontan, WMO Secretariat

The number of weather, climate and water related disasters increased five-fold between 1970 and 2019. During this 50-year period, 11 000 disasters were reported as resulting from hydrometeorological events. These caused over 2 million deaths and US$ 3.64 trillion in losses.[1] However, over that period there was a three-fold decrease in deaths from the first decade to the last – this thanks to improved early warning systems (EWSs). Unfortunately, the economic losses associated with weather, climate, and water extremes increased by a factor of seven.

Over the coming decades, scientists project with a high degree of confidence that the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation and drought, as well as more frequent high-intensity tropical cyclones, will increase as a result of climate change (IPCC 2012, 2014, 2021). This is even more alarming given it is the most vulnerable– women, children, people with disabilities, minorities, the poor, etc. – that suffer a disproportionate share of disaster impacts and are most at risk in the climate crisis. About nine in ten deaths associated with hydrometeorological events in the 1970 to 2019 period occurred in developing countries. It is estimated a third of people globally – mostly in developing countries – are still not covered by EWSs.[2]

The Global Multi-Hazard Alert System (GMAS) Framework, an initiative of the WMO in which many partner agencies have engaged, aims to enhance Member alerting capabilities to close the EWS coverage gaps. Moreover, the Framework aims to strengthen connections between EWSs and decision-making processes – and trust in and collaboration among the people behind the systems and processes – across a range of time and spatial scales. The Framework will support disaster risk reduction, preparedness and response – that is, action to save lives and livelihoods – and thus protect development gains in regions repeatedly battered by high-impact events.

The vision of GMAS, as articulated by the Executive Counsel in 2017, is "to be recognized globally by decision makers as a resource of authoritative warnings and information related to high-impact weather, water, ocean and climate events". Two years later, in 2019, the World Meteorological Congress (Cg-18) approved the development of a GMAS Framework Implementation Strategy and Plan. WMO established the Expert Team on GMAS to realize this vision.

"The GMAS Framework will leverage existing WMO arrangements and capacity development mechanisms to accelerate support to countries to enhance their alerting capabilities to meet the growing demands for this authoritative information in a changing climate." – Fred Branski, Chair, Expert Team on GMAS

1   *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes 1970–2019* (WMO-No. 1267).
2   WMO State of Climate Services Report

WMO steps-up its support to Members to enhance alerting capabilities

Least Developed Countries (LDCs), Small Island Developing States (SIDS) and many developing countries face specific challenges with EWSs, which warrant immediate attention in view of their higher vulnerability and risk levels that, often greatly exceed their capacity to respond to and recover from disasters. In these countries, disasters often undo years of progress and reverse development trajectories.

WMO launched a "Fast-Track" initiative in early 2021 to support Members, initially in Africa where 33 of the 46 United Nations designated LDCs are found, in developing and strengthening their Multi-Hazard Early Warning Systems (MHEWS). This initiative is providing immediate support to Members and enabling learning to inform the forward trajectory and development of the GMAS Framework Strategy and Implementation Plan.

The "Fast-Track" initiative is focusing initially on the implementation of the Common Alerting Protocol (CAP) as a key building block for the success of GMAS. Since 2006, WMO has recognized CAP as the key standard for all-hazards, all-media public warning and alerting from authoritative sources, however, uptake of the standard in National Meteorological and Hydrological Services (NMHSs) has remained relatively low (see Communicating for Life Saving Action: Enhancing messaging in Early Warning Systems on page 38).

The "Fast-Track" initiative has engaged experts to assist African countries in setting up the appropriate software components for CAP and to provide practical training in a learn-by-doing environment to agilely address obstacles as they arise in implementation. Figure 1 highlights the success of this effort, which started in 2021 when 2 African countries were issuing CAP and in February 2022 recorded 16 countries issuing CAP alerts. Given the Fast-Track's success in Africa, WMO will work with the newly established Service or GMAS working groups in the WMO Regional Associations (RA) in the coming year to develop and advance GMAS "Fast Track" activities, for example, in South America and Asia.

To support Members in operationalizing CAP, WMO is collaborating with partners to create a CAP HelpDesk to support country level implementation of CAP through the provision of information, methods and tools. The CAP HelpDesk community will support the scale up of CAP by inspiring further coordination and collaboration through a community of support to scale up CAP. A scoping workshop was held by WMO, ITU and IFRC in the fall of 2021 to discuss the common technical capacity-based gaps and barriers to CAP implementation and inform CAP HelpDesk design. A directory of available software tools, training materials, step-by-step implementation guide, and a compilation of frequently asked questions will be included. Further development and building of the CAP HelpDesk will continue in 2022.

To promote the use of CAP in public alerting for hydrological hazards, the WMO is collecting and
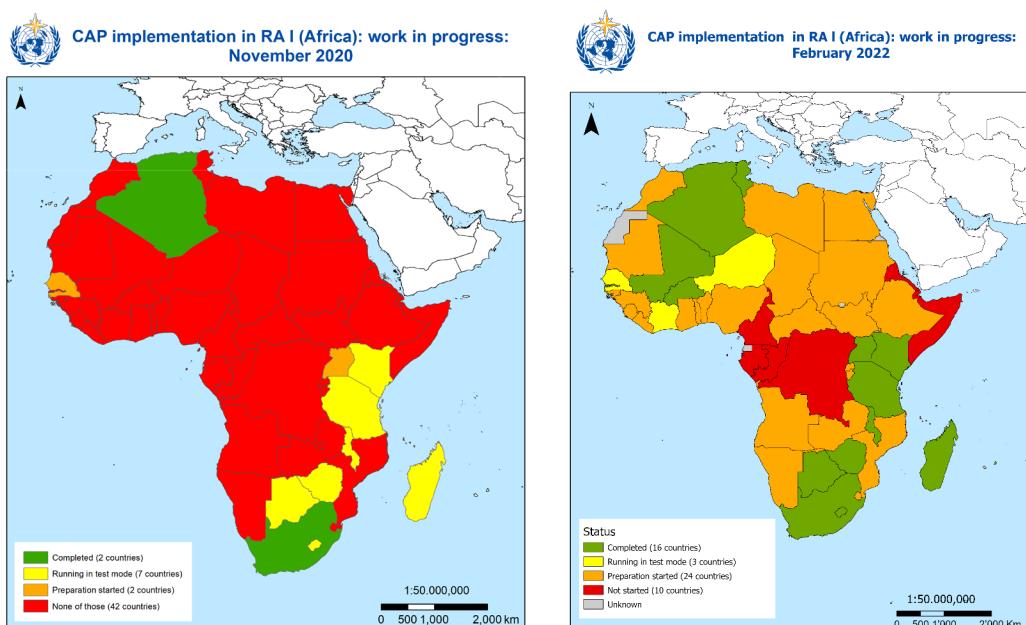
Figure 1. "Fast-Track" success in RAI

developing case studies describing the experiences of countries that have applied CAP to hydrology. It is envisioned that the case studies will cover NMHSs of different degrees of development from as many WMO Regions as possible and will highlight the benefits and challenges derived from using CAP.

GMAS – the path forward

To achieve the vision of the Executive Council's vision for GMAS, the Expert Team is currently working on tasked deliverables in coordination with the WMO Regional Associations and relevant expert teams in its Services Commission (SERCOM) and its Commission for Observation, Infrastructure and Information System (INFCOM). Plans for how GMAS will achieve the following are expected to be delivered for consideration to the Nineteenth Session of the World Meteorological Congress in 2023:

1. The GMAS Framework Implementation Strategy and Plan, leveraging all relevant WMO entities and capacity development activities, as well as other relevant institutions dealing with other types of hazards. The Plan includes the blueprint for a repository of warnings and defined information flows that builds on WMO standards and infrastructure, which will be used to share authoritative warning information produced by Members.

2. A roadmap for capacity development (on national, sub-regional and regional levels, including sharing of good practices) to enable Members that need to strengthen their warning systems to issue higher quality warnings more effectively and efficiently.

3. Improve availability, affordability and accessibility of Members' MHEWSs as envisioned in the Sendai Framework for Disaster Risk Reduction 2015-2030, ensuring that all citizens have access to the available authoritative warning information (sources) to anticipate, mitigate, prepare for and respond to weather, water, ocean and climate events.

4. Enhance the authoritative voice of the NMHSs of WMO Members in issuing official early warnings for weather, water, ocean, climate and space weather events so that decision-makers and those at risk receive authorative information to prepare for and respond to hazardous events.

5. Improve the visibility of NMHSs in their governments and with development agencies, as well as that of WMO, as key contributors to the United Nations Sustainable Development Goals (SDGs).

6. Enhance cooperation in disaster risk management and MHEWSs at the national, regional and global levels, including cross-border and interregional collaboration, and create a community of practice to share warning information and to promote harmonization.

7. An investment framework for development agencies to support MHEWS capacity development projects for Members.

The GMAS Framework transformation map in Figure 2 provides initial actions for the GMAS Framework Strategy and Implementation Plan to support countries. The GMAS Framework will leverage existing components of the WMO observation and modelling infrastructure as well as its science and innovation and capacity support activities to enhance alerting capabilities in Members- no new standalone alerting system will be established.

The GMAS Expert Team is currently interrogating the various elements of the EWS value cycle to identify gaps and opportunities for transformation as well as entry points to accelerate alerting capacities in Members. The EWS value cycle includes several elements (Golding, 2019; Vogel, 2019; WMO, 2018):

- vulnerability/coping capacities/exposure of systems/people to hazards.
- the decision context, decision maker's level of trust in authoritative sources of information, and due consideration of any additional trusted sources of information to inform decision-making.
- member alerting capacity.
- monitoring, forecasting, trust in downscaling of the physical attributes of hydrometeorological hazards.
- calculating and communicating forecast reliability.
- quantifying and communicating the anticipated primary and tertiary impacts of hazardous events.
- behaviour change as a result of warning dissemination.
- assessment of benefits and/or unintended outcomes behaviour change.
- post assessment and learning to refine MHEWS design.

WMO components and strategic partnerships to bridge gaps are being mapped and leveraged to enable transformational change in alerting capabilities and the EWS value cycle. Regional

GMAS Framework - 3 Year Transformation Map
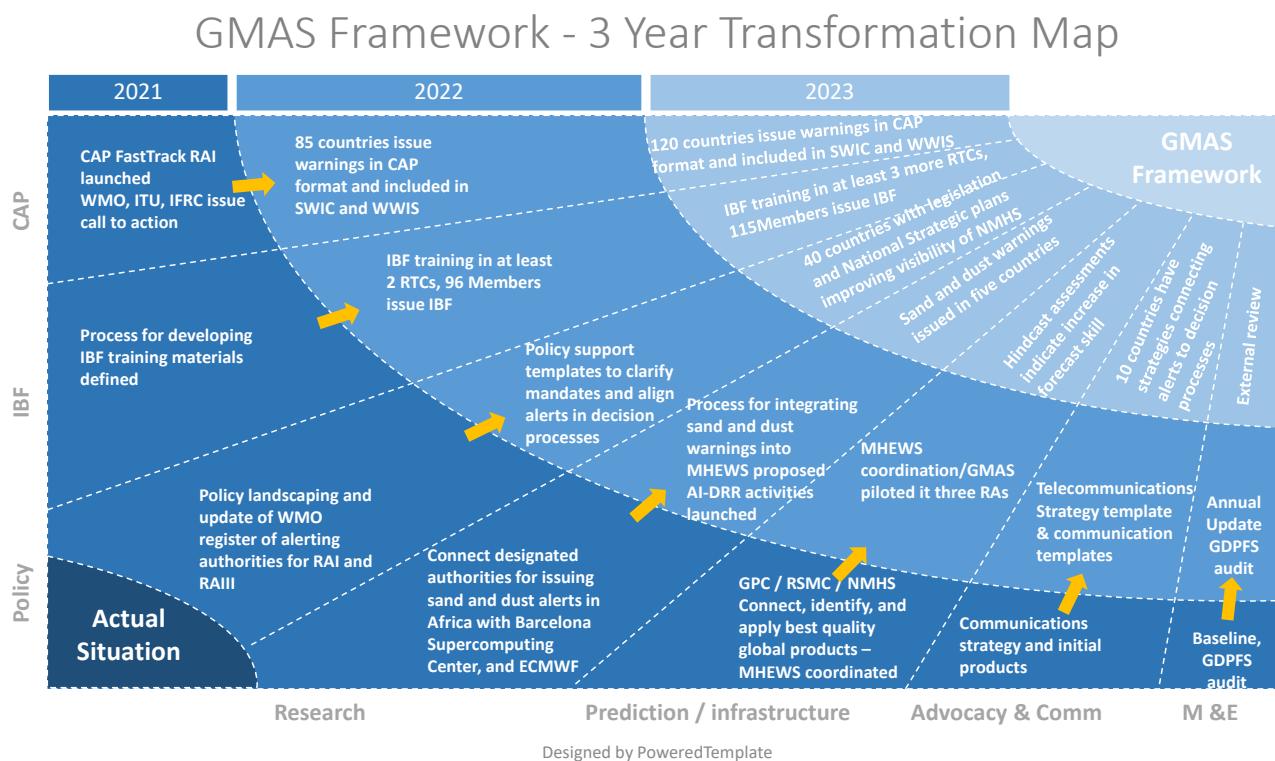
Figure 2. GMAS Framework transformation map

arrangements between NMHSs and Regional Specialized Meteorological Centres (RSMC) within the Global Data-Processing and Forecasting System (GDPFS) will be leveraged to scale capacity support to Members. Moreover, it is envisioned the new Centre of Excellence for Climate and Disaster Resilience (CoE) will also play a role in supporting the alerting capacities of Members, including through collaborative development of training material and resources.

The initial approach of the GMAS Expert Team also proposes the use of other existing tools – such as the WMO Severe Weather Information Centre and the Register of WMO Members Alerting Authorities – to create a repository of authoritative warnings and information related to high-impact weather, water, ocean and climate events Arrangements with the International Maritime Organization (IMO) and NAVAREA Coordinators through the International Hydrographic Organization (IHO) World-wide Navigational Warning Service Sub-Committee(WWNWS-SC) to acquire historical

ocean alerts broadcasted via the Global Maritime Distress and Safety System (GMDSS) into the central GMAS Framework repository will also be explored.

WMO remains committed to supporting Members through the GMAS Framework by enabling multi-hazard, all-media emergency alerting to ensure citizens have access to information and the ability to act. The need is pressing: MHEWS are critical for managing systemic disaster risk and enabling climate change adaptation.

The ultimate success of the GMAS Framework would be to have warnings from all Members produced, aggregated, available and connected to decision making processes. Efforts will be made to link the resulting socioeconomic benefits – decreases in the loss of lives and livelihoods that set back development – to the monitoring mechanisms for the Sendai Framework, the Paris Agreement of the United Nations Framework Convention on Climate Change, and the SDGs.

GMAS Framework – moving to a more agile results-based approach

Are we on track to deliver on the Sendai Framework for Disaster Risk Reduction 2015-2030 by ensuring there are fewer people killed and affected by disasters, and lower economic losses? Are national adaptation efforts guided by the Paris Agreement, specifically on early warning systems, building resilience? Are alerts and services supporting decision making processes to safeguard advances in the Sustainable Development Goals?

Currently, the effectiveness of MHEWS is self-assessed by reporting countries by using metrics such as level of application of disaster risk knowledge, detection, monitoring, analysis and forecasting of hazards and possible consequences, dissemination and communication of warnings and associated information on likelihood and impact. However, are our efforts effective?

The WMO and UNDRR partnership is shifting the monitoring and evaluation paradigm. Through a joint initiative supported by CREWS, the agencies are considering how countries can better assess and monitor the effectiveness of their national EWS. A set of custom indicators were developed for countries to choose from in the Sendai Framework Monitor, so that they can measure, on a voluntary basis, the effectiveness of their MHEWS as per their own individual contexts. In addition to this, the proposed custom indicators could facilitate the measurement of other hazard EWS effectiveness, notably for those related to geo-hazards and biological hazards EWSs, among others; therefore, securing coherence and a holistic reporting to Sendai Framework Monitor. A basic set of indicators have now been developed and reviewed by an expert working group composed of government hydrometeorological and DRR experts. A learning package is being developed to pilot the indicators in in the sub-regions of West Africa and the Pacific in addition to a learning lab at the Global Platform Disaster Risk Reduction 2022 to collect feedback and refine the elements.

References

Golding, B., M. Mittermaier, C. Ross, B. Ebert, S. Panchuk, A. Scolobig, & D. Johnston, 2019: *A value chain approach to optimising early warning systems*. Contributing paper to GAR2019. UNDRR.

Intergovernmental Panel on Climate Change (IPCC), 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Special Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press.

IPCC, 2014: *Fifth Assessment Report (AR5) Climate Change 2014: Impacts, Adaptation and Vulnerability*. Cambridge, Cambridge University Press.

IPCC, 2021: *AR6 Climate Change 2021: The Physical Science Basis*. Cambridge, Cambridge University Press.

Vogel, C. et al, 2019: *Climate Services in Africa: Re-imagining an inclusive, robust and sustainable service*. Climate Services. Vol 15.

WMO, 2019: *World Meteorological Congress: Abridged Final Report of the Eighteenth session* (WMO-No. 1236). Geneva, WMO.

WMO, 2017: *Executive Council - Sixty-ninth session: Abridged final report with resolutions and decisions* (WMO-No. 1196). Decision 3. Geneva, WMO.

Gender equality in the context of multi-hazard early warning systems and disaster risk reduction

By Christa Pudmenzky, University of Southern Queensland, Australia, and SERCOM Gender Focal Point, Ian Lisk, Met Office, United Kingdom, and SERCOM President, Lisa Vitols, Environment and Climate Change Canada, Claudia Ribero, Servicio Meteorológico Nacional (SMN), Argentina, and Gender Focal Point for WMO Services for Aviation, Branwen Millar, United Nations Office for Disaster Risk Reduction (UNDRR), Rahel Steinbach, UN Women, Victoria Bannon and Rosanna Drew, Humanitarian Consulting, Australia, and Erica Allis, Lina Sjaavik, Stephanie Gallasch, Ramesh Tripathi and Barbara Tapia, WMO Secretariat

The impacts of severe hydrometeorological events are not gender neutral. Gender, along with class, race, age and other intersecting social identities, contributes to shaping the roles, power and resources available to women, men and non-binary in any culture, including the resources necessary for resilience. Women, for example, are often directly responsible for the care of children, sick or older family members and are thus less likely to be able or willing to evacuate alone[1] or may delay evacuation to rescue family members or valuables.[2]

Furthermore, women are often placed at greater risk through a lack of timely and relevant information about imminent hazards. Women often do not have equal access to technology, communication and services, and thus miss out on critical information. This is particularly true for women and other marginalized groups in rural or isolated areas. The channels through which women and men get information from also differs. A study in Nepal determined that 71% of men received early warning information through a formal source, such as government or nongovernmental organizations (NGOs), whereas 51% of women received their information through informal social sources such as word of mouth from community or family members.[3]

A UN Women-UNICEF study focusing on the missing voices of women in disaster risk reduction (DRR) efforts confirmed that gender norms and

Girls standing on a sea-wall built from plastic bags to prevent flooding in South Tarawa, Kiribati. 29 January 2020. Copyright: UN Women/Rahel Steinbach

barriers to their participation affect women's vulnerability to disasters. Women's higher illiteracy rates, lower mobility rates and limited access to communications technology, including radios and mobile phones through which early warnings tend to be communicated, all increase their vulnerability. Men also tend to be considered household decision-makers, which can put women at risk. In some cases, women remain at home because their husbands have decided not to evacuate or to wait for their husband to return before leaving. Due to gender-specific roles and expectations, women are more likely to be at home when disaster risks arise and to take on the responsibility for evacuating their family to safety[4].

---

1   *Community early warning systems: guiding principles*. 2012. Geneva, International Federation of Red Cross and Red Crescent Societies (IFRC).

2   *Gender and Age Inequality of Disaster Risk*. 2019. Geneva, UN Women and UNICEF.

3   Brown et al., 2019: *Gender Transformative Early Warning Systems: Experiences from Nepal and Peru*. Rugby, UK, Practical Action.

