

# A Strategic Roadmap for Advancing **Multi-hazard Impact-based Early Warning Systems and Services** in the Caribbean



**CREWS** CLIMATE RISK & EARLY  
WARNING SYSTEMS



**GFDRR**  
Global Facility for Disaster Reduction and Recovery  
Administered by the World Bank



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Suggested citation: *Multi-hazard Impact-based Early Warning Systems and Services in the Caribbean*

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# Acknowledgments

The World Bank team would like to thank the institutions and individuals whose continuous efforts are strengthening and making multi-hazard impact-based early warning systems and services more accessible to all the people of the Caribbean. We are grateful for the support of a wide group of experts and organizations whose contributions informed the creation of this Roadmap.

We would like to especially thank the regional partner organizations – Caribbean Meteorological Organization (Headquarters) (CMO HQ), Caribbean Institution of Meteorology and Hydrology (CIMH), Caribbean Disaster Emergency Management Agency (CDEMA), as well as the Meteorological Service of Jamaica for their active participation in the process of preparing the Roadmap and for their continued support. The team is grateful for the inputs and contributions provided by the national meteorological, hydrological and disaster risk management agencies, as well as implementing partners – World Meteorological Organization (WMO) and United Nations Office for Disaster Risk Reduction (UNDRR). The team appreciates the participation of other regional organizations, such as the Caribbean Community Climate Change Centre, CARICHAM, CTU, and members of the Regional Early Warning Systems Consortium, as well as experts with the National Oceanic and Atmospheric Administration, Hydrologic Research Center, Red Cross and Red Crescent Climate Center, CIMA, Decision Analysis partners, the University of the West Indies Seismic Research Center, the University of the West Indies Centre for Resource Management and Environmental Studies, Caribbean Regional Public Health Agency, OECS Commission, EWISACTS consortium, Varysan Hydromet Network, and the UNDP office for Barbados and the Eastern Caribbean.

The team would also like to express its special appreciation to the colleagues from the Global Facility for Disaster Reduction and Recovery and the CREWS Initiative Secretariat for the support extended to the team throughout the process.

# Abbreviations and acronyms

<b>AAL</b>	average annual losses
<b>AI</b>	artificial intelligence
<b>AOD</b>	Aerosol Optical Depth
<b>ARISE</b>	Private Sector Alliance for Disaster Resilient Societies (UNDRR)
<b>BHA</b>	Bureau for Humanitarian Assistance
<b>BCP</b>	business continuity planning
<b>BCPs</b>	business continuity plans
<b>BCR</b>	benefit-cost ratio
<b>CAHN</b>	Caribbean Aerosol Health Network
<b>CAP</b>	Common Alerting Protocol
<b>CAPEX</b>	capital expenditure
<b>CARICHAM</b>	Caribbean Network of Chambers of Commerce
<b>CARICOM</b>	Caribbean Community
<b>CARPHA</b>	Caribbean Public Health Agency
<b>CBA</b>	cost-benefit analysis
<b>CCCCC</b>	Caribbean Community Climate Change Centre
<b>CCCES</b>	Caribbean Centre for Climate and Environmental Simulations
<b>CCREEE</b>	Caribbean Centre for Renewable Energy and Energy Efficiency
<b>CCRIF</b>	Caribbean Catastrophe Risk Insurance Facility
<b>CDB</b>	Caribbean Development Bank
<b>CDEMA</b>	Caribbean Disaster Emergency Management Agency
<b>CDM</b>	Comprehensive Disaster Management
<b>CHOP</b>	Caribbean Hydrometeorological Operational Plan
<b>CIFI</b>	Coastal Inundation Forecasting Initiative
<b>CIMH</b>	Caribbean Institute for Meteorology and Hydrology
<b>CMO</b>	Caribbean Meteorological Organization
<b>CMO HQ</b>	Caribbean Meteorological Organization Headquarters Unit
<b>CPAGCC</b>	Caribbean Planning For Adaptation To Global Climate Change
<b>CRIS</b>	Caribbean Risk Information System
<b>CREWS</b>	Climate Risk and Early Warning Systems
<b>CWWA</b>	Caribbean Water and Wastewater Association
<b>DRM</b>	disaster risk management
<b>EAS</b>	emergency alert systems
<b>EPS</b>	ensemble prediction systems
<b>E2E</b>	End to End
<b>EWISACTs</b>	Early Warning Information Systems Across Timescales in the Caribbean
<b>EWS</b>	early warning systems and services
<b>FFG</b>	flash flood guidance
<b>FFGS</b>	WMO Flash Flood Guidance System
<b>FHRC</b>	Flood Hazard Research Center
<b>GDP</b>	gross domestic product
<b>GEO</b>	Group on Earth Observations
<b>GIS</b>	geographic information system
<b>GWE</b>	Global Weather Enterprise
<b>HHAP</b>	heat-health action plan

<b>HHWS</b>	heat-health warning system
<b>Hydromet</b>	hydrometeorological
<b>HVR</b>	Hazard, Vulnerability and Risk
<b>IBF</b>	impact-based forecasting
<b>IFRC</b>	International Federation of Red Cross and Red Crescent
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>Lidar</b>	light detection and ranging
<b>MHEWS</b>	multi-hazard early warning systems
<b>ML</b>	machine learning
<b>MPLNET</b>	Micro-Pulse Lidar Network
<b>MSME</b>	micro-, small- and medium-sized enterprise
<b>NCEP</b>	National Centers for Environmental Prediction
<b>NDMO</b>	national disaster management organization
<b>NESDIS</b>	National Environmental Satellite Data Information Service
<b>NGO</b>	nongovernmental organization
<b>NHC</b>	National Hurricane Center (United States)
<b>NMHS</b>	National Meteorological and Hydrological Services
<b>NOAA</b>	National Oceanic and Atmospheric Administration (United States)
<b>NWP</b>	numerical weather prediction
<b>NWS</b>	National Weather Service (United States)
<b>OECS</b>	Organization of Eastern Caribbean States
<b>O&amp;M</b>	operation and maintenance
<b>PAHO</b>	Pan American Health Organization
<b>PM</b>	particulate matter
<b>PS</b>	Participating States
<b>QGIS</b>	Quantum Geographic Information Systems
<b>RCC</b>	Regional Climate Center
<b>REWSC</b>	Regional Early Warning Systems Consortium
<b>RTFS</b>	Real Time Impact Forecasting System
<b>SI</b>	strategic initiative
<b>SLOSH</b>	Sea, Lake and Overland Surges from Hurricanes (model)
<b>SMASH</b>	Simple Model for the Advection of Storms and Hurricanes
<b>SWAN</b>	Simulating Waves Nearshore
<b>SWFP</b>	Severe Weather Forecasting Programme (WMO)
<b>SOP</b>	standard operational procedures
<b>SRC</b>	Seismic Research Centre (UWI)
<b>TCOP</b>	Tropical Cyclone Operational Plan
<b>UNDRR</b>	United Nations Office for Disaster Risk Reduction
<b>UNESCO-IOC</b>	United Nations Educational, Scientific and Cultural Organization – Intergovernmental Oceanographic Commission
<b>URISA</b>	Urban and Regional Information Systems Association
<b>USAID</b>	United States Agency for International Development
<b>UWI</b>	University of the West Indies
<b>WCRN</b>	Weather and Climate Ready Nations
<b>WMO</b>	World Meteorological Organization
<b>XSR</b>	Excess Rainfall (model)

All dollar amounts are U.S. dollars.

# Partner statements



## Caribbean Meteorological Organization Headquarters Unit

The Caribbean Meteorological Organization (CMO) Headquarters Unit, which coordinates joint scientific and technical regional activities in weather, climate, and water, is pleased to advance Multi-Hazard Early Warning Systems (MHEWS) and Impact-Based Forecasting and Warning Services, particularly regarding the contribution of the Caribbean Community (CARICOM) National Meteorological and Hydrological Services (NMHS). CMO-HQ believes that the proposed activities will foster growth in MHEWS, thus enabling risk-informed, early actions to protect lives, livelihoods, and assets. When implemented the initiatives will augment existing and planned strategic priorities for MHEWS, while integrating weather, water, climate, and other geophysical hazards, and socio-economic Information into policies and actions for climate resilience and sustainable development in the Caribbean.



## Caribbean Institute for Meteorology and Hydrology (CIMH)

CIMH is pleased to be one of the institutions of the Caribbean Community (CARICOM) invited to work with the global Climate Risk and Early Warning Systems (CREWS) implementation team to further advance multi-hazard early warning systems (MHEWS) and impact-based forecasting (IBF) in the Caribbean. The CIMH believes the various initiatives being developed and piloted, when operationalized and integrated with existing and planned initiatives in the areas of weather, water, climate, marine, and geological hazards will significantly transform the MHEWS and IBF across the region.



*Resilient States · Safer Lives*

## Caribbean Disaster and Emergency Management Agency (CDEMA)

CDEMA is committed to supporting our nineteen (19) Participating States in strengthening people-centered MHEWS that are responsive to the needs of the people of the Caribbean. Effective MHEWS are a critical aspect of the Comprehensive Disaster Management Strategy 2014-2024 which has a goal of building resilience to the diverse, complex hazards facing the region including those exacerbated by climate change. CDEMA remains committed to building a culture of safety and security with harmonized national MHEWS policies and roadmaps, and to a shift from reactive to proactive approaches in mindset and operations, through the development of impact-based warnings and risk-informed action planning so that the region cannot just survive but thrive.



## World Meteorological Organization (WMO)

WMO's Vision 2030 foresees a world where all nations are more resilient to the socioeconomic impacts of extreme weather, climate, water and other environmental events. Especially in the Caribbean, a region that is highly affected by extreme events, MHEWS that provide timely, accurate and actionable information are critical to protecting lives, livelihoods and property. This Strategic Roadmap for Advancing Multi-hazard Impact-based Early Warning Systems and Services in the Caribbean provides an excellent set of strategic actions which would enable decision makers to trigger appropriate and inclusive preparedness and response measures. This is critical for building resilience into the future.



## United Nations Office for Disaster Risk Reduction (UNDRR)

Early warnings that trigger early action can save many lives. The importance of multi-hazard preparedness was proven with the La Soufrière volcanic eruption where timely evacuations following effective response in the simultaneous context of the hurricane season, the COVID-19 pandemic and the dengue epidemic, were very effective. Many more deaths could be prevented in the Caribbean by continuing to advance the understanding of such complex and interconnected risks, and using this knowledge for improved policies, forecasting and response capacities. It is thus imperative to accelerate the implementation of the Strategic Roadmap for Advancing Multi-hazard Impact-based Early Warning Systems and Services in the Caribbean.



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The World Bank remains committed to supporting climate resilient development in the Caribbean and building regional capability to strengthen and streamline impact-based, multi-hazard, early warning systems and services for risk-informed decision making. The purpose of this Strategic Roadmap for Advancing Multi-hazard Impact-based Early Warning Systems and Services in the Caribbean is to support regional and national agencies in leveraging the human, technical, and financial resources needed to implement a set of transformational strategic initiatives aimed at building stronger foundations for the MHEWS.

# Preface

**T**his strategic roadmap was developed under the World Bank's Strengthening Hydro-Meteorological and Early Warning Services in the Caribbean project, financed by the Climate Risk and Early Warning Systems (CREWS) Initiative (box P.1).

This roadmap is informed by "A Situation Analysis of the Caribbean Multi-Hazard End-to-End Early Warning System" (World Bank 2020), developed in collaboration with key regional stakeholders—the Caribbean Disaster Emergency Management Agency (CDEMA), Caribbean Meteorological Organization Headquarters, and Caribbean Institute for Meteorology and Hydrology, and the Caribbean Community Climate Change Centre (CCCCCs), which are part of the CREWS Caribbean project—in consultation with members of the Regional Early Warning Systems Consortium (Annex 1). It is also informed by, and aims to contribute to, the delivery of multi-hazard early warning services aligned with regional frameworks for advancing early warning system and services (EWS) policy, comprehensive disaster risk management, climate-resilient development, and sustainable oceans.

## BOX P.1. CLIMATE RISK AND EARLY WARNING SYSTEMS INITIATIVE

The CREWS Initiative supports and provides funding to Least Developed Countries and Small Island Developing States to significantly increase their capacity to generate and communicate effective, impact-based, multi-hazard, gender-informed early warnings to protect lives, livelihoods, and assets. The CREWS Initiative is operationalized by three implementing partners: World Bank/Global Facility for Disaster Reduction and Recovery; World Meteorological Organization (WMO); and UN Office for Disaster Risk Reduction. WMO provides secretariat services, and the World Bank serves as trustee. For more information, see <https://www.crews-initiative.org/en>.

The Caribbean Community's (CARICOM) Regional Framework for Achieving Development Resilient to Climate Change<sup>1</sup> can benefit from strengthening regional multi-hazard early warning systems and services (MHEWS) to deliver in the five focus areas of the resilience pathway adopted by CARICOM heads of government<sup>2</sup> in 2018. These are: social protection for the marginal and most vulnerable; enhancing economic opportunities; safeguarding infrastructure; environmental protection; and operational readiness and recovery (Granderson 2018). The CDEMA Council of Ministers' formal adoption of the Model National MHEWS Policy and Adaptation Guide<sup>3</sup> in July 2020 sets the stage for mainstreaming EWS into the resilient development pathway through harmonized national and regional implementation of the roadmap.

Priority Action 4.3 of the Regional Comprehensive Disaster Management (CDM) Strategy and Results Framework (2014–24) (CDEMA 2014) requires countries to establish end-to-end, integrated, and fully functional early warning systems to warn the population of impending danger and take appropriate actions. CDEMA participating states are to apply the EWS Checklists (WMO 2018), adjusted for the region by CDEMA (CDEMA 2018), as a monitoring mechanism every three years in conjunction with the

<sup>1</sup> <https://www.caribbeanclimate.bz/forging-a-climate-resilient-development-pathway-in-the-caribbean/>.

<sup>2</sup> CARICOM member states: Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Trinidad and Tobago.

<sup>3</sup> [http://www.thebahamasweekly.com/publish/caribbean-news/The\\_CDEMA\\_Council\\_recognises\\_the\\_role\\_of\\_the\\_Agency\\_in\\_the\\_fight\\_against\\_COVID-1966134.shtml](http://www.thebahamasweekly.com/publish/caribbean-news/The_CDEMA_Council_recognises_the_role_of_the_Agency_in_the_fight_against_COVID-1966134.shtml).

CDM Audit Tool, to capture EWS achievements and gaps, and inform the regional MHEWS roadmapping process.

This strategic roadmap is aligned with this cycle to support and guide the strengthening of the regional MHEWS in the Caribbean (box P.2). It is also harmonized and aligned with these global frameworks for disaster risk reduction and climate resilient development:

- Sendai Framework for Disaster Risk Reduction<sup>4</sup> Global Target G, to “substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030”
- Small Island Developing States Accelerated Modalities of Action (SAMOA) Pathway<sup>5</sup>
- Sustainable Development Goals (SDGs),<sup>6</sup> particularly: SDG 3 good health and well-being; SDG 8 decent work and economic growth; SDG 13 climate action, SDG 14 life below water; SDG 15 life and land; SDG 16 peace, justice, and strong institutions; and SDG 17 partnerships for the goals
- United Nations Decade of Ocean Science for Sustainable Development (2021–30),<sup>7</sup> where science responds to the needs of society to foster a transparent ocean with open access to data, information, and technologies, for a safe and predicted ocean, among other themes.

#### **BOX P.2. GEOGRAPHIC SCOPE OF THE STRATEGIC ROADMAP FOR ADVANCING IMPACT-BASED MHEWS IN THE CARIBBEAN**

For the purposes of this strategic regional multi-hazard impact-based early warning systems and services impact-based MHEWS roadmap process, the Caribbean region is considered to comprise CARICOM's 15 member states—Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, and Trinidad and Tobago—and five associate states and territories, Anguilla, Bermuda, British Virgin Islands, Cayman Islands, and Turks and Caicos. To promote harmonizing disaster management policy and investment, which will ultimately require political endorsement, it also recognizes that strengthening and streamlining a CARICOM regional impact-based MHEWS will necessitate effective collaboration with MHEWS strategies adopted by the Caribbean territories of the Netherlands, France, the United Kingdom, and the United States, and in some instances may need to involve wider Caribbean coastal countries.

<sup>4</sup> <https://www.undrro.org/publication/sendai-framework-disaster-risk-reduction-2015-2030>.

<sup>5</sup> <https://sustainabledevelopment.un.org/sids2014/samoopathway>.

<sup>6</sup> <https://sdgs.un.org/goals>.

<sup>7</sup> <https://en.unesco.org/ocean-decade>.

# Executive summary

**A s a region that is impacted by multiple shocks, multi-hazard early warning systems (MHEWS) that provide timely, actionable information are critical to protecting lives, assets and livelihoods in the Caribbean.**

Every year, the region suffers over \$1.6 billion in average direct natural hazard-triggered disaster damages (World Bank 2018). The number of people exposed to floods in the region increased by 70 percent between 2000 and 2020 and will keep rising with climate change (Rozenberg et al.). And while advances in science and technology make it possible to forecast many hazards and disseminate warnings, this is not enough. Ensuring risk-informed decision making requires countries to continually improve and update their understanding of the potential impact of complex hazards so authorities, people, and businesses can take appropriate anticipatory action. And to access the high-quality information they need to mitigate hazard impacts, national and regional cooperation is essential.

**As the region experiences the compound and cascading effects of multiple hazards, the need to find cost-effective ways to improve regional and national impact-based MHEWS is growing.** Although the region's states and overseas territories vary in size, capacity, institutional arrangements, culture, and language, most rely on maritime trade, security, food resources, and tourism. With disasters costing small Caribbean states nearly 2 percent of gross domestic product (GDP) each year (Acevedo Mejía 2016), the effects of the COVID-19 pandemic have highlighted the value of anticipatory action to prevent and mitigate economic losses.<sup>8</sup>

**Although a few Caribbean Community (CARICOM) countries have an operational MHEWS dealing with hydrometeorological hazards, there is not yet an operational system addressing an ensemble of multiple hazards of different origins such as hydrometeorological, geophysical or biological in a MHEWS context.** So far, the focus of the region has been to develop and operate early warning systems (EWS) for hydromet hazards, although the

acute need for MHEWS in the Caribbean, given the multiple hazards including geophysical and biological hazards affecting the region has been recognized. The roadmap highlights this need. To implement MHEWS, all CARICOM member states will need to establish supporting policies, with major investment required in national institutions' legislative, infrastructural, technical, and human resources as well as regional and national coordination mechanisms. Taking a regional approach will leverage existing capabilities and collaborations that support MHEWS, although these are yet to be reflected at national level in most member states.

**This roadmap focuses on achieving people-centered and self-sustaining regional impact-based MHEWS that ensure participation from gender groups, community leaders, vulnerable groups, and the private sector.** It is centered around 10 strategic initiatives which, implemented together, can help transform national and regional delivery of the MHEWS required for the Caribbean to thrive. This roadmap presents these initiatives, the vision, inclusive guiding principles, and an analysis of the social and economic benefits of EWS. Finally, it makes recommendations for implementing.

## Vision and guiding principles

**The vision is a regional model for inclusive and reliable impact-based MHEWS to protect lives, assets, and livelihoods, and increase resilience in the Caribbean.** Designed to strengthen and build on existing capabilities to realize a people-centered, end-to-end, and sustainable regional impact-based MHEWS, it is not intended as a substitute for institutional, national, and regional strategies and plans. Rather, it contributes to enhanced delivery and coherence across regional strategies for disaster risk management (DRM), resilience, and adaptation to climate change.

**Its proactive vision builds on foundational work by the Caribbean Disaster Emergency Management Agency (CDEMA), Caribbean Meteorological Organization (CMO**

<sup>8</sup> Interview with Ulric Trotz, deputy director and science advisor emeritus at CCCCCs (March 16, 2020).

**HQ), Caribbean Institute for Meteorology and Hydrology (CIMH), the Caribbean Community Climate Change Centre (CCCCCs), the Caribbean Public Health Agency (CARPHA), the University of the West Indies Seismic Research Centre, and others.** Lessons from the COVID-19 pandemic and recent extreme events underscore the need to understand the vulnerability of individuals, communities, and societies to provide reliable, targeted guidance and warnings and ensure willingness and capacity to prepare for reasonable worst-case scenarios based on risk-informed action planning.<sup>9</sup>

**To realize the full benefits of MHEWS in the region, countries require support to establish and resource their MHEWS policies and implementation roadmaps and harmonize these efforts** to ensure a coherent and sustainable regional strategy that aligns multiple approaches and efforts in strengthening EWS. Together, countries should also strengthen the regional cascading system for optimized national and regional coordination and collaboration, and leverage funding to strengthen and sustain MHEWS and its components at regional as well as national levels.

**Investing in MHEWS is one of the most cost-effective ways to build sustained measurable value and strong regional institutions** that provide timely, high-quality risk information to all segments of the population, including sectoral stakeholders (CARICOM 2017). The roadmap is therefore shaped along three cross-cutting principles:

### **Principle 1: People-centered EWS**

Focusing on people and their livelihoods, from risk to response, enables a truly efficient end-to-end EWS that responds to people's exposure and vulnerability to hazard impacts. Different groups face different restrictions on participation and power that can heighten risk and drive a downward spiral of disaster-driven poverty. This roadmap strives to capture historically neglected social segments, empower people and communities to become resilient to hazards, and deliver needs-responsive services for all social groups.

### **Principle 2: Expanding EWS to MHEWS**

Coping with multi-hazard events is a reality. Implementing CDEMA's Model National MHEWS Policy offers a strong regionally harmonized foundation for examining the institutional and legislative frameworks that govern

mandates for EWS. A multi-hazard system considers the differences and similarities between hazards, the compounding effects of overlapping hazards, and cascading impacts, as one process. Having a common framework for coping with complex disasters helps all stakeholders understand the full spectrum of secondary and tertiary effects and provide targeted warnings (Rogers et al. 2020a). This facilitates the required level of preparedness and responses to warnings. It can also help to optimize the cost-benefit, encourage coherence in national expenditures, and improve donor investments.

### **Principle 3: From MHEWS to impact-based MHEWS**

The impact-based forecasting (IBF) approach shifts the focus from what a hazard will be to what a hazard will do—that is, who will be affected, where, when and how? IBF is expected to become a trusted tool and core element of every national disaster risk management system. Focused on hydromet hazards to date, IBF is advancing meteorology and hydrology applications, which Caribbean countries already use in health and other sectors (Rogers et al. 2020a). The ability to understand and respond effectively to warnings through appropriate anticipatory action is central to a resilient society. Impact-based MHEWS offers a common approach that countries can progressively apply and tailor for all hazards, enabling all stakeholders and sectors to anticipate and effectively manage the complexity of current and future risks (Rogers et al. 2020a). This transition has already begun, with institutions in the region already developing and implementing various regional initiatives with support from the development community. Standardized frameworks under development include, among others, CDEMA's Model National MHEWS policy; its Comprehensive Disaster Management Strategy 2014–24; CARICOM and CDEMA's Caribbean Pathway for Building Resilience; and the Early Warning Information Systems Across Timescales in the Caribbean (EWISACTs) Roadmap and Plan of Action 2020–30.

<sup>9</sup> Interview with Ulric Trotz, deputy director and science advisor emeritus at CCCCCs (March 16, 2020).

## Strategic Initiatives for building a resilient future

MHEWS delivery is built around the four pillars of EWS:

**Pillar 1. A data-informed understanding of risk**

**Pillar 2. Regionally coordinated hazard monitoring, detection, and forecasting**

**Pillar 3. Tailored communication**

**Pillar 4. Shock-responsive planning to trigger effective anticipatory actions in all potentially impacted households, communities, and sectors.<sup>10</sup>**

Linking the four EWS pillars, this roadmap charts a set of mutually reinforcing strategic initiatives (SIs) that build on national and regional capacities to provide a framework for action that is achievable in the near to middle term. When carried out together, they strengthen existing transformational efforts in the region by focusing on a set of key building blocks for continually improving impact-based MHEWS delivery that will benefit the citizens and residents of the Caribbean in the long term.

### **SI1. Supporting the transition to IBF and warning services:**

Providing routine and actionable information on potential hazard impacts, in a form that all stakeholders understand and can use to protect lives, livelihoods, assets, and property, is vital. This work will build on existing progress in the region, developing a common terminology and agreed color coding of risk levels, and providing regional training.

### **SI2. Toward a Caribbean geospatial platform:**

Improving the availability of high-quality geospatial data in the region will benefit all countries, including through professional organizations, such as the Urban and Regional Information Systems Association (URISA) Caribbean Chapter, which strives to be the leading medium of the Caribbean geospatial community to support sustainable development, giving geospatial professionals opportunities for advocacy, educational development, networking, leadership, collaboration, coordination, and representation.

It has delivered considerable training through various projects and programs to date. A fully-fledged Caribbean geospatial platform will: create a political and technical environment with support from the region's leaders; strengthen and expand regional data-sharing; advance interoperability; and improve education and training opportunities in software development, geographic information systems (GIS), geospatial technologies, and similar fields.

### **SI3. Toward a regional multi-sensor precipitation grid:**

**Developing a high-resolution grid of observed and predicted rainfall in and near coastal areas across the region will significantly increase National Meteorological and Hydrological Services (NMHS) capacity for forecasting and using MHEWS. Combining rainfall data, satellite-derived rainfall data, and radar data, a high-resolution grid of estimated rainfall for the next 24 hours will be linked to a forecast rainfall grid for input to flood and flash flood early warning systems. Its integration with radars and rain gauge networks means that improved prediction will primarily occur near land masses for island states. However, where appropriate, the grid will also provide increased accuracy within the radar umbrella over the ocean, which can support future enhancement of marine warning services.**

### **SI4. An integrated approach to flood and drought risk forecasting and warning:**

Providing forecasts and warnings with enough lead time to avoid or mitigate losses will reduce potential impacts of flash, riverine, and coastal flooding for exposed populations. There have been regional and national efforts to address this significant challenge, and leveraging from existing work, this initiative will continue the integration process, progressively building in an integrated system of systems for anticipating all types of flooding. Building an integrated flood forecasting system and linking it to existing seasonal to inter-annual climate forecasting can inform preventative measures and flood mitigation strategies, and scaling up includes a drought forecasting capability needed for effective drought mitigation and integrated water resource management.

### **SI5. Integrating health impacts into the impact-based MHEWS:**

Expanding the weather and climate-related impact-based MHEWS to include public health

**10** In this roadmap, we differentiate between IBF as an activity focusing on observation and forecasting while including warning message design and an impact-based system that also considers inclusive dissemination, preparedness, and early action planning, such as implementing additional communication channels to enable the delivery of warnings to persons in at-risk catchments or neighbourhoods, updating community emergency plans, implementing drills, and so on.

risks—including those from impacts of climate change, such as excessive heat—has already started through weather and climate services with CARPHA, the Pan American Health Organization, CIMH, and the EarthMedic program. CIMH and CDEMA have also discussed the complexity that COVID-19 presented within the MHEWS, along with possible frameworks for integration. Adopting IBF as a common, understandable, and trusted approach for regional health hazards will benefit the whole of society in a true multi-hazard approach to coping with complex disasters.

**SI6. Air quality Health Impacts:** Progressively developing and operationalizing national and community level observation and effective air quality early warning systems will reduce risk and exposure to at-risk communities and persons of a host of airborne particles, gaseous contaminants and pathogens impacting the human and environmental health as well as key sectors in the region.

**SI7. Toward a Caribbean multi-hazard operational plan:** Establishing a regional multi-hazard operational plan that integrates existing mechanisms for each hazard and is flexible, practical, and regularly reviewed and updated will leverage collective regional strength to overcome national weaknesses. This will reduce the burden on national institutions by promoting best practice in producing forecasts and warnings for different hazards.

**SI8. Regional emergency alert system:** Implementing an effective, people-centered regional impact-based emergency alert communication and dissemination system that prompts appropriate action by everyone will ensure timely, consistent, authoritative, and targeted end-to-end advisories and warnings reach the public before and during emergencies.

**SI9. Community-based action planning:** Establishing national processes to change community perceptions of and reactions to alerts will strengthen community resilience and trigger appropriate anticipatory actions by raising awareness of hazard impacts, developing anticipatory action plans and improving understanding of and advocacy for IBF.

**SI10. Sectoral impact-based MHEWS, the private sector, and business continuity planning (BCP):** Engaging stakeholders from across the private sector spectrum as contributors to and beneficiaries of impact-

based MHEWS will help mitigate the loss of critical physical assets and disruptions in vulnerable supply chains and business services.

For each strategic initiative, the regional roadmap provides a clear summary of the rationale, objective, approach, main tasks, and actors, which can be used as a guide to inform harmonized development of national roadmaps and to take implementation of the SIs forward.

## Social and economic benefits of improved EWS

**Natural disasters cost the Caribbean region an estimated \$143.4 billion in the decade up to 2017, when weather-related losses spiked at \$86 billion.** Lower-income countries already facing other challenges tend to be more vulnerable to weather extremes, and recovery can take decades.

**Applying cost-benefit analysis (CBA) to investments in modernizing hydromet services has found that investing \$1 in hydromet EWS services results in at least \$3 in socioeconomic benefits** (WMO et al. 2015). This is a 3:1 benefit-cost ratio (BCR). Applying the IBF approach and modernizing hydromet services will broadly improve institutional capacities, regional collaboration, and information flow and use. Improving the resolution, timeliness, and accuracy of warnings and information will allow regional, national and local authorities and the public to take timely anticipatory measures, saving lives and avoiding or reducing asset losses.

**An economic analysis of the overall benefits of implementing the roadmap provides a more detailed estimate of economic value added.** With a BCR almost double that of a national approach, regional investments are likely to generate twice the benefits per dollar than a series of parallel national investments, as shown in Chapter 4, the economic analysis of the roadmap. Unsurprisingly, a regional approach that leads to national cost savings and overall reduced costs across all countries is more efficient than countries investing individually. Confidence in the economic efficiency of proposed investments is also higher for a regional versus national approach. This is recognized in the Caribbean and regional institutions facilitate this type of investment. An additional advantage of the regional investment model is lower transaction costs.

**The economics of hydromet and early warning services is driven by the benefits derived from improved DRM and optimizing the productivity of weather- and climate-sensitive economic sectors.** This assessment uses three models to quantify how improving the resolution, timeliness, and accuracy of warnings and information improves stakeholder decision making and subsequent actions, reducing fatalities and asset damage, and improving the economic productivity of weather-sensitive sectors. Probabilistic modeling and conservative estimates of the benefits enhance its robustness and confidence in the results.

**Assuming an annual economic growth rate of 4 percent on a GDP base of about \$100 billion, the average annual losses (AAL) for the hazards considered in the analysis are about \$1 billion, or 1.96 percent of GDP.** The model calculates that the proposed roadmap investments will lead to average AAL savings of 2.8 percent, and save 300–600 lives per year, accounting for 14 percent of all estimated economic benefits from improved DRM.

**Full MHEWS modernization would cost on average \$4–6 million per country, or \$80–120 million for the region, with potential regional benefits in agricultural, energy, and water supply productivity conservatively estimated at \$24–148 million per year.** Pursuing a regional approach through the roadmap would save an estimated \$30–40 million, with total regional costs of \$50–80 million. For individual national modernization investments, operation and maintenance (O&M) costs are estimated at 10–15 percent of capital expenditure (CAPEX). With many of the proposed investments shared among several countries, O&M for regional investments is estimated at 4–10 percent of CAPEX.

**As the Caribbean grows economically, so will its exposure and by extension regional AAL, which in turn will boost the expected benefits and BCR resulting from delivering enhanced impact-based MHEWS through this roadmap.** According to the economic model, the highest potential benefits can be generated by investing in improving forecasting accuracy, timeliness, and resolution. However, without a fully functional impact-based MHEWS, benefits of these initiatives would not be maximized, as this depends on all stakeholders taking effective decisions and actions based on the warnings. The current MHEWS

arrangement is not fully implemented but does deliver tangible benefits. To fully leverage the improvement of the regional system and service delivery, supporting countries is essential to unlocking the full protective and productive benefits of impact-based MHEWS information, and delivering “effective information efficiently” is vital.

## Implementation approach

**The roadmap's phased approach will allow countries to capitalize on quick and easy wins in the short term, build new and sustainable capacities in the medium term, and harness emerging opportunities over the longer term.** Multiple actors will be able to coordinate activities, prioritize tasks according to their financial and human resources, and optimize the sequencing of national and regional activities. The lead agencies for each strategic initiative will also be able to redefine roles and responsibilities with their implementation partners as required, mobilize financing for subsequent stages, and establish a workable regionally-led sustaining framework.

**To ensure legislative support for a regionally coherent approach, streamlining interagency data-sharing, application development, and modeling is crucial.** In the medium term, this roadmap will help accelerate the ongoing harmonization of the national implementation of interoperability agreements for monitoring and detection systems, as well as regional data standards. This will pave the way for greater use of Big Data and artificial intelligence, and continually improving the speed and accuracy of assessments and decision making over the long term. Establishing open data policies in the medium term will also accelerate this process. The World Bank worked with the Eastern Caribbean Central Bank on a 2022 data challenge that is already moving the Eastern Caribbean in this direction<sup>11</sup>, and other institutions have planned similar challenges using different mechanisms. The CIMH has trained several staff members in this area and has already begun construction of a data lake. Due to the complexity of systems engineering, a phased approach will be necessary to integrate state-of-the-art hazard forecast and warning systems and develop a impact-based MHEWS system of systems that will operate seamlessly in a computer workstation. The Caribbean DEWETRA Platform has already begun to support much of this, and

<sup>11</sup> <https://www.eccb-centralbank.org/p/grd-2022-climate-resilience-data-challenge>

CIMH has been laying the groundwork for an advanced integrated MHEWS framework.

**A systematic approach to designing and delivering training will ensure organizations involved in MHEWS implementation have the capacity they need to effectively manage the new techniques or technologies and sustain development.** To ensure countries and institutions can identify gaps between existing status and a future state of adequate capacity, training must align with national strategic objectives, deliver the competencies required to achieve them, consider existing staff capacity levels, and include a tailored capacity development plan.

**Involving private sector actors as contributors and beneficiaries will strengthen demand for sustaining impact-based MHEWS.** A new service driven business model needs to be explored and developed. Larger, regional-level enterprises can also shoulder some of the responsibility for ongoing maintenance and improvement to ensure needs-responsive EWS, while engaging micro-, small- and medium-sized enterprises (MSMEs) in national processes will help services reach the last mile and strengthen inclusion by enabling business owners to define their needs and help build the impact-based MHEWS. Leveraging private sector capabilities without jeopardizing public hydromet service provision is key to maximizing socioeconomic benefits (World Bank 2019). However, this is not achievable in the Caribbean without an additional layer of entrepreneurs and innovators who will build the new products and services and essentially act as intermediaries. NMHS will not have the capacity to do this. CIMH is currently working with U.S. Agency for International Development (USAID) to experiment with initiating this approach.

**The transformative gender and inclusion methodology is integral to roadmap implementation.** As well as ensuring an ongoing examination of who is most at risk, who has access to the information needed to generate early warnings, how and to whom warnings are issued, and the adequacy of anticipatory actions triggered by alerts, this will help ensure vulnerable groups participate in and contribute to disaster risk reduction, preparedness, response, and recovery.<sup>12</sup>

## Recommendations

**Providing early and actionable information to protect lives, assets, and livelihoods is crucial for avoiding and alleviating fiscal shocks from the multiple hazards that regularly impact the Caribbean.** The region experiences multiple shocks each year, caused by hydromet, seismic, environmental, and health-related events; and the costs associated with these are increasing, resulting in disasters that have led to an ongoing deterioration of the fiscal situation in many Caribbean states. As such, it is important that the process of progressively developing the impact-based MHEWS is closely aligned with the ongoing development of national disaster risk financing strategies.

**When building the regional MHEWS, focusing on impact is critical.** A warning for any hazard—no matter how accurate—is not enough. Being able to understand and respond effectively to warnings through appropriate anticipatory action is central to a resilient society. To take appropriate anticipatory action, authorities and the general population need to understand the potential impacts of any hazard. A culture of preparedness is a key ingredient for desirable outcomes of such actions.

**Regional ownership of the roadmap is vital, as the successful implementation of the strategic initiatives will require collaboration and resourcing at international, regional, and national levels.** To implement the roadmap, regional organizations and their member state agencies will need to provide direction, leadership, and commitment. Prepared as a strategic document to guide regional actions for developing a MHEWS, which will over time be strengthened into a robust, cascading, national-regional impact-based MHEWS, implementation will be largely at a national level and will require strong national and local operational coordination and interoperability to be sustained and remain relevant.

**Regional roadmap investments would generate twice the benefits per dollar spent than a patchwork of parallel national investments.** The mutually reinforcing strategic initiatives are expected to demonstrate return on investment that will inform strategic planning and may help leverage regional funding to build and sustain Caribbean capacity to deliver national and regional impact-based MHEWS. Securing the necessary financial resources

<sup>12</sup> Globally, the connection between EWS and the rights of vulnerable groups stems from the interaction of the Sendai Framework, Beijing Declaration and the Platform for Action, and the Convention on Human Rights of People with Disabilities.

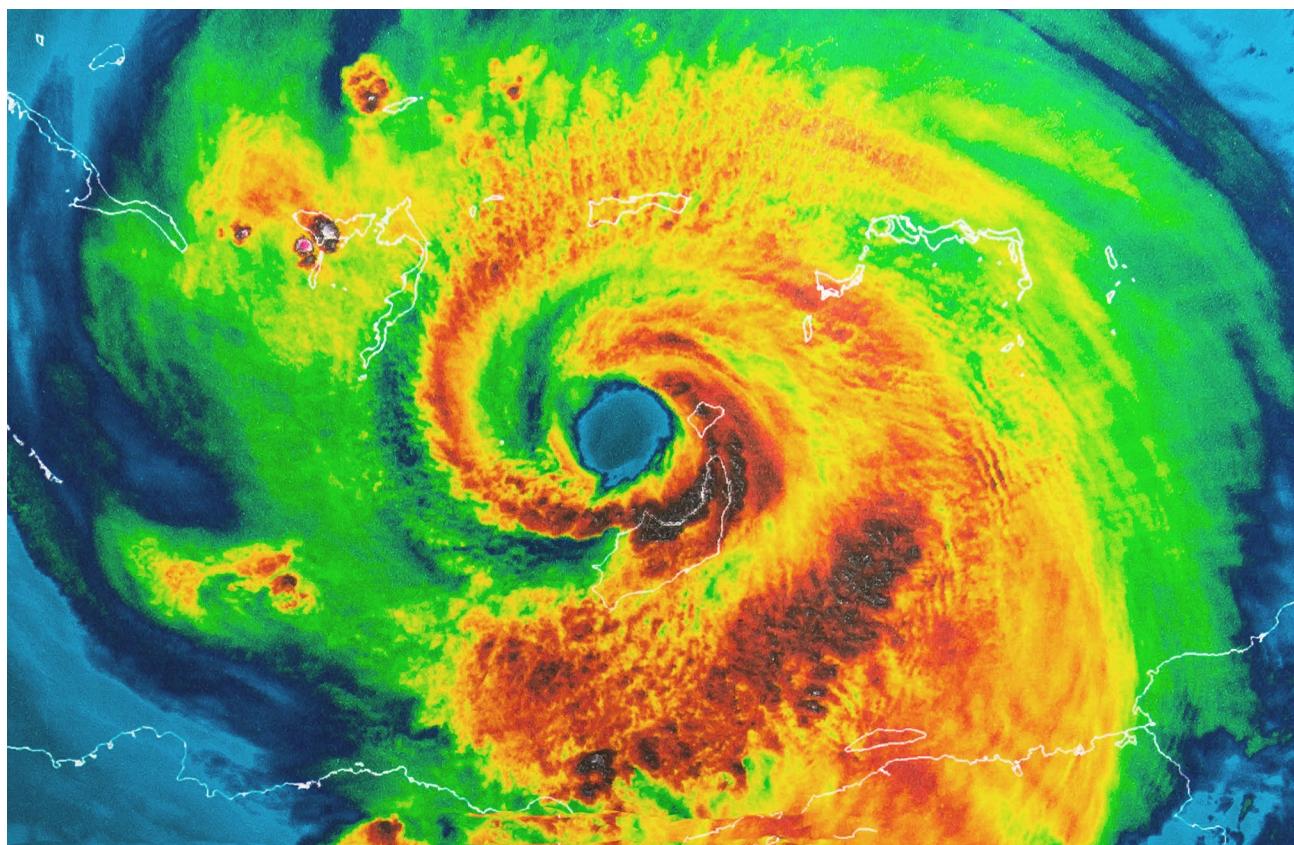
requires government endorsement to ensure national budgets support ongoing operationalization; resourcing national MHEWS roadmaps has been a challenge, however Cost-Benefit-Analysis shows a regional approach will lead to national cost savings; the fact that there is also greater confidence in its economic efficiency should assist in leveraging needed investments.

**The policy and regulatory environment will need to advance in concert with technical progress**, with all participating states implementing CDEMA's Model National MHEWS Policy. Supporting a regionally harmonized approach is essential for interagency data-sharing, developing the applications and modeling that are crucial for IBF transition, and facilitating the expansion of private sector collaboration along the whole EWS value chain.

**Data policy development is challenging, yet crucial for impact-based MHEWS delivery.** Although there is considerable capacity in the region, there are also significant challenges. Chief among these is the ability and willingness to share data, and the lack of understanding of the consequences of withholding data—on weather,

water, climate and geophysical hazards, exposure, and vulnerability—needed to produce risk-based warnings for communities and sectors. Such constraints adversely affect key institutions' ability to understand causal hazard processes and develop robust methodologies for delivering continually improving impact-based services.

**Countries should prioritize capacity building and retention to ensure the sustainability of impact-based MHEWS implementation and ongoing change management.** Knowledge and skills training are required at all levels to apply available tools and techniques to ensure the relevant institutions can manage change effectively to ensure the sustainability of introducing new techniques or technologies. A systematic approach to preparing and implementing a tailored capacity development plan should allow for identifying capacity gaps. Organizations should be able to offer an interesting career path, higher salary, and opportunities for self-development to attract professionals and address the risk of brain drain. Without these prospects, retaining skilled and qualified staff is difficult.



**Civil society plays a crucial role in the implementation of MHEWS and its inclusion in all efforts to strengthen the regional impact-based MHEWS is vital. It guides an inclusive approach to gender and vulnerable groups to ensure it reaches the people, sectors, and businesses that are most at risk.** Ensuring inclusive service design and delivery and measuring effectiveness by the ability to trigger appropriate action will help create accessible products and services that benefit all community members (Stough and Kang 2015). Acknowledging different groups' roles adds knowledge and experience to ensure the delivery of people-centered services.

**Involving private sector actors—from MSMEs to large enterprises—is vital.** Doing so will enable countries to leverage new technologies, reach the last mile through more effective dissemination, ensure communications are locally tailored, improve the shock responsiveness of communities and businesses, strengthen demand for developing and sustaining services, and help provide continuity in maintenance and continual improvement.

**The academic sector is an important vehicle for growth in the hydromet and other hazard domains.** Research and development ensure the ability to innovate and push the

boundaries of the entire global weather enterprise from the public, private, and academic sectors (Thorpe and Rogers 2018). Applying scientific advances to strengthening early warning systems and building new technologies to address community, national, regional and global challenges is crucial for bringing about some of the changes proposed in the roadmap.

**Together, the strategic initiatives outlined in this roadmap chart a course to bring timely and actionable impact-based MHEWS to all exposed people, communities, and sectors while also lessening overall costs.** Implementing the roadmap requires an enabling policy, legislative, and regulatory environment that keeps up with technical advances; smart investments for strengthening institutional and human resources capacity in a sustainable manner, involving the private sector; and a people-centered approach inclusive of gender, community stakeholders, and vulnerable groups. The Caribbean stands to gain from a regional IBF approach to strengthening and streamlining end-to-end impact-based MHEWS. A phased approach to implementation will capitalize on quick and easy wins in the short term, build new and sustainable capacities in the medium term, and harness emerging opportunities over the longer term.

# 1

## VISION AND PURPOSE OF THE ROADMAP



## Regional context

The Caribbean is impacted every year by multiple shocks caused by hydrometeorological (hydromet), seismic, environmental, or health-related events. Characterized by high levels of multi-hazard risk across states and overseas territories of different sizes, with diverse technical and human resource capacities, institutional arrangements, cultures, and languages, and with exclusive economic zones that rely on maritime trade, security, food resources, and tourism, the Caribbean region suffers over \$1.6 billion in direct natural hazard-triggered disaster damages on average each year (World Bank 2018). The number of people exposed to floods in the region increased by 70 percent between 2000 and 2020 and will keep rising with climate change (Rozenberg et al. 2021).

These impacts are expected to become more diverse and important. The Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report sets out the undeniable reality of climate change, with severe implications for Small Island Developing States, including the Caribbean. According to the IPCC's high confidence projection, in the coming decades, the Caribbean region will witness a declining trend in summer rainfall, with higher evapotranspiration leading to increased aridity and more severe agricultural and ecological droughts. In parallel, excessive heat is a growing public health threat—for every degree Celsius above a threshold level, deaths can increase by 2–5 per cent (WHO-WMO 2012).

Advances in science and technology have made it possible to forecast many hazards, and for responsible institutions to disseminate accurate warning information in a timely fashion. Yet the global challenge is that each year, hazardous events cause avoidable casualties and damage to property and infrastructure, with adverse economic, social, and environmental consequences for communities that can persist for many years. This is exacerbated by chronic underfunding faced by the region for maintaining, forecasting, and delivering targeted early warning services, and building capacity to take risk reduction, preparedness, and response actions. Regional and international cooperation are essential for societies to get timely access to high-quality, actionable information to mitigate the threat of these hazards. But warnings alone are not enough; to take appropriate action, civil protection and emergency

management authorities and the general population must also understand the potential impact of hazards.

Impact-based MHEWS that provide early and actionable information to protect lives, assets, and livelihoods are a critical requirement for dealing with these shocks. The region increasingly needs to find cost-effective ways to improve regional and national impact-based MHEWS as it experiences the compound effects of multiple hazards and—as the COVID-19 pandemic (Tilleray and Gill 2020) and 2021 volcanic eruption on St. Vincent<sup>13</sup> highlighted—cascading impacts when different hazards intersect.

The costs associated with increasing incidences of natural disasters have contributed to the further deterioration of the fiscal situation in many small Caribbean states. On average, the annual cost of disasters for small states is estimated to be nearly 2 percent of gross domestic product (GDP) (Acevedo Mejía 2016).

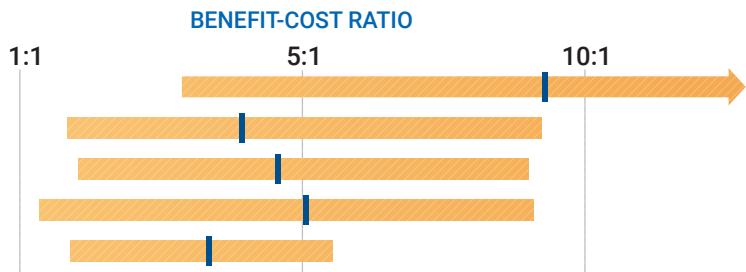
Investing in MHEWS is one of the most cost-effective ways to build measurable value. The Global Commission on Adaption finds that investments to strengthen early warning systems and services (EWS) have the most advantageous benefit-cost ratio (BCR) of all the adaptive investments analyzed (figure 1.1.) (GCA 2019). Further studies estimating the regional economic benefits of MHEWS found an average range of 3–15 times per dollar invested (Subbiah, Bildan and Narasimhan 2008), while a World Bank study on improving hydromet and warning services in developing countries (Hallegatte 2012) reached even greater BCRs (factors of 4–35) through a policy mix that targeted both direct benefits from disaster risk reduction actions and indirect impacts via resilience building actions, with the caveat that institutional fragmentation and coordination issues made this extremely difficult in practice.

<sup>13</sup> <https://reliefweb.int/sites/reliefweb.int/files/resources/Executive%20Summary%20SVG%20PDNA%20Volcanic%20Eruption.pdf>.

## FIGURE 1.1. COMPARATIVE BENEFIT-COST-RATIOS OF EWS AND OTHER ADAPTATION INVESTMENTS

### ADAPTIVE INVESTMENTS

- Strengthening early warning systems
- Making new infrastructure resilient
- Improving dryland agriculture crop production
- Protecting mangroves
- Making water resources management more resilient



Source: GCA 2019

A 2016 desk review of EWS in the Caribbean (Collymore 2016) recommends developing a regional MHEWS strategy or roadmap and suggests that the rapidly changing nature and complexity of hazards, society, and technology means that countries need to transition from a predominantly techno-scientific approach to warning system architecture toward a new people-centered, impact-based MHEWS culture. Recommendations include anchoring EWS in stakeholders' risk management plans at all levels, embracing harmonized and standardized monitoring and evaluation frameworks to assess performance, and applying value chain analysis and prioritization to areas of focus, actions, and limited resources. It notes that achieving all this ultimately calls for a change in mindset.

The compounding effects and cascading impacts of the COVID-19 pandemic in the region highlight the value in anticipating, preventing, and mitigating negative effects and economic losses to major revenue-producing sectoral industries, as well as micro-, small- and medium-sized enterprises (MSMEs). The latter have a specific gender dimension, and broadly support livelihoods and community resilience with critical goods and services.<sup>14</sup> Providing timely, high-quality risk information to all segments of the population and sectoral stakeholders is crucial for keeping people safe, protecting livelihoods, and bolstering the sustainability of economic planning, trade facilitation, and long-term development strategies (CARICOM 2017).

### Vision

This roadmap has a proactive, rather than reactive, vision. Formulated in consultation with the Regional Early Warning Systems Consortium (REWSC), the vision statement aspires to create a thriving regional culture of safety through *"a regional model for inclusive and reliable multi-hazard impact-based early warning systems and services that are effective in protecting lives, livelihoods and increasing resilience in the Caribbean"*. In its role as a strategic and advisory body for advancing and strengthening EWS coordination within the Caribbean, the REWSC envisions this strategic impact-based MHEWS process as a Caribbean-owned tool to increase coherence, enhance coordination and collaboration at national and regional levels, effectively address weaknesses, harmonize efforts, provide a regional framework for national-level goal setting and activities, and ultimately leverage and coordinate investments to achieve cost-efficient solutions for the region. The principal focus is on achieving people-centered and sustainable regional impact-based MHEWS. The roadmap is designed to contribute to the process for strengthening and streamlining MHEWS to realize this transformational vision for the region.

### Purpose of the roadmap

Given the multiple hazards affecting the Caribbean, having an operational MHEWS is vital. But ensuring there is one in each Caribbean Community (CARICOM) member state will require major investment in national institutions' legislative,

<sup>14</sup> Interview with Ulric Trotz, deputy director and science advisor emeritus at CCCCCs (March 16, 2020).

infrastructure, technical, and human resources as well as regional and national coordination mechanisms. The region needs a system of systems to achieve an integrated end-to-end impact-based MHEWS structure to maximize efficiency and effectiveness in the use of often limited resources.

This roadmap offers a common framework to optimize benefit-cost ratio and encourage coherence in national expenditure as well as a framework for donor investments and activities that do not always align with national and regional priorities, leading to fragmentation and inefficiencies. The strategic initiatives presented here offer a set of approaches to leverage regional-level capacities and build stronger foundations at national level while transitioning from an EWS for hydrometeorological hazards to impact-based MHEWS. This roadmap does not purport to present an all-inclusive set of initiatives accompanied by a prescriptive implementation plan, and as such, does not outline required investments or implementation timelines. However, a phased approach is recommended to help optimize the sequencing of implementing the various roadmap activities. There is also more than one way to take forward the strategic initiatives, thus it is up to the regional and national agencies to decide on the most appropriate implementation modality.

By exploring existing opportunities and challenges, this roadmap addresses the need to develop a standardized regional framework or architecture and associated interoperable standards. It presents ten strategic initiatives that build on national and regional capacities to bring timely and actionable impact-based MHEWS to all exposed people, communities, and sectors while also improving overall cost-efficiencies. The theory of change driving the roadmap is threefold:

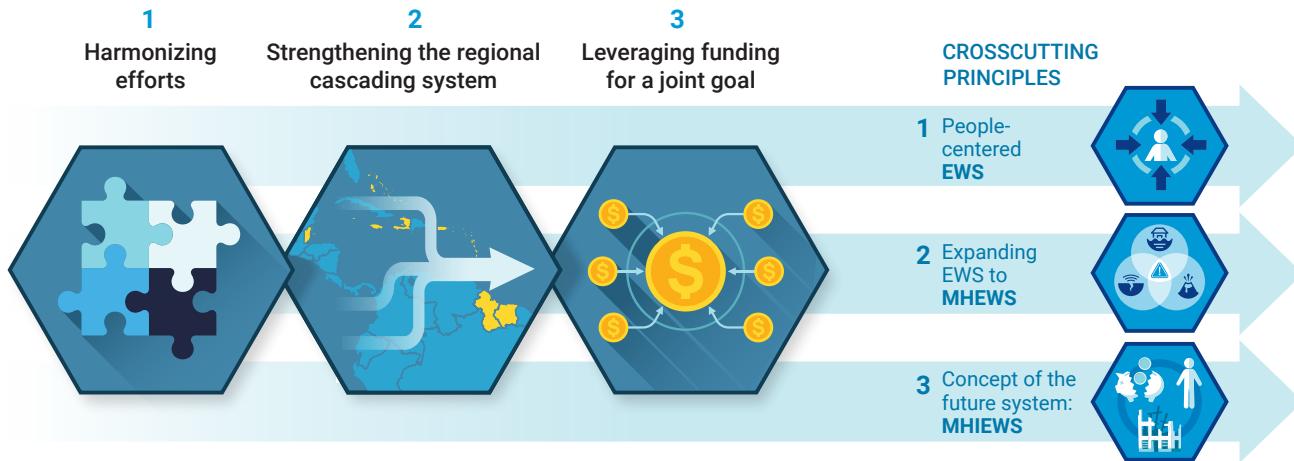
- **Harmonization of efforts:** A coherent and sustainable regional strategy can align the multiple approaches and harmonize national efforts in strengthening EWS.
- **Strengthening the regional cascading system:** A regional MHEWS can optimize coordination and collaboration at national and regional levels, including through benchmarking and assessment to inform progress.
- **Leveraging funding for a joint goal:** Efficient and targeted efforts improve return on investment and attract necessary funding, including climate financing to strengthen and sustain a MHEWS and its

components at regional and national levels.

Regional entities have done much foundational work in the Caribbean. Standardized frameworks already being developed in the Caribbean include the Caribbean Disaster Emergency Management Agency's (CDEMA) Model National MHEWS Policy, Comprehensive Disaster Management (CDM) Strategy 2014–24, Caribbean Pathway for Building Resilience, and the Early Warning Information Systems Across Timescales in the Caribbean (EWISACTs) Roadmap and Plan of Action 2020–30.