4   *Gender and Age Inequality of Disaster Risk*. 2019. Geneva, UN Women and UNICEF.

Moreover, the needs of women are inadequately met and their gender-specific contributions and solutions remain unleveraged because their voices are often absent in the design and decision-making processes for multi hazard early warning systems (MHEWS). When women in all their diversity are actively engaged in the development and implementation of disaster management laws, policies, operational plans and procedures and MHEWS identify and address the diverse needs of different groups, DRR efforts become more inclusive and accessible and, ultimately, more successful. Despite growing recognition by international institutions and development practitioners that a gender lens is crucial to understand and promote resilience to climate and security risks, it has yet to be meaningfully applied to research and in practice in climate resilience and DRR efforts (Ide et al., 2021).[5] This article explores what WMO, the United Nation Office for Disaster Risk Reduction (UNDRR) and UN Women are learning with regard to gender evaluations in DRR and early warning systems (EWS), and how UN partners are working together to better support Members.

> "Well-designed disaster risk reduction and climate change initiatives that provide for the full and effective participation of women can advance substantive gender equality and the empowerment of women, while ensuring that sustainable development, disaster risk reduction and climate change objectives are achieved." – Committee on the Elimination of Discrimination against Women Recommendation 37.

What we are learning

In 2017, the Caribbean experienced its most costly hurricane season with 17 named storms, 6 of them major hurricanes. Most of the damages were inflicted by Hurricanes Harvey, Irma and Maria. An evidence-based assessment of the early warning system was carried out by WMO, which included gender considerations.

The following outlines the major findings of the assessment:

- The Caribbean region was found to have legislative frameworks affirming the equality of men and women, yet structural gender inequalities persist, and these **structural**

---

5   Ide, T., M.O. Ensor, V. Le Masson and S. Kozak, 2021: *Gender in the Climate-Conflict Nexus: "Forgotten" Variables, Alternative Securities, and Hidden Power Dimensions*. Politics and Governance, 9(4), 43-52.

inequalities hinder the ability of women to fully participate in EWS processes.

- Gaps were found in the knowledge and understanding of how to include gender in EWS efforts, however, participants expressed willingness to address this need at both the regional and national levels.

- Preparation for the 2017 hurricane season included hazard mapping and risk identification, however, **little systematic work had been undertaken to understand gender differentiated risks at the community level**. As a result of the insufficient use of existing social vulnerability data, the capacity of vulnerable groups to undertake the required actions for their preparedness and safety was not optimally supported.

- Both genders were noted to have received the messages sent by the authorities. However, **there were differences in how men and women responded to the messages**. These differences related to how each gender uses time, how households are structured – for example, households headed by women, intergenerational families and so forth – to income levels and to the diversity in risk perceptions. Noteworthy observations included:

  - Men seemed to act out their risk perception through behaviours involving procrastination. It was suggested by male participants in focus groups that such procrastination was an expression of a certain "machismo". However, this was a stumbling block to making timely preparations.

  - The limited economic and physical resources of single female heads of impoverished

Sunita Rai, 40, living in Bangladesh, suffers due to a spinal cord ailment stemming from an injection during a C-section delivery. Her house was seriously damaged by Cyclone Amphan in September 2020. She used cash support from UN Women to set up a drinking water tank. Copyright: UN Women/Fahad Kaizer

Taronga, 16, holds her two-year-old sister Teaborenga while standing in a flooded area in the village of Eita, South Tarawa, Kiribati, Thursday 28 January 2016. Copyright: UNICEF/UN056626/Sokhin

households were found to hinder their ability to take the required actions to safeguard themselves and their families, putting them at extreme risk in multi-hazard environments.

– Communities with strong social support networks and social capital facilitated men and women's identification of risk and understanding and sharing of knowledge of risks.

Key recommendations included:

• Hazard monitoring functions of the National Meteorological and Hydrological Services (NMHSs) and National Disaster Offices (NDOs) need strengthening and system-wide testing should be regularized.

• Systematic efforts to build credibility and trust in the warnings should be undertaken.

• There is an urgent and continuous need to replace and maintain communication systems and equipment for EWSs due to the impacts of multiple hazards and the destruction of property (vandalism).

• Greater use should be made of a socioeconomic, evidence-based EWS programme design. There should be more and better targeting of vulnerable groups in EWS messaging – including single female heads of households, single, elderly male heads of households, chronically ill and disabled individuals – when the preparation and dissemination of information on preparedness and response is being considered.

• Further research should be encouraged on how gender and other axes of social differentiation, such as age, race/ethnic community, household income, etc, intersect with weather and climate events to produce differential security risks for women and men of different backgrounds.

Ignoring these dynamics threatens to disempower and exclude socially marginalized people in interventions and policies, leading to lopsided and weak solutions.

• EWS messaging should make greater use of Information and Communication Technology (ICT). This should be coupled with improved tailoring of messages to women and men.

• An effort should be made to deepen programmatic understanding of the roles and engagement of transnational families with respect to EWSs in the Caribbean so that they may receive the maximum benefit from EWSs.

• Gender Bureaux should be better integrated in the work of NDOs and NMHSs in order to more efficiently use existing capacity within government structures.

UNDRR Case Study

In 2021, UNDRR, in partnership with Shifting the Power Coalition and ActionAid Australia, undertook a study on the women-led EWS in the Pacific. The Fiji Women's Weather Watch, Vanuatu's Women Wetem Weta, Papua New Guinea's Meri Got Infomesen and Fiji's Disabled People's Federation Emergency Operations Centre were the focus of the study. Using existing community networks and a range of different technologies, these initiatives have successfully demonstrated how to communicate real-time information to help diverse groups of women and their communities better prepare for and take early action before disasters strike, ultimately saving lives and livelihoods.

These initiatives use different approaches to empower women and marginalized groups across the Pacific region through early warning information-communication systems. They demonstrate how women's innovation and use of appropriate and accessible information and communication technology and systems support effective early warning messages in real-time and in local languages, contributing not just to building the resilience of their communities but to supporting women's agency, leadership, and gender equality.

The study found that these women-led initiatives provide valuable insights for strengthening people-centred, inclusive, accessible, effective and sustainable MHEWS. They are of particular importance in several areas:

1. **Establishing connections with communities:** Listening, learning and engaging with existing

networks, particularly women's networks, helps to build strong community connections and permits MHEWS to benefit from locally-led information gathering. Ensuring positive, safe and inclusive participation, and engagement that acknowledges and respects women's experiences and reflects the diversity within each community, helps broaden ownership and community buy-in for MHEWS. A key component of this is ensuring universal design through effective communication in different languages and improving accessibility.

2. **Strengthening community knowledge:** Improving community awareness, in particular women's understanding of climate change and disaster risks, by using both traditional and modern scientific knowledge helps to inform community level disaster risk management and empowers women to participate. Improving knowledge of disasters also increases the likelihood that early warnings will be actioned when received.

3. **Facilitating community-based data collection and hazard monitoring:** Supporting communities through appropriate resourcing and capacity-building helps to improve engagement in systematic data collection about hazards, socio-economic vulnerabilities and disaster impacts in their local area and to strengthen information and data sharing between the community and national level.

4. **Delivering effective early warning messages:** By involving communities in the development of messaging and by using different communication

Saleha Begum, 45, living in Bangladesh, is a single mother with two physically challenged children and is also in charge of her grandchild. She lost her job as a daily labourer due to the Covid-19 pandemic. Her house was ravaged by Cyclone Amphan in 2020. She used cash support from UN Women to pay off her debts and receive medical treatment for everyone in her family. Copyright: UN Women/Fahad Kaizer

channels to transmit messages, they ensure that early warning messages are received and acted upon. Establishing a two-way communication feedback mechanism that allows communities to share real-time information helps to support continued improvement.

5. **Mainstreaming community- and women-led MHEWS:** Officially recognizing and supporting community- and women-led MHEWS initiatives and connecting them to broader national and regional MHEWS ecosystem can help to increase access to information. In addition, strengthening links between women-led MHEWS and scientific entities ensures that accurate risk knowledge is communicated widely. This may require the adaptation of laws and policies, annual budget allocations and the composition of decision-making bodies to be more inclusive of women, persons with disabilities and community-led initiatives.

6. **Empowerment and transformative change:** There are wide-spread positive ripple effects from well supported community- and women-led MHEWS, including greater gender equality and improvements in the status of women, and broader community-level engagement and empowerment.

Mainstreaming gender considerations in MHEWS

The 2015 Conference on the Gender Dimensions of Weather and Climate Services[6] served as a milestone of renewed WMO engagement with partner agencies on gender equity efforts. Following the conference, WMO updated its policy on gender equality and developed an action plan to mainstream gender in its governance, working structures, programmes and throughout service delivery. The 2019 publication *Gendered Impacts of Weather and Climate: Evidence from Asia, Pacific and Africa* presents 18 gender case studies by WMO Members. The case studies provide practical recommendations to NMHSs for bridging information asymmetries and developing gender-responsive services in terms of content, dissemination channels and feedback mechanisms, with the overall goal of enhancing adaptive capacity and reducing negative impacts of weather and climate.

---

6   Organized by WMO, Food and Agriculture Organization of the United Nations (FAO), International Union for Conservation of Nature (IUCN), UN Women, United Nations Educational, Scientific and Cultural Organization (UNESCO), UNDRR, World Health Organization (WHO), and the World Bank.

"Words into Action"

The WMO, UNDRR and UN-SPIDER, together with other partners, are currently developing the Words Into Action (WiA) guide on MHEWS, which will be reviewed at MHEWC-III. This document will guide governments, stakeholders and partners on how to institutionalize, operate, monitor, and strengthen people-centred inclusive approaches for MHEWS that enable early action.

Dominica Northeast Women Farmers Group received support from UN Women to get labour and equipment to bring their farms back into production following Hurricane Maria in September 2017. Some 76% of women farmers reported major losses following the hurricane and some women couldn't immediately return to work because of the damages to their homes. Copyright: UN Women/Sharon Carter-Burke

The first session[7] of the WMO Commission for Weather, Climate, Water and Related Environmental Services and Applications (Services Commission or SERCOM) in 2021 established a Focal Point on Gender Equality to facilitate and monitor the successful implementation of the WMO Gender Action Plan within SERCOM. The Focal Point was tasked with creating, maintaining and expanding a network of gender focal points and female experts involved in the work of SERCOM. Through their engagement with Gender Focal Point networks in other WMO bodies and UN organizations and the consideration of relevant studies,[8] they will promote a better understanding of gender-specific

Gender equity in the Volta Basin Adaptation Fund Project

WMO extrabudgetary projects present an opportunity to strengthen gender considerations in EWSs. An example of this is the Volta Basin Adaptation Fund project being implemented in Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo. So far, eight national workshops have been organized on mainstreaming gender into the end-to-end EWS for flood forecasting (E2E-EWS-FF) and Integrated Flood Management (IFM) in the Volta Basin countries. The main objective of the workshops was to better understand gender-related issues and needs as well as to develop knowledge and skills on E2E-EWS-FF and IFM. Based on discussions, recommendations and an action plan were submitted to the decision-makers for mainstreaming gender at local and national levels.

Moreover, through a close collaboration with UNDRR, projects to strengthen MHEWS in the Pacific and South East Asia are undergoing analysis to integrate gender and disability across the early-warning-early-action value chain.

Children in the Solomon Islands. Copyright: UNDRR/ Rose

user needs and consequent delivery of gender-responsive weather, hydrological, climate and environmental services.

The Third Multi-Hazard Early Warning Conference (MHEWC-III)[9] – From Stock take to Scale on Target G: Accelerating the knowledge and practice of

---

7   Commission for Weather, Climate, Water and Related Environmental Services and Applications: Abridged Final Report of the First Session (WMO-No. 1259), WMO, 2021.

8   See, for example, the recommendations arising from Beyond vulnerability to gender equality and women's empowerment and leadership in disaster risk reduction: critical actions for the United Nations system

9   Co-organized by WMO, UNDRR and the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) from the United Nations Office for Outer Space Affairs (UNOOSA), together with other IN-MHEWS partners

MHEWS for risk informed resilience – on 23 and 24 May aims to propose recommendations to further mainstream gender considerations into WMO MHEWS activities. A gender segment at the Conference will also share good practice. WMO plans to integrate the MHEWC-III outcome statement, including the recommendations on gender, into its interventions and engagement at the Global Platform for Disaster Risk Reduction on 22, 23 and 28 May.

WMO recognizes that diversity and gender equality are crucial for better governance, improved performance and higher levels of organizational creativity. Gender equality and the empowerment of women are of paramount importance for scientific excellence and essential to meeting the challenges of climate change, DRR and sustainable development, particularly Sustainable Development Goal 5: Gender equality. WMO is pleased to be an active contributor to the United Nations Plan of Action on Gender and is resolved in its efforts to work with Members and partners to achieve gender equality, empower women as leaders in disaster risk reduction and climate action and build climate resilient societies.

Artificial Intelligence for Disaster Risk Reduction: Opportunities, challenges, and prospects

By Monique Kuglitsch, Fraunhofer Heinrich Hertz Institute, Germany; Arif Albayrak, NASA Goddard Space Flight Center, USA; Raúl Aquino, Universidad de Colima, Mexico; Allison Craddock, NASA Jet Propulsion Laboratory and California Institute of Technology, USA; Jaselle Edward-Gill, Fraunhofer Heinrich Hertz Institute, Germany; Rinku Kanwar, IBM, USA; Anirudh Koul, Pinterest, USA; Jackie Ma, Fraunhofer Heinrich Hertz Institute, Germany; Alejandro Marti, Mitiga Solutions and Barcelona Supercomputing Center, Spain; Mythili Menon, International Telecommunication Union; Ivanka Pelivan, Fraunhofer Heinrich Hertz Institute, Germany; Andrea Toreti, European Commission Joint Research Centre, Italy; Rudy Venguswamy, Pinterest, USA; Tom Ward, IBM, USA; Elena Xoplaki, Justus Liebig University Giessen, Germany; and Anthony Rea and Jürg Luterbacher, WMO Secretariat

Artificial intelligence (AI), in particular machine learning (ML), is playing an increasingly important role in disaster risk reduction (DRR) – from the forecasting of extreme events and the development of hazard maps to the detection of events in real time, the provision of situational awareness and decision support, and beyond. This raises several questions: *What opportunities does AI present? What are the challenges? How can we address the challenges and benefit from the opportunities? And, how can we use AI to provide important information to policy-makers, stakeholders, and the public to reduce disaster risks?* In order to realize the potential of AI for DRR and to articulate an AI for DRR strategy, we need to address these questions and forge partnerships that drive AI in DRR forward.
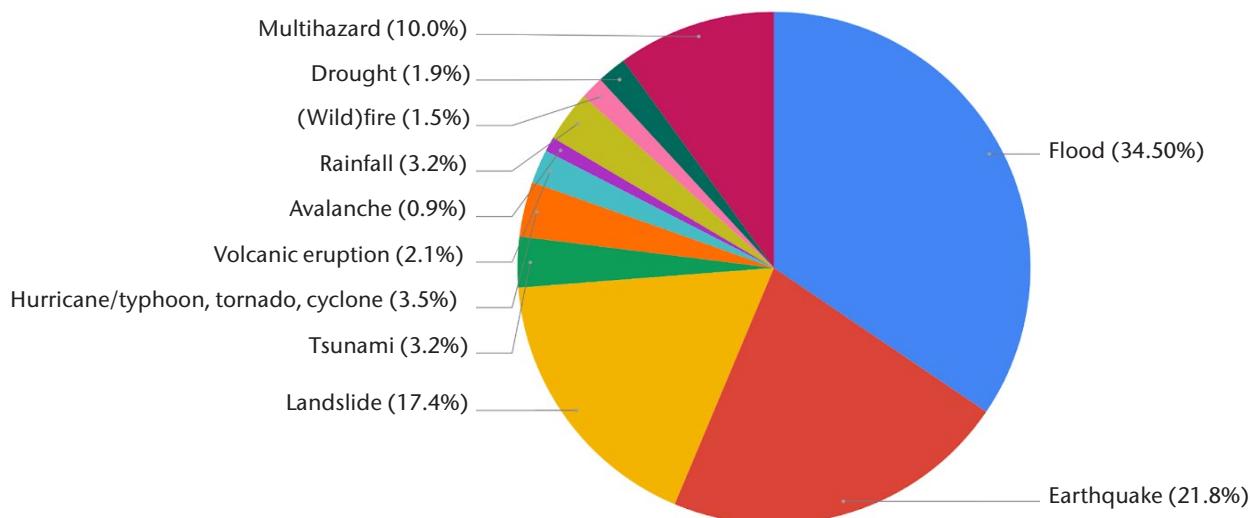
AI and its use in DRR

AI refers to technologies that mimic or even outperform human intelligence when performing certain tasks. ML, which is a subset of AI that includes supervised (e.g., random forest or decision trees), unsupervised (e.g., *K*-means) or reinforcement (e.g., Markov decision process) learning, can be simplified as parsing data into algorithms that learn from data to make classifications or predictions. AI methods offer new opportunities related to applications in, for instance, observational data pre-processing as well as forecast model output post-processing. The methodological potential is strengthened by novel processor technologies that allow heavy-duty, parallel data processing.

In general, the performance of ML for a given task is predicated upon the availability of quality data and the selection of an appropriate model architecture. Through remote sensing (e.g., from satellites, drones), instrumental networks (e.g., from meteorological, hydrometeorological, and seismic stations) and crowdsourcing, our foundation of Earth observational data has grown immensely. In addition, model architectures are constantly being refined. Therefore, it is to be expected that ML will be growing more prominent in DRR applications (Sun et al., 2020). For instance, a preliminary survey of recent (2018–2021) literature shows that ML approaches are being used to improve early warning and alert systems and to help generate hazard and susceptibility maps through ML-driven detection and forecasting of various natural hazard types (see Figure 1, note that this survey excludes research that is purely focusing on method development but does not target future DRR application).

This preliminary survey clearly demonstrates that AI-related methods are being applied to help us better manage the impacts of many types of natural hazards and disasters. In the next paragraphs we present four specific examples of where AI is being implemented to support DRR.

In Georgia, the United Nations Development Programme (UNDP) is creating a nation-wide multi-hazard early warning system (MHEWS) to help reduce the exposure of communities, livelihoods and infrastructures to weather and climate-driven natural hazards. For its operation, this system requires accurate forecasts and hazard maps of severe convective events (i.e., hail- and windstorms).
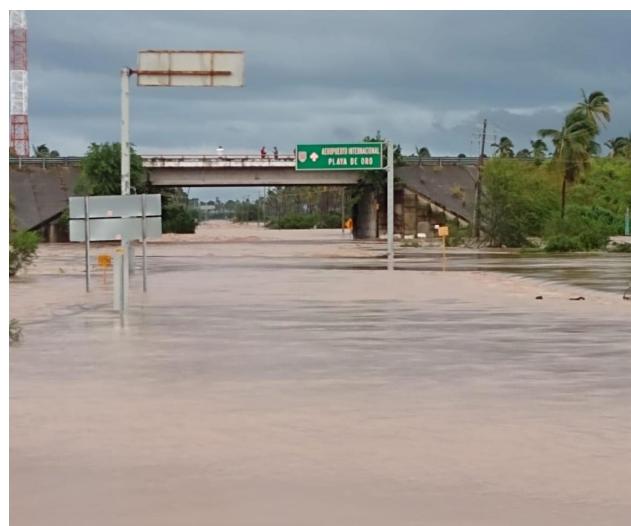
Figure 1. Application of AI to the detection and forecasting of natural hazards and disasters derived from a preliminary literature survey covering articles published between 2018 and 2021 with a focus on (future) DRR applications. These results show an overrepresentation of certain natural hazard types, particularly floods, earthquakes, and landslides.