In particular, supporting countries in establishing CDEMA's Model National MHEWS Policy provides a framework for developing harmonized national impact-based MHEWS. CDEMA's EWS checklist has begun to establish a baseline, which can be used as a regionally harmonized national assessment process that can also be rolled up to provide regional benchmarking. At the same time, the Caribbean Institute for Meteorology and Hydrology (CIMH) and the Caribbean Meteorological Organization Headquarters Unit (CMO HQ) have developed robust regional institutional mechanisms and technical foundations that are already delivering regional hydromet services and furthering the development of impact-based forecasting (IBF) in the region. To add value to these foundations, sustained institutional and policy efforts and investments are required to build the enabling environment that will ensure people-centered MHEWS delivery.

The roadmap does not substitute institutional, national, and regional strategies and plans. Rather, it builds on the work that has been done in the region and contributes to enhanced delivery and coherence across regional strategies for disaster risk management (DRM), resilience, and adaptation to climate change. It proposes a phased approach to help optimize the sequencing of implementing national and regional activities over the course of the roadmap.

**FIGURE 1.2. PURPOSE OF THE ROADMAP AND CROSCUTTING PRINCIPLES**

### Crosscutting principles

The roadmap is shaped along three crosscutting principles: people-centered EWS, expanding EWS to MHEWS, and gradually incorporating impact-based forecasting (IBF) to embrace a regional culture of impact-based MHEWS.

#### Principle 1. People-centered EWS

End-to-end EWS are inclusive of all at-risk groups, since reaching the last mile means that all groups must participate in preparedness and response so that everyone's needs and capacities inform action planning. Focusing on people and their livelihoods from risk to response enables a truly efficient end-to-end EWS that responds to the situation of most at-risk people. Inclusivity also directly improves the functionality and impact of MHEWS by centering people and last mile needs in the system design.

Disasters affect gender and age groups differently, as they face different levels of exposure, participation, power, and vulnerability, which influences risk. Gender inequality and social marginalization of vulnerable groups—such as youth, elderly people, or people with disabilities—increases vulnerability, heightens exposure to risk, and restrains response and recovery capacity, often resulting in a post-disaster downward spiral of poverty.

A people-centered approach allows the roadmap to capture historically neglected social segments, and the EWS checklist provides a mechanism for periodic national

assessment that can also inform regional benchmarking to ensure needs-responsive progress. For example, in the private sector, building MSME resilience not only neatly overlaps with gender and youth, but also directly contributes to reducing poverty and other forms of labor and economic vulnerability. As such, it is essential to look at the Caribbean private sector as people driven.

#### Principle 2. Expanding EWS to MHEWS

Coping with simultaneous multi-hazard events is a reality in the Caribbean. The need to transition from EWS to MHEWS is well recognized across the region, and some elements are already being operationalized, though at a slower-than-needed speed (which can also challenge developed countries). Implementing CDEMA's Model National MHEWS Policy offers a strong regionally harmonized foundation for examining the institutional and legislative frameworks that govern mandates for MHEWS.

A multi-hazard system harmonizes efforts by considering the differences and similarities between hazards, the compounding effects of multiple hazards overlapping, and their cascading impacts as a process that starts with understanding risks, monitoring and forecasting hazard events, disseminating and communicating warnings, and includes processes for effective community and sectoral planning, preparedness, and response.

Having a common framework for coping with complex disasters helps authorities, sectoral stakeholders, and at-

risk populations understand the full spectrum of secondary and tertiary effects and therefore provide more targeted warnings, on where to focus preparedness and response efforts (Rogers et al. 2020a).

### **Principle 3. Concept of the future system: impact-based MHEWS<sup>15</sup>**

In an impact-based approach, the focus shifts from “what a shock will be”—for example, how many millimeters of rain will fall or what the windspeed will be—to “what a shock will do”; that is, who will be affected, where, and how. It is not only a case of analyzing, monitoring, observing, and forecasting risk (as is common under IBF). It is also necessary to tailor and direct communication to persons and businesses at risk and develop shock-specific action planning at appropriate timescales to ensure effective preparedness, risk reduction, and response planning and actions are carried out in all potentially impacted households, communities, and sectors.

This roadmap recognizes the fundamental distinction between a general hazard warning and an impact-based warning by including the specific vulnerability of the people, livelihoods, and assets or property at risk. For example, when considering hydromet hazards, conventional weather forecasts and warnings focus on determining meteorological thresholds for extreme events.

Impact-based forecasts and warnings, on the other hand, integrate information about the potential severity and likelihood of occurrence of weather impacts. Tailoring IBF communications to different audiences makes an important difference in how effectively recipients can prepare for, respond to, and act on the communicated information.

Lessons from the COVID-19 pandemic and extreme weather events underscore the need to understand the vulnerability of individuals, communities, and societies to provide reliable, targeted guidance and warnings and ensure people’s willingness and capacity to prepare for a reasonable worst-case scenario based on informed action planning. Meteorology and hydrology are making good progress through IBF in addressing social determinants of vulnerability and understanding underlying issues in preparation and action planning, a process that is now also being applied to health and other sectors in the region (Rogers et al. 2020a).

The ability to understand and respond effectively to warnings through appropriate anticipatory action is central to a resilient society; and impact-based MHEWS offers a common approach that can over time be applied and tailored for all hazards, so all stakeholders and sectors can anticipate and effectively manage the complexity of current and future risks.

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<sup>15</sup> In this roadmap, we differentiate between IBF as an activity focused on EWS observation and forecasting pillars (box 3.1) while including the design of warning messages, and an impact-based EWS, which also considers pillars that encompass inclusive dissemination, preparedness, and early action planning—for example, implementing additional communication channels to deliver warnings to specific persons in at-risk catchments or neighbourhoods, updating community emergency plans, implementing drills, and so on.

# 2

## OPPORTUNITIES AND CHALLENGES



To achieve the roadmap vision, it is necessary to first recognize the foundations the region has built, including CDEMA's CDM Strategy, the REWSC, the Caribbean Meteorological Organization (CMO) network of national hydromet services and specialized committees, and CIMH serving as the Caribbean Regional Climate Center, with its sectoral alliance, EWISACTs. Combined with recent advances in science and technology, these and other developments open significant opportunities to address the challenges the Caribbean faces.<sup>16</sup>

Key opportunities include enhancing collaboration and supporting regional institutions to build on existing skills and knowledge across various agencies at national and regional levels, investing in access to, analysis and use of different types of data using modern technologies, and providing the necessary ongoing and additional training and capacity building to overcome barriers that hamper effective preparedness and response. Using multiple channels and tools for people-centered information dissemination also offers a ready opportunity to begin delivering tangible benefit at the national level from the implementation of the roadmap at the regional level.

The roadmap also recognizes the challenges inherent in building synergies and adding value across the region, with activities requiring different timings and diverse partners. For example, mainstreaming existing and emerging tools and techniques—such as ensemble prediction systems (EPS), artificial intelligence (AI), and machine learning (ML) for dealing with uncertainty through probabilistic forecasting—and developing risk-based warnings for communities and sectors is a complex challenge well worth harnessing as an explicit objective (box 2.1).

## BOX 2.1. OVERCOMING CHALLENGES IN ACCESSING AND USING EPS DATA IN THE REGION

With the exception of the French Overseas Territories and Cuba<sup>17</sup>, there are no other EPS operating in the Caribbean. Although countries have access to limited EPS products, the underlying data are not shared, except by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) and National Centers for Environmental Prediction (NCEP). For example, through the Eastern Caribbean Severe Weather Forecasting Programme (SWFP), weather forecast offices have access to ensemble prediction products from Canada, Europe, and the United States.

Forecasting of extreme weather in the mid-latitudes has tremendously improved over recent decades through the use of limited-area models with higher space and time resolution. But if Caribbean countries wish to use limited-area EPS or other limited-area numerical weather prediction (NWP) systems, EPS data are not available for the boundary conditions of the limited-area models. The Global Basic Observing Network is intended to provide more data from World Meteorological Organization (WMO) members for higher-resolution NWP models. Reciprocal arrangements could be made for more model output and products from NWP centers to be made available to National Meteorological and Hydrological Services (NMHS), but would require changing the rules NWP centers operate under, over time.

The recent eruption of La Soufrière volcano in St. Vincent and the Grenadines highlights the need for national and regional air quality measurement networks. This is further underscored by the need to track other contributors of diminished air quality in the region, including high Sahara dust concentrations—composed of elevated particulate matter (PM) PM2.5 and PM10 concentrations<sup>18</sup>—across the region, which are known to pose adverse health conditions (box 2.2).

## BOX 2.2. HEALTH-RELATED IMPACTS OF SAHARA DUST AND THE SOUFRIÈRE VOLCANO ERUPTION

Ash from the 2010 Soufrière volcano eruption in Montserrat has been linked to an increase in asthma admissions in Guadeloupe (Cadelis et al. 2013), while another study of air pollution and respiratory health among elementary school children in Guadeloupe (Amadeo et al. 2015) finds that, in over 70 percent of the schools exceeded mean PM10 levels in the WHO Air Quality Guidelines, with Saharan dust strongly suspected to be the driver. Humidity interacting with dust from the Sahara has been shown to produce particulate matter in Barbados, Grenada, Trinidad and Tobago, and U.S. Virgin Islands, resulting in increased visits to the emergency department with exacerbated asthma (Akpinar-Elci et al. 2015; Garrison et al. 2014; Gyan et al. 2005; Monteil 2008). Recent studies (Akpinar-Elci et al. 2015) have linked dust exposure to low birth weight and other effects on fetal growth.

<sup>16</sup> The status quo is presented in detail in World Bank (2020).

<sup>17</sup> <https://www.mdpi.com/2673-4931/19/1/5/htm>

<sup>18</sup> PM2.5 is particulate matter 2.5 microns or less in diameter and is generally described as fine particles. PM10 is particulate matter 10 microns or less in diameter. By way of comparison, a human hair is about 100 microns, so roughly 40 fine particles could be placed on its width.

## Strong regional institutions foster collaboration along the EWS value chain

Growing societal vulnerabilities, coupled with the rapid pace of technical advances in anticipating hazards at different spatial and temporal scales, build pressure to improve the services that existing EWS can deliver. In a diverse island region where high-resolution surface-based observation systems are already technically and financially challenging, fragmentation between monitoring systems and forecasting capabilities for different types of threat further inhibits efficient collaboration. For example, in Saint Lucia, there are observation platforms (Automatic Weather Stations (AWS), rain gauges, and stream gauges) from three different equipment manufacturers that are not interoperable. Because they transmit data differently, decoding and processing is difficult. Neither the National Meteorological Services (NMS) nor the National Hydrological Services (NHS)/Water Resource Management Agencies (WRMA) have the expertise or finances to maintain three different systems, resulting in a breakdown of the data network.

Making sense of the region's mosaic of MHEWS monitoring, modeling, and forecasting systems will require economies of scale, cooperation to minimize duplication, and analysis of the institutional and legislative frameworks that govern EWS mandates in a tightly constrained fiscal space. Implementing CDEMA's Model National MHEWS Policy offers a strong foundation to build on, and countries need support to realize this. The ability to understand and respond effectively to warnings through appropriate behaviors and early action is central to resilient societies and communities, and hydromet services worldwide are transitioning toward impact-based MHEWS (Rogers et al. 2020). Cooperation is crucial, and as hazards do not observe borders the interconnectedness of multi-hazard impacts in the Caribbean is a strong motivator (CMO 2018).

Recognizing the solid foundations and unique strengths of the region's institutional architecture and the considerable capacities of regional, national, and international organizations—including the CARICOM Secretariat and its institutions, such as CMO HQ, CIMH, CDEMA, the Caribbean Public Health Agency (CARPHA), and the Caribbean Community Climate Change Centre (CCCCCs), as well as the Organization of Eastern Caribbean States (OECS) and its Commission, the Caribbean Water and Wastewater Association (CWWA), the Global Water Partnership – Caribbean (GWP-C), the University of the West Indies

(UWI), national gender bureaus, the NOAA, and the United Nations Educational, Scientific and Cultural Organization–Intergovernmental Oceanographic Commission (UNESCO-IOC)—strong interinstitutional coordination, cooperation, and collaboration are essential.

## Leveraging the power of data sharing and efficient information use for event forecasting

Data are the necessary fuel for MHEWS. Fully harnessing the power of data requires new norms for looking at how weather, water, climate, and geophysical processes affect productivity. Building institutions' ability to access, understand, and manipulate hazard, exposure, and vulnerability data is vital, to inform decisions under dynamic conditions. Efficient data collection, management, and use—vital for continually improving impact-based warning services—would allow the region to transition from deterministic forecasting to using and interpreting probabilistic forecasts. This, in turn, would increase the integration and uptake of risk-informed decision-making platforms.

Coping with simultaneous multi-hazard events is also a reality. The outbreak of COVID-19 occurring concurrently with one of the most active hurricane seasons in the Atlantic basin in 2020 presented challenges that resulted in adjustments to the single-hazard response system—for example, in shelter and evacuation protocols and related information for pandemics coinciding with hurricanes. Haiti's experience of an earthquake followed by a direct hit from a tropical storm in 2021 showed that regional institutions can deal with multiple simultaneous hazards through regional and national partnerships. Similarly, in 2021, St. Vincent and the Grenadines showed its ability to simultaneously deal with COVID-19 and volcanic activity. These events demonstrate the growing ability of the Caribbean disaster and hydromet communities to rank the risks of multiple simultaneous hazards and rapidly identify priorities and needs.

As well as the dramatic growth in data volume, a revolution is taking place in using ML and AI analytics to merge data from different aspects of society, distinguishing signals from noise and enabling data on one aspect to inform seemingly disparate, yet indirectly related, aspects of society (Thorpe and Rogers 2022). While observational data have always been important in meteorological forecasting, the advent of ML and AI as prediction algorithms highlight the high

value of meteorological, hydrological, and ancillary datasets, particularly for applying to high-resolution, very short- and short-range high-impact weather and flood forecasts. For example, it is possible to produce aspects of the high-resolution forecasts that depend on the lower-resolution elements of the atmospheric flow using post-processing methods based on ML (Palmer 2019, Rogers et al. 2020, Rogers and Tsirkunov 2021). Unlocking the potential for Big Data, ML and AI are on the horizon. The national MHEWS roadmaps completed to date indicate that countries in the Caribbean region face common limitations with hazard maps, repositories for central data and consolidated risk information, as well as disaggregated infrastructure exposure and social vulnerability data. Significant investment has gone into expanding hydromet observation and real-time early warning networks across the region over the last two decades, with the CCCCCs coordinating the delivery of funds from development partners and the CIMH identifying target locations for these new investments. In spite of the many stations that have been installed to date, there is an urgent need for more stations, and for standardized protocols, hardware, expertise, and technology. While a multiscale approach is needed to strengthen overall capacity in the region, ensuring national repositories are strong enough to feed into regional repositories is also a key priority requiring support.

### Using multiple channels and tools to disseminate people-centered information

An accurate forecast is only useful if it is communicated effectively and received in time to allow for risk mitigation measures. This is especially important for IBF, which requires a detailed understanding of the target audience, including any emergency contingency and business continuity measures that need to be considered if the normal dissemination routes fail. IBF requires developing decision support systems and expanding dissemination efforts, to achieve responsiveness and resilience. This means optimizing graphical displays and deploying a variety of modern two-way as well as traditional dissemination methods—including radio, television, cell phones, internet-based platforms and apps, web pages, social media, and community and religious leaders and institutions—to ensure warning information reflects exposure and vulnerability, is

accessible and useful to a wide range of the population.

### Using technology and information systems to unlock impact-based MHEWS' potential

Accuracy and timeliness of warnings translate into more confidence in risk-informed decisions and actions. In terms of accuracy, NMHS ability to provide essential forecasts and warnings for extreme events is curbed by deficiency in both the integration of other data needed for useful IBF information—such as social determinants of vulnerability, land use and topographic models—and human capacity and skills, such as the ability to use ensemble forecasting. The transition to IBF involves a shift from decision support founded on experience to decision support based on geospatial and risk probabilities. Although it will take time, this is a necessary process.

The popularity of smartphones and mobile devices offers new warning communication and alert delivery methods, and cellphone-based alert systems are key for disseminating early warnings—that is, before disaster strikes. But while cell broadcasting services and wireless emergency alerts have gained international recognition<sup>19</sup> for increasing the reach of warnings, their use in the Caribbean has been limited. Severe weather exposure of critical communications infrastructure, such as cell towers, is a known risk. CIMH is in parallel working on low-cost and sustainable solutions for shock-resilient hydromet services to make sure there is no disruption in service provision to the population. It is also important to understand how audiences interpret and respond to these alerts. Social media platforms offer an opportunity for officials to tune into the perceptions and emotions of those at risk, adjust the warnings and risk communications to reduce fear and anxiety, and provide the information people need in ways that are actionable.

### Building capacity to overcome barriers to effective preparedness and response

The progressive development and integration of risk information, together with ongoing IBF-strengthening efforts, constitute an excellent foundation for the systematic

<sup>19</sup> As an example, a European Union directive on December 11, 2018 mandated all member states to implement public warning systems by June 21, 2022 to better protect citizens, visitors, and tourists during natural disasters and other crisis situations. Article 110 of the directive states that this public warning system must be cell phone-based and capable of sending geolocated mass alerts.

application of risk-informed early action planning at the community level and risk-informed business continuity planning (BCP) within all levels of the private sector.

But disseminating and communicating targeted warning information does not ensure that at-risk people, communities, and sectors will take timely and appropriate action before an anticipated hazard hits. Building on strong regional disaster management skills in scenario planning, drills, and simulation exercises, national disaster management organizations (NDMOs) and the Red Cross movement in the Caribbean region are uniquely positioned to mobilize participatory training that is inclusive of all vulnerable groups. Normative training can ensure that every community develop an anticipatory community-based risk-informed action plan that identifies actions linked to specific risk forecasts so that individuals, households, and communities know who needs to do what, when.

Building on regional efforts within the private sector, including through the Caribbean Network of Chambers of Commerce (CARICHAM) and the United Nations Office for Disaster Risk Reduction (UNDRR) Alliance for Disaster Resilient Societies (ARISE) network<sup>20</sup>, the French Red Cross regional platform (PIRAC)<sup>21</sup> and cooperation with NDMOs, a similar focus on increasing capacity and strengthening BCP will benefit businesses at all scales. Outreach and training are needed to ensure that, as well as large national and regional or international enterprises, MSMEs and youth and women-headed businesses also develop multi-hazard risk-informed action plans.

### Strong initiatives offer strong opportunities to overcome challenges

This roadmap helps to navigate the key institutional, capacity building, and awareness-raising constraints identified in the region (Fanning et al. 2021). National Road Map priorities identified by CDEMA Participating States (PS) that can be addressed through implementation of the

roadmap include updating Hazard, Vulnerability and Risk (HVR) data and analysis; updating and enacting legislation and SOPs to guide agencies; technical training; increased frequency and targeting of communications campaigns; better communications reach, targeting and resilience; multistakeholder communications strategy; standardised methodologies; data and information sharing mechanisms and protocols; and increased tests and exercises.

Building on the activities and achievements of ongoing projects and initiatives that strengthen MHEWS and hydromet services in the CARICOM region opens avenues for consolidating regional and national resources through effective coordination at all levels. For example, operational ocean services in the wider Caribbean region provide up-to-date, vital information for coastal communities, small-scale fishers, enterprises, and governments, enabling them to take decisions on sustainable development and the Blue Economy.

Opportunities to use, coordinate, and share geospatial information and satellite data can enhance each country's observation network, and some state-of-the-art components are already in place in the region. The WMO Flash Flood Guidance System (FFGS)<sup>22</sup> is operational in Haiti and the Dominican Republic, while Saint Lucia is in the process of implementing its FFGS. The Coastal Inundation Forecasting Initiative (CIFI),<sup>23</sup> funded by the U.S. Agency for International Development's (USAID) Bureau for Humanitarian Assistance (BHA) and led by the NOAA National Hurricane Center (NHC in Miami) is operational for Haiti and the Dominican Republic, and capable of providing detailed prediction of coastal flooding from tropical cyclone surges. USAID BHA plans to expand CIFI to other Caribbean countries over five years (from 2023). With the establishment of an operational regional center in Martinique, the WMO's SWFP<sup>24</sup> is in pre-operational phase for the Eastern Caribbean (as of 2022); CMO HQ and CIMH are leading the training for its use, and most countries are building their capability.

20 <https://www.caribbeanchambers.net/caricham-bcp>

21 PIRAC has developed Small Business Disaster Preparedness tools for the Eastern Caribbean: <https://pirac.croix-rouge.fr/en/our-missions/disaster-preparedness/>

22 <https://public.wmo.int/en/projects/ffgs>.

23 <https://community.wmo.int/activity-areas/Marine/CIFI>.

24 <https://community.wmo.int/swfp-eastern-caribbean>.

# 3

## STRATEGIC INITIATIVES FOR BUILDING A RESILIENT FUTURE

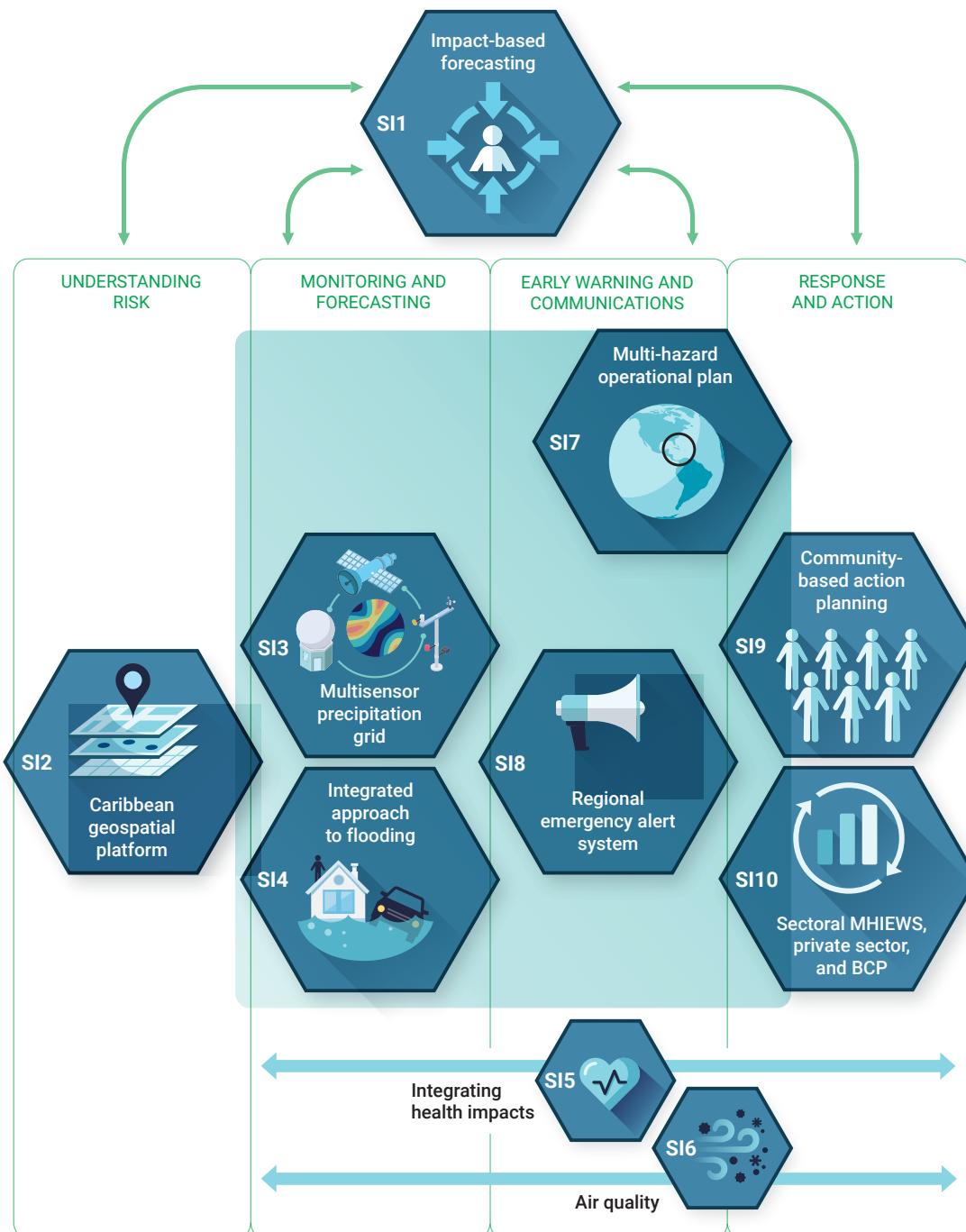


There is a solid foundation for building a Caribbean impact-based MHEWS, as identified in the Climate Risk and Early Warning Systems (CREWS) Caribbean Situation Analysis (World Bank 2020) and consultative process. Based on the findings of the analysis, this roadmap focuses on a set of strategic initiatives (SIs) with breakthrough potential for the

region, which together provide a framework on which to scaffold further actions that may be achievable in the near to mid-term.

Most of the strategic initiatives depend, to a large extent, on access to data. The national MHEWS roadmaps

**FIGURE 3.1. OVERVIEW OF THE STRATEGIC INITIATIVES ACROSS EWS PILLARS**



completed to date indicate that countries face common limitations with hazard maps, repositories for central data and consolidated risk information, as well as disaggregated infrastructure exposure and social vulnerability data. Significant investment has gone into expanding hydromet observation and real-time early warning networks across the region over the last two decades, with the CCCCCs coordinating the delivery of funds from development partners and the CIMH identifying target locations for these new investments. In spite of the many stations that have been installed to date, there is an urgent need for more stations, and for standardized protocols, hardware, expertise, and technology. While a multiscale approach is needed to strengthen overall capacity in the region, ensuring national repositories are strong enough to feed into regional repositories is also a key priority.

Many Caribbean islands have made progress in addressing hydromet and marine hazards, but due to population size and financial resources, some may never be able to do their own forecasting and will require external support. The forecasting arrangements among CMO member states recognize that there is enough capacity at the regional scale for some states and institutions to provide meteorological forecasts to other states. But issuing reliable flood forecasts requires an intimate knowledge of, among other issues, the topography, land use, infrastructure conditions, geology, hydrology, and antecedent conditions of local watersheds. This makes it difficult for external parties to provide effective guidance on flooding without ready access to aggregated datasets.

The Caribbean DEWETRA Platform was established to address this challenge by providing regional access to

a range of country-level datasets (dynamic and static) that characterize evolving hazards and associated vulnerabilities, which allows skilled individuals to rapidly assess the elements of exposure and risk in watersheds that is essential for supporting early warning, planning, and decision making. Sahara dust monitoring is also part of the regional hydromet system and, alongside coral bleaching forecasts, is integrated into the Caribbean DEWETRA Platform; sargassum detection is available at CIMH, but forecasting is through several partnerships; volcanic ash monitoring is supported through daily modeling at CIMH, which has also initiated some work to address oil spills.

The SIs form a next critical step toward gearing up a regional MHIEWS. Figure 3.1 shows how the principles of an impact-based approach are fully crosscutting and encompass hazards monitoring, forecasting, warning dissemination, and community engagement in preparedness and response. When implemented together, complementarities across SIs fortify feedback loops among the four EWS pillars (box 3.1). Over time, creating a multi-hazard operational plan will build on hazard monitoring and forecasting, harnessing risk information and developing/enhancing alert and dissemination platforms.

The SIs presented below are closely linked to, and aligned with, ongoing or planned initiatives in the region, which should make the proposed efforts more sustainable. Leveraging this close integration between the roadmap and existing regional efforts should help to accelerate, strengthen, and potentially contribute directly or indirectly to realizing the vision. Appendix A maps regional and national activities and details their linkages with the roadmap SIs.