However, developing these products is challenging, given the lack of on-site observation networks across the country. Therefore, experts are using AI to create a tool that predicts the probability of observing a convective event for a specific day at a given location under certain meteorological and climatological conditions. The ML model is able to predict severe convective conditions – that is, the model detects days with a high potential of severe convection resulting in hail- or windstorms – by combining the available on-site observations with data from National Oceanic and Atmospheric Administration's (NOAA) 70-year Storms Events Database and from European Centre for Medium-Range Weather Forecasts' (ECMWF) 5th-generation atmospheric reanalysis dataset (ERA5). The tool uses historical data from data-rich regions to extrapolate to other locations worldwide with limited data availability using transfer learning. Finally, a downscaling approach is used to simulate and analyze these events with the Weather Research and Forecasting (WRF) numerical weather prediction model (Skamarock et al., 2019) and the ERA5 data. This has shown great potential for forecasting severe convective storms and producing hazard maps in Georgia, which is a particularly challenging region for hail- and windstorm prediction due to its complex topography.

The second example, which relates to flash floods, also leverages AI to assist with limited datasets. Flash floods are particularly hazardous because there is often little or no forewarning of the impending disaster. To detect such events as they occur, it is important to have a dense network of sensors to monitor and detect changes in discharge or stage across the catchment. In Mexico's Colima River basin, the elevation of which ranges from 100 to 4 300 metres (m), hydrological stations are supplemented by a multi-sensor network consisting of RiverCore sensors (for stage and soil moisture) and weather stations (Mendoza-Cano et al., 2021; Ibarreche et al., 2020; Moreno et al., 2019). The data from these are used to train ML models, which can detect flash floods (Figure 2). The results from the ML models are compared with hydrological/hydraulic models and performance metrics are calculated, including: overall accuracy (OA), F1-score, and Intersection Over Union (IoU). Due to the success of this use case in

Figure 2. A photograph of a flash flood in Manzanillo, Mexico. (Credit: Ricardo Ursúa)

Colima, the same methods are being expanded to detect flash floods in city tunnels in the Guadalajara metropolitan area.

The third example shows how AI can be used in geodesy to detect tsunamis and avoid issues around sensitive data crossing national borders. The application of advanced Global Navigation Satellite System (GNSS) real-time processing for positioning and ionospheric imaging provides very significant improvements to Tsunami Disaster Early Warning. GNSS is used in seismology to study ground displacements as well as to monitor perturbations in ionospheric total electron content (TEC) that commonly follow seismic events. Ten years ago, when Japan's northern coastal areas were hit by the Tohoku tsunami, it took several days to grasp the entirety of the vast damage. Earth observations, combined with AI and ML, can be used to assess threats (Iglewicz and Hoaglin, 1993) and prepare ahead of time, to evaluate impacts as they unfold (as little as 20 min after earthquake occurrence) (Carrano and Groves, 2009), and to respond more quickly in the aftermath to save lives during recovery operations (Martire et al., 2021). Geodesy4Sendai, a Group on Earth Observations (GEO) Community Activity led by the International Association of Geodesy (IAG) and the International Union of Geodesy and Geophysics (IUGG), is participating in a new tsunami early warning collaboration with the International Telecommunication Union (ITU), WMO, and United Nations Environment Programme (UNEP) Focus Group on Artificial Intelligence for Natural Disaster Management (FG-AI4NDM). Within the *Topic Group on AI for Geodetic Enhancements to Tsunami Monitoring and Detection,* experts have started to look at relevant best practices in use of Global Navigation Satellite Systems (GNSS) data (Astafyeva, 2019; Brissaud and Astafyeva, 2021). Specifically, the experts are exploring the feasibility of using AI to process GNSS data in countries where exporting real-time data is prohibited by law, and to establish protocols for development and sharing of export-permitted products derived from AI and related methods. The group is also considering innovative communication technologies for transmitting real-time GNSS data to countries or regions with limited bandwidth capacity, where using AI for decentralized, data-derived product sharing could enable the transmission of life-saving information over limited communications infrastructure. Such an effort lays the groundwork for expanding the use of these methods in developing countries that suffer from increasing tsunami threats, in addition to climate change impacts such as sea level rise (Meng et al., 2015).

The fourth example explores how AI can be used to provide effective communication in the case of natural hazards and disasters. Specifically, it looks at how AI can help natural disaster responders assess the severity of risk and prioritize when and where to respond. Structured and unstructured data, including risk alert sources, vulnerability, susceptibility and resilience indicators, and news sources are fed into Operations Risk Insight (ORI), a platform that applies natural language processing and machine learning to visualize and communicate multi-hazard risks in real-time and assist with decision-making.[1] As part of the IBM Call for Code Program, which was held between Hurricanes Florence and Michael (autumn of 2018), IBM made ORI available to qualified natural disaster non-profit organizations. Since then, IBM and several nongovernmental organizations (NGO) have partnered to improve and customize a platform for disaster response leaders. For example, ORI provides Day One Relief, Good360 and Save the Children with customized hurricane and storm alerts as well as layered data sets to generate map overlays to increase situational awareness.[2]

Challenges to the use of AI for DRR

When applying AI for DRR, challenges can appear at any stage of the life cycle (Figure 3): at the data, model development or operational implementation stage.

During the collection and handling of data, it is important to consider: (a) biases in training/testing datasets, (b) new distributed AI technologies within the data domain and (c) ethical issues. In terms of biases in training/testing datasets, it is important to ensure that data are correctly sampled and that there is sufficient representation of each pattern for the problem in question. Consider, for instance, the challenge of building a representative dataset containing examples of extreme events (which are, by nature, rare). Also, imagine the possible costs of failing to provide appropriate data, for instance, wrong predictions or biased outcomes.

Once we have ensured that a dataset is not biased, we also need to decide how to integrate new distributed AI technologies within the data domain. Strategic modifications on the construction of space-based instruments like multiple small satellites[3] and the

---

1   https://newsroom.ibm.com/ORI-nonprofits-disaster

2   https://www.ednc.org/nonprofits-and-artificial-intelligence-join-forces-for-covid-19-relief/

3   https://www.nasa.gov/content/about-cubesat-launch-initiative

Data collection
Considerations include data custodianship, curation, preparation, annotation, validation, ethics, privacy, ownershiip, and open source.

Model deployment
Opportunities include real-time detection systems for alerts and early warming systems (see **flash flood** and **tsunami** examples), forecast and hazard mapping systems (see **hail- and windstorm** example), and situtional awarness and decision support systems (see **ORI** example).

Model development
Considerations include handling of missing values in training data, problem formulation, selection of machine learning method, performance metrics, and trustworthiness.

Figure 3. A schematic of key steps in the AI lifecycle for DRR.

introduction of edge computing (Nikos et al., 2018) have resulted in petabytes of data. Because AI relies on data transmission and computation of complex machine learning algorithms, centralized data processing and management can impose difficulties. On the one hand, real-time disaster applications require strong partnerships and data sharing between countries (recall the tsunami use case; Figure 4). On the other hand, ML algorithms are often operated in a centralized fashion, requiring training data to be fused in data servers. A centralized approach can also introduce additional challenges, such as privacy risks to personal and country-specific data. Furthermore, centralized data processing and management can limit transparency, which could lead to a lack of trust from end-users as well as difficulty in complying with regulations (e.g., GDPR).

Figure 4. Creating AI-based models that can detect certain events, such as tsunamis, can be hindered by data export limitations. This image captures the aftermath of the 2011 Tohoku tsunami (Credit: ArtwayPics, iStock: 510576834).

Another data-related challenge is tied to ethical considerations. These centre on how AI-driven tools ought to be implemented from development to deployment, ensuring, for example, that socio-economic biases in underlying data are not propagated through the models developed by the system. Such principles are championed so that potential harms associated with AI, such as underrepresentation due to bias (either technical or human-based), can be mitigated – if not removed, and so that the benefits of AI can be realized for all, especially those made more vulnerable by the impacts of natural hazards.[4]

After a dataset has been curated, we also need to consider challenges at the model development stage. Here, we focus on the computational demands and transparency. AI models tend to rely on complex structures and, as a result, can be computationally expensive to train. For example, the VGG16 model (Simonyan and Zisserman, 2015), which is used for image classification, has approximately 138 million trainable parameters. Training models of this size requires large and expensive computing capacity, which is not always accessible.

Once an AI model is developed, it is important that the results are humanly understandable and acceptable. This can be challenging to obtain because there is no general out-of-the-box human-machine interface that provides information about how and why certain decisions are made by the AI model.

---

4   https://www.worldbank.org/en/news/feature/2021/07/20/in-europe-and-central-asia-the-poor-lose-more-when-disaster-strikes

Consequently, many researchers are working toward developing trustworthy AI solutions. In modelling and model evaluation, for instance, it is important to have a precise formulation of the problem and the requirements and expectations of the AI-based solution. Only then can a suitable model and learning strategy be developed to tackle the problem. Moreover, understanding the precise setup also helps in choosing and developing corresponding evaluation criteria.

For an AI-based model that is deemed ready for operational implementation, it is important to consider the aforementioned – data and model development-related – challenges as well as user notification challenges. These are explored using AI-based communications technologies. To improve and facilitate interpretation of AI model outputs, these need to be translated and visualized according to end-user needs. Therefore, it is critical that stakeholders – from local communities to emergency system managers – and NGO disaster response leaders be included in the design and evaluation of alert and early warning systems, forecasts, hazards maps, decision support systems, dashboards, chatbots and other AI-enhanced communications tools. Timely feedback and evaluation of AI model insights from disaster responders is essential to improve the quality and precision of insights. Transparency into the data sources ingested, the frequency of data refresh and the algorithms used for the communication tools is essential to develop trust and refinement of machine learning-based recommendations. As with traditional modelling approaches, conveying confidence levels, uncertainties and limitations of an AI-enhanced system in an understandable way is crucial for informed decision-making. Ultimately, trust in timely and fully transparent AI-based communications tools is the biggest challenge to be overcome. This requires effective collaboration among experienced disaster responders, AI developers, geoscientists, regulators, government agencies, NGOs, telecom companies and others, to meet the needs of all stakeholders. Each disaster type is unique, and each region has different vulnerabilities and resiliency levels.

Efforts to address challenges to the use of AI for DRR

Concerted efforts are being made to address the many challenges when using AI for DRR and to facilitate its use. These efforts support greater data availability, provide tools and packages to assist with AI development, enhance model explainability,

offer new applications for AI-based methods (i.e., digital twins), and contribute to the development of standards.

As already highlighted, one of the biggest challenges when developing an AI algorithm for DRR is the collection of data with correct sampling and sufficient representation of each pattern for a given problem. Here, open datasets (or "benchmarking" datasets)[5,6,7] can be a valuable resource. By open sourcing their data, teams hope to allow other researchers to use the data collected to improve and augment existing solutions. To achieve this goal, the data provided must be well documented – include metadata – and be accessible. Steps should be taken to block, remove or edit the data to avoid the inadvertent release of personally identifiable language. Furthermore, it is advisable to provide clear documentation on how to download and begin working with the data. Many teams open source their projects with stellar documentation but fail to see a rise in use cases due to a lack of discoverability. This can be resolved by providing links to the open data on Google Datasets, Kaggle, Github or other data discovery platforms. The Group on Earth Observations, the National Aeronautics and Space Agency, the European Space Agency, and others, have created guidelines and/or databases to support open-sourcing data.[8]
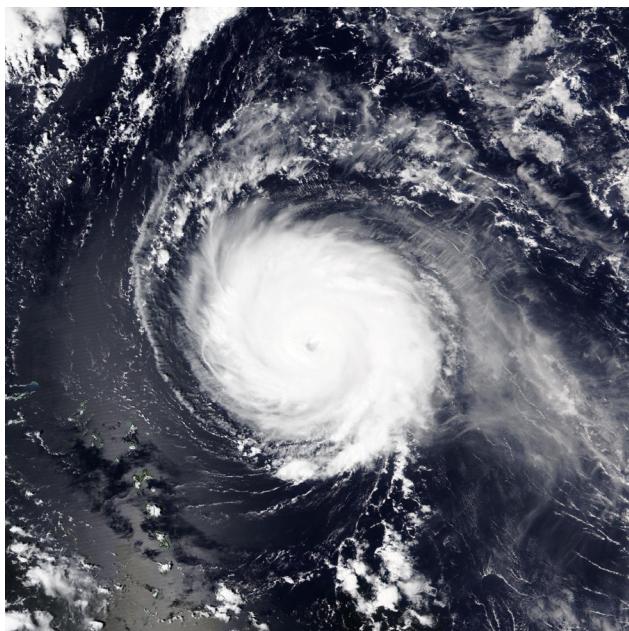
Alongside open-source data, AI developers can benefit from an array of tools that assist with the major aspects of AI deployment: data gathering, model development, model deployment and model retraining/monitoring. Within each of these aspects, there are several private and open-sourced tools for AI developers. For example, many scientists rely on open-source imagery to be hand labelled by a research team. However, shared file systems that assist with data collection and automate annotation (e.g., relevant features in satellite imagery; Figure 5) can increase efficiency. Once data have been labelled, the machine learning/data science practitioner should use the most familiar packages (e.g., Python Tensorflow, Keras, and Pytorch). Many popular model architecture and training frameworks allow for AI efforts to be simplified. For instance, Pytorch Lightning is built on top of Pytorch and is a framework to help manage data within individual models. Lastly, with respect to model deployment and monitoring,

5   https://gmd.copernicus.org/articles/14/107/2021/

6   https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020MS002203

7   https://www.ecmwf.int/sites/default/files/elibrary/2009/8250-set-benchmarks-tests-jules.pdf

8   https://earthdata.nasa.gov/earth-observation-data

Figure 5. Annotated image retrieved from SpaceML's NASA Worldview Search tool, which shows Hurricane Sam *over the Atlantic Ocean on 29 September 2021 as captured by NOAA-20/VIIRS. Innovative (AI based) tools can automate the identification of atmospheric phenomenon and natural disasters – such as hurricanes – from satellite imagery.*

there are solutions that can be run internally (i.e., without the cloud). This requires a dedicated model server with guarantees on model availability and latency. Before running such a solution, however, it would be wise to consider the use case, the cost of resources, the number of trained staff to ensure the model's availability, and, lastly, how often you expect you will need to retrain your model. Systems like AWS Lambda and Gateway, Sagemaker, Google AI platform, and Watson model deployment manage servers for ML-specific tasks but still require on-call machine learning/data science resources to ensure model accuracy, retraining and model availability.

When a model has been developed, one caveat to its use for high-stake applications is the "black box" predicament. How can we trust the model if we cannot unfold its decision-making? EXplainable AI (XAI) is a highly active research field, which is producing tools that can be used during different stages of an AI lifecycle. For instance, AI models are often trained on a large dataset to obtain very high accuracies. However, the reasons why a certain model performs better or worse than another are often not clear. Using XAI tools such as integrated gradients (Sundararajan et al., 2017) or layer-wise relevance propagation (Bach et al., 2015), one can analyze the model and its learned feature importance in the input data to determine what is most relevant

for a prediction. Moving from such local to global XAI methods, data imbalances can also be discovered and artifacts can even be unlearned (Anders et al., 2022).

Revolutionary opportunities to leverage AI to enhance DRR approaches and services are motivating the sharing of open-source data, the development of tools and the enhancement of AI-related research (e.g., in XAI). For instance, digital twins of the Earth (i.e., digital replicas of the Earth system and its components) are expected to trigger key advances in building innovative digital ecosystems (Nativi et al., 2021) with user/service-oriented federations of GPU-CPU HPCs as well as dedicated software infrastructure (Bauer et al., 2021). In this context, the European Commission has launched the Destination Earth initiative, with some of the first identified twins and use cases being DRR oriented. AI will play a key role in the implementation and effective use of digital twins, enabling, for instance, the full coupling and representation of the human component as part of the Earth system.

Another important activity that can support the implementation of AI in DRR is standardization; that is, the creation of internationally recognized guidelines. Core standardization activities within the disaster management sphere are currently being undertaken by international standards developing organizations (SDOs), including the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and ITU. Other United Nations agencies, including WMO, UNEP, United Nations Office for Disaster Risk Reduction (UNDRR) and World Food Programme (WFP), are also contributing to the production of technical regulations, frameworks, recommended practices and de-facto standards within this field.

While these technology-centric standards are generally aimed at employing existing ICT solutions for improving operational efficiency of early warning systems and maintaining the required services for disaster recovery, the standardization of AI for DRR has remained largely uncharted territory. Recognizing this, in December 2020, ITU, together with WMO and UNEP, established the Focus Group on Artificial Intelligence for Natural Disaster Management. The Focus Group is currently a) examining how AI could be used for the different types of natural hazards that can cascade into disasters and b) drafting best practices related to the use of AI in supporting modelling across spatiotemporal scales and provision of effective communication during such events. The Focus Group has ten active topic groups exploring the use of AI for floods, tsunamis, insect

plagues, landslides, snow avalanches, wildfires, vector borne diseases, volcanic eruptions, hail- and windstorms, and multi-hazards, and is actively reviewing proposals on additional topics. In order to underscore and comprehend the standardization gaps in this application, the Focus Group is also developing a roadmap containing existing standards and technical guidelines on this topic from different international, national and regional SDOs. This roadmap will let us identify future areas requiring attention on the standardization front. In addition, the Focus Group is preparing a glossary, which maps the existing terms and definitions associated with the topic to ensure clear and unambiguous communication and consistency within the DRR standardization stream.

Next steps…

Within the field of DRR, there is considerable interest in exploring the benefits of using AI to bolster existing methods and strategies. This article introduced several use cases demonstrating how AI-based models are enhancing DRR; however, it also showed that AI comes with challenges. Fortunately, the promise of AI in DRR has motivated research to find solutions to these challenges and inspired new partnerships; bringing together experts from multiple United Nations agencies, from various scientific fields (computer science, geosciences), from diverse sectors (from academia to NGOs) and from around the globe. Such partnerships are key for driving AI in DRR forward. In particular, we believe that efforts are still needed in the creation of educational materials to support capacity building, for ensuring the availability of computational resources and other hardware and for bridging the digital divide. Only this way can we make sure that no one is left behind as AI for DRR advances.

For members of the WMO community with an interest in learning more about the use of AI for DRR, there are many committees, conferences, and reports, which can serve as a resource. For instance, the American Meteorological Society's Committee on Artificial Intelligence for Environmental Science and Climate Change AI offer the opportunity to liaise with other experts in this field. The "AI for Earth Sciences" session at the recent Neural Information Processing Systems (NeurIPS) meeting or the "Artificial Intelligence for Natural Hazard and Disaster Management" session at the upcoming European Geosciences Union General Assembly are two examples of conferences featuring groundbreaking research and use cases. Finally, reports such as "Responsible AI for Disaster Risk Management: Working Group Summary" can provide additional guidance.

References

Anders, C. J., L. Weber, D. Neumann, W. Samek, K.-R. Müller, S. Lapuschkin, 2022: Finding and removing Clever Hans: Using explanation methods to debug and improve deep models. Information Fusion, 77, 261-295.

Astafyeva, E., 2019: Ionospheric detection of natural hazards. Reviews of Geophysics, 57, 1265-1288. doi: 10.1029/2019RG000668

Bach, S., A. Binder, G. Montavon, F. Klauschen, K.-R. Muller, and W. Samek, 2015: On pixel-wise explanations for non-linear classifier decisions by layer-wise relevance propagation. PLoS ONE, 10(7):e0130140.

Bauer, P., P.D. Dueben, T. Hoefler, T. Quintino, T.C. Schulthess, and N.P. Wedi, 2021: The digital evolution of Earth-system science. Nature Computational Science 1, 104-113.

Brissaud, Q., and E. Astafyeva, 2021: Near-real-time detection of co-seismic ionospheric disturbances using machine learning, Geophysical Journal International, in review.

Carrano, C., and K. Groves, 2009: Ionospheric Data Processing and Analysis. Workshop on Satellite Navigation Science and Technology for Africa. The Abdus Salam ICTP, Trieste, Italy.

Ibarreche, J., R. Aquino, R.M. Edwards, V. Rangel, I. Pérez, M. Martínez, E. Castellanos, E. Álvarez, S. Jimenez, R. Rentería, A. Edwards, and O. Álvarez, 2020: Flash Flood Early Warning System in Colima, Mexico. Sensor Journal 20(18), 5231. doi: https://doi.org/10.3390/s20185231

Iglewicz, B., and D. C. Hoaglin, 1993: Volume 16: How to Detect and Handle Outliers. The ASQC Basic References in Quality Control: Statistical Techniques.