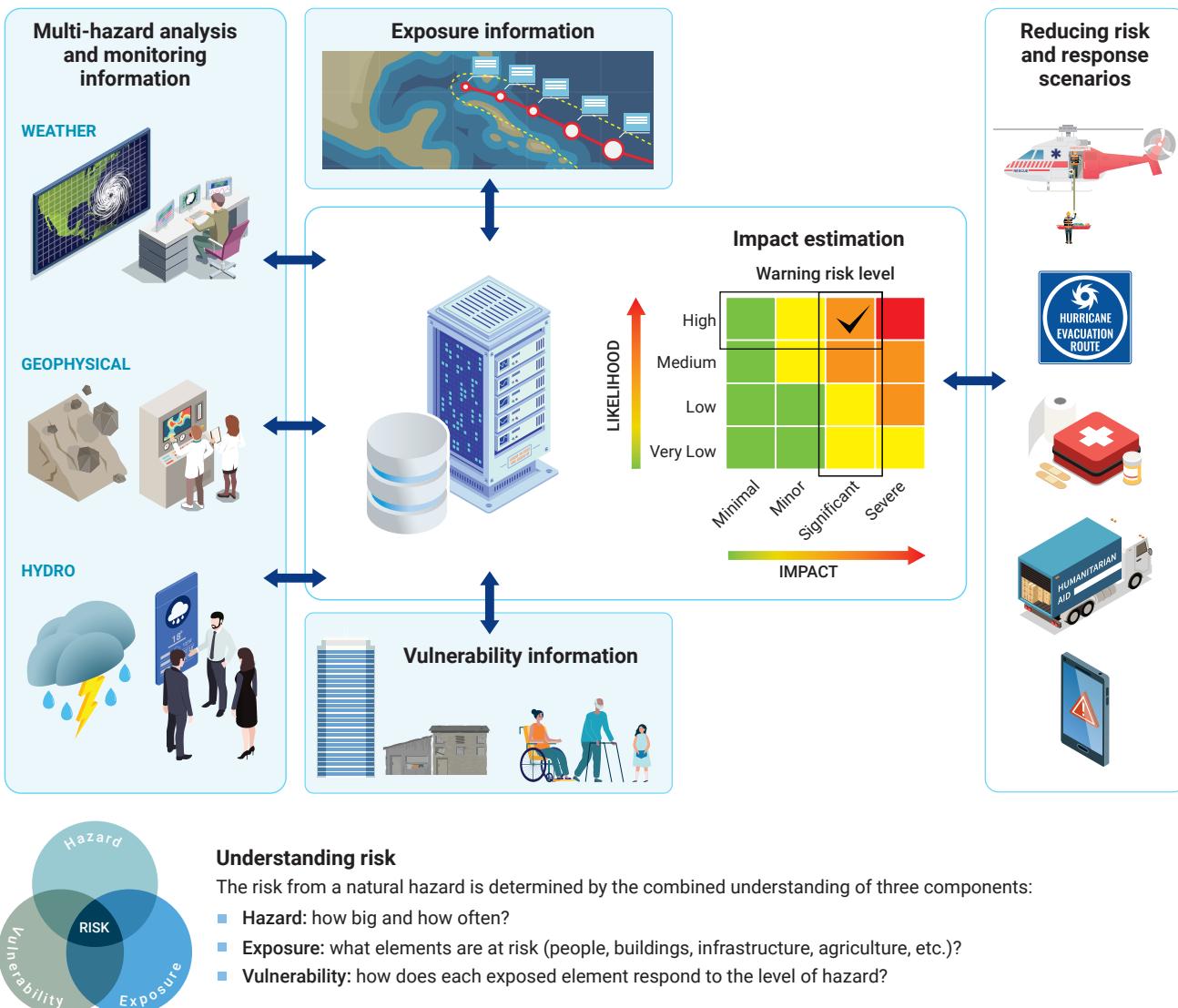
### BOX 3.1. THE FOUR EWS PILLARS

Early warning services are an integral component of DRM as a means to prevent loss of life and reduce the economic and material impact of hazard events. Effective end-to-end and people-centered EWS encompass four interrelated elements or pillars, which form the structure for conducting the scoping exercise and organizing the findings informing this roadmap:

- **Pillar 1. Disaster risk knowledge based on systematic data collection and disaster risk assessments.**
- **Pillar 2. Detecting, monitoring, analyzing, and forecasting hazards and possible consequences.**
- **Pillar 3. Official dissemination and communication of authoritative, timely, accurate, and actionable warnings and associated information on likelihood and impact.**
- **Pillar 4. Preparedness at all levels to take timely action to respond to warnings received.**

The successful implementation of the roadmap will be determined by the ability to engage with and glean critical experiential information from individuals and communities concerning their vulnerability when exposed to the range of hazards that might reasonably be expected to affect them. That is to say, to succeed, any regional initiative needs to be people centered.

**FIGURE 3.2. HOW IMPACT-BASED FORECASTING (IBF) WORKS**



## SI1. Supporting the transition to IBF and warning services

### Rationale

Insufficient understanding of the impacts of severe hydromet hazards—by both the authorities responsible for managing emergencies and the at-risk population—can lead to loss of life and have significant adverse economic and social consequences. This is a major gap in EWS in most countries, including in the Caribbean, despite NMHS dissemination of generally accurate and timely forecasts

and warnings. Simply put, although people may realize what the hazard is, they often lack an understanding of what it might do. Focusing on impacts should strengthen climate resilience by ensuring exposed people have a better understanding of the anticipated risk and are therefore more likely to take appropriate action to protect lives, property, and livelihoods. For the impacts to be linked to the forecast, data must be shared between the technical institutions or agencies with expertise in the phenomena being predicted, the agencies with information about the area to be impacted, and the persons likely to be affected (Figure 3.2). For example, providing IBF for a heavy rain

event requires information on the physical geography of the area affected, vulnerabilities of the population and infrastructure, as well as other useful data such as traffic patterns at certain times of day. Ensuring prediction centers have adequate power, network connectivity, and staffing, whether at permanent locations or in temporary field centers, is also fundamental to the delivery of these services. This was a challenge during the COVID-19 pandemic, as health protocols required reduced numbers of staff in forecast centers. Public education and outreach is also a crucial element of IBF, which needs to be pursued in parallel with tackling the more technical challenges.

Regional bodies have already done much of the groundwork required for the transition. CDEMA's Model National MHEWS Policy provides a common framework for developing national multi-hazard impact-based early warning systems. CIMH has been leading the shift to IBF since 2007, when it started providing weather scenarios and related potential impacts to CDEMA. Within the last decade, this service has expanded to include members of the Caribbean Partner Development Group for Disaster Management and other regional and national partners. IBF concepts are core to CIMH (Caribbean Climate Centre (RCCs) climate services program, and the broader regional climate adaptation program is anchored on IBF principles.

Over the last four years, CIMH has been working with the US National Weather Service and USAID BHA to pilot national-level IBF through the Caribbean Weather and Climate Ready Nations (WCRN) Program. This includes a partnership between the Barbados Meteorological Service and the Barbados Department of Emergency Management. The Bahamas, Jamaica, St. Vincent and the Grenadines, and Grenada have all started adopting elements of IBF in their routine Meteorological Service operations, primarily by using simple matrices to convey the likely risks associated with impending weather. With appropriate training and investment, these small beginnings can be expanded into fully operational national IBF services. But nearly all countries need additional resources to develop their MHEWS policy and to implement IBF warning services.

Over the last decade, extendable online multiuser

collaborative platforms—such as the Caribbean DEWETRA Platform<sup>25</sup> and the Caribbean Risk Information System (CRIS)<sup>26</sup>—integrate significant information and, when fully utilized, could accelerate region-wide IBF implementation. Other platforms in the region, such as the CIMH- Virtual Reality (VR) platform, also support IBF, providing a lens into new technology applications. Such platforms support decision making and are designed to support simulation training exercises to improve forecaster and responder competence. While the Caribbean DEWETRA, CRIS, and other platforms are powerful tools for integrating the variety of data required for forecast-based decision making, they do not have data from all the countries. Data sharing is crucial for the initiative's success.

Although much has been done, efforts have been fragmented. A common IBF approach will enable the region to progress more quickly and efficiently. This is in line with one of the three principles of the theory of change—harmonization of efforts—as part of the underlying philosophy of using a cost-effective regional approach for establishing MHEWS. IBF has been initiated mainly in the hydromet context, but the methodology is readily adaptable to any hazard and can help to balance a wider MHEWS focus.

To elicit the required response to warnings, ongoing public education is a critical element of IBF. Acknowledging that there is some capacity in this field, countries could start by translating meteorological and hydrological hazards into understandable information for decision making to help deliver qualitative impact-based forecasts. Countries that already practice qualitative IBF can adopt a technically more complex approach to blend hazard forecasts with information on exposure and vulnerability in a more quantitative manner.

## Objective

This initiative aims to strengthen routinely operational IBF services to provide actionable information on the potential impact of hazards in a form that the general public, disaster managers and first responders, private sector actors, and other stakeholders understand and can use to protect lives, livelihoods, assets, and property. Beginning with hydromet hazards, and building on experience with compound hazard

**25** The Caribbean DEWETRA Platform is a spatiotemporal, decision-making, data fusion platform capable of seamlessly integrating evolving hazard data with socioeconomic and vulnerability information to support improved decision making within the disaster management community (Boyce 2018). DEWETRA is a fully operational platform used by the Italian Civil Protection Department and designed by CIMA Research Foundation to support operational activities at national or international scale.

**26** <https://cdema.org/cris/>.

risks (for example lahars caused by rain falling on volcanic ash) this will be achieved by synchronizing regional efforts—for example, by developing a common terminology, agreeing on a standard color coding for risk levels, adopting agreed messaging, and developing blueprint guidance that countries can consistently apply at a national level.

## Approach

Building on progress the region has already made, establishing structures to consolidate ongoing regional and national efforts and activities is vital. This will require:

- Regional and national-level dialogues with partners and stakeholders to explain IBF and the rationale and potential benefits of adopting it
- A blueprint to advance national IBF implementation that considers social and cultural norms, and NMHS, NDMO, and stakeholder capacity to understand who is at risk
- Detailed national plans outlining the mechanisms, actors, roles and responsibilities, capacity building, and communications involved.

## Main tasks for regional-level implementation

- Establish a regional dialogue around IBF to develop a common understanding of and approach to IBF, including identifying ways to strengthen the policy and institutional enabling environment. Formal partnerships through high-level operational partnership agreements should follow. These would describe the commitment of the various agencies to sharing data, information, and expertise and, respective roles and responsibilities.
- Develop a regional IBF blueprint that reflects the outcome of regional engagements to serve as guidance for countries to elaborate their national plans. The agreed regional blueprint should outline partnerships, education and training, communication, and monitoring and evaluation requirements.
- Mobilize a regional training plan on the IBF concept, principles and techniques aligned with ongoing efforts in the region led by CIMH. Existing regional training platforms and mechanisms should be used with new mechanisms developed as required. The initial focus will be on establishing a region-wide baseline for the qualitative translation of weather forecasts into impact-based forecasts and warnings. The training program will contain more advanced modules

leading to GIS-enhanced impact-based forecasts and warning services, such as integrated meteorological, hydrological, and impact-based modeling, which will be delivered as the countries develop expertise and engage in IBF on a routine basis. As vulnerability is one of the key components of risk knowledge, gender and specific group-related vulnerabilities should be explicitly included.

## Main tasks for national-level implementation

- Engage all national operational agencies, local authorities, gender bureaus, and community representatives, to solicit their views and discuss practical, logistical, and operational arrangements for implementing IBF. This includes identifying the kinds of messages that would generate appropriate action and may involve structured learning exchange with practitioners from countries already engaged in IBF.
- Apply the IBF blueprint to develop a national IBF plan, reflecting national and community requirements, building on each country's capacities and prior experience, and providing operational guidance on coordination mechanisms, processes, and stakeholder selection, including a focus on inclusion.
- Based on the regional plan, prepare national IBF training plans for all members of the national operational teams, including NMHS, DRM specialists and responders, and community representatives. Regional trainings also include business associations, guilds, chambers of commerce and small business associations.
- Strengthen the systematic collection of national data, maps, and information on vulnerability and exposure as a key IBF tool, including historical records for understanding impact thresholds and demographic data on gender (using national gender bureau knowledge), disability, vulnerable groups, and local governance, and critical infrastructure data on roads, bridges, schools, hospitals and clinics, shelters, individual homes, electricity supplies, water, and sanitation systems. This information could also capture important economic and commercial zones, such as ports, markets, storage facilities, hotel districts, and logistical points, as well as cultural sites which play an important role in preserving the culture of communities and people.

- Develop risk matrices that identify thresholds linking the severity of an impact with the likelihood of occurrence. Access to hazard and impact data catalogues and archives is essential for this task because historical hazard and impact data are needed.
- Establish regular reviews to examine and refine the system after implementing impact-based forecasts and warnings and create feedback loops with communities and other beneficiaries to adjust future warning thresholds and messages.

### Actors

Implementing IBF and warning services requires regional and national-level coordination and partnerships across many disciplines and organizations at the regional level and in each country. These include, but are not limited to, CMO HQ, CIMH, CDEMA, CCCCCs, NMHS, NDMOs, national information and gender bureaus, social scientists—such as gender, vulnerable group, and behavior specialists—government and academic institutions with expertise in geographic information systems (GIS) techniques, government agencies responsible for national census and ordnance surveys, community leaders, Red Cross societies, and nongovernmental organizations (NGOs). The U.S. National Weather Service has supported several countries in implementing IBF through the Caribbean WCRN Program, and its continued involvement is important. USAID plans to link the CIFI warning system to WCRN and expand the program to more Caribbean nations in the next five years, as outlined in USAID BHA strategic planning.

## SI2. Toward a Caribbean geospatial platform

### Rationale

The Caribbean requires a trustworthy, standardized, and sustainable geospatial platform to share hazard and risk information and data. Acknowledging that there are obstacles to creating such a platform, the need for a harmonized and coordinated data sharing mechanism is a requisite for building IBF capacity in the region. Although information on droughts, tropical cyclones, marine climatology, and geological hazards is readily available at regional level and there are several online information dissemination platforms, fuller risk information related to these and other hazards is generally lacking.

There are data silos in each Caribbean country. Data

sharing needs to be legislated at national level, which can take considerable time and effort. The global meteorological community has a long tradition of sharing limited data in real time for weather forecasts and at longer timescales for climate services; but other sectors may not have such an established tradition.

At the 11th meeting of CARICOM, its institutions, and the UN system in 2021, one session was dedicated to the importance of data sharing for policy making and other decisions. In that session, CMO HQ and CCCCCs articulated the case for sharing data for EWS purposes—especially in real-time for rapidly evolving situations like flashfloods—and to expand climate knowledge to inform climate action.

National-level funding to sustain the technical resources is key to the success of a Caribbean geospatial platform. Although most organisations and development partners prefer open source applications, some agencies have systems built around user-friendly, licensed software. Funding the renewal of software licenses will help maintain those systems and ensure the regional platform is user-friendly and data can be disaggregated in multiple formats that different countries can reuse.

Any future system should also build on and integrate existing regional data-sharing platforms such as CRIS and the Caribbean DEWETRA platform. Agreement by individual countries to share critical data to benefit the whole region is key to the success of any future Caribbean platform. This must be predicated on trust in the national and regional agencies these data will be shared with and an understanding of the mutual benefits of sharing these data and the need for sharing in real time. Recognizing mutual benefits will require transferring knowledge and building capacity as decision makers in individual countries seldom appreciate the need to share data. Establishing clear policies that address concerns such as data security and privacy will help build trust.

Building an effective portal will require access to geospatial education and technology and this must be made more equal across the region. Encouraging the development of data literacy and analysis capability and using free and open source software tools will also support these efforts. Putting in place mechanisms such as regular pooled procurements and fair cooperation agreements that respect data ownership with industry leaders will give smaller countries access to proprietary software if and

when they need it.

## Objective

This initiative aims to significantly improve the availability of the region's high-quality geospatial data for the benefit of all countries. Achieving this will require: consensus on a common direction and standards for geospatial data and technologies; Caribbean leaders' support for developing national and regional capability for handling geospatial information; enhanced information and communication technology capabilities; technically skilled human resources; coordination and collaboration among all practitioners; a legal enabling environment for data sharing within and between countries; decisive and coordinated political leadership at regional level; political will; and organizational will to share geospatial data and technologies regionally.

## Approach

Considering the region's political, cultural, and capacity challenges—which have hindered the development of a standardized and sustainable geospatial platform—the first step to achieve this strategic initiative is creating a political and technical environment that is conducive to strengthening and expanding regional data-sharing, advancing interoperability, and improving education and training opportunities in fields such as software development, GIS, and geospatial technologies in the region.

## Main tasks

- Create systematic and standardized processes for collecting, storing, assessing, and sharing data to inform MHEWS in a participatory manner through a top-down engagement of regional organizations to define legislation and governance arrangements, and roles and responsibilities. Use bottom-up, national-level engagement with communities to educate people on the methods for determining exposure and vulnerability and the data and information requirements for these calculations. Where possible, use existing tools—including, for example, those available through CDEMA and the International Federation of Red Cross and Red Crescent's (IFRC) Vulnerability and Capacity Assessment—to collect disaggregated data,<sup>27</sup> while respecting the privacy of the persons involved in these

assessments in line with best practices for handling personally identifiable information.

- Develop a technical and political dialogue on advancing interoperability to strengthen and expand regional data sharing. The focus is on facilitating the integration of nationally available hazard, exposure, and vulnerability data to enable risk-informed decision making and make data accessible at regional level, thus building IBF capability. Examine the roles of existing regional hazard and risk data systems—specifically CRIS and the Caribbean DEWETRA platform—and the feasibility of integrating data from both systems for national use. The OECS Commission may promote steps to overcome barriers and leverage data- and technology-sharing benefits for countries.
- Formulate potential solutions to improve education and training focused on Caribbean-specific applications in software development, geography, geospatial technologies, and GIS. This can be done through regional internship opportunities, training, twinning, and exchange programs through universities in the Caribbean, and the regional professional body, Urban and Regional Information Systems Association (URISA) Caribbean.
- Increase involvement in developing standards by:
  - Expanding the membership of existing professional organizations, such as URISA, to all Caribbean countries and territories
  - Encouraging local practitioners to establish chapters of the Open Source Geospatial Foundation in Caribbean countries
    - Encouraging national institutions to join and participate in activities of key regional organizations such as CDEMA, CIMH, NGOs, companies or private sector organisations, regional universities, and the Open Geospatial Consortium, which defines the key interoperability standards between proprietary and open source geospatial hardware and software.
  - Increasing national institutions' participation in international professional and standards development organizations such as the United Nations Global Geospatial Information Management Committee, and the ISO Technical Committee 211 on Geographic Information/Geomatics.

<sup>27</sup> Sex-, age and disability disaggregated data as a minimum, but this may be extended to other vulnerabilities.

- Improve access to technology by:
  - Developing regional/national spatial data infrastructures
  - Increasing regional technical professional and student participation in international geospatial organizations and conferences
  - Establishing regional agreements on group purchases of geospatial technology (hardware and software)
  - Expanding the inclusion of free and open source software geospatial curriculum in regional post-secondary institution, as is already being done for QGIS (Quantum Geographic Information Systems).
  - Offering support to companies and non-profit organizations that specialize in geospatial software development or services in the region
  - Fostering a culture of shared open source software development.
- Strengthen national standards and regular data collection and provision to regional organizations toward a sustainable geospatial portal. This requires effective and strong regional leadership, a willingness from partners to work within the guidelines defined by decision makers, and resilient operations at the prediction centers, ensuring they have adequate power, network connectivity, and staffing irrespective of their location. The OECS Commission may consider the feasibility of piloting a subregional initiative.

## Actors

Organizations with a key implementing role in this strategic initiative include the REWSC for defining roles and responsibilities, regional partners such as CDEMA, CMO HQ and CIMH, 5Cs, regional universities, NMHS, NDMOs and national gender bureaus and, geospatial, statistics and planning stakeholders within and among the OECS and CARICOM member states. The United Nations Platform for Space-based Information for Disaster Management and Emergency Response<sup>28</sup> and SERVIR-Amazonia<sup>29</sup> may also play a role in providing satellite hazard information; and an emerging market of private start-ups is offering satellite information for humanitarian purposes, specifically for post-disaster response. Group on Earth Observations (GEO) participation is also encouraged, as it has already

supported similar projects—for example, the Caribbean Satellite Disaster Pilot Project, which CIMH participated in, was funded through a GEO initiative.

## SI3. Toward a regional multi-sensor precipitation grid

### Rationale

The current spatial and temporal resolution of rainfall data in the Caribbean region is insufficient to meet expanding needs for disaster risk and emergency management, water resource management, agriculture, and so on. This is principally because of the wide ocean area, complex topography of volcanic islands and archipelagos, NMHS difficulties in maintaining local automated weather stations, rain gauges, and other observation stations due to limited financial and human resources and attrition from natural hazards, and limited sharing of rainfall data between countries (Figure 3.3).

Eleven Caribbean countries<sup>30</sup> operate radars, which provide rainfall estimates at a high temporal and spatial resolution for the countries where they are located. A weather radar base reflectivity mosaic is already in place and although countries share some radar products, they do not yet share the full volumetric data required for developing a multi-sensor precipitation grid. Radars are expensive to operate and maintain, so it is not cost-effective for every country to buy and operate a radar. The 11 countries that already operate radars could share more of their data with others located within the effective hydrologic coverage, but are reluctant to do so, limiting the use of radars as an effective regional tool for NMHS in the Caribbean. They share raster reflectivities to produce a regional radar mosaic, but this is subjective and of limited value.

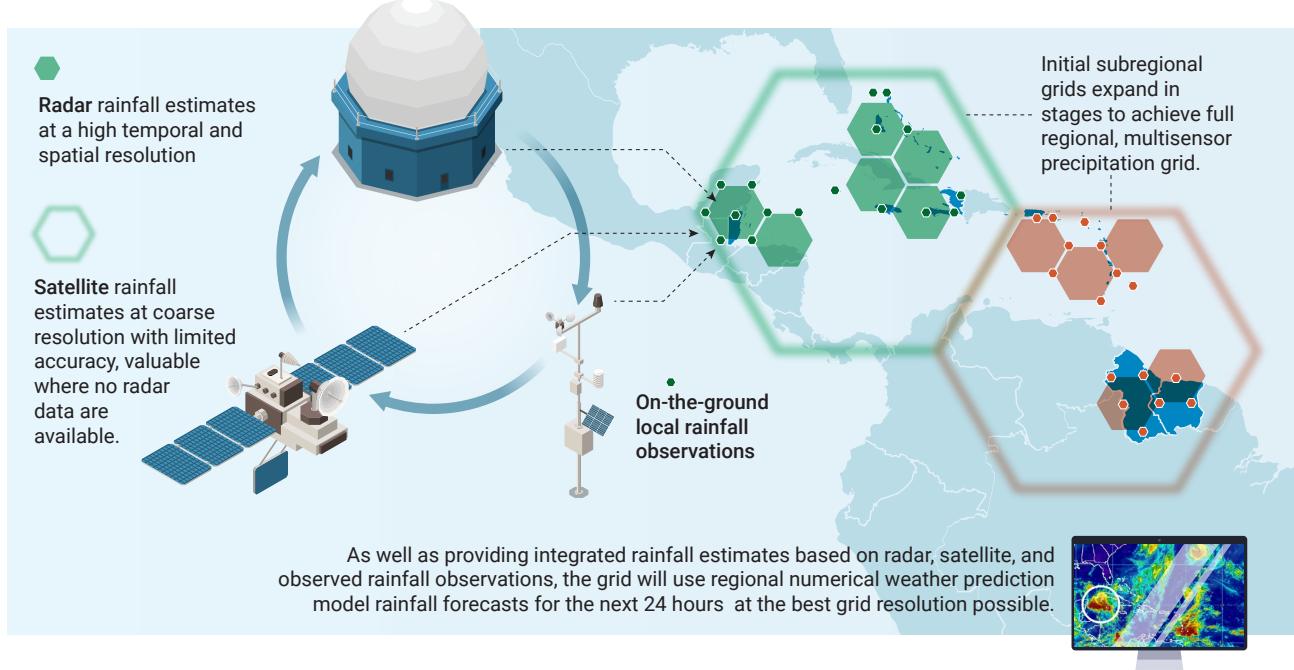
It is possible to use satellite data to estimate rainfall at very coarse resolution with limited accuracy. NOAA's National Environmental Satellite Data Information Service (NESDIS)<sup>31</sup> operates the Global Hydro Estimator, which estimates rainfall from geostationary and orbiting microwave satellites, providing hourly rainfall estimates

<sup>28</sup> <https://www.un-spider.org/network/regional-support-offices/water-center-humid-tropics-latin-america-and-caribbean-cathalac>.

<sup>29</sup> <https://servir.ciat.cgiar.org/servir-amazonia-to-engage-with-caribbean-stakeholders-to-foster-geospatial-service-development/>.

<sup>30</sup> Guyana, Trinidad and Tobago, Barbados, Belize, Martinique, Guadeloupe, French Guiana, Cayman Islands, Curaçao, Puerto Rico, and The Bahamas.

<sup>31</sup> <https://www.nesdis.noaa.gov/>.

**FIGURE 3.3. REGIONAL MULTISENSOR PRECIPITATION GRID**

over the Caribbean at a 1-kilometer grid scale. These data are available for the Caribbean in real time and are valuable where no radar data are available.

For a robust regional MHEWS, high-resolution precipitation information is a critical input for flash flood modeling, slope stability analyses, drought monitoring, and more.

### Objective

This initiative aims to significantly increase NMHS hydromet forecasting capacity and MHEWS use by developing a high-resolution grid of observed and forecast rainfall across the region. Over time, Caribbean rainfall grid analyses will provide a definitive, quantitative rainfall climatology that will help the region's water-sensitive economic sectors plan climate change adaptation and other related strategies. While it is possible to derive gridded rainfall estimates from existing radars, these must be adjusted with in-situ rainfall observations, alongside historical climatological data. This will also create valuable input and an incentive for a regional expansion of FFGS and needed community flood EWS. Realizing that public domain data such as satellite data already exists and is accessible by all countries and that sharing data significantly increases their accuracy and value for all stakeholders, regional

strategies or approaches are needed to provide incentives for countries to share their data.

### Approach

The first step will address the data gap issues and demonstrate the value of combining rainfall, satellite-derived rainfall, and radar data to establish a high-resolution grid of estimated rainfall for the past 24 hours, linking it to a forecast rainfall grid that would input into flood and flash flood EWS. This will follow a phased approach, building from an initial subregional grid to expand in stages to achieve full regional coverage. The initiative will coordinate with SI2 to address data-sharing requirements and demonstrate the increased benefit of combining the extremely valuable regional precipitation measurement systems to create a regional grid. As well as providing integrated rainfall estimates based on radar, satellite, and observed rainfall observations, the regional grid will also use regional numerical weather prediction model rainfall forecasts for the next 24 hours at the best grid resolution possible. A number of real-time forecast models will be evaluated for use in this initiative. The next step is to pursue the opportunity to develop a regional FFGS center that could also provide the necessary regional precipitation grid to support flood EWS.

## Main tasks

- Develop a phased plan for integrating multiple precipitation platforms and creating progressively expanded and linked subregional operational rainfall grids. This will involve identifying and prioritizing tailored products to be developed—and the end users for these services—and outlining knowledge-sharing feedback loops, testing and evaluation for inclusive learning and to inform next steps.
- Develop a roadmap that:
  - Outlines the importance of radar, addresses the issue of host countries not receiving compensation for the considerable costs of buying and maintaining radar that other countries benefit from but do not share costs, and develop incentives for host radar countries to share radar data
  - Outlines the steps and commitments needed to produce the grid—such as sharing rainfall observations—and add value to users
  - Identifies issues and solution approaches to overcome barriers to data sharing, and
  - Identifies the hardware, software, and system capability requirements to develop, maintain, and analyze (sub) regional rainfall gridded estimate accuracy.
- Demonstrate the value of the gridded rainfall estimates—for example, for flood early warning systems, communities at flood risk, private sector users, government sector users for agriculture, tourism, energy, and transportation planning, and water resource management—noting the importance of water and connected sectors from gender and vulnerable group perspectives.<sup>32</sup> The tailored services would show impacts through visual flood risk maps and other means, and the needs of end users would feed back into the delivery system design.

The radar assessment study conducted for the region will inform the required activities and investments for a reliable radar data and imagery network. The regional rainfall grid contributes to SI1 by providing IBF input for the end-to-end impact-based MHEWS system and creating tailored products for NDMO use to improve disaster risk reduction decision making. It also links with the MHEWS Operational

Plan and the Caribbean Hydrometeorological Operational Plan (CHOP) (SI7) by facilitating the development of flood and flash flood standard operational procedures (SOPs). Sharing data in the region is vital. The rainfall grid project can provide a foundation for building the case of the importance of rainfall observations to the region and hence the need to share this data.

## Actors

CMO HQ will need to collaborate with CIMH, CWWA, CDEMA, and WMO to develop the Caribbean rainfall grid and establish a regional FFGS. WMO, with flash flood guidance (FFG) partners NOAA, HRC, and USAID's BHA, is developing guidance on establishing and maintaining regional FFG centers. This strategic initiative will also require the participation of:

- NMHS that own and operate a radar and are willing to share real time and historical data, and countries that are willing to collect and share in-situ rainfall data, and disseminate the gridded rainfall data to end users
- Gender bureau knowledge, for understanding the needs of gender and vulnerable groups as end users
- NOAA, through NHC Miami and NESDIS.

## SI4. An integrated approach to flood and drought risk forecasting and warning

### Rationale

The region faces risks of both too much water - resulting in flooding, and too little water - resulting in drought. All Caribbean countries are vulnerable to riverine flooding, flash flooding, and coastal inundation, caused mostly by strong convective systems triggering intense rainfall events with significant run-off, storm surge, and significant swells migrating from northern latitudes. While less frequent, coastal inundation from tsunamis caused by earthquakes and volcanic activities continues to be an ongoing concern, given the experiences associated with the 2010 Haiti earthquake and the threat posed by the Kick'em Jenny underwater volcano north of Grenada. Storms and floods are the most devastating hazards, causing the greatest losses in terms of lives and economy (WMO 2020).

<sup>32</sup> For example, water and related sectors play a specific role for women, who are more connected to household water and overrepresented in connected economic sectors such as agriculture, despite the land ownership structure favoring men.

Riverine floodplains and coastal areas, with the highest density of population and economic activity, have potential for heavy economic losses and human casualties. In recent years, several Caribbean countries have started developing real-time monitoring of watersheds where significant risk is concentrated. These efforts are expected to expand in coming years through emerging new investments, including climate finance. As well as installing flood observation and early warning systems in watersheds, there are ongoing efforts to support flood forecasting by implementing operational numerical prediction systems, with several models—including Weather Research and Forecasting (WRF)-Hydro<sup>33</sup> and Telemac—currently under evaluation by CIMH. The region's experience with coastal monitoring and prediction systems has been mixed. Sea level monitoring stations installed during the early 2000s under the Caribbean Planning For Adaptation To Global Climate Change (CPACC) program suffered from equipment and other failures as well as design limitations that could not be easily remedied.

In recent years, new designs implemented through NOAA and CIMH have resulted in the deployment of more robust stations that have functioned as designed and support ongoing sea level and tsunami monitoring. Regional high-resolution significant wave-height models, such as CIMH's WaveWatch-3, are also being run routinely. The Barbados Meteorological Service is running SWAN (Simulating Waves Nearshore) model operationally over the near coastal regions of Barbados. CIMH is testing implementation of Telemac-2D and -3D, and the Caribbean Catastrophe Risk Insurance Facility (CCRIF) is providing storm surge predictions for the region using the TAOS Real Time Impact Forecasting System (RTFS) model, based on the earlier "The Arbiter of Storms (TAOS/L)" model used by CIMH. These various model outputs and observation data are integrated into the Caribbean DEWETRA Platform. Improved marine observation and modeling data should become available once the Regional Marine Forecast Support Center for the Caribbean hosted by CIMH is fully operational.

Storm surge warnings are provided at least 24 hours ahead. And although there have been improvements in issuing them, they are very broad in terms of location and impact and do not reflect the significant variability in flooding that will result along the coastline. To further improve these

warnings, several projects and programs are developing storm surge and marine modeling skills and collecting near-coastal topography and bathymetry data. This includes a recent CCCCs program that actively collects this type of data in several states using Light Detection and Ranging (Lidar). Accelerating these activities through ongoing training and frequent bathymetric and topographic data collection is essential.

Due to their 24x7 operations, NMHS have default warning responsibility because torrential flash floods can occur any time of day or night; but they can only issue heavy rainfall forecasts and cannot describe the magnitude of flooding that will result. The lack of adequate rainfall data, modeling capability, hydrological forecasting systems, and coordination between the national meteorological services and national hydrological services, where they exist, represent barriers to establishing a credible end-to-end hydrologic forecast and warning service for flash floods, riverine floods, or landslides. It should be noted that accurate dynamic prediction of the latter is generally difficult in most, if not all, parts of the world, but many states do have landslide hazard maps.

The region is working toward achieving an integrated approach to flooding, and many of the essential components are being put in place. Flash flood modeling and forecasting is available in selected watersheds in some countries, but others recognize that this technology needs to expand to more watersheds. Few countries have adequate real-time hydrologic forecasting systems, which predict riverine flood and water supply for water management, though they recognize that this situation needs to improve. Coastal flooding is often the result of both riverine flooding and coastal surge from waves, swell, tides, storms, tsunamis, and so on. To adequately predict the magnitude of coastal flooding, countries must first predict riverine flows using rainfall runoff models with a 1 or 2-dimensional hydraulic model and use these alongside the marine model to predict the timing and extent of the resulting inundation.

This necessary coupling of models is not yet available in the Caribbean, a situation that urgently needs addressing. Achieving an integrated approach to flooding will take time. More countries need to adopt flash flood modeling and forecasting and implement real-time hydrologic

33 [https://ral.ucar.edu/projects/wrf\\_hydro](https://ral.ucar.edu/projects/wrf_hydro)

forecasting systems. Hispaniola (Haiti and the Dominican Republic) has an operational state-of-the-art storm surge forecasting system but, as it is not coupled to a hydrologic model, it cannot accurately predict coastal inundation. One proposal for producing an initial integrated impact-based MHEWS for flooding in the Caribbean involves combining a storm surge forecasting system with FFGS in the SWFP and expanding the CIFL to all countries in the region. The benefits of establishing an integrated flood forecasting system are enormous. Establishing an end to end flood forecasting with the components of data collection, a hydrometeorological data base, meteorological models coupled to hydrological models also establishes a water management forecasting system as well as a drought prediction potential. Linking seasonal climate prediction model forecasts to the E2E integrated hydrologic forecasting-based system will establish needed IBF drought forecasting to provide necessary information needed to minimize impact of droughts.

Much of the discussion to date has excluded tsunami-driven coastal inundation. Tsunami warnings do not yet provide full coverage of the region and lead times are normally much shorter. Including the Caribbean Tsunami Warning System in a regionally integrated operational coastal inundation framework requires careful consideration. A WMO study, investigating the feasibility and need to include the Global Tsunami Warning System (as well as flash floods, severe weather, hurricanes, and coastal flooding warning systems) in the development of an integrated MHEWS, concludes that scientists and practitioners have not reached consensus on how or whether these systems could be integrated effectively (WMO 2019). The underlying issues revolve around data collection (common standards), data exchange (interoperable systems), and data access and use (data-sharing policies). The USAID BHA and NOAA are planning to expand the TsunamiReady Program to some Caribbean islands. The CIMH has expressed an interest in helping to implement this initiative to bolster long-term sustainability.

Scaling up this integrated approach will also address drought resilience. Ensuring early warning systems for sustainable water resource management address flood and drought risks, and actively involve the people and communities exposed, through expedited public education and awareness of anticipated impacts, and efficient dissemination of messages and warnings, will ensure a constant state of preparedness and that early action is

enabled to protect those at risk.

### Objective

This initiative aims to first reduce potential threats from flooding of all types—from intense, short-duration flash flooding from small creeks to larger river flooding and coastal flooding caused by multiple maritime factors, including tropical storms, tides, and tsunamis. The focus of this strategic initiative is on using an integrated approach to reduce the impact of flood events for the at-risk population by building a impact-based MHEWS operational hydromet environment. Building this impact-based MHEWS will also need to include drought forecasting. The establishment of a hydrological forecast capability is a necessary step towards building a drought forecast system in a subsequent phase. The hydromet environment is created by:

- Supporting the expansion of FFGS principles in the Caribbean through regional capacity building and sensitization workshops and identifying human and financial resources to develop and sustain a regional FFGS center
- Running workshops to promote the implementation of hydrologic modeling systems in national and regional institutions with appropriate mandates
- Supporting a model and data integration framework that includes national and regional observation or data collection networks, the Caribbean DEWETRA Platform, FFGS, CIFL, and SWFP, and others
- Eventually linking climate data and seasonal to interannual climate forecasting models to hydrologic modeling systems to produce Impact Based drought forecasting capabilities.
- Strengthening regional storm surge forecasting through capacity building, improved data collection networks, and by introducing new and more robust technologies, including modeling platforms
- Determining the feasibility of integrating a tsunami warning system into this multi-hazard operational environment.

### Phased approach

Phase 1 capitalizes on existing efforts, such as FFGS, CIFL, SWFP, and WCRN. Phase 2 marks the initiation of impact-based MHEWS, starting with an integrated flood forecasting system linked to SWFP and climate forecast

models, and then building in IBF to provide an overall tool that combines the different information tools used for each EWS pillar, allowing them to be visualized as a whole. If considered advisable and feasible, Phase 3 would integrate geological triggers such as tsunamis. It is important to carefully examine the advantages and disadvantages of keeping these systems and programs separate or the extent to which they can usefully be integrated, with the final decision taken by impact-based MHEWS stakeholders in the region.

### Phase 1 and 2 approach and main tasks

NOAA NHC runs the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model<sup>34</sup> using bathymetry data, the same data used for tsunami models. SLOSH-generated risk maps can be stored on a computer and selected by forecasters using the latest NHC hurricane forecast track. It is also possible to use other platforms that can support similar actions—such as the Delft3D FM and Adcirc—to build the lookup tables, as these are built prior to the event. Key tasks are to:

- Develop a strategic plan that will integrate various WMO initiatives (SWFP, CIFI and FFGS) into an NMHS environment.
- Develop a prototype integrated flood roadmap—bringing together national and regional meteorologists, hydrologists, experts, and organizations including CIMH, CMO HQ, CDEMA, CWWA and WMO—and include CIFI in a multi-hazard environment, with these experts defining the linkages, cooperation, and an integrated architecture toward developing and implementing an integrated flood forecast and warning environment.
- As a next step after developing the Integrated Flood Roadmap, develop a Drought Forecast Roadmap which follows the development of the Integrated Flood system by adding a Drought Forecast capability. This will be achieved by including coupling of seasonal climate forecasting models to the hydrologic forecasting system to produce drought forecast products linked to Integrated Drought Management program.

- Promote and advance CIFI, especially the storm surge component for Caribbean countries facing high coastal risks, by developing risk maps, training, and educational materials via joint CIMH, CDEMA, WMO and CMO HQ efforts.
- Promote and advance the inclusion of CIFI in the Caribbean Multi-hazard Operational Plan (SI7).
- Develop a strategy to link or couple the SLOSH model or similar models with a hydrologic or hydraulic modeling system to improve the accuracy of predicting coastal inundation.
- Link CIFI implementation to IBF through the Caribbean WCRN Program, and create a regional plan for adoption by CDEMA, CIMH, and CMO HQ as a medium-term goal.
- Facilitate linkage of the regional multi-sensor precipitation grid (SI3) to existing flood and flash flood EWS, water resources management, land-use planning and flood management organizations.
- Support the development of a concept of operations for the Caribbean Multi-hazard Operational Plan (SI7) by developing an integrated flood SOP to standardize and coordinate flash flood, riverine flood, and coastal flood warnings and operations with NMHS.

WMO has tentatively planned an impact-based MHEWS project to link the three systems using interoperable tools and applications in a single workstation environment, develop prototype impact-based MHEWS SOPs, and include linkages with the Caribbean Multi-hazard Operational Plan (SI7) and IBF (SI1) in the Dominican Republic.

### Phase 1 and 2 actors

Organizations with a key implementing role in this strategic initiative include NOAA HQ International Office and NHC, WMO (especially Region IV Hurricane Committee and Hydrology Committee), CIMH, CMO HQ, NMHS, EWISACTs, WMO IDMP, the Caribbean Global Water Partnership (GWP-C),<sup>35</sup> and the Hydrologic Research Center.

### Phase 3 approach and main tasks

A multidisciplinary team should consider the advantages

34 <https://www.nhc.noaa.gov/surge/slosh.php>.

35 <https://www.gwp.org/en/GWP-Caribbean/ABOUT-GWP-C/>.

and disadvantages of integrating the Caribbean Tsunami Warning System into the impact-based MHEWS. It may also consider investigating the feasibility and suitability of including seismic and some biological hazards (such as sargassum) in a Caribbean impact-based MHEWS or whether to cluster these under a longer-term separate impact-based MHEWS operational environment. The main tasks are to:

- Investigate the feasibility and benefits of linking tsunami or geological warning systems into the regional impact-based MHEWS hydromet operational environment
- Establish a coordination mechanism between NOAA, UNESCO-IOC, the UWI Seismic Research Centre (SRC), CDEMA, CIMH, WMO, and others to determine the way forward in linking the Caribbean Tsunami Warning System to the hydromet impact-based MHEWS
- Promote the expanded implementation of a tsunami warning system through an IBF initiative such as the TsunamiReady Program, which is to be expanded in the Caribbean.

### Phase 3 actors

WMO, UNESCO-IOC,<sup>36</sup> UWI SRC,<sup>37</sup> CMO HQ, CDEMA, CIMH, REWSC, NOAA, academia, and operational experts must all be involved in assessing the desirability of integrating tsunami warnings into the regional hydromet operational environment. Specifically:

- It is a recommendation of this roadmap that CMO HQ, CIMH, and CDEMA include adoption of CIFI in their regional strategies
- There is a need to investigate the feasibility and suitability of including seismic related hazards or considering a longer-term separate impact-based MHEWS operational environment.
- CIMH and NOAA/NHC should provide training on coastal flooding and should investigate building risk-based flood maps.

- WMO needs to establish standards, share best practices, and provide guidance to NMHS to develop SOPs with their regional partners
- Following development of the Integrated Flood Roadmap, develop a Drought Forecasting Roadmap as a later phase to eventually produce both impact-based flood and drought forecast products. EWISACTs should be included in the development of the drought forecasting Roadmap.
- UNESCO-IOC—specifically the Caribbean Information Center—and UWI SRC will be key actors in determining the feasibility of integrating Tsunami warnings into the MHEWS in Phase 3.
- NOAA will play an important role through the NWS NCEP<sup>38</sup>, the NHC, and the Caribbean Tsunami Warning Program.<sup>39</sup>
- Other national and regional institutions that provide seismic information for their areas of responsibility will also play an important role.
- CCCCCs will offer strategic support on building and providing access to regional topographical and bathymetric data (including Lidar capability).
- Representatives of national gender bureaus and vulnerable groups will need to be kept informed and consulted on the needs and contributions of gender and other vulnerable groups in the different phases.
- CARPHA collaborates with CIMH on public health issues and should be approached for guidance around biological hazards.

USAID BHA and NOAA NHC have agreed to expand CIFI to more Caribbean Islands. Given the vulnerability of all Caribbean countries to coastal inundation, CIFI should be progressively implemented throughout the CARICOM region.

<sup>36</sup> IOCARIBE (<http://iocaribe.ioc-unesco.org/>) is a regional subsidiary body of the UNESCO-IOC. As the IOC sub commission for the Caribbean and adjacent regions, it is responsible for promoting, developing, and coordinating IOC marine scientific research programs, ocean services, and related activities, including training, education, and mutual assistance in the area.

<sup>37</sup> <https://uwiseismic.com/>.

<sup>38</sup> <https://www.weather.gov/ncep/>.

<sup>39</sup> <https://www.weather.gov/ctwp/>.

## SI5. Integrating health impacts into the impact-based MHEWS

### Rationale

The COVID-19 crisis and extreme weather events provide important lessons in understanding risk and the need for impact-based MHEWS. In the case of communicable diseases, the COVID-19 pandemic has demonstrated the need to understand the vulnerability of individuals, groups, communities, and societies to provide reliable, targeted guidance and warnings that respond to, among other things, the gendered impacts of pandemics.<sup>40</sup> It has also demonstrated the need to prepare for a reasonable worst-case scenario based on risk-informed advance planning (Rogers et al. 2020b). Resources are needed to prepare the groundwork for this process.

Excessive heat is a growing public health hazard, and heatwaves are among the most dangerous natural hazards. But, lacking the spectacular and sudden violence of other hazards, such as tropical cyclones or flash floods, they rarely receive adequate attention. With no universally accepted definition, heatwaves are understood to be periods of unusually hot and dry or humid weather, usually with a discernible impact on human and natural systems. Due to this lack of absolute universal value—such as a given temperature—to define extreme heat, heatwaves are relative to the local climate. Demographic and socioeconomic characteristics such as age (elderly or very young), pre-existing disease, working in exposed environments, living alone, social isolation, homelessness, no access to heat-

health information, immobility, and mental illness may determine an individual's level of heat risk (box 3.2).

The CIMH-led EWISACTs Consortium leverages CARPHA expertise and co-develops, co-designs, and co-delivers products that share climate information for the health sector on a seasonal timescale. The Caribbean Health-Climatic Bulletin, jointly developed and disseminated by CARPHA, the Pan American Health Organization (PAHO), and CIMH, helps the health sector manage climate risk by providing a Caribbean outlook for the upcoming quarter and advising on the human health implications of climate forecasts. Caribbean experts also participate in the WMO Study Group for Integrated Health Services, which works on the integration of physical and social sciences.

Countries are increasingly developing capacity to use ensemble forecasting methods for meteorological phenomena, and apply probabilistic forecasting techniques to warning systems, making them more reliable and extending the lead time within which they can take action to prevent or reduce risks. Applying similar approaches to epidemiological forecasts, countries are using multimodel ensemble techniques, which produce broader and more realistic possible trajectories of epidemics. Probabilistic forecasting of complex cascading catastrophes remains a challenge but can be addressed using a variety of tools, including AI techniques. Many countries' disaster management laws treat epidemics or pandemics as disasters, so integrating them into the regional impact-based MHEWS is a rational approach to improve coordination, forecasting, warning, and response.

**40** According to the UN Secretary General, the pandemic has already reversed decades of limited and fragile progress on gender equality and women's rights. This is due to the heavier socioeconomic effects that disasters, including pandemics, have on women and vulnerable groups, which increases existing inequalities.

### BOX 3.2. GLOBAL HEATWAVES IN 2022

The 2022 heatwave in India and Pakistan was an extreme weather event affecting a large part of India's northwest and Pakistan, resulting in the hottest March in India since 1901. Combined with a drought, several cities across India, including New Delhi, experienced maximum heatwave temperatures of 45°C, and Pakistan recorded 49.5°C. As of May 9, at least 90 people had died from heat across both countries.

In the United States, daily temperature records were set or equaled in at least 16 cities in June, according to the NWS. Phoenix, the country's hottest city, recorded 44°C, and the temperature there did not drop below 27°C for two weeks. The impact of heat is cumulative, and the human body only begins to recover when temperatures drop below 27°C. According to the US Environmental Protection Agency, the frequency, duration, and intensity of heatwaves have been rising steadily over the past 50 years.

Persistent heatwaves affected parts of Europe in June, July, and August, causing wildfires, evacuations, and heat-related deaths. The highest recorded temperature (47°C) was in Portugal, where 1,063 excess heat-related deaths had been recorded by July 18. In other parts of Europe, temperatures of 40–43°C were recorded throughout June, with the most severe temperature anomalies in:

- France, where Météo-France activated a red alert in 12 departments and an orange alert in another 25, with more than 17,000 hectares estimated to be burnt by wildfires, causing more than 24,000 people to be evacuated
- United Kingdom, where temperatures surpassed 40°C and the UK Met Office issued its first ever red extreme heat warning
- Germany, where temperatures reached 39.2°C and there were 1,636 probable heat-related deaths
- Italy, where the number of wildfires tripled the historical average and Rome temperatures reached 40.8°C
- Spain, which recorded temperatures above 40°C at 47 stations in the Spanish meteorological agency's observation network
- Switzerland, where MeteoSwiss activated orange and yellow alerts for heatwaves in most of the country, with maximum temperatures reaching 32–37°C
- Ireland, where temperature records for July were broken when 33°C was reported in Dublin.

Combining epidemiological surveillance with hydromet forecasting also makes it possible to predict water- and vector-borne diseases such as malaria, dengue, and cholera. For example, Pasetto et al. 2018 use a near real-time cholera prediction model based on rainfall forecasts to identify hotspots of risk following Hurricane Matthew in Haiti. The Red Cross, in dialogue with CARPHA and CIMH and working with the NMHS and ministries of health in Barbados and Guyana, has piloted an IBF methodology for anticipating the risk of dengue outbreak and defining triggers for preventive early action.

A renewed effort to include the health sector in impact-based MHEWS is important to effectively streamline disaster management response. Linking hazards and their impacts motivates a coordinated approach. CARPHA has established such an approach with the PAHO, through strong operational collaboration with CDEMA, policy

dialogue in the REWSC, and research with CIMH and the EWISACTs Consortium.<sup>41</sup> This includes significant work on mosquito-borne disease risk,<sup>42</sup> while examples national-level efforts include developing Climate and Health Country Profiles for Dominica and Grenada.<sup>43</sup>

### Objective

This initiative aims to advance national guidelines for using climate and health information to improve health risk preparedness and will provide benefits across society by: expanding impact-based MHEWS—originally developed for weather- and climate-related hazards—to encompass public health risks; gaining valuable insight in risk communication methodologies and approaches; and adopting impact-based MHEWS as a common, understandable, and trusted approach for regional health hazards, to be used as a basic element of all national DRM systems. Achieving this will

41 <https://rcc.cimh.edu.bb/ewisacts/>.

42 <https://www.paho.org/en/documents/caribbean-mosquito-awareness-week-2017-infographic-what-you-need-know-about-aedes-aegypti>.

43 <https://reliefweb.int/report/dominica/health-and-climate-change-country-profile-2020-dominica> and <https://www.who.int/publications/i/item/WHO-HEP-ECH-CCH-20.01.05>.

require a common framework for coping with complex disasters to help authorities understand the full spectrum of secondary and tertiary effects of hazards, and therefore how best to provide more targeted warning, risk reduction, preparedness, and response services.

### Approach

To bridge the gap between forecast and warning information, and effective impact-minimizing actions, countries need to take an all-encompassing approach to observe, detect, model, and predict risks and the potential cascade of multiple hazards through to impacts. Tackling this problem through a multidisciplinary approach will initially identify, understand, assess, and address health-related risks that are linked to hydromet hazards. The dengue prevention trigger methodology research begun in Barbados and Guyana<sup>44</sup> will serve as a foundation for scaling up the method to other public health risks and other countries across the region. Building on the work of CIMH, priorities include developing a heat-health warning system (HHWS) to alert decision makers and the general public to impending dangerous hot weather and developing and implementing a heat-health action plan (HHAP), which outlines a range of actions to reduce the negative health effects of hot weather extremes.

### Main tasks

- Develop and implement recommendations on setting up and sustainably financing national level health risk IBF models
- Adapt and apply the IBF/Forecast-based Action Trigger model for arboviral diseases early action planning with interested ministries of health and respective NMHS
- Develop an HHWS, based on CIMH seasonal forecasts and the Caribbean Health-Climatic Bulletin, that will determine heat-stress thresholds for action and provide a system of graded alerts/actions for communicating to the general population or target groups about an impending period of heat and its intensity and to government agencies about the possible severity of health impacts
- Develop an HHAP that covers public education and awareness raising about heat; stakeholder and

responder training; guidance on heat risk governance; roles and responsibilities for implementing strategies; advice on longer-term strategies for reducing heat risk, such as climate-sensitive building, urban design and town planning; and monitoring and evaluating the effectiveness of interventions and how to improve them

- Promote dialogue among key actors to progressively apply IBF for managing additional health risks, such as cholera and dust.

### Actors

A regional working group led by CARPHA in collaboration with CIMH, CDEMA, CCCCCs, the UWI, and IFRC-Caribbean, will lead the main tasks. This initiative will build on health-related IBF research undertaken in the Caribbean. Given that pandemics, tropical cyclones, tsunamis, heatwaves, and droughts may pose health-related risks to multiple countries simultaneously, cooperation with international agencies such as PAHO and IFRC, and at the highest levels of government and industry is important to ensure tools and materials are available and actions are appropriate. Vulnerable groups and communities must also be included in the risk assessment and communication processes, and action planning must consider the different groups in society that are at risk.

## SI6. Air quality health impacts

### Rationale

A recent WHO report suggests that 99 percent of the global population breathes air that contains levels of pollutants—including particulate matter, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide—that exceed WHO guideline limits.<sup>45</sup> Low- and middle-income countries suffer from the highest exposures to these and other pollutants. While air quality has markedly improved in certain high-income countries since the 1990s, it has generally deteriorated in most low- and middle-income countries, in step with large-scale urbanization and economic development. Many Caribbean islands are experiencing significant urban and economic development, which has led to changes in lifestyle, with increased vehicular transport and power consumption.

<sup>44</sup> <https://www.paho.org/en/dengue-prevention-and-control-barbados-and-eastern-caribbean-countries>.

<sup>45</sup> <https://www.who.int/publications/i/item/9789240034228>.

Exposure to air pollution causes millions of deaths and the loss of healthy years of life. The WHO estimates that one in eight deaths worldwide in 2012—that is, approximately 7 million persons—resulted from complications due to poor air quality.<sup>46</sup> In 2015, the World Health Assembly adopted a landmark resolution on air quality and health recognizing air pollution as a significant risk factor for persons with noncommunicable diseases such as ischemic heart disease, stroke, chronic obstructive pulmonary disease, asthma, and cancer, and their resulting economic toll. This represents a major concern for the Caribbean region, where a significant portion of the elderly and middle-aged population suffers from noncommunicable diseases, and there is a growing concern around the increasing number of children and young adults affected by these diseases.

According to Cifuentes et al. (2005), exposure to particulate matter in 26 cities across the Caribbean and Latin America is more than twice as high as in the United States. The WHO has indicated that Americas subregion B, which includes the Caribbean, has 30 attributable deaths and 307 disability-adjusted life years due to outdoor air pollution per 1,000 population, compared to 28 deaths and 200 disability-adjusted life years per 1,000 in Americas subregion A, which includes Canada and the United States.