Lu, Y., L. Luo, D. Huang, Y. Wang, and L. Chen, 2020: Knowledge Transfer in Vision Recognition. ACM Computing Surveys 53(2), 1-35. https://doi.org/10.1145/3379344

Martire, L., V. Constantinou, S. Krishnamoorthy, P. Vergados, A. Komjathy, X. Meng, Y. Bar-Sever, A. Craddock, and B. Wilson, 2021: Near Real-Time Tsunami Early Warning System Using GNSS

Ionospheric Measurements. American Geophysical Union, New Orleans, Louisiana, USA.

Mendoza-Cano, O., R. Aquino-Santos, J. López-de la Cruz, R. M. Edwards, A. Khouakhi, I. Pattison, V. Rangel-Licea, E. Castellanos-Berjan, M. A. Martinez-Preciado, P. Rincón-Avalos, P. Lepper, A. Gutiérrez-Gómez, J. M. Uribe-Ramos, J. Ibarreche, and I. Perez, 2021: Experiments of an IoT-based wireless sensor network for flood monitoring in Colima, Mexico. Journal of Hydroinformatics 23(3), 385-401. doi: https://doi.org/10.2166/hydro.2021.126

Meng, X., A. Komjathy, O. P. Verkhoglyadova, Y.-M. Yang, Y. Deng, and A. J. Mannucci, 2015: A new physics-based modeling approach for tsunami-ionosphere coupling. Geophysical Research Letters 42, 4736–4744. doi:10.1002/2015GL064610

Moreno, C., R. Aquino, J. Ibarreche, I. Pérez, E. Castellanos, E. Álvarez, R. Rentería, L. Anguiano, A. Edwards, and P. Lepper, 2019: Rivercore: IoT device for river water level monitoring over cellular communications. Sensor Journal 19(1), 127. doi: https://doi.org/10.3390/s19010127

Nativi, S., P. Mazzetti, and M. Craglia, 2021: Digital ecosystems for developing digital twins of the Earth: the Destination Earth case. Remote Sensing 13, 2119.

Nikos, K., M. Avgeris, D. Dechouniotis, K. Papadakis-Vlachopapadopoulos, I. Roussaki, and S. Papavassiliou, 2018: Edge Computing in IoT Ecosystems for UAV-Enabled Early Fire Detection. IEEE International Conference on Smart Computing (SMARTCOMP) 106-114. doi: 10.1109/SMARTCOMP.2018.00080

Simonyan, K. and A. Zisserman, 2015: Very Deep Convolutional Networks for Large-Scale Image Recognition. ICLR.

Skamarock, W.C., J.B. Klemp, J. Dudhia, D.O. Gill, L. Zhiquan, J. Berner, W. Wang, J.G. Powers, M.G. Duda, D.M. Barker, and X. Y. Huang, 2019: A Description of the Advanced Research WRF Model Version 4. NCAR Technical Note NCAR/TN-475+STR. doi: http://library.ucar.edu/research/publish-technote.

Sun, W., P. Bocchini, and B.D. Davison, 2020: Applications of artificial intelligence for disaster management. Natural Hazards 103, 2631–2689. doi: https://doi.org/10.1007/s11069-020-04124-3

Sundararajan, M., A. Taly, and Q. Yan, 2017: Axiomatic attribution for deep networks. Proceedings of the 34th International Conference on Machine Learning, 3319–3328.

Troung, N., K. Sun, S. Wang, F. Guitton, and Y. Guo, 2021: Privacy preservation in federated learning: An insightful survey from the GDPR perspective. Computer & Security 110, 10/2021. doi: https://doi.org/10.1016/j.cose.2021.102402.

Communicating for Life-saving Action: Enhancing messaging in Early Warnings Systems

By Eliot Christian (Consultant), Carolina Cerrudo, Argentina National Meteorological Service (SNM), Elizabeth Viljoen, South African Weather Service (SAWS), Nathan Cooper, International Federation of Red Cross and Red Crescent Societies (IFRC), Ronald Jackson, United Nations Development Programme (UNDP), Vanessa Gray, International Telecommunication Union (ITU), and Adanna Robertson-Quimby, WMO Secretariat

Hazards can be natural or technological (or man-made), and multi-hazard conditions are common. When hazards cascade, they can lead to a large-scale disaster. For example, a severe rainstorm can cause flooding, which may contaminate water sources, which in turn may precipitate a cholera outbreak. Disaster risk can be viewed as a function of multiple factors, including hazard, exposure, vulnerability and capacity building. To mitigate risks and avoid hazards cascading into disaster, early warning system (EWS) require partnerships, enabling environments, enhanced communication, capacity building and effective messaging using all available media (Figure 1).

The *Sendai Framework for Disaster Risk Reduction (2015–2030)* calls for nations to substantially increase the availability of and access to multi-hazard early warning systems (MHEWSs), disaster risk information and assessments for the public, emergency services providers and market sectors. EWSs seek to provide timely and actionable information to the public as well as to others involved in the emergency. EWS, also known as Emergency Alerting Systems, help people to take action to save lives and livelihoods in emergency situations, and thereby avoid situations escalating into disasters.[1]

Risk Knowledge

- Systematically collect data and undertake risk assessments
- Are the hazards and the vulnerabilities well know by the communities?
- What are the patterns and trends in these factors?
- Are risk maps and data widely available?

Dissemination & Communication

- Communicate risk information and early warnings
- Do warnings reach all of those at risk?
- Are the risks and warnings understood?
- Is the warning information clear and usable?

Monitoring & Warning

- Develop hazard monitoring and early warning services
- Are the right parameters being monitored?
- Is there a sound scientific basis for making forecasts?
- Can accurate and timely warnings be generated?

Response Capability

- Build national an community response capabilities
- Are response plans up to date an tested?
- Are local capacities and knowledge made use of?
- Are people prepared and ready to react to warnings?

Figure 1. Integrated Early Warning System (Source: ITU)

---

1   For more information, watch Early Warning Systems

Strong growth in information and communication technology networks and services is increasing the number of communication platforms and channels and bringing new opportunities to reach communities at risk. Before and during emergencies, EWSs can include: hazard threat monitoring, forecasting and prediction, risk assessment, communication and other activities that enable individuals, communities, governments, businesses and others to take timely actions that protect lives and livelihoods. It therefore requires experts in many roles pulling together and a sound understanding of threats, the environment and the users of information.

WMO promotes two widespread practices that strengthen EWSs with an emphasis on improving messaging for action:

- The international standard Common Alerting Protocol (CAP) for communicating the key facts for any kind of emergency over all available media.[2]
- Impact-based Forecasting and Warning Services (IBFWS), that is to say public messaging focused on the exposure and vulnerability of people in harm's way.

CAP and IBFWS are complementary and are often used in combination.

Common Alerting Protocol (CAP)
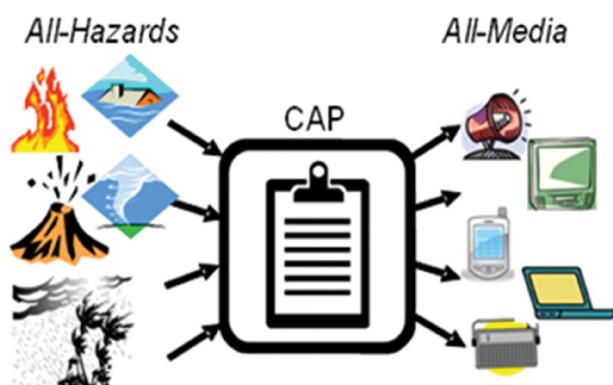
The international standard CAP (ITU-T Recommendation X.1303) provides a format for communicating the key facts for all kinds of hazards across all media:

- What is the emergency?
- Where is the affected area?
- How soon should people act?
- How bad will it be?
- How certain are the experts?
- What should people do?

Multiple authorities with distinct responsibilities are often involved in complex emergencies. For example, scientific and technical agencies are experts at characterizing a hazard and its potential impacts, but are not usually empowered to instruct people on actions such as evacuation. Their CAP alerts might instruct people to "Monitor local media for instructions from your civic authorities." The CAP

alert from a civic authority can use the emergency description provided by the scientific and technical agency and add instructions such as evacuation routes.

When an emergency is extensive, it is common to have overlapping jurisdictions, and different authorities might issue more alerts as the emergency evolves. Use of CAP by all alerting authorities to communicate key facts as the emergency unfolds helps ensure coherent messaging (Figure 2). This applies to private communications among alerting authorities and affiliates as well as to public messaging.

Figure 2. CAP as a clipboard with a standard business form that contains basic relevant information for everyone involved in the emergency.

As most emergencies are small-scale and occur often, people become familiar with routine local alerting systems such as the weather alerts. In contrast, disasters are always larger scale and much less frequent. Ideally, these routine alerting systems should be able to scale up to handle disaster early warnings. People would then be alerted to a pending disaster situation through the same system they know and trust.

Benefits of CAP – Traditionally, societies everywhere had a patchwork of alerting systems, often designed just for particular emergencies and specific communications media. A patchwork approach is not only wasteful but may also be dangerous if:

- People miss out on alerts they should have received.
- People receive alerts that are not intended for them.
- People receive confusing messages that are difficult to confirm.

---

2   For more information, watch Common Alerting Protocol. The WMO Education and Learning Moodle site also offers a self-study course on CAP

CAP works for all types of emergencies and media because messages are a mixture of information and data. They contain text information that people can read, such as a headline, event, instruction and area description, and data that are crucial for automated processing such as the area polygon and coded values.

CAP makes it quicker and easier to issue alerts. Authorities can issue alerts by making phone calls, sending e-mails and posting to online media, among others, but such activities consume valuable time, distracting from the mission of composing accurate and actionable alerts. With CAP, a single message disseminates quickly over multiple alerting channels. CAP is the fastest and the least error-prone way to disseminate emergency alerts to people in harm's way.

In a complex emergency, many types of information from many sources have to be assimilated at all scales. Alerts are a big part of that. Without CAP, alerts are difficult to get, use and share, because they are communicated in so many media and formats. Information gathering and analysis is much easier

CAP Hubs

At a national scale, the United States Integrated Public Alert and Warning System (IPAWS) is a CAP Alert Hub aggregating alerts from more than 1 600 alerting authorities.

At a regional scale, MeteoAlarm aggregates alerts from 37 National Meteorological and Hydrological Services (NMHSs) in Europe.

At the global scale:

- the WMO Alert Hub, contributed by the United States, aggregates CAP alerts from some 100 countries so far

- the Hong Kong Observatory operates the WMO Severe Weather Information Centre as a CAP Alert Hub

- *Google* operates a CAP Alert Hub to bring users relevant emergency alerts through everyday services like *Google* Search, *Google* Maps, and Android push notifications.

- The IFRC Alert Hub is another free online CAP Alert Hub. Its expected consumers include Red Cross and Red Crescent National Societies, news organizations, telecommunications providers, and international and national emergency managers and disaster relief organizations.

with CAP alerts, helping support "Shared Situational Awareness" or maintaining a "Common Operating Picture."

Many people in harm's way – for example, the blind, deaf, cognitively impaired or those who do not understand the language used in the alert – are underserved by traditional public alerting systems. The data features of CAP can be exploited to address all of these audiences, and includes automated translation.

Some hazards occur so suddenly that seconds can mean the difference between timely, life-saving alerts and alerts that arrive too late, for examples: earthquakes, tornadoes, tsunami, flash floods, volcanoes, landslides and avalanches. CAP alerts can be posted immediately through an online facility that immediately disseminates to many media.

CAP messages are digital, enabling immediate action by people and devices, such as sirens, highway signs, train controls and other automated mechanisms, that help save lives. For example, CAP was used by the National Emergency Management Organisation of Saint Vincent in April 2021 to issue a public alert for a volcanic eruption.

Although 85% of the world's population live in countries that are using CAP, uptake of CAP has been weakest among developing countries and especially the 46 Least Developed Countries (LDCs), even though those are the most vulnerable to disaster (Christian, 2022*).* This is why international organizations, international NGOs, and multi-national companies involved in emergency alerting are urged to endorse the Call to Action on Emergency Alerting:

To scale up efforts to ensure that by 2025 all countries have the capability for effective, authoritative emergency alerting that leverages the Common Alerting Protocol (CAP), suitable for all media and all hazards.

Knowing the Authoritative Sources – CAP is very useful for communicating key facts, but it is essential to know those facts are right. Given that alerting relies on large networks like the Internet, it is not possible to know all of the sources personally. How can people know which alerting sources are officially

recognized as authoritative? The international Register of Alerting Authorities was set up in 2009 by WMO and ITU for that purpose. The Register is somewhat like a referral service – you have a degree of trust in a registered alerting authority because you trust the institutions that registered them. Each WMO Permanent Representative (PR) maintains entries for their nation. The PR represents the entire nation and should register all nationally recognized alerting authorities.

CAP Alert Hubs – A CAP Alert Hub provides simplified access to aggregated CAP alerts. This is necessary given the many thousands of CAP alert news feeds now operating. The alerts can be aggregated around any theme, any time frame, or any geospatial scale: city, province, nation, region or global.

Impact-based Forecasting and Warning Services

Impact-based forecasting is a structured approach for combining hazard related information with exposure and vulnerability data to identify risk and support decision-making (Figure 3). Its ultimate objective is to encourage early action that reduces damages and loss of life from natural hazards by providing information about the hazard, about the potential impacts it may cause and recommended actions to minimize the effects of these impacts for society (UNESCAP, 2021 and WMO 2021).
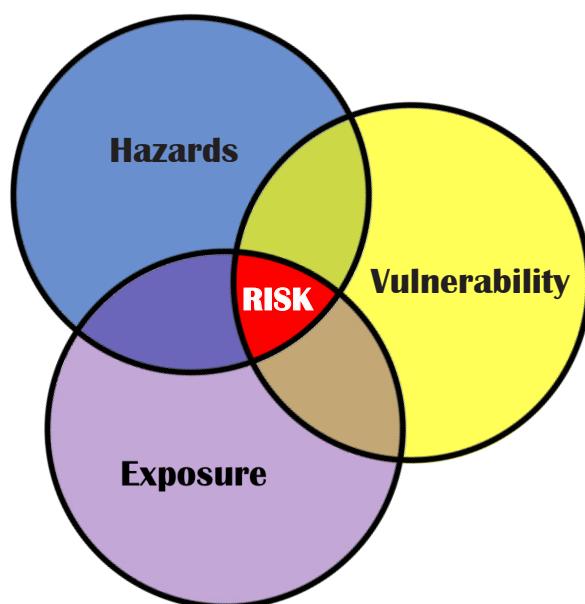
Figure 3. Risk expressed as the probability and magnitude of harm attendant on human beings and their livelihoods and assets because of their exposure and vulnerability to a hazard. (Source: WMO-No. 1150)

The introduction of the concept of risk in weather forecast represents a paradigm shift from providing information on "what the weather will be" to "what the weather will do". The *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services, Part II: Putting Multi-Hazard IBFWS in Practice* (WMO-No. 1150) focuses on partnerships, training, communication, the value of IBFWS and impact information and methodologies for analysis. Here the focus is on some of the considerations in the *Guidelines*' chapters on partnerships and communication, however, the importance of the availability of impact, exposure and vulnerability data for achieving this change of paradigm in weather forecast services cannot be understated.

Many players have a crucial role in emergency management: governments, international institutions, non-governmental organizations (NGOs), humanitarian aid agencies, volunteer organizations, community initiatives and numerous others at local, national, regional and international levels. Depending on the scale of the emergency, multiple levels of government are likely to be involved in emergency management functions in a monitoring role if not operationally. Governmental authorities can include the agency responsible for coordinating the government's response, the telecommunications regulatory authority, scientific or technical agencies with expertise in the particular natural or technological hazard that is threatening, and responder agencies such as police, firefighters, civil protection and health workers. For a disaster situation at the national or cross-border level, the Head of the Government and the Ministry of Foreign Affairs would also be involved. Many national institutions with a key role in emergency management have intergovernmental counterparts in the United Nations system that can lend assistance, especially with regard to trans-border issues and coordination.

One of the key factors of an effective IBFWS is thus the building of partnerships with this broad range of key players. The aim of such partnerships is to improve the overall response to hazards and avoid disaster situations and other adverse outcomes. Enhanced, substantial engagement between meteorological service providers and decision-makers is required with roles and responsibilities defined as clearly as possible, and resources provided to ensure ongoing and sustainable engagement.

Collaboration among the alliance of actors in the delivery of services will be key to ensure that efforts are adequately resourced, sustainable, harmonized and deliver real impact. In the Caribbean, for

example, efforts have been advanced to establish a coordinating mechanism aimed at identifying and defining a vision, agreeing on areas of priorities, and harmonizing programmes and project investments. Among the key EWS actors are scientists, technocrats, policymakers and users, as well as international, local and private sector organizations.

Training is an important part of IBFWS and its partnerships. IBFWS requires an understanding of information that is not covered during the formal training of meteorology and therefore there is a need to develop competencies within the NMHSs and partner organizations. For IBFWS to progress, NMHSs and partner organizations must provide the means to develop the required skill sets and competencies, as well as knowledge of how partners mutually use information to deliver on their mandates.
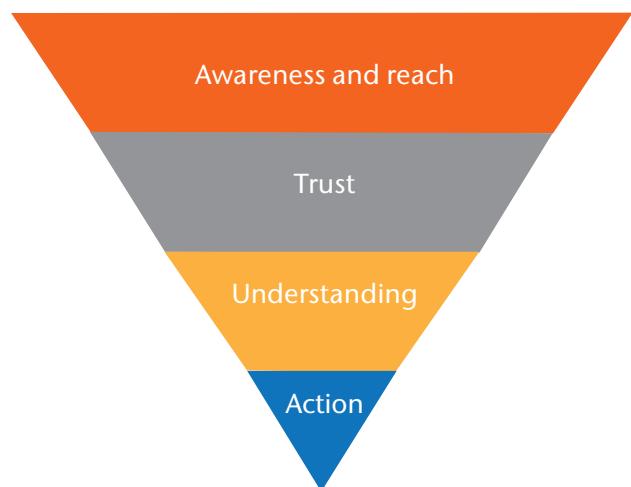
Once the essential and strategic partnerships are in place and the necessary information gathered, this information needs to be effectively communicated.

Excellence in communication is necessary for effective transfer of information, knowledge and experience between partners. Good communication practices build trust. Many countries make use of advisors with a good background understanding in meteorology to bridge communication gaps and act as links between the NMHS and its partners.

The risks associated with a hazard also need to be communicated for appropriate actions to be taken. IBFWS are about driving effective actions, and clear, understandable communication of potential risks is an essential element in achieving this. Risk communication is closely bound up with the communication of probability.

For persons to take appropriate actions in response to a hazard, they must be able to form an accurate perception of the risks – to themselves if they are individuals, or, if they are agencies, to protect the communities, facilities or infrastructure for which they are responsible. IBFWS provide an overview of the concepts of awareness and reach, and describes a structured approach to considering what level of information should be matched with each communication medium (Figure 4).

Broadcasters and other media play a crucial role in disseminating relevant information before, during and after disasters. These include wireless

Figure 4. A marketing "Reach Model" can be used to show the steps to be implemented for risk communication for forecasts and warnings:
 - Awareness and reach for understanding users' needs and access to, risk advice
 -Trust making sure users trust this advice
 -Understanding ensuring users accurately perceive their risks and know how the advice applies to them
 -Action enabling users to take the right actions on the timescales they need

and fixed service providers, as well as satellite providers, public safety radio networks, TV and radio broadcasters, and Internet service providers, among others. Today, more than 60% (4.9 billion people) of the world's population are using the Internet (ITU, 2021). This has given rise to many new emergency alerting services, including mobile apps, or app-based alerting system. IBFWSs, in turn, need agility to evolve at correspondent speed to include social media as well as other emerging communication technologies to issue messages that are clear and consistent.