Sahara dust is another emerging predictable threat. Although CIMH provides seasonal temperature outlooks and dust and air quality forecasts for the region, there is a serious gap in public perceptions of these risks. While the focus of the impacts of poor air quality is understandably on human and animal health, air quality also impacts key sectors, including the region's transition from fossil fuels to renewable energy. High concentrations of Sahara dust reduce photovoltaic production and trap heat in the near surface, increasing power demand. The presence of aerosol gases and dust in the atmosphere also impacts wind turbines, depending on the mineralogy of the dust, and gases released from large masses of sargassum seaweed on beaches have had an adverse effect on near-coastal populations, the tourism and marine sectors.<sup>47</sup> Addressing

these emerging risks requires environmental, economic, and public health preventative measures, which need to include monitoring hydrogen sulfide levels.

Global monitoring and observation networks for air quality monitoring across the Caribbean space are quite limited. There is no systematic large-scale regional air quality measurement networks and air quality regulations and enforcement are lacking. Some islands—such as Puerto Rico, Martinique, and Guadeloupe—continuously record and report national measurement networks. Others, including Barbados, have started periodic recording, but there is an increasing demand for national air quality measurements that can feed into regional platforms. With the exception of Guadeloupe<sup>48</sup>, in most cases, there are no EWS or air quality testing and monitoring associated with these events. A number of regional initiatives can however be enhanced to formulate a more structured approach to providing regional air quality alerts, involving the way the platforms are used, their protocols, and how information is disseminated to stakeholders and end users.

## Objectives

The health challenges faced by Caribbean populations that are exacerbated by exposure to poor air quality will not be mitigated in the near future. To reduce risk and exposure, countries will need to progressively develop and operationalize national and community air quality observation and early warning systems that effectively communicate warnings to all at-risk communities and persons.

## Approach

Building on the expertise, products, and services provided by regional institutions and global networks in the region, strengthening the MHEWS will require investments in three strategic areas:

- Expanding observation and early warning networks, including examining urban air quality issues in major cities and rural air quality in specific locations

**46** [https://www.niehs.nih.gov/research/programs/geh/geh\\_newsletter/2014/4/articles/air\\_pollution\\_accounts\\_for\\_1\\_in\\_8\\_deaths\\_worldwide\\_according\\_to\\_new\\_who\\_estimates.cfm](https://www.niehs.nih.gov/research/programs/geh/geh_newsletter/2014/4/articles/air_pollution_accounts_for_1_in_8_deaths_worldwide_according_to_new_who_estimates.cfm).

**47** Sargassum has been a cause for concern, due to its effect on marine life and tourism, but it also carries a potential risk of human airborne poisoning. Resiere et al. (2019) indicate that acute inhalation of hydrogen sulfide produced after 48 hours of decomposition may result in potentially fatal hypoxic cardiac, respiratory, and neurological failure, while chronic exposure may also produce neurological and cognitive impairments. Since 2018, a disturbing number of consultations and hospital admissions related to the effects of both acute and chronic exposure to hydrogen sulfide has been reported in the Caribbean.

**48** <http://www.gwadair.fr>

- Strengthening numerical prediction systems
- Building capacity across the NMHS, health, environment, energy, and other sectors to support building and using new early warning products and services.

Existing networks provide valuable baseline information that allows local authorities to determine how national-level activities contribute to changes in air quality at national level. Information from these networks may also provide early warning information related to large-scale events that may be of concern, whether episodic, short-term events such as Sahara dust or long-term events such as greenhouse gas concentrations. Some global observation networks in the region include:

- University of Miami Barbados Atmospheric Chemistry Observatory, Ragged Point, Barbados <https://baco.rsmas.miami.edu/>
- University of Bristol's Advanced Global Atmospheric Gases Experiment, Ragged Point, Barbados <https://agage.mit.edu/>
- NASA's AErosol RObotic NETwork <https://aeronet.gsfc.nasa.gov/>
- NASA's Micro-Pulse Lidar Network (MPLNET) <https://mplnet.gsfc.nasa.gov/>
- Barbados Cloud Observatory, Deebles Point, Barbados <https://mpimet.mpg.de/en/barbadosstation1>

National air quality observation and monitoring networks are emerging that address national and specific communities' needs. More mature networks are present on Martinique, Guadeloupe and Puerto Rico, which have the finances and capacity to sustain them. These measure a range of air quality parameters, including PM10, PM2.5, ozone, nitrous oxide, and sulfur oxide (with the latter measured in Guadeloupe but not Martinique) and often update the information on these parameters online.<sup>49</sup> With the emergence of the significant beaching of sargassum across the Caribbean, Martinique and Guadeloupe have implemented coastal community early warning systems

to report on the noxious gases—including ammonia and hydrogen sulfide—generated by its decay.<sup>50</sup> The aerosol early warning system for sargassum is supported by sargassum observation and predictions systems, and the Centre for Resource Management and Environmental Studies at the University of the West Indies Cave Hill Campus issues a useful three-month Sub-regional Outlook Bulletin for the Eastern Caribbean,<sup>51</sup> which informs communities of the likely onset and duration of impacts.

These examples can help guide the development of air quality networks that would serve all the Caribbean islands. Barbados, St. Vincent and the Grenadines, and Trinidad and Tobago are at relatively early stages of developing and operationalizing national air quality monitoring and early warning networks. Other air quality-alerting products include Sahara dust advisories for the health and energy sectors. Daily health advisories, based on the CIMH Sahara dust modeling platform, available satellite imagery, and MPLNET products from the limited number of stations across the region, are sent to CARPHA and the PAHO while hazardous conditions persist. The energy sector advisory, also co-developed by CIMH with the CARICOM Regional Task Force on Climate-Resilient Energy Supplies, uses many of the same products as the health advisory as well as aerosol optical depth (AOD) observations and predictions. The advisory is shared with the Caribbean Centre for Renewable Energy and Energy Efficiency (CCREEE) and utilities across the region. The WMO-designated RCC for the Caribbean also provides a seasonal air quality outlook.

## Main tasks

- Expand the air quality network in CMO member states and garner resources to sustain the network, including through a strategic plan to guide the development and sustainability of the network
- Expand the Caribbean Centre for Climate and Environmental Simulations' (CCCES) computational infrastructure to improve the resolution and timeliness of air quality prediction products, including volcanic, Sahara dust, and local aerosol transport products, as required by communities.

**49** For example, <https://aqicn.org/city/france/martinique/sainte-luce/>; <https://aqicn.org/city/france/guadeloupe/st-de-baie-mahault>.

**50** [http://www.gwadair.fr/images/H2S\\_NH3\\_Sargasses\\_GPE.pdf](http://www.gwadair.fr/images/H2S_NH3_Sargasses_GPE.pdf).

**51** <https://www.cavehill.uwi.edu/cermes/projects/sargassum/outlook-bulletin.aspx>.

- Build capacity to help downstream users better integrate products and services into their activities.
- Establish a subregional Volcanic Ash Advisory Centre for the Caribbean.

### Actors

CIMH will lead these activities in partnership with the Caribbean Aerosol Health Network (CAHN), PAHO, CARPHA, EarthMedic, the Caribbean Electric Utility Services Corporation, CCREEE, the WMO's Sand and Dust Storm Warning Advisory and Assessment System, the WMO's Global Atmosphere Watch, CDEMA, UWI, national environment and health ministries, and OECS Secretariat's Environmental Division. Other actors may include DRM agencies that wish to support household and community-level early action planning to ensure that people know what to do and take appropriate action when warnings are issued, or sectoral and private sector actors that wish to support the integration of aerosol warning preparedness measures into BCP. CCCCs and the Caribbean Development Bank (CDB) could help in garnering resources, especially if aerosols can be included in climate adaptation financing for the region.

CIMH's Dust and Air Quality Forecasting Centre platform<sup>52</sup> provides forecasts of dust concentration, PM2.5 and PM10 concentrations, AOD, and ozone<sup>53</sup> for the Caribbean region using the WRF-CHEM model. The energy sector will use AOD as part of its planning early warning system. The Volcanic Hazards platform<sup>54</sup> daily simulates the ash, tephra, and sodium dioxide transport from three of the region's 19 active volcanoes. During the April 2021 eruption of the La Soufrière Volcano on St. Vincent, NMHS, NDMO, the health sector, and other actors used valuable air quality information from the platform for their early warnings.

## SI7. Toward a Caribbean multi-hazard operational plan

### Rationale

Countries must harness common approaches to different hazards to increase efficiency, capacity, and cost-

effectiveness across the region, especially among the less developed NMHS. While mechanisms for dealing with many individual hazards are already in place, developing a system of systems to strengthen and streamline MHEWS helps capture hazard interactions and causal chains. A Caribbean multi-hazard operational plan will enable the technical advantages of a regional approach to many common hazards and can help enhance the recognition of joining forces to mitigate multihazard impacts, beginning with severe hydromet and marine-related hazards that threaten the region.

The Caribbean WCRN Program provides a starting point, anchored in the transition to IBF (supported by SI1), for developing an initial common operational plan for hydromet and marine-related hazards. For example, the Tropical Cyclone Operational Plan (TCOP) coordinates hurricane monitoring and forecasting guidance products, available observing networks, rules, and criteria for warnings, as well as backup arrangements, data communications systems, and a regional directory. Reviewed, discussed, updated, and agreed annually by the heads of all the region's national meteorological services, TCOP also includes a three- to five-year vision of research and development, technical capacities, and training. For other hazards, similar collaborative mechanisms provide guidance, technical knowledge, and advice to the region, including SWFP, CIFI, and FFGS. UNESCO-IOC and the UWI SRC coordinate regional tsunami warning and mitigation activities in the Caribbean, with the Pacific Tsunami Warning Center serving as regional center.

### Objective

This initiative aims to establish a regional multi-hazard operational plan that integrates existing mechanisms for each hazard and is flexible, practical, and regularly reviewed and updated. Such a plan would leverage the collective regional strength to overcome individual national weaknesses through regional coordination, collaboration, and harmonized national implementation. This will reduce the burden on national technical, academic, and financial agencies—including NHMSS, NDMOs, universities, and financing institutions—through standardized SOPs that represent best practices in producing forecasts and

52 <http://dafc.cimh.edu.bb/>. The platform is sustained through CCES located at CIMH.

53 Ozone is not shown on website, but is available.

54 <http://dev2.cimh.edu.bb/volcano/src/#/>.

warnings for different hazards and other approaches.

### Overall approach

Building on the Caribbean WCRN Program, this initiative has two steps or phases. The first is expanding the TCOP to a Caribbean multi-hazard operational plan that clusters weather, water, and climate-related operational plans; and the second is integrating other hazard clusters into multi-hazard operational plans. The plan will complement the TCOP in time and scope by operating not only during hurricane season but year-round and addressing all hydromet and marine-related hazards.

### Phase 1 main tasks

- Develop the CHOP, under the leadership of CMO HQ and CIMH, who will identify and assemble a group of key players for this task, including regional operational centers working on the different hazards covered by the operational plan, regional experts from institutions, committees, NMHS, NDMOs, gender bureaus, academia, social scientists, and so on, who are mainly involved in hydromet risk management and specialize in the four EWS pillars (box 3.1).
- Draft a structured outline/skeleton CHOP, guided by elements of other regional operational plans (such as TCOP and SWFP) and strategies, focusing on the highest-priority hazards in the subregion, to adapt and expand the principles, structure, and methodologies of existing plans to the other hydromet hazards; this methodology will be progressively applied to all hazards.
- Educate and get input from national and local disaster managers, gender bureaus, sectoral stakeholders, meteorologists, and hydrologists on the operational plan's implications for their day-to-day operations, providing technical support and working with them to gradually implement changes to procedures as necessary. Guide and support national institutions to downscale the operational plan to national level with a view to expanding and strengthening their national operational plans.

### Phase 2 main tasks

- Guide and support national institutions to downscale the CHOP to national level with a view to expanding

and strengthening their national operational plans.

This may include mapping relevant institutions, their roles and responsibilities, and identifying pertinent actors, and identifying lead institutions that should take responsibility for each hydromet and marine-related hazard and the services they can provide.

- Implement outreach or educational programs that consider the specificity of the region and use examples of existing structures and mechanisms. Such outreach programs will help educate national and local disaster managers, gender bureau workers, meteorologists, and hydrologists on the CHOP implications for their day-to-day operations, provide technical support, and work with them to gradually implement changes to procedures to strengthen and streamline operations.

Based on the lessons learnt during Phase 1, the process can be iterated in next steps, to develop operational plans for further hazard clusters (beyond hydromet phenomena), and progressively build the overall Caribbean MHEWS operational "plan of plans".

### Actors

National agencies will need to agree to the operational arrangements and codify these agreements in the multi-hazard operational plans already established under international frameworks and agreements under CARICOM, WMO, UNESCO-IOC, and others. For climate hazards, the EWISACTs consortium of sectoral agencies with CIMH offers a coordination mechanism that already provides information and develops products and services for climate-sensitive sectors.<sup>55</sup>

## SI8. Regional emergency alert system

### Rationale

Although all Caribbean countries have mechanisms for disseminating alerts and warnings, these are generally far from optimal. And, given budgetary constraints, they may not yet take full advantage of all available technologies. There is limited use of newer technologies, including the Common Alerting Protocol (CAP), cell broadcast, and social media, and little understanding of how different genders and vulnerable groups receive, interpret, and react to alerts.

55 <https://rcc.cimh.edu.bb/cimh-ewisacts-consortium-the-caribbeans-champions-for-climate-services-info/>.

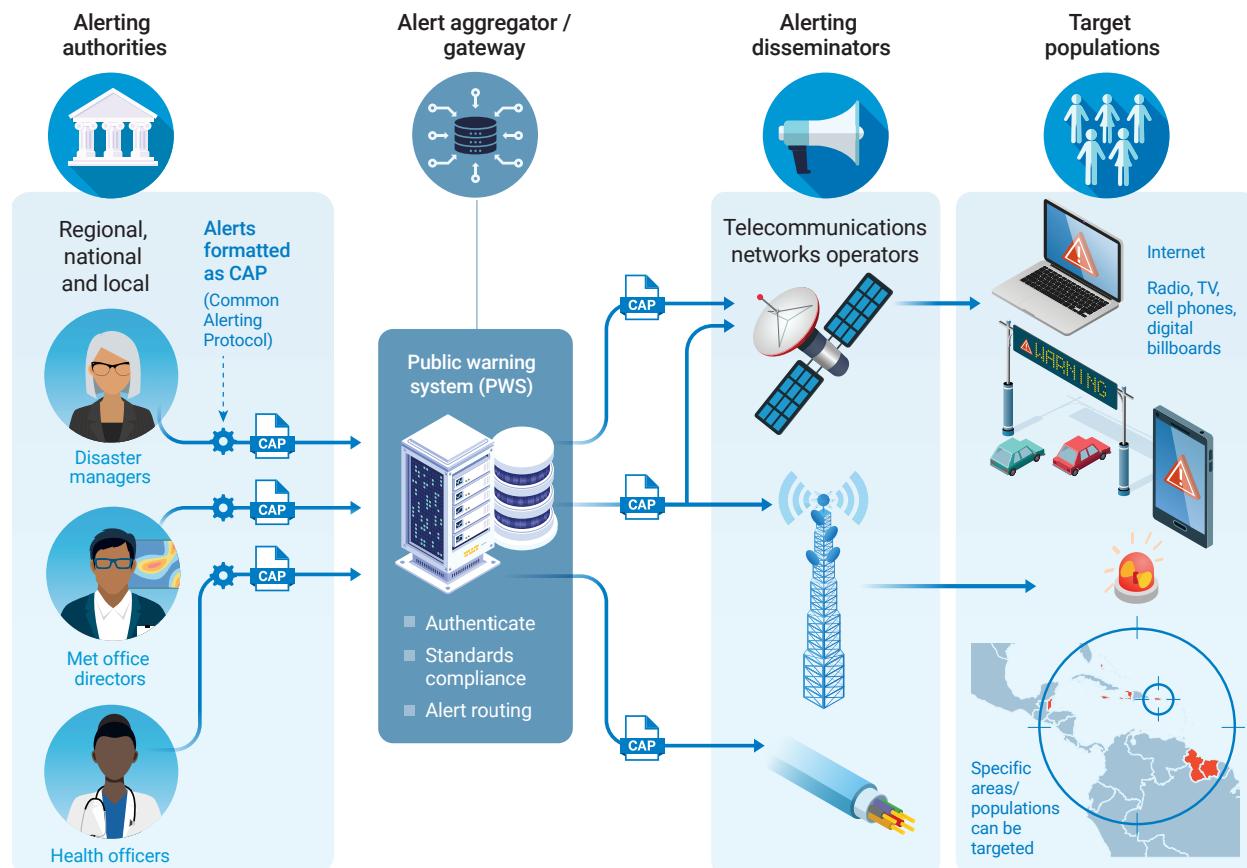
Communication disruptions are also common during and in the aftermath of extreme events.

Effective communication of multi-hazard early warning information is complex. EWS should consider different populations' risks, needs, and vulnerabilities, and help groups and individuals make appropriate decisions and take anticipatory action. Resilient public warning tools using multiple pathways—including traditional media, social media, and mobile applications—are key to ensuring timely access to vital information for all. At national level,

there are challenges with bringing providers on board and a need for supporting legislation. While traditional media operations are covered by protocols in most Caribbean countries, this is not the case for mobile communication.

In some parts of the world, alerting authorities use emergency alert systems (EAS) to send warnings via a variety of communications networks. A regional approach that takes advantage of economies of scale could implement EAS to strengthen and streamline MHEWS in the Caribbean (Figure 3.4)

**FIGURE 3.4. REGIONAL EMERGENCY ALERT SYSTEM**



### Objective

This initiative aims to implement an effective people-centered, impact-based, regional emergency alert communication and dissemination system that prompts appropriate action by everyone, including all target groups. The envisaged EAS would permit regional and national authorities to reach the public before and during

emergencies with timely, consistent, authoritative, and targeted end-to-end advisories and warnings.

### Approach

A well-defined and sustainable regional architecture for emergency alerts would allow advisories and warnings to be consistently and reliably communicated regionally,

nationally, and locally, depending on the emergency. This will strengthen and streamline the dissemination of risk information and warnings, using the best available technology without locking into today's technology. A regional multi-hazard operational plan (SI7) will need to reflect the EAS architecture; and since communication channels and technologies keep changing and evolving, the REWSC will need to clarify who is responsible for regularly updating the plan.

This EAS can be based on the CAP, a standard data format for exchanging public warnings and emergencies between alerting technologies. CAP allows a warning message to be consistently disseminated simultaneously over many warning systems to multiple applications—such as Google public alerts and cell broadcast—to reach agencies, authorities, and/or the general public, in anticipation of and throughout emergencies.

### Main tasks

- Develop a general design of regional EAS architecture and carry out a feasibility study for implementing a regional wireless EAS that emphasizes sending warning and alert messages to cell phones users.
- Develop and agree on institutional and policy arrangements at regional, national, and local levels; ensure integration of the EAS as part of the Caribbean Multi-hazard Operational Plan (SI7) and review CDEMA's Model National MHEWS Policy and Adaptation Guide to ensure it supports regional EAS harmonization.
- Establish strong partnerships to supply and deliver specified warning services, based on documented agreements, between alert issuers (NMHS, NDMOs, and so on) and alert disseminators, including TV and radio broadcasters, mobile wireless operators, and internet service providers.

- Assess CAP-based communication systems to evaluate options that could be deployed as a regional integrated alert and warning system to best address the interface between scientific alerting protocols and their dissemination or communication to targeted populations.
- Train all regional, national, and local EAS users in the process and protocols to issue timely, consistent, authoritative, end-to-end advisory and warning messages using the system, to ensure that messaging is designed and delivered in ways that respond to the needs of women, men, and vulnerable groups and is effectively reaching and triggering appropriate action by all people and sectors.<sup>56</sup>
- Define platform operations and maintenance, conduct tests and exercises, and keep pace with emerging technologies.

### Actors

The network of national-level implementing actors for this initiative includes national and local disaster management agencies and the Red Cross; scientific and technical agencies; health, military, and civil authorities; telecommunication organizations (national regulators, satellite and mobile-cellular network operators); gender bureaus; and media organizations. At the regional level, agencies such as CDEMA, CIMH, and the Caribbean Telecommunication Union have an important role to play, closely collaborating with national and local governments in those initiatives that could benefit from regional implementation. For example, CDEMA and CIMH could focus on improving the EAS while the Caribbean Telecommunication Union establishes performance standards, procedures, and testing requirements for EAS participants. As operators of most of the communication channels—from broadcast media to mobile networks and satellites—private sector actors are key for the success of this initiative.

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<sup>56</sup> Alerting and messaging must consider the different situations in which women and men live. For example, women often have responsibility for young, elderly, and disabled family members, which can heavily influence their ability to react to standard alerts, while directing people to shelters that do not have the necessary protection measures in place heavily disrupts the quality of the entire MHEWS for most of its end users (women and children).

## SI9. Community-based action planning

### Rationale

EWS has traditionally focused on disseminating information and warnings to effectively reach the last mile. But, as well as informing all people, including vulnerable groups, of risks that can be anticipated, MHEWS must use IBF (figure 3.2) to inform anticipatory action to protect people, assets, infrastructure, and livelihoods. Inclusive and appropriate risk-informed planning and action can only happen with appropriate support for participatory processes. These include public awareness and education, training and capacity building, forecast-based SOPs, drills and exercises. Community-based early warning early action, a proven method for applying IBF at the community level, requires risk knowledge that is inclusive of gender and vulnerable groups; warnings that integrate impacts; and communications that are designed to reach and be actionable by all at-risk target groups. It also defines thresholds and triggers for pre-planned early action, and identifying sources of support for implementing community action plans, which can include the rapid release of funds necessary to carry them out.<sup>57</sup> All four EWS pillars need to work together seamlessly (figure 3.1), as failure in one or a lack of coordination across pillars can prevent communities from fully benefitting from IBF. As such, key national actors' commitment to progressively build anticipatory action capacity for warnings in all communities is essential.

### Objective

This initiative aims to strengthen community resilience and respond to the needs of all people by establishing national processes for systematically applying IBF to advance community-based early warning early action planning and implementation. Raising awareness of the impact of hazards at community level, improving understanding and advocacy for IBF to better inform risk reduction and preparedness planning, and inclusive engagement to change community perceptions and reactions to alerts and trigger appropriate anticipatory action are all key results. The overarching outcome is to launch inclusive and effective community-based early warning early action learning-by-doing processes so that all communities in each country fully benefit from the availability of continually improving impact-based MHEWS.

### Approach

The approach for implementing this community-driven strategic initiative is in the context of a broader community-based resilience-building framework and the regional resilience pathway with which the roadmap is aligned. Regional knowledge-sharing among IBF-implementing partners involved in the other strategic initiatives will help inform and strengthen the development of national partnerships or alliances to guide and support systematic community engagement in applying IBF. To mobilize all communities to develop early action capacity, national partners must commit and agree on their respective roles. To establish community-based early warning early action, they must also engage community stakeholders in participatory risk mapping and anticipatory action planning that includes setting and implementing thresholds and evaluating effectiveness after action to inform regular updating, based on evolving risk information and learning.

Early action plans may include risk reduction measures aimed at preventing and mitigating anticipated impacts to people, property, and livelihoods, alongside preparedness measures to accelerate the response once a hazard hits.

### Main tasks

- Form partnerships under the umbrella of NDMOs with national implementing partners, including but not limited to NMHS and the Red Cross, to outline a joint national approach for systematically and progressively developing community-based early warning early action plans in all communities.
- Establish agreements for collecting, analyzing, and publishing sex, age, and disability-disaggregated data in risk mapping, damage, and needs assessments
- Collaborate and coordinate to establish the learning cycle of after-action assessments and feedback loops to communicate needs and gaps to enable ongoing participatory improvement of the effectiveness of community-based action plans
- Systematically apply the IBF methodology in initial test case communities and then rolling out the validated approach to other communities to progressively establish inclusive, risk-informed, and community-based early warning early action planning in all communities.

<sup>57</sup> The programming of financing necessary to carry out an anticipatory action plan, with the release of funds triggered by reaching a predefined risk forecast threshold, is referred to as forecast-based financing.

- Ensure community-based hazard, exposure, and vulnerability assessments are inclusive of gender, vulnerable groups, and MSMEs, using NDMO and NMHS information and participatory tools such as the IFRC's Enhanced Vulnerability and Capacity Assessment<sup>58</sup> and the CDEMA Caribbean Community Risk information tool.
- Ensure early action plans systematically include community knowledge in both planning and after-action effectiveness evaluations, using tools such as the knowledge, attitudes and practices surveys used by the Red Cross Caribbean Disaster Risk Management and many others in the region.<sup>59</sup>
- Create templates for impact-based MHEWS messaging that are tailored to the different needs of women, men, and people with disabilities, and reflect the different ways in which these groups process, interpret, and respond to information, in coordination with SI8 (regional emergency alert system).
- Address the need for reliable, adequate, and timely financing linked to forecast triggers to ensure timely implementation, and developing national and local capacity to plan, manage, and advocate for early warning early action plan budgeting. This task may benefit from collaboration with SI10 (sectoral impact-based MHEWS, the private sector, and BCP).

### Actors

NDMOs and their national partners will primarily drive IBF implementation by systematically rolling out risk-informed, community-based early action planning. The network of implementing actors includes NMHS, national Red Cross Societies, the IFRC, UN agencies including UNDRR, UNDP, the World Food Programme (WFP), OCHA, UN Environment and others, as well as academia, gender bureaus, disability experts, communities, local businesses, and the wider private sector. This will require supportive guidance and regional cooperation from CMO HQ, CIMH, CDEMA, its Regional Gender Working Group, and the REWSC to ensure they share the tools and knowledge they develop, so progress continues to scale up over time.

## SI10. Sectoral impact-based MHEWS, the private sector, and BCP

### Rationale

Engaging the private sector to co-develop and co-deliver products that meet their needs is key to an effective impact-based MHEWS. The region's vulnerable MSME sector faces two primary challenges, around data availability and access, and awareness of the importance of business continuity and anticipatory action planning.

Private sector groups are recognizing that they benefit from better EWS as business flourishes when society is able to bounce back after experiencing impacts of hazards. Businesses are also seeking information about future climate for long-term strategic planning and engaging the private sector in developing products that meet their needs is key to effective MHEWS. For example, the CMO HQ provided information to the American Chamber of Commerce in Trinidad and Tobago that included Caribbean climate projections (the results of research published by the UWI Climate Studies Group at Mona) and connected them with the local meteorological service, where they obtained climatological rainfall data. For hydromet hazards, efforts to engage with the private sector in the Caribbean align with the WMO's 2019 Geneva Declaration on public-private engagement.

Private sector actors need access to hydromet data and warnings that they can readily use. And, as highlighted by the ongoing COVID-19 pandemic, health-related data must also be incorporated into business continuity plans (BCPs). Enhancing IBF throughout the region can help identify the impact of hazards on specific sites and ecosystems at a local level. Information on hazards—and the exposure and vulnerability of people and infrastructure to hazard impacts—can help inform business decisions around building location and design, asset storage, and employee safety. Engaging gender, youth, and vulnerable groups in the MSME sector is also essential for measuring the effectiveness of early warning information and early action plans. Additionally, bringing enhanced and timely MHEWS information to Caribbean MSMEs can help business owners take action—for example, by informing critical supply chain providers or moving assets, products, and machinery—avoiding losses and speeding up both recovery

58 <https://www.ifrcvca.org>.

59 <https://www.cadrim.org/kap-webinar-series>.

and a return to normal operation with less disruption.