Research shows that people often find emergency alert messages confusing. Sometimes messages are understood but the phrasing does not prompt actions. The International Federation of Red Cross and Red Crescent Societies (IFRC) *Public awareness and public education for disaster risk reduction: key messages* offers a field tested set of globally relevant messages for different hazard types and alert levels (Figure 5). Messages can be adapted and harmonized by national governments and civil society organizations, leading to a common, agreed upon set of messages that can be transmitted in tandem with hazard warnings. This helps to ensure that people in a given country receive the same information about what actions to take to stay safe no matter what the source. PAPE messages are based

Public awareness and public education for disaster risk reduction: key messages

www.ifrc.org
Saving lives, changing minds.

International Federation
of Red Cross and Red Crescent Societies

Figure 5. The IFRC's Public awareness and public education for disaster risk reduction: key messages offers a field tested set of globally relevant messages for different hazard types and alert levels

on case studies where individuals at risk received and understood emergency messages then took the actions prompted.

The Internet, social networks, cellular operators and smart apps can communicate certain kinds of information and official alerts to help keep people informed. Warning systems based on sirens or public address systems connected to sensors can be useful to quickly trigger an alert in certain settings when a set threshold is reached. Satellite networks provide communications services that have very little dependence on terrestrial infrastructure. Private telecommunication services include networks serving firefighters, police, ambulances, relief teams, civil protection, transport, and utilities as well as other public and private sector entities.

The ITU estimated that by the end of 2021, 95% of the world's population would have access to a mobile broadband network. Active mobile broadband subscriptions worldwide reached more than 6 billion in 2021. Mobile services have become an essential part of most people's lives. A growing number of countries are taking advantage of cellular networks and technologies to send alerting messages, including location-based technologies, such as Short Message Service (SMS) or Cell Broadcast (CB). Some are putting specific regulations in place. As telecommunication networks, services and platforms grow, they are shaping the way people acquire information and playing an increasingly important role in EWSs by offering more options for delivering timely alerting messages to those at risk. For example, sending the same CAP alert message over multiple platforms increases coverage and impact, and minimizes confusion. CAP offers the best solution for communicating to all of these audiences – public, private, commercial – in any emergency situation (Figure 6).

CAP : All-Hazards, All-Media Message Format

| Hazards | Common Alerting Protocol | Communication channels | Actions |

Figure 6. CAP alert by itself does not include everything about the emergency, it just carries some facts that everyone needs. (Source: ITU)

Demonstrating the value of IBFWS

Numerous methods exist for the collection of weather information, however, there is no global standard for the collection of impact data, which make it difficult to demonstrate the value of IBFWS. However, impact information can be collected from various sources, including government ministries, newspapers and universities.

The socioeconomic benefits of IBFWS need to be validated by collecting and analysing case studies that can demonstrate their value to key decision-makers in government and other sectors as well as current and potential partners. There is no one measure of the value of IBFWSs, but there are three broad categories for measuring such value: timeliness, relevance and outcomes. Some examples of how value can be measured are provided in Chapter 5 of the afore mentioned *WMO Guidelines*. It is important to measure the value as this can enhance products and services.

Creating enabling environments

National legislation, rules and regulations are very important to create an enabling environment for emergency management. These can define the responsibilities of those who play a role in emergency management and determine coordination mechanisms. One national-level planning document that is especially relevant to EWS is the National Emergency Telecommunications Plan (NETP). An NETP sets out a strategy to ensure communications availability during all phases of the disaster, by promoting coordination across all levels of government, between public and private organizations, and within communities at risk. Some countries have also passed specific regulations to ensure that communities at risk benefit from digital platforms and communication channels. For example, the European Electronic Communications Code Article 110(1) stipulates that by 21 June 2022:

- Public warning system must be able to send geo-targeted emergency alerts. (Official Journal of the European Union, 2018)

- The public alerting system must be able to operate without an opt-in requirement. (Official Journal of the European Union, 2018)

- They must be accurate enough to reach a very high percentage of people quickly, including visitors in their native languages. (Official Journal of the European Union, 2018)

A lot remains to be done

For all kinds of hazards and across all media, the international standard CAP provides a format for communicating the key facts about an emergency. IBFWS offer a structured approach for combining hazard related information with exposure and vulnerability data to identify risk and support decision-making, with the ultimate objective of encouraging early action that reduces damages and loss of life from natural hazards. As complementary practices, the benefits of using CAP and IBFWS to enhance EWSs are very evident. Even though much progress has been made globally to advance these practices, there still remains a lot to be done.

A 2018 WMO commissioned[3] evidence-based assessment of EWSs during the 2017 Caribbean hurricane suggests that losses of lives, livelihoods and assets are still excessive. It goes further to indicate that "with climate change and rapid development along coastlines, strengthening capacity to issue multi-hazard early warning that lead to effective response by institutions and people remains a priority...."

The Sendai Framework advocates EWS that empower individuals and communities threatened by hazards to act in sufficient time and in an appropriate manner to reduce the possibility of personal injury, loss of life and damage to property and the environment. In pursuit of the *Sendai Framework's 2030 goals*, CAP and IBFWS, enabling environments, enhanced collaboration and partnerships and communication are integral parts of more effective disaster risk reduction efforts.

References

Christian, E., 2022: CAP Implementations Status Report.

International Telecommunication Union (ITU), 2021: *Internet, Use, Facts and Figures*.

Official Journal of the European Union, 2018: Directive 2018/1972 of the European Parliament and of the Council, 15 December.

United Nations Economic and Social Commission for Asia and the Pacific (ESCAP)/World

---

3   Funded by the Climate Risk and Early Warning Systems initiative

Meteorological Organization (WMO), 2021: *Manual for Operationalizing Impact-based Forecasting and Warning Services (IBFWS)*, Thailand.

WMO, 2021: *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services, Part II: Putting Multi-Hazard IBFWS into Practice* (WMO-No. 1150). Geneva.

WMO, 2015: *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150). Geneva.

Stepping Up Support to the UN and Humanitarian Partners for Anticipatory Action

By Alicia Pache, Pamela Probst, Isabelle Bey and Thomas Röösli, MeteoSwiss; David N. Bresch, ETH Zurich and MeteoSwiss; Andrew Kruczkiewicz, Red Cross Red Crescent Climate Centre; Ege Seçkin and Ruth Hanau Santini, PhD, World Food Programme (WFP); Kara Devonna Siahaan, Gantsetseg Gantulga and Lydia Cumiskey, International Federation of Red Cross and Red Crescent Societies; and Gavin Iley, WMO Secretariat

The High-Level Humanitarian Event on Anticipatory Action: A Commitment to Act Ahead of Crisis in New York in September 2021 gathered senior officials from the United Nations, humanitarian and donors agencies, and government. It urged all to "act ahead of disaster" to mitigate and reduce impacts and thereby save lives and livelihoods. The vital importance of **Anticipatory Action** was made evident to all.

The landmark Sendai Framework for Disaster Risk Reduction 2015–2030 clearly references in Target G the importance of the underpinning Early Warning Systems (EWSs) to substantially increase the availability of and access to multi-hazard early warnings and disaster risk information and assessments to people by 2030. By 2015, the United Nations Office for Disaster Risk Reduction (UNDRR, then UNISDR) had already developed the initial Early Warning System Checklist outlining the key

elements required in developing people centred Early Warning Systems. The Checklist has since been updated through the joint efforts of UNDRR and WMO in 2018.

It could be argued that the concepts of Early Warning and Anticipatory Action have been recognized for many, if not thousands of years. Throughout history communities have looked to nature to predict and prepare for the "weather" ahead. This is still the case today, farmers or an indigenous community still look to harness all important local knowledge to help predict the weather over the next few days or hours. A study of archives has shown that some early weather forecasts were developed after a specific disaster. For example, in the United Kingdom the first storm warning forecast was produced following the sinking of the Royal Charter and the loss of over 400 lives.

Flooded villages and fields the day after the cyclone struck Bangladesh in 1991. (Source: Staff Sergeant Val Gempis/USAF)

A damaged village surrounded by flooded fields, nearly three weeks after the cyclone. (Source: Airman 1st Class Cheryl Sanzi/USAF)

The 1991 Bangladesh cyclone caused a 6.1 m (20 ft) storm surge, which inundated the coastline. The cyclone caused an estimated 138,866 deaths and about US$1.7 billion (1991 USD) in damage. Before the cyclone moved ashore, an estimated 2–3 million people had been evacuated the Bangladeshi coast. In a survey by the American Centers for Disease Control and Prevention, the main reason more people did not evacuate was underestimating the severity of the cyclone.

Today, the hydrometeorological community continues to improve and enhance services by learning from each time it is called into action. A noteworthy example of this occurred in 1991 when a devastating cyclone hit Bangladesh, resulting in the loss of tens of thousands of lives. While the hydrometeorological community had forecast the cyclone, an important lesson was learnt: forecasts must drive action. As a result, forecasts processes were re-designed and coupled with actions, informing the eventual development of the Cyclone Preparedness Program (CPP), which today helps to protect vulnerable communities, saving many lives every year. (*Haque, C.E., 1997. Atmospheric hazards preparedness in Bangladesh: a study of warning, adjustments and recovery from the April 1991 cyclone. In Earthquake and Atmospheric Hazards (pp. 181-202). Springer, Dordrecht*)

Having understood the principles of Anticipatory Action and developed an EWS tool set, where and how is the hydrometeorological community today supporting United Nations efforts as well as those of the humanitarian sector? How can the expertise within National Meteorological and Hydrological Services (NMHSs) be leveraged to support progress towards Anticipatory Action? And, how can climate and weather-related actions and decisions within the humanitarian sector inform future priorities of the hydrometeorological community?

Anticipatory Action – Globally

The United Nations Inter-Agency Standing Committee (IASC) is the longest-standing and highest-level humanitarian coordination forum of the United Nations system where it leads policy formulation, priority setting and coordination of crisis response. One of the many workstreams of the IASC decision-making machinery is the Risk, Early Warning and Preparedness Group, which brings together diverse technical experts from across the UN and other humanitarian organizations to assess potential or escalating humanitarian risks. In support of the IASC, WMO harnesses analyses from NMHSs and feeds these into discussions with meteorological experts from International Federation of Red Cross and Red Crescent Societies (IFRC), World Food Programme (WFP), Food and Agriculture Organization of the United Nations (FAO) who assess the potential for hydrometeorological risks. This analysis is then combined with that from other sectors to inform Anticipatory Actions, preparedness, advocacy or specific interventions. Once complete, these multi-sector assessments are provided to senior IASC decision-makers and through them

to UN country-level resident and humanitarian coordinators.

The IASC convening power also comes to the fore when La Niña or El Niño events threaten with detailed impact-based analytical and stakeholder engagement processes commencing once WMO and International Research Institute for Climate and Society (IRI) forecasts reach a specific threshold. Outreach activities alongside regional partners, including experts from the WMO Regional Climate Outlooks Forums, are facilitated to ensure the required information reaches decision-makers responsible for triggering Anticipatory Action, if necessary.

WMO is now looking to further enhance and broaden this support to UN and humanitarian agencies. The WMO Coordination Mechanism will harness the important underpinning contributions from WMO Members to further support humanitarian action. A component of this work is receiving generous support from Switzerland through MeteoSwiss. The latter part of this article will look at how MeteoSwiss is collaborating with ETH Zurich to provide a prototype for WMO Coordination Mechanism.

IFRC at the heart of Anticipatory Action

IFRC is at the forefront of Anticipatory Action. It has a long history of harnessing expertise from civil societies, governments and other actors to build highly effective and efficient Anticipatory Action systems to prepare and protect those at risk. Below, Gantsetseg Gantulga from IFRC, and Andrew Kruczkiewicz (IFRC & IRI) and Lydia Cuminskey from the Anticipation Hub describe a number of successful Anticipatory Action initiatives.

Anticipatory actions in practice are realized and implemented by local actors. For the Red Cross and Red Crescent (RCRC) network, the staff and volunteers of National Societies are closest to, and sometimes part of, the communities they serve, equipped with local knowledge and practices at the forefront of disaster and crisis response. Since 2018, IFRC has allocated a funding mechanism, Forecast-based Action by Disaster Relief Emergency Fund (FbA by the DREF), to enable anticipatory actions for National Societies with approved and pre-agreed work-plans, known as Early Action Protocols (EAP).

First and foremost, accurate, available and accessible meteorological information, provided by WMO Members and other subject matter experts, makes it possible to plan the early actions. For

example, in Vietnam, the Institute of Meteorology, Hydrology and Climate Change conducted a study which showed that the frequency and duration of heatwaves have increased in the last 58 years and are projected to further increase. To this end, Vietnam Red Cross is implementing a forecast-based financing project focusing on heat waves in Hanoi, with a two-component trigger based on the value of heat index with a 37 ° threshold. The early actions implemented were the establishment of community cooling centres to offer an air-conditioned place to vulnerable outside worker groups and providing water, cold tea and fresh towels to visitors.

In 2019, Ecuador Red Cross had their EAP for volcanic ash approved to be funded as a Forecast-based Action by the Disaster Relief Emergency Fund. This protocol seeks to reduce health impacts on vulnerable populations and damages to crops and livestock arising from exposure to volcanic ashes. The local RCRC volunteers work with the communities – including provision of training and awareness raising – to implement the required EAP up to 7 days ahead of a potential eruption, which together with the prepositioning of essential supplies enables communities to swiftly take the required action when needed. On 21 September 2020, the Ecuadorian Red Cross activated its EAP for volcanic ash in response to the significant increase in the level of eruptive activity of the Sangay volcano. A couple of days later, the National Society had managed to timely reach 1000 families in 7 different communities with health and livelihood kits and cash-based interventions, which were delivered using COVID-19 sensitive protocols.

In Bangladesh, an EAP for cyclones covering 13 sea-facing coastal districts was approved in 2018. In May 2020, when Cyclone Amphan reached the pre-agreed 30-hour impact threshold, it triggered outreach, communications and warning protocols. This provided an approximately 30-hour window to reach the population and support their evacuation ahead of impact. Early actions were implemented in 10 districts and the National Society managed to reach 36 000 people with evacuation support, food, water and first aid services in the evacuation centres. This was a notable success, reaching well in excess of the initial plan to target and support 20 000 people.

Equally important is capacity strengthening of local RCRC National Societies' disaster risk management (DRM) systems, policies and strategies to enable the anticipatory actions. For instance, there is the case of the Forecast-based Financing (FbF) programme in Morocco supported by the German Red Cross.

Bangladesh tropical cylcone practice drill
(Source: IFRC)

After establishing forecasts for early actions, it was essential to assess and develop a plan of action to strengthen the overall institutional preparedness of the Moroccan Red Crescent. This involved developing an overarching DRM strategy where anticipatory actions are an integral part, establishing procurement systems at the headquarters and branches, and training branch volunteers on community early warning systems for early actions.

To ensure the paradigm continues to shift from reactive emergency response to proactive anticipatory action, strong cross-sector and multi-stakeholder collaboration is needed between academia, humanitarian and development actors. As indicated in the examples, country level leadership from national hydrometeorological institutions, disaster risk management bodies, universities in-country and RCRC Societies is central to ensuring that anticipatory action becomes the new norm and is scaled-up to reach more people at risk. While integrating anticipatory action within standard operating procedures within organizations is a crucial step that is needed immediately, the enhancement of national level capacity should also include a longer term vision to enable future generations of anticipatory action personnel – across science, policy and practice. Doing so requires more direct engagement with national universities and other academic institutions to design programs, degrees and specializations related to the development,

dissemination and translation of quality controlled meteorological data. Programs also need to include anticipatory action and its sub-elements such as triggers, identification of the most effective early actions for specific hazards development, monitoring and evaluation, and governance and mandates of forecast data. An example of a successful partnership between RCRC, an NMHS and national universities can be found in Mongolia where the Mongolian Red Cross developed an EAP for extreme winters, locally known as dzud, with the Mongolia University

IFRC dzud response in Mongolia (Source: IFRC)

of Life Sciences providing vital analytical services. This example demonstrates one way to design collaboration, and should be used to have discussions around higher-order design of academic curricula involving applied climate and meteorological science more broadly.

There is also a need to share knowledge and learnings so that the Anticipatory Action community

Mongolia's Information and Research Institute of Meteorology, Hydrology and Environment estimates that nationwide *dzuds* will occur every four to five years, instead of every 10. Here's the percentage of the total national livestock population that perished each winter, including the 21.5 million total livestock lost during the 1999-2002 and 2009-2010 *dzuds.*

Mongolia expects harsher and more fequent dzuds Source: National Statistical Office of Mongolia/Nick Underwood/NPR

can learn from good practice elsewhere. The recently established Anticipation Hub serves that purpose.

Anticipation Hub

Anticipatory action is being embedded in the humanitarian system, particularly within the programmes and plans of the RCRC) Network, UN agencies, WMO Members and NGOs, who work in close collaboration with government agencies, universities and research institutions, and other stakeholders. Since 2014, these actors have been generating extensive knowledge, lessons and expertise on the design, implementation and review of anticipatory action initiatives. Implementation has proved successful when forecast-based triggers and EAPs are co-designed with the NMHS and other government agencies.

Global and regional dialogue platforms on anticipatory humanitarian action have brought this community together to exchange knowledge and collaborate on anticipatory action. In 2020, Anticipation Hub was launched to further nurture this community by continuously facilitating knowledge exchange, learning, guidance and advocacy around anticipatory action both virtually and in-person. Anticipation Hub is a joint initiative between the German Red Cross (GRC), IFRC and the RCRC Climate Centre with 80+ partners across the RCRC Movement, universities, research institutes, non-governmental organizations NGOs, UN agencies, governments, NMHSs, donors and other network initiatives. Anticipation Hub seeks to engage with, learn from and inspire actors across sectors to bridge the humanitarian, development and climate sectors, and to capture synergies between investments in disaster risk management, early warning systems and anticipatory action.

To stimulate collaboration, innovation and co-creation around different thematic topics, Anticipation Hub hosts global working groups. As an example, the Earth Observation (EO) for Anticipatory Action working group brings together the producers and users of forecasts to better understand users' needs and to create opportunities to inform the testing of ideas generated in projects. Furthermore, the Hub connects learning and experiences captured through multi-stakeholder national and regional technical working groups on anticipatory action, for example in the Asia-Pacific Region. Such working groups are vital for facilitating multi-stakeholder coordination between humanitarian and hydrometeorological actors. For example, they can be used to co-develop Impact-Based Forecasts

(IBF) and harmonize triggers for early action, as recommended by the *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services* (WMO-No. 1150), Part II, the RCRC and the Met Office (UK). National societies, NGOs and other local actors can support government efforts to ensure warnings are disseminated, understood and used for early action. The Anticipation Hub can help to strengthen local actors' access to knowledge, guidance and expertise, for example through blog posts, training materials, and databases of early action and triggers.

Research partnerships are also successfully supporting the co-creation of triggers and early action protocols, as well as building the evidence-base for early action. In the Forecasts for AnTicipatory HUManitarian action (FATHUM) project, for example, scientists from the University of Reading worked with government agencies in Uganda to capture local knowledge to enhance the skill of global flood forecasts as an interim solution to trigger early action. In the Forecast-based Preparedness Action (ForPaC) project, Kenyan and UK based researchers analysed the skill of seasonal forecasts and its potential for anticipatory action. While an interdisciplinary academic consortium between universities in the Bangladesh, Lesotho, Mozambique, Namibia, Philippines, Uganda and US aims to generate more evidence of the benefits of anticipatory action. The Anticipation Hub is uniquely positioned to host the growing knowledge and learning emerging from such partnerships, which bridge science, policy and practice.

W4UN Pilot Project overview

MeteoSwiss Weather4UN Pilot Project

The Weather4UN project aims to contribute to the establishment of the WMO Coordination Mechanism, which will enhance WMO support to UN and other humanitarian agencies. The project itself consists of two complementary Work Packages. The first one seeks to improve access to products, information, expertise and added-value advice provided to the

humanitarian community by harnessing authoritative products made available by WMO Members. The second Work Package facilitates collaboration between academia (ETH Zuerich in particular), the IFRC and WMO Members to enhance impact analysis ahead of potentially destructive hydrometeorological events. Both packages aim to rely on authoritative products, to use probabilistic weather forecasts and to follow a globally consistent approach. The project will capitalize on NHMSs capacities and enhance the close collaboration between WMO Members, the Secretariat, and UN and other humanitarian agencies.

Most WMO Members already work in partnership with stakeholders to combine hazard, exposure and vulnerability data to estimate the impacts of hydrometeorological events to inform forecast-based financing, decisions and Anticipatory Actions. Thus, a common understanding and definition of these three components (hazard, exposure, vulnerability) are needed to harness impact forecasts to support Anticipatory Actions. To this end, Work Package II aims to deliver a multi-hazard, multi-sector risk outlook prototypes using probabilistic and authoritative hydrometeorological forecasts. The prototype will be implemented within the globally consistent probabilistic open-source risk model CLIMADA (Aznar-Siguan and Bresch, 2019), developed at ETH Zurich.

Hydrometeorological forecasts as well as exposure and vulnerability information come with high degrees of uncertainty. Work Package II will therefore harness probabilistic forecast information to quantitatively assess uncertainties in exposure and vulnerability to facilitate a structured decision-making process, building on an existing first version of such an impact-based forecasting system (Röösli et al. 2021).

During the development and prototyping phases, Work Package II will target the needs of the IFRC in particular, enabling IFRC to integrate this information into their existing decision support tools. Over time, as the system matures, the intention is to catalyse discussions with other humanitarian agencies and WMO Members to make this information, tools and the underpinning knowledge available to the wider WMO family, the UN and other humanitarian agencies.

WMO and Anticipatory Action

Anticipatory Action touches many aspects of society in one way or another, however, the underpinning

support provided by WMO Members is the foundation stone upon which weather, climate and water-related Anticipatory Action is built. WMO support to Anticipatory Action starts at the very beginning of forecast production as Members produce the vital observations, both terrestrial and space-based, required to feed the modern forecasting engine, which is built on years of scientific research and innovation and is framed under the WMO Global Data-processing and Forecasting System (GDPFS).

GDPFS is a three-level system with various functions carried out at the global level by the World Meteorological Centres (WMCs), at the regional level by Regional Specialized Meteorological Centres (RSMCs), including Regional Climate Centres, and at the national level by National Meteorological Centres (NMCs). WMCs produce high quality data and products, which are shared with all Members for assimilation into their own forecasting processors. RSMCs and NMCs then work with stakeholders and communities to understand specific vulnerabilities and risk appetites to inform the development and production impact-based forecasts. Thereby, NMCs ensure forecasts catalyse actions – that is to say, they are "useful, useable and used".

Next steps

Anticipatory Action should be a routine – almost a sub-conscious thought in all our lives. For Anticipatory Action to be integrated into community level policy and decision-making, governments and development partners should prioritize mainstreaming Anticipatory Action across all elements of their portfolio. To do so, engagement and support to the hydrometeorological community must be increased. Concerted efforts are needed between humanitarian, climate and development actors to break down silos and ensure that more at-risk populations act ahead of disasters.

The hydrometeorological community must also develop and enhance links with academia as its often said that while governments change, policy moves on and society evolves, academia provides a constant space for innovation and discussion. It is vital, to embed Anticipatory Action principles in the next generation of leaders through curriculum development in climate, meteorological and disaster risk related disciplines, and to incentivize substantive connectivity between universities. The hydrometeorological community also needs to constantly review operational and research activities to seek out areas for improvement. For example, during El Niño and La Niña events, seasonal forecasting in certain parts of the world has more skill, meaning that this information has perhaps a higher degree of reliability than it does at other times of year. Might further research and innovation identify other forecast-to-impact linkages to exploit?

One final thought: Should Anticipatory Action only be about mitigating impacts from destructive meteorological and climatological events? Can we also exploit this expertise to take advantage of predicted favourable conditions and therefore realize additional opportunities perhaps not currently considered? Maybe that could be a topic for a future edition of the *Bulletin*.

Regional trends in extreme events in the IPCC 2021 report

By Valérie Masson-Delmotte and Panmao Zhai

This summary is based on the Intergovernmental Panel on Climate Change (IPCC) Working Group 1 contribution to the 6th Assessment Report (AR6): "Climate Change 2021: The Physical Science Basis." Around 1/3 of the report is dedicated to regional climate information, with an assessment of observed and projected changes in climatic impact-drivers which are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. This is the physical science contribution to the assessment of climate-related risks, without anticipating whether their impacts provide potential opportunities or are detrimental (i.e., as for hazards). More detailed information on extreme events in a changing climate is available in the full report, especially in Chapter 11 (Weather and climate extreme events in a changing climate), Chapter 9 (Ocean, cryosphere and sea level change), Chapter 12 (Climate change information for regional impact and for risk assessment), and the Technical Summary as well as in the AR6 online interactive atlas (interactive-atlas.ipcc.ch). Syntheses of regional changes are also available in 2-page summaries

for large regions (regional fact sheets, www.ipcc.ch/AR6/WG1).

Human-induced climate change is already affecting many weather and climate extremes in every region across the globe

During the last decade, the increase in global surface temperature has reached around 1.1 °C above 1850–1900 level. This observed warming is the best estimate of human caused warming. It is now unequivocal that human influence has warmed the climate system.

The evidence for observed changes and attribution to human influence has strengthened for many types of extreme events since the previous IPCC assessment was published in 2013 (AR5). This is particularly the case for heatwaves, extreme precipitation events, droughts, tropical cyclones, marine heatwaves, extreme sea levels, and compound extremes (Table 1).
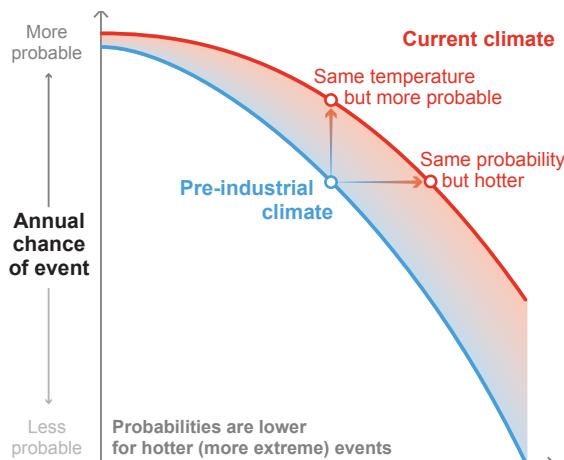
Table 1. Summary table on observed changes in extremes, their attribution since 1950 (except where stated otherwise), and projected changes at +1.5 °C, +2 °C and +4 °C of global warming, on global and continental scales. (Source: AR6 WGI TS, Table TS.2)

Change in Indicator	Observed (since 1950)	Attributed (since 1950)	Projected at GWL (°C)		
			+1.5	+2	+4
Warm/hot extremes: Frequency or intensity	↑	✓ Main driver	↑	↑	↑
Cold extremes: Frequency or intensity	↓	✓ Main driver	↓	↓	↓
Heavy precipitation events: Frequency, intensity and/or amount	↑ Over majority of land regions with good observational coverage	✓ Main driver of the observed intensification of heavy precipitation in land regions	↑ in most land regions	↑	↑ in most land regions
Agricultural and ecological droughts: Intensity and/or frequency	↑ in some regions	✓ in some regions	↑ in more regions compared to observed changes	↑ in more regions compared to 1.5°C of global warming	↑ in more regions compared to 2°C of global warming
Precipitation associated with tropical cyclones	↑	✓	↑ Rate +11%	↑ Rate +14%	↑ Rate +28%
Tropical cyclones: Proportion of intense cyclones	↑	✓	↑ +10%	↑ +13%	↑ +20%
Compound events: Co-occurrent heatwaves and droughts	↑ (Frequency)	✓ (Frequency)	↑ (Frequency and intensity increases with warming)		
Marine heatwaves: Intensity & frequency	↑ (since 1900)	✓ (since 2006)	↑ Strongest in tropical and Arctic Ocean		
Extreme sea levels: Frequency	↑ (since 1960)	✓	↑ (Scenario-based assessment for 21st century)		

medium confidence   likely/high confidence   very likely   extremely likely   virtually certain

Understanding about past and future changes in weather and climate extreme events has increased due to better observation-based datasets, physical understanding of processes, a greater proportion of scientific literature combining different lines of evidence, and improved accessibility to different types of climate models. New techniques and analyses drawing on several lines of evidence have provided heightened confidence when attributing changes in regional extreme events to human influence.

In particular, event attribution is now an important line of evidence for assessing changes in extremes on regional scales. The attribution of extreme events has emerged as an important field for climate research with a growing body of literature. It provides evidence that greenhouse gases and other external forcings have affected individual extreme events by disentangling anthropogenic drivers from natural variability. The regional extreme events that have been studied are geographically uneven. A few events, for example, extreme rainfall events in the United Kingdom, heatwaves in Australia, or Hurricane Harvey that hit Texas in 2017, have been heavily studied. While many highly impactful extreme events have not been studied, particularly in the developing world where event attribution studies are generally lacking for various reasons, including the lack of observational data, of reliable climate models and of scientific capacity. Though the events that have been studied are not representative and results may also be subject to selection bias, the large number of such studies provide evidence that changes in the properties of these local and individual events are in line with expected consequences of human influence on the climate and can be attributed to external drivers.

Figure 1. Changes in climate result in changes in the magnitude and probability of extremes, illustrated here for hot events (Source: AR6 WG1, Chapter 11, FAQ11.3)

At the global scale, hot extremes (including heatwaves) (Figure 1) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver of these changes (Figure 2).

Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. While cities intensify human-induced warming locally, no-till farming, irrigation and crop expansion have attenuated increases in summer hot extremes in some regions, such as central North America (*medium confidence*).
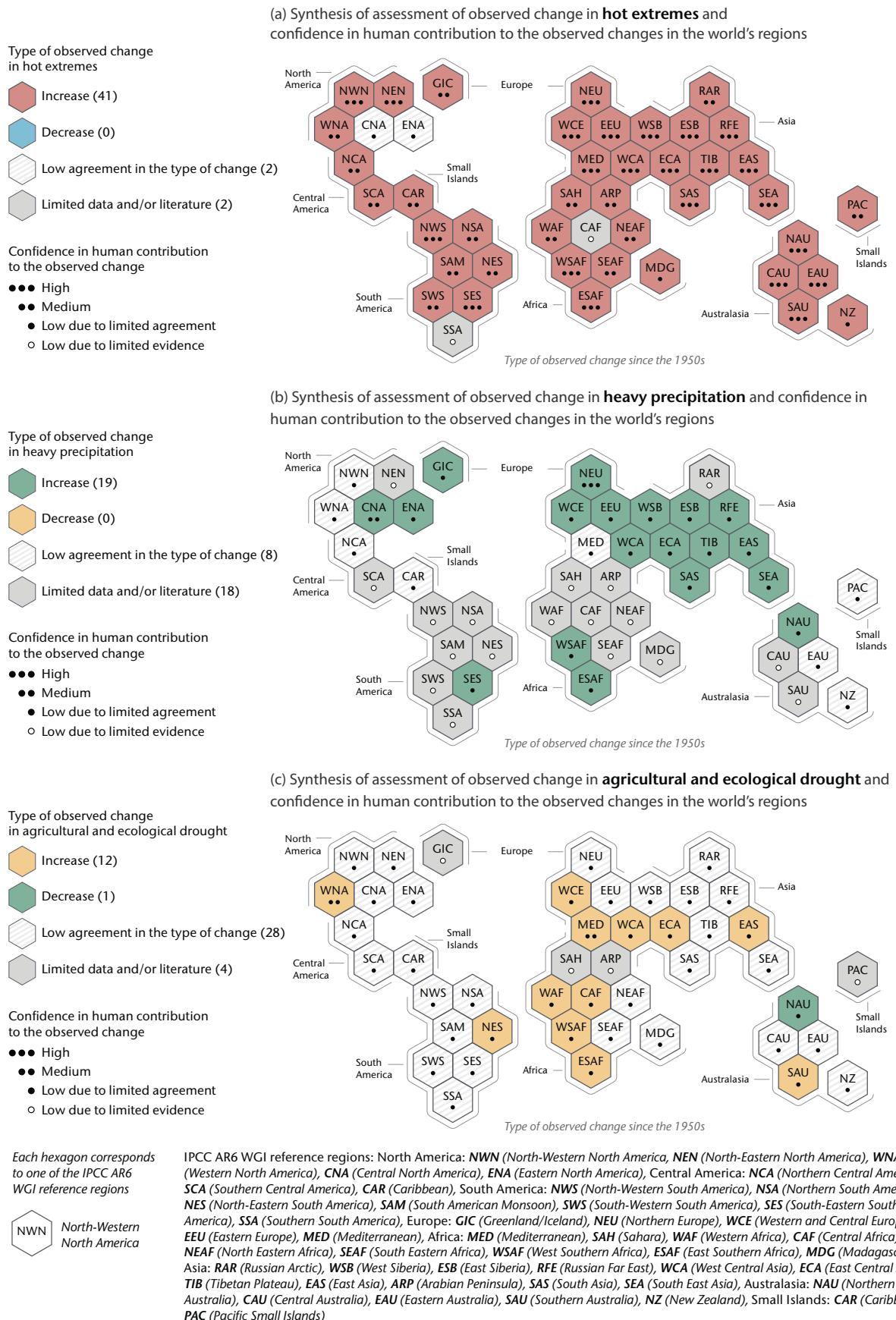
Marine heatwaves have approximately doubled in frequency since the 1980s, and since at least 2006 human influence has very *likely* contributed to most the increasing frequency.

The frequency and intensity of heavy precipitation events have increased since the 1950s over most land areas for which observational data are sufficient for trend analysis (in particular, North America, Europe and Asia), and human-induced climate change is *likely* the main driver (Figure 2).

Human-induced climate change has contributed to increases in agricultural and ecological droughts in drying regions due to increased land evapotranspiration (Figure 3).

It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and that the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward. These changes cannot be explained by internal variability alone. Confidence in long-term (multi-decadal to centennial) trends on the frequency of all-category tropical cyclones is low. Event attribution studies and physical understanding indicate that human-induced climate change increases the heavy precipitation associated with tropical cyclones (*high confidence*) but data limitations inhibit clear detection of past trends on the global scale.

Human influence has *likely* increased the chance of compound extreme events since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (h*igh confidence*); fire weather in some regions (e.g. southern Europe, northern Eurasia, the USA,

(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in hot extremes

■ Increase (41)

■ Decrease (0)

▨ Low agreement in the type of change (2)

⬡ Limited data and/or literature (2)

Confidence in human contribution to the observed change
●●● High
●● Medium
● Low due to limited agreement
○ Low due to limited evidence

Type of observed change since the 1950s

(b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in heavy precipitation

■ Increase (19)

■ Decrease (0)

▨ Low agreement in the type of change (8)

⬡ Limited data and/or literature (18)

Confidence in human contribution to the observed change
●●● High
●● Medium
● Low due to limited agreement
○ Low due to limited evidence

Type of observed change since the 1950s

(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in agricultural and ecological drought

■ Increase (12)

■ Decrease (1)

▨ Low agreement in the type of change (28)

⬡ Limited data and/or literature (4)

Confidence in human contribution to the observed change
●●● High
●● Medium
● Low due to limited agreement
○ Low due to limited evidence

Type of observed change since the 1950s

Each hexagon corresponds to one of the IPCC AR6 WGI reference regions

⬡ NWN | *North-Western North America*

IPCC AR6 WGI reference regions: North America: **NWN** (North-Western North America, **NEN** (North-Eastern North America), **WNA** (Western North America), **CNA** (Central North America), **ENA** (Eastern North America), Central America: **NCA** (Northern Central America), **SCA** (Southern Central America), **CAR** (Caribbean), South America: **NWS** (North-Western South America), **NSA** (Northern South America), **NES** (North-Eastern South America), **SAM** (South American Monsoon), **SWS** (South-Western South America), **SES** (South-Eastern South America), **SSA** (Southern South America), Europe: **GIC** (Greenland/Iceland), **NEU** (Northern Europe), **WCE** (Western and Central Europe), **EEU** (Eastern Europe), **MED** (Mediterranean), Africa: **MED** (Mediterranean), **SAH** (Sahara), **WAF** (Western Africa), **CAF** (Central Africa), **NEAF** (North Eastern Africa), **SEAF** (South Eastern Africa), **WSAF** (West Southern Africa), **ESAF** (East Southern Africa), **MDG** (Madagascar), Asia: **RAR** (Russian Arctic), **WSB** (West Siberia), **ESB** (East Siberia), **RFE** (Russian Far East), **WCA** (West Central Asia), **ECA** (East Central Asia), **TIB** (Tibetan Plateau), **EAS** (East Asia), **ARP** (Arabian Peninsula), **SAS** (South Asia), **SEA** (South East Asia), Australasia: **NAU** (Northern Australia), **CAU** (Central Australia), **EAU** (Eastern Australia), **SAU** (Southern Australia), **NZ** (New Zealand), Small Islands: **CAR** (Caribbean), **PAC** (Pacific Small Islands)

Figure 2. Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes (Source: AR6 WGI SPM, Figure SPM.3)

Figure 3. Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming (Source: AR6 WGI SPM, Figure SPM.6)

Climate **average**

Climate **extreme**

Future **changes in temperature** averages and extremes will be **similar**

0°C   2   4   6   8°C

Warmer

Climate **average**

Climate **extreme**

Future **changes in precipitation** averages and extremes can be **very different**

-40%   -20   0%   20   40%

Drier   Wetter

Figure 4. Illustration of the spatial patterns of changes in the warmest three-month season temperature and annual mean precipitation, and extreme temperature and precipitation (simulations for 4°C global warming by 2100) (Source: AR6 WGI Chapter 11, FAQ 11.1)

Changes in storms with increasing global warming

Global

Regional

Tropical cyclones
Extratropical cyclones
Atmospheric river

Average and maximum precipitation rates increase with warming

Tropical cyclones

Increase in strength

Decreased or unchanged genesis frequency

Extratropical cyclones

Changes (increase or decrease) in wind speed following storm tracks poleward shift in some regions

Tropical cyclones

Decreased exposure   Increased exposure   Slower motion

Severe convective storms

Longer season

60°N
30°N
equator
30°S
60°S

Figure 5. Summary schematic of past and projected changes in tropical cyclone, extratropical cyclone, atmospheric river, and severe convective storm behaviour. (Source: AR6 WGI Chapter 11, Figure 11.20)

Australia); and compound flooding in some locations, including the US coastlines (*medium confidence*).