Expanding awareness of the importance of BCPs and anticipatory action planning is also vital. Many private sector actors in the Caribbean have little to no access to risk reduction and business continuity training or information. This is especially so for MSMEs, due to a lack of institutions offering accessible information and services and a lack of people trained to lead such workshops. But a growing regional and international body of knowledge and community of practitioners is willing to share good practice and lessons learned with private sector networks. One of these is the UNDRR ARISE network, which promotes private sector resilience through BCP courses and workshops.

It is important to note that, although women are overrepresented in informal and vulnerable MSMEs and in the economic sectors that are most vulnerable to disasters, standard BCP tends not to address the structural gender issues of business continuity, nor the practical realities of women-owned MSMEs.

Disseminating and articulating messaging that is tailored to sectoral risks is vital for informing actions that MSMEs can take to increase their resilience to multi-hazard threats. Although dialogue between information producers and consumers in most Caribbean countries is limited, particularly in the MSME sector, examples of such dialogue are promising and need to be further supported. For example, when the EWISACTs consortium shares early warning information with sectors, businesses operating in those sectors benefit, and the CIMH shares information about a major Sahara dust threat directly with the energy utilities through its sectoral information bulletins. CIMH and the energy sector are also supporting integrated resource and resilience planning.

## Objective

This initiative aims to more actively engage stakeholders from across the private sector and mitigate the loss of critical physical assets and disruptions in vulnerable supply chains and business services. Larger regional and international companies have long histories of sharing multi-hazard BCPs and practices more widely. As they have the financial capacity to purchase the IBF data they need to formulate multi-hazard BCPs from international weather companies, many are discovering new pathways that can strengthen two-way impact-based MHEWS data and information flow between the public and private sectors.

To be transformative, BCP practices must also consider gender. Disaggregating data must therefore become the norm, to understand the exposure and vulnerability of women-headed MSMEs and build BCP capacity through training and networking.

## Approach

Regional private sector organizations such as the CARICHAM and the UNDRR ARISE network can play a leading role in strengthening the private sector's role as contributors to and beneficiaries of tailored impact-based MHEWS for each sector. They can also lead in developing BCP training, workshops, and expertise that is gender transformative and accessible to all, including vulnerable groups and MSMEs.

## Main tasks

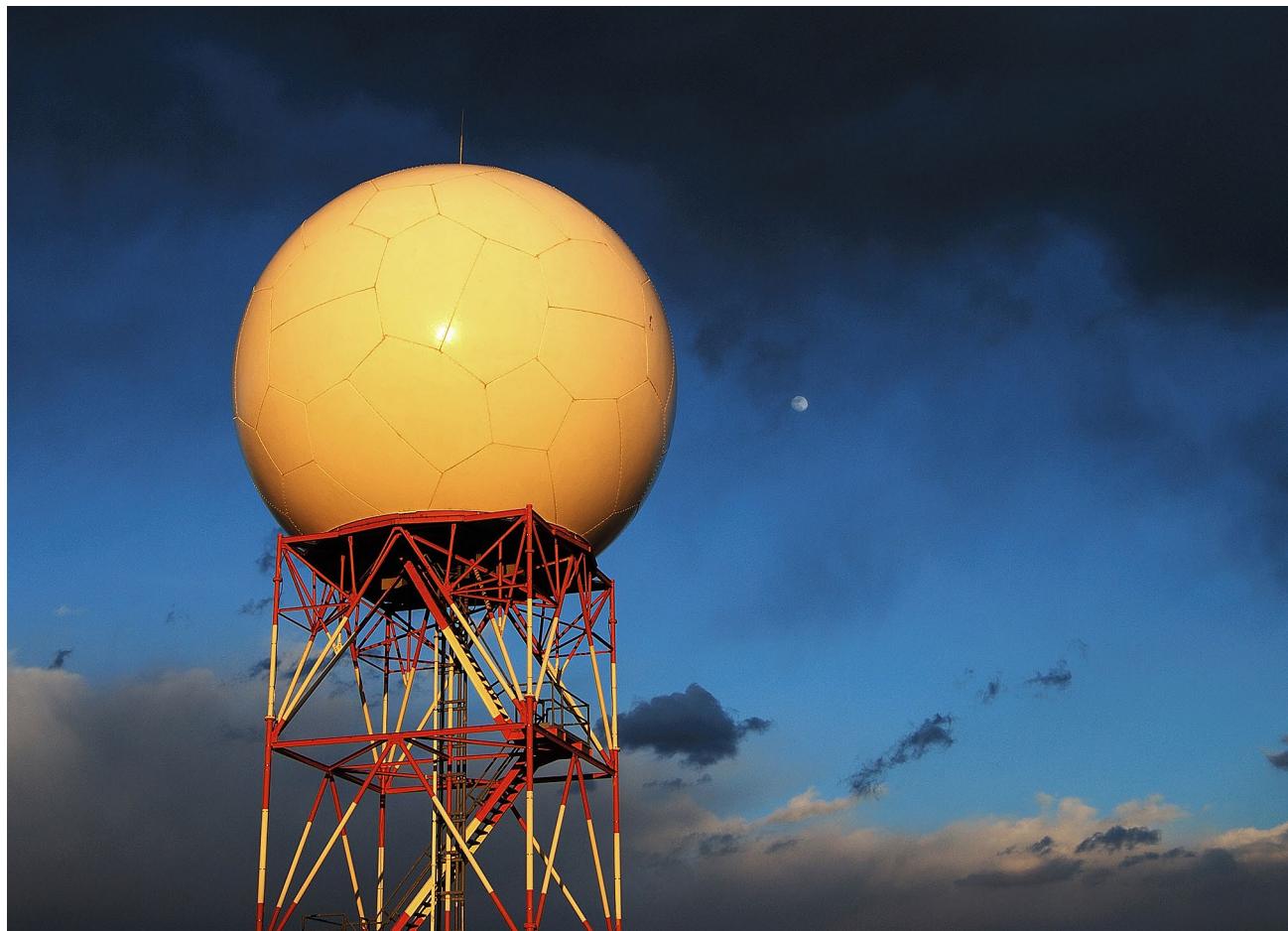
- Use an IBF approach to design impact-based MHEWS warnings that respond to the needs of different parts of the private sector, to enhance understanding of the impacts of extreme events on local economic assets, the built environment, and vulnerable livelihoods; and use suitable dissemination mechanisms to ensure all private sector actors receive the information they need to prepare in a timely fashion
- Strengthen private sector resilience, preparedness, and response capacity by raising awareness and teaching about the impacts of hazards, and addressing barriers to training within the more vulnerable MSME and economic sectors, considering intersections with vulnerable groups, such as gender and youth
- Create a broader culture of business resilience based on developing BCP strategies by engaging larger enterprises and institutions, including regional networks, to support MSMEs; ensure this support considers the realities of women-owned businesses and provides strengthened support for women-led businesses, as large, traditional business models tend not to include women's realities.

## Actors

Organizations in the region with a key implementing role in this strategic initiative include the UNDRR ARISE network, which raises awareness and co-sponsors training on BCP, and the CARICHAM, which unifies 16 chambers of commerce in the region. Both play important roles in

advocating and facilitating training for business continuity and public-private partnerships. CIMH is already making useful contributions to engaging the private sector through the sectoral EWISACTs consortium. National chambers of commerce, which provide training and have designated disaster risk reduction focal points, and small business associations, which bring much-needed resilience and BCP exposure to MSMEs, are also key.

Other important organizations include CARPHA, media broadcasting networks, mobile communications providers, social media companies, private sector alert companies, weather enterprises, key ministries—including tourism, transportation, agriculture, maritime affairs, and blue economy—and local governments. Gender bureau and social or economic scientist involvement will help elaborate and integrate a gender-transformative approach.



# 4

## SOCIAL AND ECONOMIC BENEFITS OF IMPROVED EWS



The Caribbean region's climate is its greatest magnet and economic generator, especially for the tourism and transportation sectors. But its severe weather events and geophysical hazards present the region's greatest source of intensive and extensive risk of loss. The Caribbean ranks among the top 10 most disaster-prone areas in the world when counting disasters per land area or population (CRED 2019; Eckstein, Hutfli and Winges 2019). Between 2006 and 2017, natural disasters cost the region an estimated \$143.4 billion, while total weather-related economic losses have been increasing since 2004, spiking to \$86 billion (purchasing power parity) in 2017.<sup>60</sup>

A country's GDP never experiences a rapid or immediate recovery. Recuperation often takes around 20 years, without considering subsequent impacts of events that take place in this time, such as the compounding and cascading effects of the COVID-19 crisis and the 2021 volcanic eruption on St. Vincent. The relative consequences of weather extremes and other crises depend on a country's income, extent of achieved development, and population growth. With per capita economic losses decreasing 52 percent between the Caribbean countries with the lowest and highest per capita GDP, those with lower incomes are more vulnerable to weather extremes and often tend to have lower adaptive capacity. This adds a dimension of vulnerability to countries that already face many other challenges.

While the DRM toolbox consists of many tools and approaches, EWS remains a key component in the Caribbean, which is prone to extreme events such as Category 5 hurricanes. The main benefits include reduced mortality, morbidity, property damage, and assistance and emergency costs.

This chapter provides an overview of a cost-benefit analysis (CBA) comparing the expected socioeconomic benefits to the costs that will be incurred. This CBA will help justify proposed public investments, such as the initiatives and activities presented in this roadmap. Applying a CBA to investments to modernize hydromet services and exploring different methodologies (and challenges) for quantifying benefits and costs related to weather, climate, and water information services, WMO et al. (2015) find that investing \$1 in hydromet services and EWS generally results in at least \$3 in socioeconomic benefits (a 3:1 benefit/cost ratio).

The economics of hydromet services and EWS is driven by the benefits derived primarily through improved DRM, and often also the optimized productivity of weather-sensitive economic sectors. Given the Caribbean context, this assessment includes DRM and water resource sectoral considerations, such as agriculture, energy, and water supply. At the same time, there are several complexities and uncertainties inherent in quantifying DRM that are compounded by climate change and other intangibles and—of particular importance for extreme events—in discounting the cost of future impacts.

## The challenges of quantifying benefits

Two peculiarities specific to DRM must be considered in an economic assessment of MHEWS. First, disasters involve considerable uncertainties. They are impossible to predict with great accuracy, and they cause complex and often cascading disruptions to economic and social systems. This assessment therefore uses a tailored economic modeling approach and specific quantitative technique that builds on probability theory.

Second, there is a discrepancy between financial and economic benefits. DRM investments rarely yield tangible (financial) cash flows, as benefits usually consist of avoided (economic) damages. Benefits can therefore be difficult to visualize and quantify, as the ultimate benefit is that nothing happens during a hazardous event. However, by comparing a baseline (the status quo) to the situation where investments have been implemented and with assumptions on their effectiveness, it is possible to estimate potential avoided losses.

When investments aim primarily to improve the provision of information, such as early warning, it is necessary to quantify the value of delivered information needs, based on the decision making and actions it informs and enables. And while the accuracy and timeliness of delivered information determine how useful it is for improved decision making and response, so does stakeholder capacity to interpret and act on the information. Despite these challenges, a growing body of expertise regards the economics of hydromet services and EWS (box 4.1).

**60** <https://germanwatch.org/en/cris>.

#### BOX 4.1. DRM ECONOMICS IN DEVELOPMENT

Though a somewhat technical niche, the economics of hydromet services and EWS has a community of practice of its own. However, it is not always applied in development projects, for two reasons. First, larger DRM projects often entail other structural components that yield enough benefits to achieve cost-effectiveness without needing to consider softer components such as EWS. And second, the lack of standardized practice for assessing the value of softer components such as EWS—usually based on behavioral change—requires assumptions that may be difficult to inform and/or justify and models that are highly sensitive to input variations.

On the latter point, the limited costs of hydromet forecasting and EWS (compared to infrastructure investments) and their potentially high benefits can yield what appear to be unrealistic results, such as internal rates of return over 100 percent, which are sometimes difficult to explain and may be challenged.

#### Producing benefits

The proposed investments in modernizing hydromet services and EWS in the Caribbean will pursue broad improvements to institutional capacities, regional collaboration, and information flow and use. But a critical and more quantifiable goal is to improve the resolution, timeliness, and accuracy of warnings and information delivered to the relevant authorities and the public, allowing them to pursue timely precautionary protective measures to save lives and assets.

This economic analysis is therefore structured around two main questions relating to early warning and its use:

- How much extra lead time (box 4.2) and increased information quality will the improved EWS provide? Quality considers forecast reliability, accuracy, uncertainty, and resolution, its targeting, and the efficiency with which it is communicated to vulnerable stakeholders. Benefits are expected to rise with increases in lead time and information quality.
- How can countries convert lead time and quality improvements into economic benefits? A marginal gain of time and quality can yield variable amounts of avoided damages, depending on the efficiency of use of the delivered information.

#### BOX 4.2. KEY TIME CONCEPTS RELEVANT TO THE ECONOMIC ANALYSIS OF HYDROMET SERVICES AND EWS

*Maximum warning time* is the time lag between a forecast and the moment when a variable representing the hazard exceeds a predefined threshold when the hazard is considered to become dangerous—for example, when water breaks the riverbanks and starts flooding, when a cyclone hits the coastline, and so on.

*Lead time* is the time between the moment a potential threat is identified and when it occurs, minus the decision and notification time. The *forecast lead time* is the sum of the lead time and the time for decision making and communication—that is, the lag time between the moment the threat is recognized and the moment where the threshold is exceeded.

The *lead time* is a portion of the *maximum warning time* during which anticipatory action can take place.

The *maximum warning time* is therefore the sum of the time for observation and data analysis (forecasting), decision making—for example, to issue a warning or communicate a lower risk level though a flood watch notice—communication to all relevant stakeholders, including local representatives and the general population, and the *lead time*, which ends when the hazard threshold is exceeded.

Whether information produces benefits relates to the extent to which decisions and actions based on the information reduce the exposure and vulnerability of people and their assets. Primary data collection to help quantify this is often unavailable, so secondary data, expert judgement, and transfer from studies and assessments in other locations and contexts are often employed.

The concepts introduced above are valid for the three models employed in this study, reflecting potential to reduce asset damage, reduce fatalities, and improve the economic productivity of weather-sensitive sectors. In all three models, the impacts of improved hydromet services and EWS are quantified as the difference between a baseline (status quo) and the with-investments scenario.

## Reflecting uncertainty

It is important to acknowledge that any model involves a trade-off. It should ideally remain simple and robust, yet not overlook any key features of the phenomenon it aims to represent. Because DRM involves high levels of complexity and uncertainty, it is necessary to strike the right balance between model accuracy and the capacity to obtain and/or generate reliable input data. This assessment uses two guiding principles for this: a conservative estimate of the benefits, and probabilistic modeling.

Using conservative assumptions and estimates of the benefits enhances the assessment's robustness and confidence in the results. The cost-efficiency of hydromet service and EWS investments are considered more valid when assessments avoid overly optimistic estimates of benefits. The main conservative assumptions used in the assessment are:

- The model does not consider all the hazards that could be impacted by the investments. Table 4.1 lists the hazards used to compute the baseline of damages and fatalities. It does not include volcanic activities, droughts, earthquakes, coral bleaching, or pandemics.
- The model assumes that even in the best-case scenario, the shortest maximum lead time—namely that for flash floods (30 minutes)—is delivered for all hazards, a strict limitation that significantly reduces the

benefits of certain hazards. For example, hurricanes can be forecast with 1–3 days' notice, reducing exposure and vulnerability.

- The scope of damages is limited to direct impacts of disasters—that is, destruction of assets and loss of life. Indirect, compounding, and cascading impacts of disasters, such as those resulting from disruption to economic activities, social services, connectivity, ecosystem services, and so on, are not considered.
- To aggregate the benefits of all models, fatalities are converted into economic values using assumptions for missed economic productivity rather than the statistical value of life, which would yield higher values but is controversial.<sup>61</sup>

**TABLE 4.1. DAMAGES AND CASUALTIES IN THE CARIBBEAN, BY DISASTER TYPE, 2000–22**

Hazard	Total deaths	Total damages (\$)
<b>Hydrological</b>		
Flash flood	98	1 million
Riverine flood	3,061	819 million
Other	73	10 million
<i>Flood total</i>	3,232	<i>830 million</i>
Landslide/mudslide	2	not available
Hydrological total	3,234	830 million
<b>Meteorological</b>		
Convective storm	6	not available
Tropical cyclone	5,045	21.65 billion
Other	26	not available
<i>Meteorological total</i>	5,077	<i>21.65 billion</i>
<b>Total</b>	<b>8,311</b>	<b>22.48 billion</b>

Source: EM-DAT database, maintained by the Centre for Research on the Epidemiology of Disasters at the Université Catholique de Louvain [www.emdat.be](http://www.emdat.be)

Note: The countries included in this aggregate are the same as those shown in table 4.2.

<sup>61</sup> From a social perspective, assigning monetary value to a life is questionable, particularly because the standard approach also reflects wealth.

As table 4.1 clearly shows, the EM-DAT database has several known shortcomings, particularly that hazard subcategories tend to not be reported or labelled consistently and damages are often not reported in a quantified manner. The EM-DAT is therefore considered to under-report disaster damages, contributing to the conservative nature of this assessment. Lacking any more detailed regional data, it has been used with full recognition of its shortcomings.

To further reflect the many uncertainties stemming from the complexity and variety of hazard types and the range of socioeconomic contexts within and across Caribbean countries—urban versus rural, rich versus poor—the assessment uses a *probabilistic approach*. In probabilistic modeling, inputs are represented not by deterministic scenarios, but by probability distributions, which reflect their specific uncertainties (box 4.3).

#### BOX 4.3. PROBABILISTIC MODELING IN A NUTSHELL

*Probabilistic modeling* consists of running thousands of iterations of a given (deterministic) model across all ranges of possible values of uncertain inputs.

These inputs are represented as random variables, so their respective probability distributions account for information gaps (uncertainties).

This in turn yields a large array of model results, which are ordered to build a probability distribution of the results, thus also reflecting output uncertainty.

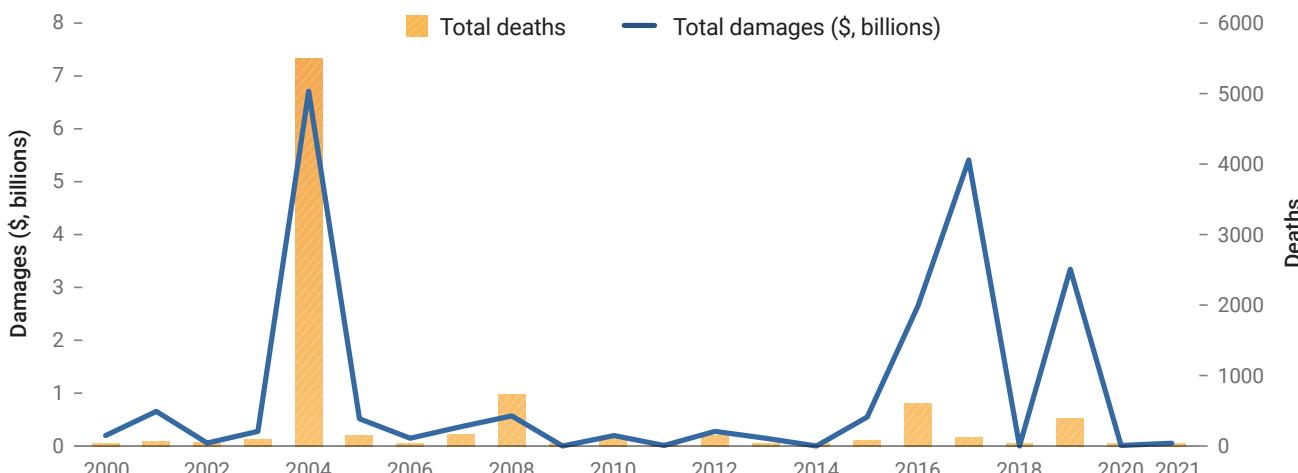
This process, known as a *Monte Carlo simulation*, allows for more refined risk analysis than deterministic models. This should not be confused with uncertainty on the hazards themselves. This assessment does not use a catalogue of many events from which to draw randomly. Instead, it uses the most common and robust approach of average annual losses (AAL).

#### Reducing disaster losses

As the baseline for current disaster losses, AAL are estimated using the EM-DAT database. Using 2000–21

data for the target countries of the proposed investments, a regional AAL of \$1 billion<sup>62</sup> is computed. Table 4.2 and figure 4.1 show the key data from EM-DAT.

**FIGURE 4.1. DISASTER-RELATED FATALITIES AND DAMAGES IN THE CARIBBEAN, 2000–2021**



Source: EM-DAT database [www.emdat.be](http://www.emdat.be)

<sup>62</sup> This average was computed from 2000 onwards. Though possible, longer time horizons may not be the wisest choice, as there is an acknowledged recording bias in the EM-DAT database, which is an issue for analyzing time series.

**TABLE 4.2. DISASTER-RELATED FATALITIES AND DAMAGES IN THE CARIBBEAN BY COUNTRY, 2000–21**

Country	Total deaths	Total damages (\$)
Anguilla	4	200 million
Antigua and Barbuda	1	260 million
Bahamas, The	404	6.03 billion
Barbados	2	5 million
Belize	55	550 million
Bermuda	4	300 million
British Virgin Islands	9	3 billion
Cayman Islands	2	3.5 billion
Dominica	96	1.96 billion
Grenada	39	890 million
Guyana	34	630 million
Haiti	7,539	2.36 billion
Jamaica	71	1.54 billion
St. Kitts and Nevis		20 million
St. Lucia	22	75 million
St. Vincent and the Grenadines	17	160 million
Suriname	5	not available
Trinidad and Tobago	3	5 million
Turks and Caicos	4	1 billion
<b>Total</b>	<b>8,311</b>	<b>22.48 billion</b>

Source: EM-DAT database [www.emdat.be](http://www.emdat.be)

Over 40 percent of the recorded total damages are concentrated in The Bahamas and the Cayman Islands. But rather than a variation of hazard levels, this reflects a much

greater level of exposure and wealth, as well as likely better post-disaster loss accounting and tracking systems in these countries. Per capita GDP in these countries is \$35,000 and \$86,000 respectively, compared to the CARICOM average of just under \$5,000, and Haiti's, which is \$1,300.

A large part of the damage was caused by a few extreme events, including Hurricanes Dorian (2019) and Frances (2004) in The Bahamas, and Ivan (2004) in the Cayman Islands. Although global disaster databases such as EM-DAT do not generally capture frequent floods with lower damages well, these tend to contribute significantly to overall average damages. So, over time, more frequent events with limited damages have more average annual impact than very harmful but rare events. This reporting bias is adjusted using a conservative estimate of a multiplier ranging between 1.5 and 2.3.<sup>63</sup>

The model assumes an annual economic growth rate of 4 percent (World Bank 2021)<sup>64</sup> on a GDP base of about \$100 billion.<sup>65</sup> This results in a baseline AAL of 1.96 percent of GDP, which is within the expected range for the Caribbean.

### Avoided damages

The assessment uses the Flood Hazard Research Center (FHRC) model (Parker et al. 2009; Carsell, Pingel and Ford 2004) to estimate the level of potential damage reduction delivered by the proposed investments. The FHRC model considers the maximum flood damages avoided with a fully effective EWS for a given lead time—that is, the reliability of forecasts, the percentage of exposed households able to respond,<sup>66</sup> the percentage of households that will respond, and the percentage that will respond effectively.

These factors are combined to reflect a percentage reduction of the baseline damage, which in this case is the AAL. The reduction of damage also varies with lead time. Table 4.3 shows a summary of benchmarks found in the literature, as well as estimates from Caribbean hydromet services and EWS experts.

<sup>63</sup> Computations performed from expert judgement. This is consistent though slightly more conservative than 3.1 suggested in UNDRR (2019): “an analysis of records in 104 countries found that between 2005 and 2017, small and medium, localized and frequent disasters caused 68 percent of all economic losses”. See also <https://www.preventionweb.net/understanding-disaster-risk/disaster-losses-and-statistics>.

<sup>64</sup> This is consistent with past trends.

<sup>65</sup> <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?end=2020&locations=S3-HT-VG-TC-BM-KY&start=2000>.

<sup>66</sup> Able to respond means being on site (assumptions are made about occupancy of vacation lodging), reachable through standard communication channels, and unlimited in ability to respond.

**TABLE 4.3. BENCHMARKING FHRC MODEL INPUT VARIABLES**

Variable	Literature			Expert opinion		
	min	mode	max	min	mode	max
Lead time (hours)				0		0.25
Maximum reduction in damages	4%	40%	80%	4%	10%	20%
Forecast reliability			70%	25%	50%	50%
Exposed households able to respond	55%		80%	20%		75%
Households able to respond that do respond	75%		80%			
Households that respond effectively	70%		95%		25%	

Source: (Literature column) Pappenberger et al. 2015; Emerton et al. 2016; Carsell, Pingel and Ford 2004; Grant 2020

Note: *Min*, *mode* and *max* respectively denote the minimum, the most likely and the maximum value of each input variable.

Table 4.4 shows the values used for the assessment, which are input as probabilistic distributions to represent the possible ranges of each variable. The spread between the literature and expert opinion for the maximum reduction in damages due to early warning is quite significant. Given the multiplicative Table 4.4 shows the values used for the assessment, which are input as probabilistic distributions to represent the possible ranges of each variable. The spread between the literature and expert opinion for the maximum reduction in damages due to early warning is quite significant. Given the multiplicative nature of the FHRC model, this uncertainty is problematic as it will directly impact the model results. As such, and following the conservative approach, this variable is capped at a relatively low level. The most likely (mode) maximum reduction in damages of 40 percent for the with-investments scenario represents the portion of the total

value that could be saved, which itself is only 20 percent of the total assets value. As such, the average value of savings is only 8 percent of total value of at-risk assets. And because the model uses assumptions based on data from high-income countries where structural (non-moveable) assets have a higher relative value than the Caribbean, the approach is again more conservative.

While the probability distribution of lead time ranges from 5 to 30 minutes, the average increase between the baseline and with-investments scenario is about 10 minutes. Based on all the combined assumptions, the average effective response of the total population increases from 18 percent for the baseline to 40 percent after investment; and the investments lead to average savings of 2.8 percent of AAL, which aligns with the lower range of values reported in the global literature.<sup>67</sup>

**TABLE 4.4. FHRC MODEL INPUT VARIABLES**

Variable	Baseline					
	min	mode	max	min	mode	max
Lead time (hours)	0	0.083	0.167	0.083	0.25	0.5
Maximum reduction in damages	0	20%	33%	20%	40%	60%
Forecast reliability	10%	25%	30%	30%	50%	60%
Exposed households able to respond	20%	40%	75%	40%	75%	80%
Households able to respond that do respond	25%	50%	75%	35%	70%	80%
Households that respond effectively	70%	82.5%	95%	80%	90%	95%

Note: *Min*, *mode* and *max* respectively denote the minimum, the most likely and the maximum value of each input variable.