Global mean sea level rose around 0.20 metres from 1901 to 2018, and the rate of rising has accelerated

since the late 1960s. Regional sea-level change has been the main driver of changes in extreme still water levels across the quasi-global tide gauge network over the twentieth century. High tide flooding events that occurred five times per year during the period 1960–1980 occurred on average more than eight

GWL 1.5°C   GWL 2.0°C   GWL 4.0°C

Heat warning index

1 day/year   3 days/year   2 weeks/year   1 month/year   3 months/year   6 months/year

GWL 1.5°C   GWL 2.0°C   GWL 4.0°C

Changes in extreme rainfall

0   5   10   15   20   25   30
% more rain on wettest day of the year
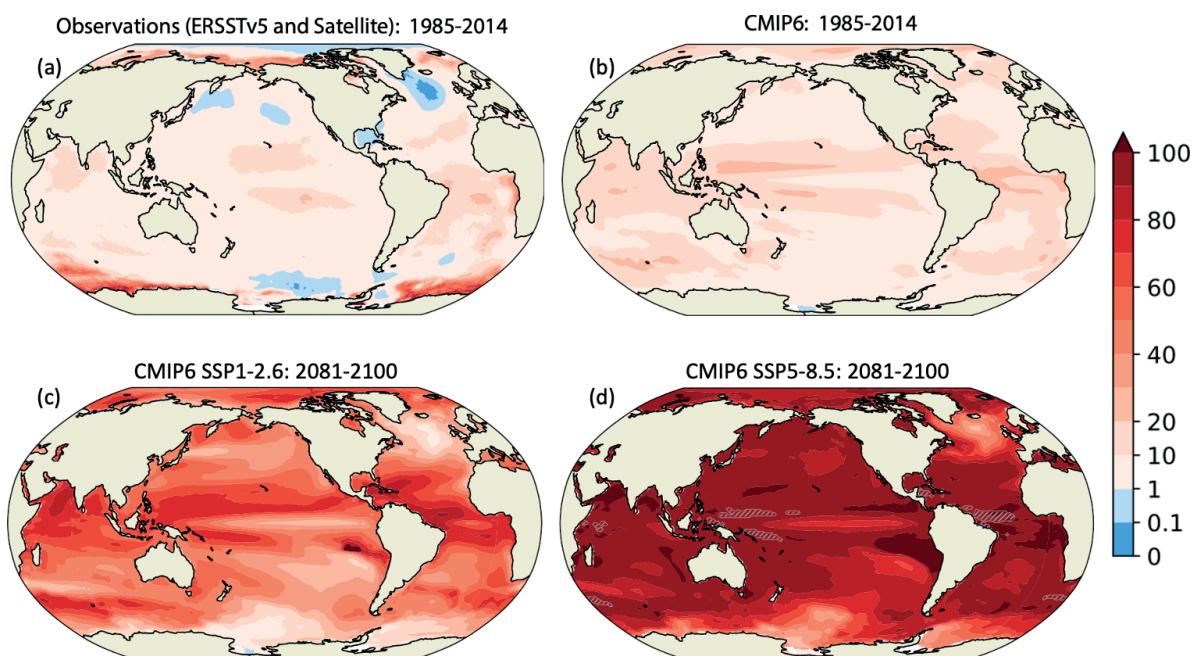
Figure 6. Projections of regional changes of the heat warning index and extreme rainfall for different levels of global warming (GWL). The heat warning index is the number of days per year averaged across each region at which a heat warning for human health at level "danger" would be issued according to NOAA. The maps of extreme rainfall changes show the percentage change in the amount of rain falling on the wettest day of a year (Rx1day, relative to 1995–2014) averaged across each region when the respective GWL is reached. (Source: AR6 WGI TS, Figure TS.6)

times per year during the period 1995–2014 (*high confidence*) (Figure 7).

Projected changes in extremes are larger in frequency and intensity with every increment of global warming. Every region will

increasingly experience concurrent and multiple changes.

Future emissions cause future additional warming. A level of 1.5 °C of global warming (averaged over 20 years) relative to 1850–1900 is expected to be

Observations (ERSSTv5 and Satellite): 1985-2014   CMIP6: 1985-2014

(a)   (b)

CMIP6 SSP1-2.6: 2081-2100   CMIP6 SSP5-8.5: 2081-2100

(c)   (d)

100
80
60
40
20
10
1
0.1
0

Figure 7. Observed and projected changes in marine heatwave probability ratio (Source: AR6 WGI Chapter 9, Box 9.2, Figure 1)

reached in the near term (2021–2040). If greenhouse gas emissions stay close to current levels for a few more decades, or increase, a level of 2 °C of global warming would be crossed in the mid-term (2041–2060), but reaching such a level of warming could be avoided with rapid and strong reductions in emissions of CO_2, methane and other greenhouse gases.

The frequency of extreme temperature and precipitation events in the current climate will change with every increment of warming, with warm extremes becoming more frequent (*virtually certain*), cold extremes becoming less frequent (e*xtremely likely*) and precipitation extremes becoming more frequent in most locations (*very likely*) (Table 1, Figures 3, 4, 5, 6). The projected increase in heavy precipitation extremes translates to an increase in the frequency and magnitude of pluvial floods.

Some mid-latitude and semi-arid regions, as well as the South American Monsoon region, are projected to see the highest increase in the temperature of the hottest days, at about 1.5 to 2 times the rate of global warming (*high confidence*). The Arctic is projected to experience the highest increase in the temperature of the coldest days, at about 3 times the rate of global warming (*high confidence*).

With additional global warming, the frequency of marine heatwaves will continue to rise (*high confidence*), particularly in the tropical ocean and the Arctic (*medium confidence*) (Figure 7).

A warmer climate increases moisture transport into weather systems, which intensifies wet seasons and events (*high confidence*). Increases in near-surface atmospheric moisture capacity of about 7% per 1 °C of warming lead to a similar response in the intensification of heavy precipitation from sub-daily up to seasonal time scales, increasing the severity of flood hazards (*high confidence*) (Figure 3). The average and maximum rain-rates associated with tropical and extratropical cyclones, atmospheric rivers and severe convective storms will therefore also increase with future warming (h*igh confidence*) (Figure 5). The interannual variability of precipitation and runoff over land is projected to increase at a faster rate than changes in seasonal mean precipitation all year round in the tropics and in the summer season elsewhere (*medium confidence*). Sub-seasonal precipitation variability is also projected to increase, with fewer rainy days but increased daily mean precipitation intensity over many land regions (*high confidence*). The proportion of intense tropical cyclones (categories 4-5) and peak wind speeds of the most intense tropical

cyclones are projected to increase at the global scale with increasing global warming (*high confidence*) (Table 1).

Every additional 0.5 °C of global warming also causes clearly discernible increases in the intensity and frequency of agricultural and ecological droughts in some regions (*high confidence*) (Figure 3). Discernible changes in the intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5 °C of global warming (*medium confidence*). Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions (*medium confidence*). Rainfall variability related to the El Niño/Southern Oscillation is projected to be amplified by the second half of the twenty-first century for intermediate or high greenhouse gas emissions, and global warming above 2 °C.

There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5 °C of global warming. Projected percentage changes in frequency are higher for rarer events (*high confidence*) (Table 2). Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*). In particular, concurrent heatwaves and droughts are likely to become more frequent. Concurrent extremes at multiple locations become more frequent, including in crop producing areas, at 2 °C and above compared to 1.5 °C global warming (*high confidence*). Some compound extreme events with low likelihood in past and current climate will become more frequent, and there will be a higher likelihood that events with increased intensities, durations and/or spatial extents unprecedented in the observational record will occur. The probability of compound flooding (storm surge, extreme rainfall and/or river flow) will continue to increase due to both sea-level rise and increases in heavy precipitation, including changes in precipitation intensity associated with tropical cyclones (*high confidence*) (Figure 8).

It is *virtually* certain that global mean sea level will continue to rise through 2100 and for centuries thereafter, and will remain elevated for thousands of years. The *likely* range of sea-level rise above 1995–2014 is from 0.15 to 0.30 m by 2050. Sea-level rise by 2100 strongly depends on future emissions, reaching around 0.40 m for very low emissions (global warming close to 1.5 °C), or around 0.8 m for very high emissions (global warming

Table 2. Observed and projected changes in low likelihood, high impact extreme conditions (Source: AR6 WGI Chapter 11, Box 11.2, Table 1)
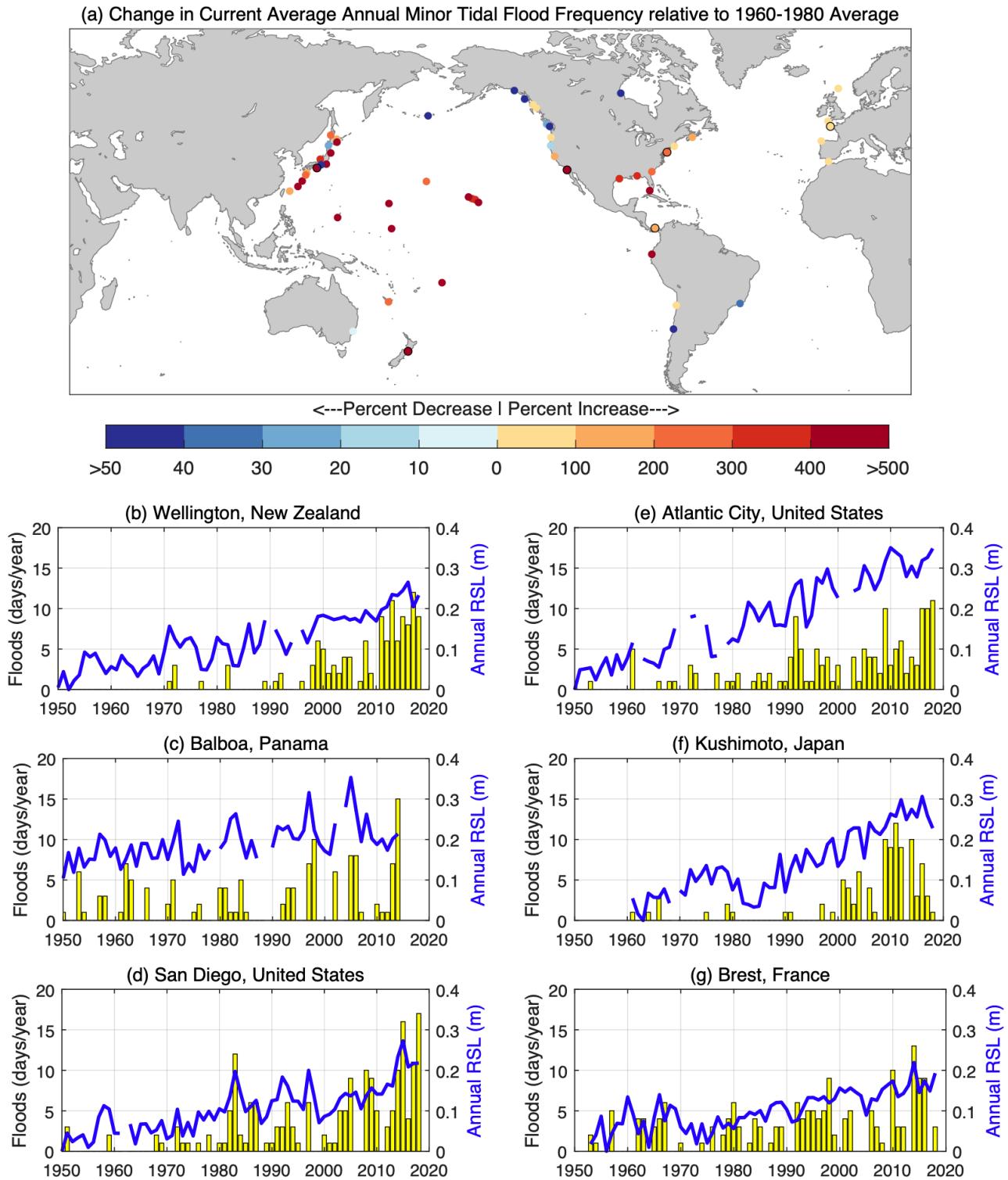
	+1°C (Present-day)	+1.5°C	+2°C	+3°C and Higher
Risk ratio for annual hottest daytime temperature (TXx) with 1% of probability under present-day warming (+1°C) (Kharin et al., 2018): Global land	1	3.3 (i.e., 230% higher probability)	8.2 (i.e., 720% higher probability)	Not assessed
Risk ratio for heavy precipitation events (Rx1day) with 1% of probability under present-day warming (+1°C) (Kharin et al., 2018): Global land	1	1.2 (i.e., 20% higher probability)	1.5 (i.e., 50% higher probability)	Not assessed
Risk ratio for 1–5 day duration extreme floods with 1% of probability under present-day warming (+1°C) (H. Ali et al., 2019) Indian subcontinent	Up to 3 in individual locations	Up to 5 in individual locations	2–6 in most locations	Up to 12 in individual locations (4°C)
Probability of 'extreme extremes' hot days with 1/1000 probability at the end of the 20th century (Vogel et al., 2020a): Global land	About 20 days over 20 years in most locations	About 50 days in 20 years in most locations	About 150 days in 20 years in most locations	About 500 days in 20 years in most locations (3°C)
Probability of co-occurrence in the same week of hot days with 1/1000 probability and dry days with 1/1000 probability at the end of the 20th century (Vogel et al., 2020a): Amazon	0% probability	About one week in 20 years	About 4 to 5 weeks in 20 years	More than 9 weeks in 20 years (3°C)
Projected soil moisture drought duration per year (Samaniego et al., 2018): Mediterranean region	41 days (+46% compared to the late 20th century)	58 days (+107% compared to the late 20th century)	71 days (+154% compared to the late 20th century)	125 days (+346% compared to the late 20th century) (3°C)
Increase in days exposed to dangerous extreme heat – measured in Health Heat Index (HHI) (Q. Sun et al., 2019) global land	Not assessed, baseline is 1981–2000	1.6 times higher risk of experiencing heat >40.6	2.3 times higher risk of experiencing heat >40.6	Around 80% of land area exposed to dangerous heat, tropical regions 1/3 of the year (4°C)
Increase in regional mean fire season length (Q. Sun et al., 2019; Xu et al., 2020) global land	Not assessed, baseline is 1981–2000	6.2 days	9.5 days	About 50 days (4°C)

above 4 °C), and 1 m more if ice-sheet instability processes associated with deep uncertainty are triggered.

It is *very likely* to *virtually certain* that regional mean relative sea-level rise will continue throughout the twenty-first century, except in a few regions with substantial geologic land uplift rates. Approximately two-thirds of the global coastline has a projected regional relative sea-level rise within ±20% of the global mean increase (*medium confidence*), with projection data available at https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool. Due to relative sea-level rise, extreme sea-level events that occurred once per century in the recent past are projected to occur 20 to 30 times more frequently by 2050 and 160 to 530 times more frequently by 2100, and at least annually at 20-30% of tide gauge locations by 2050, and at 60 to 80% of all tide gauge locations by 2100 (*high confidence*). Relative sea-level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts (*high confidence*).

Further urbanization together with more frequent hot extremes will increase the severity of heatwaves (*very high confidence*). Urbanization also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). In coastal cities, the combination of more frequent extreme sea-level events (due to sea level rise and storm surge) and extreme rainfall/riverflow events will make flooding more probable (*high confidence*).

Based on paleoclimate and historical evidence, it is likely that at least one large explosive volcanic eruption would occur during the twenty-first century. Such an eruption would temporarily affect many climatic impact-drivers (*medium confidence*). Such natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.

Figure 8. Observed change in extreme still water level. Defined as the 99th percentile of daily observed water levels over 1995-2014. (a) Percent change in occurrences over 1995-2014 relative to those over 1960-1980. (b-g) Annual mean sea level (blue) and annual occurrences of extreme still water levels over the 1995-2014 99th percentile daily maximum (yellow) at six selected tide gauge locations. (Source: AR6 WGI Chapter 9, Figure 9.31)

Changes in extremes will be more widespread and pronounced for higher warming levels

At 1.5 °C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in most regions in Africa and Asia (*high confidence*), North America (*medium to high confidence*) and Europe (*medium confidence*). Also, more frequent and/or severe agricultural and ecological droughts are projected in a few regions in all continents except Asia compared to 1850–1900 (*medium confidence*); increases in meteorological droughts are also projected in a few regions (*medium confidence*).

At 2 °C global warming, the level of confidence in and the magnitude of change in droughts and heavy and mean precipitation increase compared to those at 1.5 °C. Heavy precipitation and associated flooding events are projected to become more intense and frequent in the Pacific Islands and across many regions of North America and Europe (*medium to high confidence*). These changes are also seen in some regions in Australasia and Central and South America (*medium confidence*). Several regions in

FAQ 11.2: **Will climate change cause unprecedented extremes?**
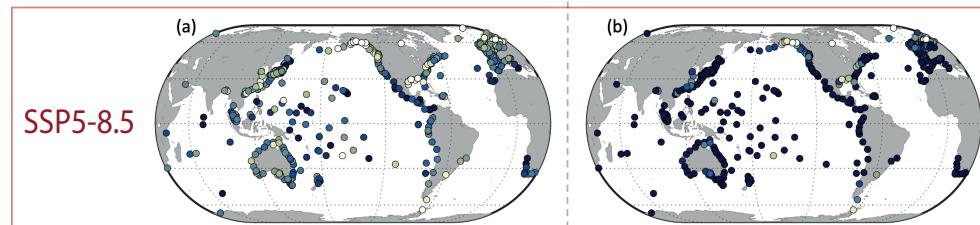
Yes, in a changing climate, extreme events may be unprecedented when they occur with...

Larger magnitude

Increased frequency

New locations

Different timing

New combinations (compound)
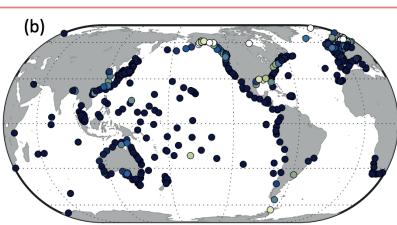
Figure 10. (Source: AR6 WGI, chapter 11, Figure FAQ 11.2)

Median Amplification Factor of Extreme Still Water Level by:
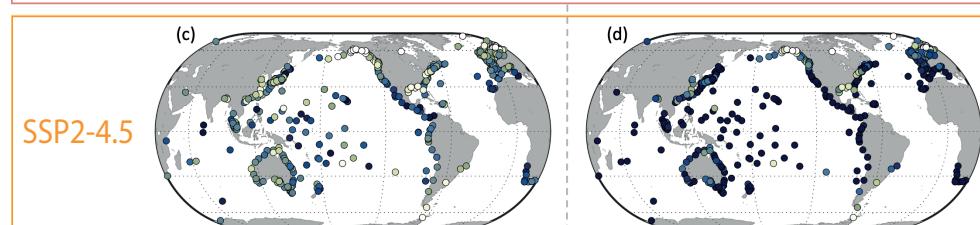
2050   2100
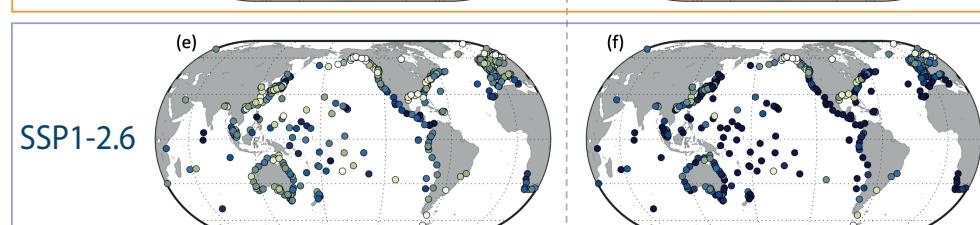
Amplification Factor [-]
<1   10   100   >1000

Figure 9. Projected change in the recurrence of extreme still water level (amplification factor) as a function of the emission scenario (very high, intermediate or low) by 2050 and 2100. (Source: AR6 WGI, chapter 9, Figure 9.32)

Africa, South America and Europe are projected to experience an increase in frequency and/or severity of agricultural and ecological droughts with *medium to high confidence*; increases are also projected in Australasia, Central and North America, and the Caribbean with *medium confidence*. A small number of regions in Africa, Australasia, Europe and North America are also projected to be affected by increases in hydrological droughts, and several regions are projected to be affected by increases or decreases in meteorological droughts with more regions displaying an increase (*medium confidence*). Region-specific changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), increases in river floods (*medium to high confidence*), and increases in fire weather (*medium to high confidence*). There is *low confidence* in most regions in potential future changes in hail, ice storms, severe storms, dust storms, heavy snowfall, and landslides.

In the future, unprecedented extremes will occur as the climate continues to warm. Those extremes will be more intense – of greater magnitude – and will occur more frequently than previously experienced. Extreme events may also appear in new locations, at new times of the year, or as unprecedented compound events. Moreover, unprecedented events will become more frequent with higher levels of warming, for example at 3 °C of global warming compared to 2 °C of global warming (Table 2, Figure 9).

In the case of low or very low greenhouse gas emissions, compared to the case of intermediate, high or very high greenhouse gas emissions in the coming decades, changes in climatic impact-drivers would be substantially smaller beyond 2040. By the end of the century, the increase in the frequency of extreme sea-level events, heavy precipitation and pluvial flooding, and exceedances of extreme heat thresholds dangerous for agriculture and health (see Figure 5) and the number of regions where such exceedances occur would be more limited.

This summary highlights the current state of knowledge on specific extreme events, and the importance of preparing for such changes, through the distillation of regional climate information. It is a co-production between scientists, practitioners and users to support adaptation and risk management decisions.

References

IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.
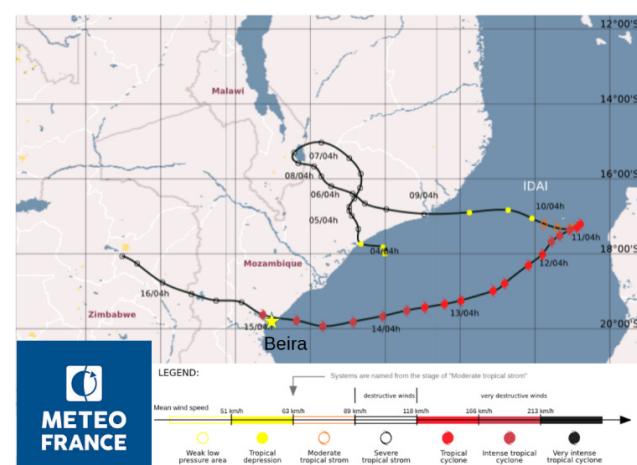
After Action Reviews – learning from experience to improve systems and partnerships and to connect with finance

By Tom Evans, Deputy Director, Pacific Region, NOAA/National Weather Service, USA, Mussa Mustafa, Deputy Director-General, Mozambique Meteorological Service, and Anne-Claire Fontan, WMO Secretariat

Tropical Cyclone *Idai* was the costliest and deadliest storm on record for the South Indian Ocean basin[1] and one of the most destructive tropical cyclones on record in Africa and the southern hemisphere.[2] The long-lived cyclone made landfall in Beira, Mozambique, on 14 March 2019 (Figure 1). Its heavy rains and strong winds caused flash flooding and massive destruction of property and crops, bringing the region into a humanitarian crisis (Figure 2). The cyclone was monitored 24 hours-a-day. Its track and intensity were forecast and timely early warnings were disseminated. However, the Post-Disaster Needs Assessment (PDNA) in Mozambique[3] estimated that 1 600 people were injured and approximately 1.8 million people were affected. Furthermore, the PDNA estimated total damages at US$ 1.4 billion and the cost of recovery and reconstruction at US$ 2.9 billion. As is the practice with early warning systems (EWS), there was a need for review to analyse where improvements could be made.

Thus, in May 2019, WMO carried out an After Action Review (AAR) on the operation of the EWS to learn the lessons from Idai in preparation for the next extreme event that might put lives at risk. The AAR specifically covered the requirements and capabilities of the National Meteorological and Hydrological Service (NMHS) and their coordination with the National Disaster Management authority for an end-to-end Multi-Hazard Early Warning System (MHEWS) in the context of disaster risk management. The Idai AAR

serves as a good exemplar of AAR practice and helps us to understand their value in identifying structural and capacity gaps, for learning from experience,

Figure 1. Track and intensity of Tropical Cyclone Idai, 4–16 March 2019: Idai tracked back and forth from Mozambique to Malawi to Mozambique then out to sea then back to Mozambique then Zimbabwe. (Source: Météo-France /RSMC La Reunion).

Figure 2. Red Cross staff briefing evacuees from Buzi on the Praia Nova beach. Cyclone Idai, Mozambique, evacuees in Beira, 21 March 2019 (Denis Onyodi: IFRC/DRK/Climate Centre)

---

1   Reporting on the State of the Climate in 2019, US National Oceanic and Atmospheric Administration
2   State of the Climate in Africa 2019 (WMO)
3   Led by the Government with the support of a global partnership that included the World Bank, the United Nations System and the European Union

for improving partnerships and for pinpointing financial requirements.

After Action Review for weather-related event

In a manner of speaking, conducting an AAR is an exercise for the next pending disaster. Getting agencies, partners, stakeholders and end users together during the AAR provides a forum for discussing actions (or inaction) taken, the reception of warnings, the application of local knowledge and the population's trust in the authority issuing the warnings.

An AAR analyses the specific objectives and scopes of operation of all involved in emergency services and the actions taken in response to the emergency to identify best practices, gaps, lessons learned and areas for improvement. It offers a cross-sector approach for stakeholders to reflect on their experiences and perceptions of the response, in order to systematically and collectively review and assess what worked and what did not, why and how to improve. The benefits are multiple. For those involved in a cross-sector approach to emergency events, there are three main benefits:

- It allows cross-sector learning and builds trust among the stakeholders
- It builds consensus on issues for follow-up
- The report can be used as an advocacy tool for domestic financing or for financial or technical support from partners.

AAR objectives for extreme weather events can be defined along the four pillars described in the
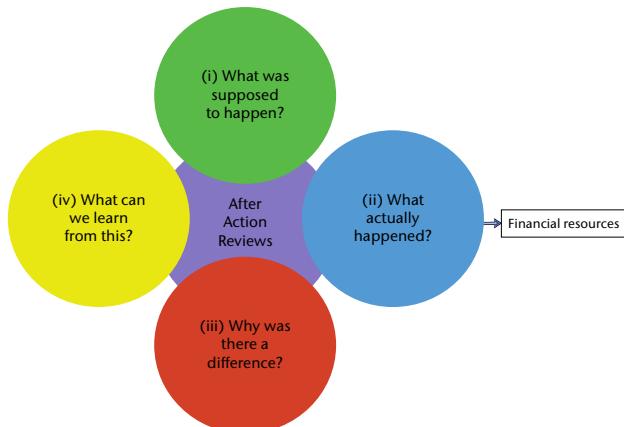
Figure 3. A visualization of the four questions that drive After Action Reviews (AARs) Source: https:// learningforsustainability.net/post/after-action-reviews/
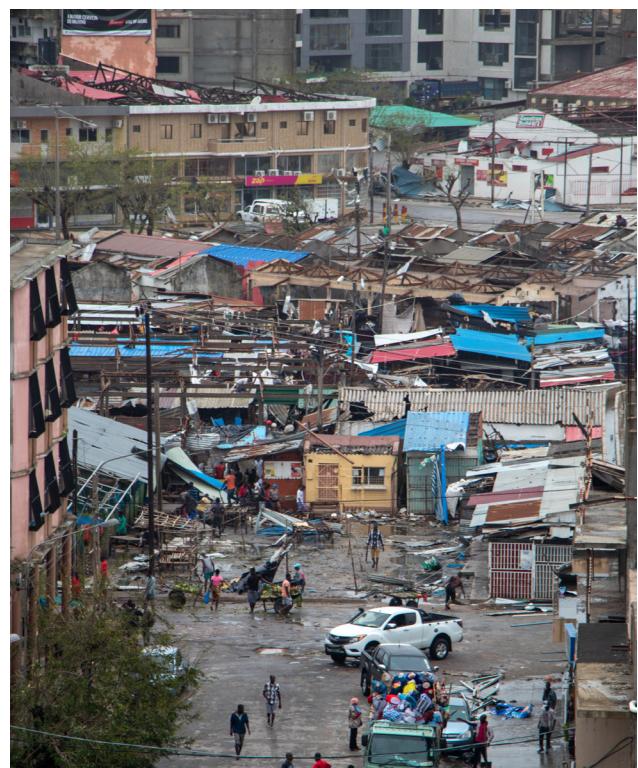
Figure 4. After the passage of the strong Cyclone Idai, the trail of destruction left in Beira City was very visible. The roofs were simply pulled out, nothing was the same! (Source: iStock/ Duarte Gouveia)

publication *Multi-Hazard Early Warning Systems: A Checklist* (or in pdf):

- disaster risk knowledge
- detection, monitoring, analysis and forecasting of hazards and possible consequences
- warning dissemination and communication
- preparedness and response capabilities.

An overarching element is the assessment of national institutional arrangements. Evolving national disaster risk reduction (DRR) policies, legislation and legal frameworks provide opportunities for a greater recognition of the NMHS by government and stakeholders, leading to strengthened partnerships and increased resources and opportunities for providing products and services.

Building trust among stakeholders

AARs provide rich value in meetings with partners, stakeholders and local communities. In Mozambique, the WMO mission met with a whole range of partners at the regional and national level, from forecast and warning providers to

MULTI-HAZARD EARLY WARNING SYSTEM

Clear roles, responsibilities and coordination mechanisms (e.g. SOPs, MOUs)

Disaster risk knowledge and detection, monitoring, analysis and forecasting of the hazards and possible consequences

HAZARD[S] INFORMATION
- Observation
- Monitoring
- Analysis
- Forecasting
- Mapping

MULTI-RISK ANALYSIS
Assessment and quantification of:
- Exposure and vulnerability of people and assets to hazards
- Multi-hazard interactions

WARNINGS
Including:
- Probability of affecting people and assets
- Possible impacts
- Message targeted at different sectors

Institutional partnerships are essential among technical agencies and other MHEWS stakeholders for the development of hazard, exposure and vulnerability information and risk analysis.

Dissemination and communication

General public

Prepare and respond

GOVERNMENT LOCAL TO NATIONAL
(all relevant hazards)

TRANSPORTATION
(road ice, street flooding, travel delays, etc.)

AGRICULTURE PRODUCTIVITY AND FOOD SECURITY
(frost, hail, flooding, etc.)

ENERGY SUPPLY & DEMAND, PROTECTION
(heat and cold waves, severe storms, etc.)

HEALTH EPIDEMICS
(excessive rainfall, cold spells, heatwaves, etc.)

WATER RESOURCE MANAGEMENT
(excessive rainfall, drought, etc.)

(Example sectors)

Feedback for system improvement

Figure 5. Schematic of a multi-hazard early warning system (Source: Multi-hazard Early Warning Systems: A Checklist)

Disaster risk knowledge
- Are key hazards and related threats identified?
- Are exposure, vulnerabilities, capacities and risks assessed?
- Are roles and responsibilities of stakeholders identified?
- Is risk information consolidated?

Detection, monitoring, analysis and forecasting of the hazards and possible consequences
- Are there monitoring systems in place?
- Are there forecasting and warning services in place?
- Are there institutional mechanisms in place?

Warning dissemination and communications
- Are organizational and decision-making processes in place and operatonal?
- Are communication systems and equipment in place and operational?
- Are impact-based early warnings communicated effectively to prompt action by target groups?

Preparedness and response capabilities
- Are disaster preparedness mesures, including response plans, developed and operational?
- Are public awareness and education campaigns conducted?
- Are public aweness and response tested and evaluated?

Figure 6. Four elements of an end-to-end, people-centred early warning systems (Source: Multi-hazard Early Warning Systems: A Checklist)

decision-makers and end-users, as well as with international donors and banks.

Interaction with vulnerable communities – in this case disaster survivors – builds trust, understanding and knowledge. The AAR may even reveal previously unknown resources that can help local communities prepare, respond and recover. AARs increase knowledge of local conditions and may discover new monitoring capabilities, such as citizen scientists that are trusted observers in the region. Citizen scientists, also known as weather spotters/river monitors, can communicate with NMHSs to provide information on actual real-time conditions and, thus, enhance the detection, verification and early response functions of early warning systems.

These interactions with local communities build trust: there is nothing more rewarding than when a connection to people occurs. These connections may lead to a better understanding of how those in harm's way receive and respond to impact-based warnings. Government entities can thus learn what is needed for the local community to respond appropriately. They can better understand possible local impacts and tailor their warnings to the community. Community reactions during Idai were slow as the areas affected had not experienced cyclonic activity since 2000 and Idai's magnitude was far greater than that of any previous event.

Furthermore, interconnections with stakeholders in national and provincial organizations for disaster management, humanitarian networks and the like allows for better, more effective and timely responses and aid for the vulnerable. The goal is to improve the methodology for collecting data on the people and places that could potentially be affected by an extreme weather event such as a tropical cyclone. The Annual Contingency Plan, an official document of the Government of Mozambique that serves as the basis for the process of coordination, response and management of extreme events, estimated that 136 382 people could be affected by an extreme weather event. Mozambique's PDNA and the WMO AAR showed that the number had been underestimated by a ratio of nearly 1:10: the annual report on implementation of the contingency plan reported that in just four provinces – Sofala, Zambezia, Manica and Tete – 1 459 941 people were affected.

A learning experience

An AAR can provide a collective vision for improving services and mitigating future disaster risks if the lessons learned are incorporated into standard operating procedures (SOP) and practice. SOPs and practice (exercises) must be inclusive in order to have the most profound results. Leaving out a partner, stakeholder and/or end user group may leave a kink in the armour and improper response during future pending disasters.

Tropical Cyclone *Idai*, was continuously monitored: the AAR states that "track forecast uncertainty had reduced and was well below usual standards, clearly indicating that *Idai* would hit the Beira area." However, the AAR team discovered several kinks in the armour with respect to timely dissemination, reception and understanding the proper response. An inclusive application of the suggestions from the report, especially since relationships have been forged with the communities affected by Tropical Cyclone *Idai*, will strengthen the resolve of the people to respond properly to the timely, impact-based warnings provided by the authorities.

Most weather-related AARs consistently pinpoint two areas for immediate action: communication/ collaboration and the identification of funding for improvements. Both can be integrated into SOPs and exercises, and generally apply to government entities, partners and end-users.

Follow-up actions – the value of partnerships

Through collaboration with stakeholders, the ARR creates consensus around actions to be implemented immediately, in the medium- and long-term to mitigate the impacts of and improve responses during the next extreme event. The collaboration creates a sense of ownership that helps ensure that actions are taken – some actions can only be fully implemented if there is a close and trusting relationship between partners.

Post weather-related event AARs usually highlight the requirement for partnership to enhance the capacities in "impact-based forecast and warning services (IBFWS)", that is forecasting, assessing associated risks, disseminating warnings and messaging. Typically, those actions require a strong collaboration with disaster response and civil protection agencies to be moved forward. These partnership can be built on the aforementioned SOPs that define clear roles and coordination mechanisms and, as important, on regular exercises. Partnership can also be developed with academia in order to provide the necessary basic technical and scientific requirements for weather forecasters. By twinning with a more advanced NMHSs, training can also be

provided on the operational use of tools, guidance and products.

In the post *Idai* AAR follow-up actions and associated budget for the National Institute of Meteorology (INAM) and the National Directorate of Hydrological Resources Management (DNGRH) were characterized according to the scope initially identified for assessing the capacities for end-to-end MHEWSs as shown in Figure 7.

The post *Idai* AAR team determined that US$ 27 million would be required to address the Earth system observation gaps and the capacity deficiencies identified. This would provide education, training, upgraded equipment and systems, additional detection systems, planning and robust infrastructure for housing government authorities. The WMO report speaks to the need to prepare for and respond appropriately to the projected impacts from natural hazard to mitigate disaster risks.

Connecting to finance

When a government decides to conduct an AAR, financial capability must be one of the first considerations. Many countries are able to finance AARs and to ensure that their recommendations are acted upon as part of recovery plans and ongoing national planning processes. This is particularly true in countries where the systematic initiation of AARs is recognized as a requirement in National Meteorological and Hydrological Plans and related operational procedures. In a certain number of developing countries, the financial assistance of development partners will be required to assist with conducting the AAR – even more so when international experts are needed to conduct the AAR.

The second consideration is the improvement of financial preparedness for disasters, which requires increasing the availability, predictability and efficiency of ex-ante resources for disaster preparedness and response.

Third is assuring that follow-up actions are budgeted, as shown in Figure 7, and a business plan developed, which can be leveraged for financial support from government or donors. The business plan allows donors to understand the needs and what the funds will be used for. A common approach inclusive of other government entities to provide a comprehensive proposal is appreciated by donors as it helps to ensure that there is no overlap in funding.

A joint proposal aimed at "Establishing an Integrated Hydro-Meteorological Early Warning System to Strengthen Climate Resilience in Mozambique" was submitted through the National Designated Authority to the Green Climate Fund (GCF) by INAM, DNGRH and Eduardo Mondlane University (UEM) following Idai. It highlights the vulnerability of the country to climate events, the current economic stress and the lack of effective MHEWS. It acknowledges the support provided by donors in case of emergency, stressing that those funds are mostly activated for response and rarely for preparedness. Therefore, the GCF funding is requested to support the establishment and improved MHEWS, which will allow for proper planning and disaster risk management, thus reducing public expenditure and increasing both institutional and human capacity.

Continuous improvement

AARs are just one of the important steps in the cycle of continuous improvement for MHEWSs. A common thread running through all of the steps is preparation and collaboration. The more inclusive and far-reaching the preparation, the greater the opportunities for success. AARs provide a glimpse into the preparation aspect of successful MHEWSs and can aid in strengthening relationships and SOPs. Tying the improvements to finance is vital in order to ensure recommendations are instituted. And, by all means apply the KISS method: Keep It Simple for Success.

Insight – WMO Expert Team for MHEWS Technical Guidance (ET-MTG) is developing comprehensive guidance materials for the NMHSs. This guide will be a resource for those looking to establish and improve national MHEWS and disaster risk management activities. It is being developed along the MHEWS requirement for effectiveness:

- Multi-stakeholder partnerships at various levels to ensure 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 stakeholders and coordination mechanisms that are documented in national to local legislation, policies, strategies and plans.

Meteorology sector		
Timing	*Summary description*	*Cost (US$) in thousands*
Forecasting		
Short-term	Training on use & interpretation of products from global and regional centres, implementation of SOP and enhanced use of available equipment	1 075
Medium-term	Training and enhanced access to products from global centres	150
Communication of warnings		
Short-term	Upgrade of website & enhanced utilization of TV weather studio	100
Medium-term	Development of a strategy for social media presence	50
Long-term	Redundant systems for warning communication	100
Public Education & Awareness		
Short to medium-term	Training on public weather services & impact-based forecasting	100
Medium-term	Further training on public weather services & impact-based forecasting	200
Observations & Infrastructure		
Short-term	Rehabilitation of destroyed infrastructure, equipment, replacement of non-operational equipment, data management & integration of data from INAM and DNGRH	2 300
Medium-term	Construction of new facility at Beira, expansion of observing network including a radar at Beira, upper air sounding, and technical & logistical support nationwide	10 070
Long-term	Further expansion of observing network & improved data management	4 660
Maintenance		
Short term	Development of Standard Operating Procedures & training of staff	100
Sub total Meteorology sector		**18 905**

Hyrolology sector		
Timing	*Summary description*	*Cost (US$) in thousands*
Forecasting		
Short-term	Land surveys for flood risk mapping & harmonized satellite rainfall estimation	1 100
Medium-term	Automation of data collection, processing procedures & improved enhanced operational coordination	650
ICT & Infrastructure		
Short-term	Acquire high speed computer & improve IT infrastructure	550
Mid-term	Development of national standards construction of infrastructure	500
Capacity building		
Short-term-term	Training on hydrological modelling, flash flood guidance system & integrated flood management	490
Medium-term	Training on appropriate floodplain management & implementation	300
Long-term	Build continuous capacity building programme including training of trainers	200
Communication and awareness		
Short-term	Network of voice communication	100
Medium-term	Development of floodplain plans & review warning dissemination procedures	350
Long-term	Public education on floods	100
Observations		
Short-Term	Installation of hydrological equipment, data base management system & improvement of & products exchange	3 300
Emergence response		
Short-term	Satellite communication for emergencies	100
Grand total Meteorology and Hydrology sectors		**26 645**

Figure 7. Example of follow-up actions and associated budget for the meteorology sector in the case of Tropical Cyclone Idai (Source: Reducing vulnerability to extreme hydro-meteorological hazards in Mozambique after Cyclone Idai)

References

Reducing vulnerability to extreme hydro-meteorological hazards in Mozambique after Cyclone Idai (WMO)

Mozambique Cyclone Idai Post-Disaster Needs Assessment: Full Report (2019) (Global Facility for Disaster Reduction and Recovery (GFDRR), 2019)

Guidance for after action review (AAR) (World Health Organization (WHO), 2019)

The global practice of after action review: a systematic review of literature, (WHO, 2019)

Reporting on the State of the Climate in 2019 (US National Oceanic and Atmospheric Administration (NOAA))

State of the Climate in Africa 2019 (WMO-No. 1253)

Weathering the Change: How to Improve Hydromet Services in Developing Countries (Working Paper, World Bank)

Multi-hazard Early Warning Systems: A Checklist (Outcome of the first Multi-hazard Early Warning Conference) (WMO, 2019)

WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services – Part I (WMO-No. 1150, 2015)

WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services – Part II (WMO-No. 1150, 2021)