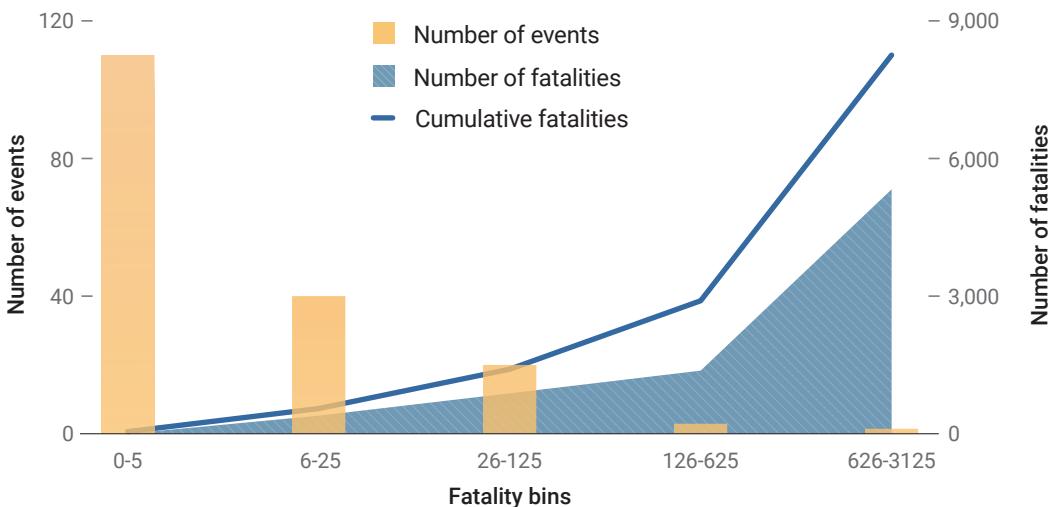
**67** For example, Hallegatte (2012) assumes that 10 percent savings of AAL is conservative.

## Avoided fatalities

As table 4.2 shows, most casualties occurred in Haiti. These occurred primarily during two major events in 2004: Hurricane Jeanne, which affected several areas, including Artibonite, Centre, Northwest, and South; and a riverine flood affecting Belle Anse, Croix-Des-Bouquets, and Jacmel. These events are responsible for 65 percent of all recorded fatalities in the region, resulting in the distribution of

The estimate of lives saved resulting from hydromet services and EWS is derived from the model discussed by Penning-Rowsell et al. (2005). This is based on floods and considers the number of fatalities, flood depth, flood velocity, destructive objects (debris) carried by the flood, river basin population, and vulnerability relating to age and infirmity. It also uses somewhat subjective scores for EWS performance and local vulnerability. Assumptions recognize that for the very rapid onset floods that dominate the Caribbean context, maximum potential warning time

**FIGURE 4.2. DISTRIBUTION OF DISASTER-RELATED FATALITIES IN THE CARIBBEAN, 2000–2021**



fatalities for the entire region taking on a Pareto-like shape (figure 4.2). The average annual number of fatalities is 378.

Due to its controversial nature, the assessment does not use the concept of the statistical value of life, using instead estimates of the missed economic productivity that results from fatalities caused by disasters. The population-weighted GDP per capita of Caribbean countries is \$4,900, with significant variance across the region. To transform fatalities into economic values, the assessment uses a fatality-weighted average, meaning the per capita GDP of countries experiencing the most fatalities is weighted more, resulting in a regional average fatality-weighted per capita GDP of \$3,100.

is extremely short. So, even the best improvements in the resolution of forecasting and warning may not save many lives. It should also be noted that the issue under consideration is the improvement or increase in lives saved, not total lives saved. However, given that hurricane warnings are available with a longer lead time, the death rate is likely attributable to people not receiving warnings, not understanding them, or being unable or unwilling to move to a safe location. Based on these assumptions, it is estimated that the variation in EWS performance that investments can trigger could save 7–13 percent of lives. This translates into 300–600 lives saved, the economic valuation of which accounts for 14 percent of all estimated economic benefits from improved DRM.

## Increased sectoral productivity

In the Caribbean, agriculture produces about \$7.7 billion in GDP.<sup>68</sup> This includes forestry and fishing, which generally do not benefit significantly from EWS, so the assessment assumes that 70 percent of total agricultural GDP is generated by crops<sup>69</sup> and can benefit from improved hydromet forecasts. Although data on GDP produced by energy and water supply are not readily available for the region, data from Jamaica<sup>70</sup> suggest that these sectors produce about 60 percent of agricultural GDP. The regional sectoral productivity expected to benefit from the proposed EWS investments is therefore about \$12.4 billion.

Kull et al. (2021) determined that, with improved decision making using hydromet forecasts, it is possible to reduce global average annual crop yield variability of 7.5 percent by 20 percent. To avoid double-counting with potential benefits from saving sectoral assets captured under avoided damages, this is further reduced by 20 percent, resulting in a total benefit of 1.2 percent of crop productivity. The same global assessment also determined 5 percent savings for renewable energy and water supply. To adhere to a conservative approach, the 1.2 percent savings is applied to all sectors, bringing the proposed investments' potential total regional annual sectoral benefits to about \$148 million.

Adopting advanced hydromet forecasting products into decision making for optimizing sectoral productivity generally takes longer than setting up EWS for the public. To account for this delayed and expected lower adoption and operationalization—particularly in terms of smallholder farmers' potentially limited financial and technical capacities—as well as additional costs to operators for adopting these new products, these benefits reduce to about \$24 million over the entire horizon (mean present value). This is considered very conservative.

## Discount rates

CBA uses a discount rate to represent societal preference for consuming in the present as opposed to saving and consuming in the future. A discount rate of zero percent indicates no preference between now and the future, while a 15 percent rate represents a high preference for

spending now. This analysis applies a 5 percent discount rate, representing an understanding that future costs and benefits are relatively important compared to the current situation, in keeping with concerns regarding climate change.

## Costs

Thorough costing of all possible measures relevant to EWS is a complex task and has not been performed for this assessment. The World Bank's Disaster Vulnerability Reduction Project for St. Lucia cost \$7 million and concentrated on addressing the biggest gaps identified in a situational analysis of the country's hydromet services. It focused on critical components of the end-to-end MHEWS, including: strengthening and automating the observation network by installing a weather radar; implementing a common hydromet database and management system; installing new workstations with analytical/forecast/visualization tools and software; installing a satellite download link; establishing numerical weather prediction capacity; developing flash flood guidance and flood EWS (including coastal flooding); installing a national emergency notification and communication system using CAP; building a website and portal to disseminate data, forecasts, and warnings to users; and establishing a user-provider committee to meet user needs and delivering relevant training (World Bank and Government of St. Lucia 2017). Not all the proposed enhancements were implemented. The benefits and improved evolution of service delivery will take years to be fully realized because of the time it will take to link the improved components and for forecasters to learn to fully use the new system's capabilities.

The St. Lucia project reflects a significant national modernization effort that not all 20 CARICOM countries need. Based on this, it is assumed that full modernization would cost each country \$4–6 million on average, so \$80–120 million for the region, with a likely estimate of \$90 million.

Resourcing national MHEWS roadmaps has been a challenge, however Cost-Benefit-Analysis shows that a regional approach will lead to national cost savings through economies of scale, and the fact that there is also

<sup>68</sup> <https://data.worldbank.org/>.

<sup>69</sup> Guyana, Haiti, and Jamaica account for more than 80 percent of total regional agriculture GDP, dominated by crop production.

<sup>70</sup> <https://statinja.gov.jm/NationalAccounting/Quarterly/NewQuarterlyGDP.aspx>.

greater confidence in economic efficiency should assist in leveraging needed investments. Pursuing a regional approach as proposed here could realize cost savings, for example by sharing radars and other observation networks, developing common regional numerical weather prediction, flash flood guidance, and flood forecasting systems, establishing regional emergency communication systems, and running regional training events.<sup>71</sup> A regional approach to investment is already being practiced in some fields, including the Caribbean Radar Project, instrument procurements, capacity development, regional computation and data storage platforms. Based on average per-country costs—as in the case of St. Lucia and specifically for established national and regional numerical weather prediction and FFGS/flood EWS in countries outside the region—this assessment estimates that a regional approach will save \$30–40 million, with total regional costs of \$50–80 million, and a likely estimate of \$66 million.

For individual national modernization investments, this assessment estimates operation and maintenance (O&M) costs of 10–15 percent of capital expenditure (CAPEX), with a most likely value of 12 percent. To further account for potential regional savings because many of the proposed investments will be shared among several countries, O&M for the regional investments is estimated at

4 and 10 percent of CAPEX, with a likely value of 6 percent.

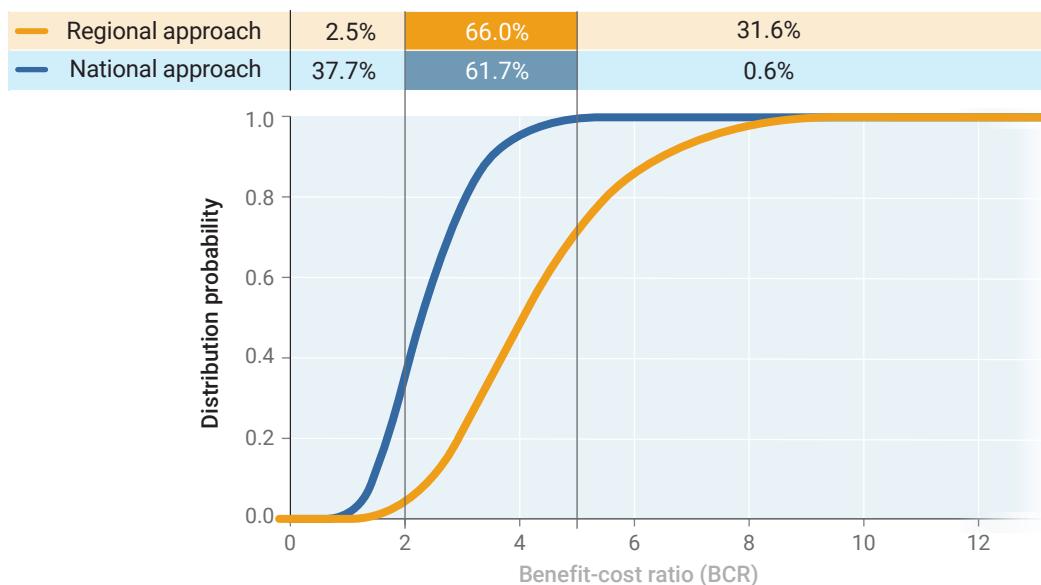
## Model outputs

The Monte Carlo simulation uses several probabilistic distributions representing warning timeliness quality and effectiveness; hazard frequency in the form of the multiplier used to correct the AAL for insufficient capturing of more frequent but smaller events; and benefits and costs. This produces a large set of possible outcomes, represented also by a probabilistic distribution. The assessment uses a 15-year time horizon, considered appropriate for hydromet service and EWS modernization investments.

While CBA produces multiple metrics, the focus here is on the BCR, which is computed by dividing the total discounted benefits by the total discounted costs. If the BCR is greater than 1.0, then the investment is considered economically efficient. The resultant aggregated BCRs are shown as cumulative probability distributions in figure 4.3 for both the assumption that there are no regional savings (national approach) and the regional approach proposed here.

The BCR ranges from 1.1 to 4.2 in 95 percent of all scenarios for the national approach, and 2.0 to 8.2 in 95 percent of the scenarios with the regional approach. Both are well above 1.0, showing strong economic

**FIGURE 4.3. CUMULATIVE PROBABILITY DISTRIBUTION OF BCR**



**71** Cost savings in a regional approach could be made by reducing investment costs (less software license fees for example), reducing implementation costs (adaptation and integration of commercial software packages for example) and reducing operational and training costs.

efficiency. The mean BCRs for the national and regional approaches are 2.4 and 4.4 respectively; the modes are 2.4 and 3.7. The probability that the BCR falls below 1 is of 1.6 percent and 0.01 percent in each case, which is a very low level of risk.

Sensitivity analysis of costs indicates significant robustness of the results. Keeping O&M costs to 6 percent of the CAPEX, the CAPEX could go as high as \$292 million before the costs outweigh the benefits (the mean BCR becomes less than 1.0). This threshold reduces to \$212 million if O&M are set at 12 percent of CAPEX.

## Discussion of results

The resultant BCR range is typical of hydromet and EWS modernization investments. As the Caribbean grows economically, so will its exposure and the AAL; this, in turn will increase the benefits and the BCR resulting from enhanced hydromet services and MIHEWS. In any case, the proposed investments can be considered economically efficient, and the results are robust vis-à-vis investment cost uncertainties, which have the greatest impacts of all the considered uncertainties.

Unsurprisingly, a regional approach that leads to national cost savings and overall reduced costs across all countries is more economically efficient than each country investing on its own in an uncoordinated manner. The BCR for a regional approach is almost twice that of a national approach, indicating the proposed regional investments would generate twice the benefits per dollar invested than a series of parallel national investments. Confidence in the economy efficiency of the proposed investments is also higher for a regional versus national approach.

It must be noted, however, that such a lumped regional approach hides a great variety of contexts and scenarios. When the next major hurricane hits, even a modest improvement in EWS would likely save hundreds of lives in Haiti and billions of dollars in The Bahamas or Cayman Islands. This is important to remember when considering the 10 transformational strategic initiatives:

- **SI1.** Supporting the transition to IBF and warning services
- **SI2.** Toward a Caribbean geospatial platform
- **SI3.** Toward a regional multi-sensor precipitation grid
- **SI4.** An integrated approach to flood and drought risk forecasting and warning

- **SI5.** Integrating health impacts into the impact-based MHEWS
- **SI6.** Air quality health impacts
- **SI7.** Toward a Caribbean multi-hazard operational plan
- **SI8.** Regional emergency alert system
- **SI9.** Community-based action planning
- **SI10.** Sectoral impact-based MHEWS, the private sector, and BCP

These strategic initiatives can be roughly grouped into two broad categories related to the model used for the economic analysis:

- A.** SI1–SI4, SI7, and SI8, which relate to enhancing forecast accuracy, timeliness, and resolution
- B.** SI1, SI5, SI6, SI9, and SI10, which relate to the efficiency of stakeholders' information use.

In this categorization, *resolution* refers not only to how geographically refined and targeted warnings are, but also to specific priority sectoral information, such as health under SI5. It should be noted that SI1 contributes to both enhanced forecast products and stakeholder product use and is therefore included in both categories. The relative benefits of SI categories A and B are estimated to be 85 percent and 15 percent of total benefits, respectively. This means that, according to the economic model, the highest potential benefits can be generated by investing in improving forecasting accuracy, timeliness, and resolution.

However, hydromet services and EWS are only as strong as their weakest link, meaning the above conclusion regarding the relative benefits of SI categories A and B can be misleading. Without a fully functional SI category B, SI category A would deliver no benefits. Improved forecasting accuracy, timeliness, and resolution can only be achieved if stakeholders take effective decisions and actions based on the warnings. Indeed, it is likely that the 15 percent of impact associated with the SI category B is quicker and cheaper to achieve than the more complex monitoring, forecasting, and warning efforts, required by category A, both in terms of capital investment and capacity building. In this perspective, it is important to unlock category B initiatives to fully leverage improvements in SI category A. Table 4.5 illustrates the overall benefits for the strategic initiatives in terms of reduced mortality, morbidity, and increased economic productivity.

**TABLE 4.5. OVERALL BENEFITS FOR CARIBBEAN COUNTRIES OF THE STRATEGIC INITIATIVES OUTLINED IN THIS ROADMAP**

SI	Risk monitoring and forecasting activities	Outcomes	Overall benefits
1. Supporting the transition to IBF & warning services	Web-based display systems	Increased effectiveness	Reduced morbidity
	High-resolution regional numerical modeling, observations, exposure, and vulnerability layers		
	Integrate gender and vulnerable groups		
2. Toward a Caribbean geospatial platform	Advance all Caribbean countries' ability to benefit from IBF for multiple hazards	Higher-quality community-level data that identifies vulnerable areas/groups	Reduced assistance costs
	Advance interoperability and value-adding in terms of risk and climate information availability		
	Facilitate the integration of hazard, exposure, and vulnerability data		
3. Toward a regional multi-sensor precipitation grid	Develop a high-resolution grid of observed and forecast rainfall	Early warnings for flash floods and riverine flooding; improved water management decision making for energy, agriculture, health, transport, environment, and tourism	Improved productivity
	Optimized radar network		
	Regional plan for operation, maintenance, calibration, backup, and data exchange		
4. An integrated approach to flooding	Flash floods guidance systems		
	Storm surge forecasting system		
	Tsunami warning system		
5. Integrating health impacts into the impact-based MHEWS	Combine epidemiological surveillance and hazard risk monitoring in impact forecasting activities	Improved public health: reduced heat stress in vulnerable populations, reduced outbreaks of COVID-19 in shelters, etc.	Improved public health in terms of hospitalization for respiratory ailments, reducing outbreaks of COVID-19 in shelters
	Protocols for compounded or cascading hazards (e.g., for shelter management during COVID-19, volcanic eruption, and hurricanes)		
6. Air quality	Monitor and forecast atmospheric composition Alerting system for thresholds related to respiratory ailments in humans, livestock, and wildlife (for sanctuaries and zoos)	Improved public health: fewer emergency visits and hospitalizations for respiratory ailments, etc.	
7. Toward a Caribbean multi-hazard operational plan	Enhanced regional impact-based MHEWS framework	Enhanced regional coordination and cooperation	
	Basis to build and integrate future hazard models		
8. Regional emergency alert system	Leverage Caribbean countries' communications assets	Public access to timely, consistent, authoritative, targeted end-to-end messaging before and during emergencies; shorter lead times; better, more effective targeting	
	Develop a public alert and warning system for regional and national authorities		
9. Community-based action planning	Participatory awareness-raising	People-centered EWS that effectively reach the last mile and are inclusive of gender, youth, disabled, vulnerable groups	
	Community assessment		
	Prioritize risks		
10. Sectoral impact-based MHEWS, the private sector and BCP	Develop tailored forecasts for anticipated sectoral impacts	Private sector actors are fully engaged in developing regional impact-based MHEWS as both contributors and beneficiaries	
	Support MSMEs in forecast-based BCP		

# 5

## IMPLEMENTATION APPROACH



EVACUATION  
ROUTE

Implementing the roadmap requires several key ingredients, including: an enabling policy, legislative, and regulatory environment which should advance in concert with technical advances; smart investments for developing institutional and human resource capacity in a sustainable manner; private sector involvement; and an inclusive approach to gender, community leaders, and vulnerable groups.

The roadmap sets out 10 strategic initiatives that would optimally be implemented under the overall auspices of disaster management at both regional and national levels, with major support from scientific and technical institutions for risk monitoring, prediction, and warnings. CDEMA has a CDM strategy, and Country Work Program (CWP) development has traditionally been guided by the CDM Audit, which is a Caribbean assessment tool and part of the shift towards more systemic risk management. Overall, 79 per cent of the CDEMA Participating States (PS) have conducted the analysis that leads and guides the CWP development. As of 2022, 37 per cent of CDEMA PSs have met the Sendai Framework target E by completing development of their CWP, with another 21 per cent in the process of finalizing their CWPs.

Implementing MHEWS requires integrated multi-hazard, multisector, and multistakeholder assessment, and an understanding of the risks of biological and geohazards that may also be compounded by hydromet events.

Implementing the strategic initiatives elaborated in this roadmap will also require the direction, leadership, and commitment of regional organizations and their member state agencies. Using a phased approach, creating an enabling environment, and building sustainable capacity will be all be necessary to manage the transformation of EWS to MHEWS and progressively to impact-based MHEWS across the region.

A phased approach will allow multiple actors to coordinate activities and prioritize tasks according to available and required financial and human resources. Strengthening the enabling environment includes translating the vision into a robust architecture of policy and legislative support, which is required to sustain a well-functioning regional impact-based MHEWS. Knowledge management is vital for internalizing practical learning and informing ongoing capacity-building to increase and sustain human resource, technical, and institutional capabilities.

Regional agreement and ownership of the roadmap process is crucial for the successful implementation of

its strategic initiatives. Defining roles and responsibilities for implementing the roadmap and achieving the vision is ultimately within the purview of the region, but to deliver each initiative, one or more agencies will need to take the lead, with other agencies participating in the process and contributing to its achievement. In general, this will involve defining the relationship between regional agencies in providing coordination and technical support, with national agencies and civil society and private sector partners sharing responsibility for carrying out activities.

Decisions on which agency serves as the lead for implementing and sustaining an initiative or agreeing a division of responsibilities among collaborating institutions will need to reflect true institutional capabilities and staff competencies rather than pure mandates; it is advisable to go where competencies are present in operating budgets rather than due to projects or programs. For each strategic initiative—some of which are launching with pilot activities—the lead agency (or agencies) may coordinate with their implementation partners to further define roles and agreed responsibilities to carry out the workplan for each stage of implementation. Sustainability planning needs to be part of these activities from the early stages. Depending on the nature of the investment, sustainability planning can be extremely expensive, and while agencies may have the requisite competence, they will not always have the resources to sustain it.

This roadmap is prepared as a strategic document to guide regional actions for enhancing existing MHEWS in the ongoing process of becoming increasingly robust and comprehensive impact-based MHEWS. And to ensure that early warning service delivery reaches the last mile and is people-centered, it will be largely implemented at national level, bringing together different national institutions (Figure 5.1). Sustainability and effectiveness require strong national and local interagency operational coordination mechanisms and SOPs that are practiced and regularly reviewed to ensure operational readiness and coordination at all levels.

A monitoring, evaluation, accountability, and learning mechanism is therefore necessary to assess progress, make revisions where course correction is advisable, develop supplementary activities that respond with agility to changing conditions, and capitalize on emerging opportunities.

**FIGURE 5.1. IMPACT-BASED MHEWS IMPLEMENTATION APPROACH**

## A phased approach

A phased approach will help optimize the sequencing of implementing various activities proposed in the roadmap. Phasing aims to capitalize on quick and easy wins in the short term, build new and sustainable capacities in the medium term, and harness emerging opportunities over the longer term. A key short-term objective is to demonstrate benefits at national level that a regional approach can augment by implementing four priority activities agreed by the regional partners:

- Supporting harmonization to strengthen IBF in the region
- Developing a multi-sensor precipitation grid
- Developing an integrated approach to flooding
- Conducting a study for a regional emergency alert system.

These initial investments represent a set of complementary initiatives that address the shift from EWS to MHEWS at national level—elements of which are already in play regionally and in several countries—while strengthening the foundations for impact-based MHEWS.

Medium-term implementation includes mobilizing financing for subsequent stages of the strategic initiatives and establishing a workable, regionally led sustaining framework. Longer-term implementation will require fulfilling the strategic vision while also integrating new challenges and opportunities as they emerge.

## An enabling environment

To implement the roadmap, the policy and regulatory environment will need support to progress with any technical advances and innovations. Underpinning the roadmap is the need for all CDEMA participating states to implement CDEMA's Model National MHEWS Policy, and for this, short- or medium-term benchmarks at subregional and regional levels could be helpful. Assessing the status of MHEWS in CDEMA participating states is an important step in this direction. National MHEWS roadmaps are available for seven CDEMA participating states, and a key goal for supporting the region would be for all participating states to develop a national MHEWS roadmap.

Strengthening IBF requires national collection, integration, and analysis of hazard, vulnerability, and exposure data that feed into both national and regional information systems. Legislative support for a regionally harmonized approach is essential to streamline interagency data sharing and application and modeling development. This can be accelerated through harmonized national implementation of agreements on the interoperability of monitoring and detection systems and regional data standards, with a view to harnessing the longer-term potential of Big Data.

Policy and legislative support can also facilitate the expansion of private sector collaboration along the EWS value chain. Private sector involvement is crucial to leveraging new technologies. This includes reaching the last mile through more effective dissemination

and locally tailored communications and applying IBF for action planning to improve shock responsiveness in communities and businesses of all sizes. Securing necessary financial resources also requires advocacy and endorsing governments to ensure that national budgets support MHEWS development and operationalization. This roadmap includes an economic analysis of the benefits of implementing a regional MHEWS (chapter 4) with a view to helping leverage the required investments. Strategies for regional financing to support implementation of the roadmap can be developed under the Caribbean CREWS initiative.

## Developing capacity

Capacity building underpins institutional development and the human resources required to sustain it. Capacity must be built to ensure efforts to introduce new techniques or technologies into organizations involved in MHEWS implementation—especially NMHS and NDMOs—are sustainable and the changes can be managed effectively. This section describes a global approach to capacity development, recognizing that some of these are already in use in the Caribbean region. As the regional training and research organization, CIMH plays a vital role in training NMHS personnel in the region.

Capacity development starts at the top of an organization, and support from the region's NMHS and other hazard and NDMO leadership and senior management is vital for the success of MHEWS capacity building efforts. Effective and efficient functioning requires institutional management skills are key to the success of innovative and modernizing programs. But such skills are weak or nonexistent in many developing and Least Developed Countries, and need to be developed or enhanced at leadership and managerial levels in most Caribbean countries. Managers should also encourage junior staff to gain knowledge, confidence, and independence in decision making.

Establishing, maintaining, and replacing an appropriate cadre of professionals is a particular challenge for NMHS. This is often due to difficulties in recruiting talent if organizations and civil service structures cannot offer an interesting career path, higher salary, and opportunities for self-development. Without good prospects, retaining skilled and qualified staff is difficult, and many developing country

NMHS struggle to maintain the human capacity they need to make the best use of new systems and technologies. Governments must therefore consider how to retain these professionals who will play the critical role in achieving regional and national MHEWS.

Successful capacity building efforts require a systematic approach to designing and delivering appropriate training that is related to the NMHS strategic objectives, delivers the necessary competencies to achieve those objectives, and is appropriate for staff capacity levels. This will allow countries to identify gaps between their current capacity and a future state of adequate capacity and should be followed by preparing and implementing a tailored capacity development plan. This systematic approach is a far cry from the ad hoc opportunistic capacity building activities most NMHS adopt. There is often a reluctance to pass over opportunities, especially if they are financed by development partners or international organizations, and NMHS often answer calls for participating in training in any hydromet field even if it does not match their needs, or the absorbing capacity of their staff. Only eight Caribbean NMHS have included capacity development plans in their strategic plans and national frameworks for weather, water, and climate services.

In developing a training plan, countries should explore and use available options, which include:

- **Training:** This involves academic-type courses using well-established, internationally accepted hydromet and multihazard material and a well-structured syllabus to develop scientific, technical, and soft skills.<sup>72</sup> This type of training should initially be based on NMHS personnel needs and follow a systematic, rather than ad-hoc, multihazard approach. It is important to dedicate enough time to training to ensure all relevant staff reach the required level of knowledge and expertise. If possible, the advantage of delivering basic/foundational meteorological training through in-house courses to new recruits ensures that as many staff as possible participate in the training. It would also enable capacity building for multiple staff members, whereas overseas training would probably be restricted to just one or two people. However, NMHS should also take advantage of opportunities for further training offered at regional training facilities and centers, and in more recent years through RCC

**72** Soft skills include service delivery, user focus, communication, consultation, relationship building with users and stakeholders, media, presentation, and management skills.

and the Global Campus initiative, as the curriculums developed for these institutions can enhance previous training. Online self-study would also allow staff to advance further after gaining sufficient knowledge in a particular field of study.

- **Experience:** This involves practical sessions and on-the-job practice starting with hydromet colleagues, supervised by trainers or other well-trained, experienced staff. To ensure training investments are sustainable, NMHS should seek to retain staff in the positions for which they have been trained, and when rotated, ensure a proper handover is in place. If staff are assigned to a completely new area of work, the NMHS should ensure they get the training they need to develop the basic skills, knowledge, and abilities for the new job and are not expected to learn these new skills through on-the-job exposure only.
- **Exposure:** This involves field visits to other NMHS to allow staff to witness operations in more advanced organizations, after receiving in-country training. Longer-term attachments also provide opportunities to gain a deeper understanding and improve skill levels by following daily operational routines and sharing lessons learnt with colleagues upon return to their country. Twinning arrangements with more advanced NMHS aimed at providing practical guidance also help build staff confidence, improving practical skills and knowledge. On-the-job training is conducted under the CIMH program, and arrangements are also made for visits by personnel of NMHS to the U.S. NWS Weather Prediction Center Tropical Desk.

To build sustainability in capacity building, training experts and institutions should follow up training with mentoring and monitoring to ensure trainees are using their new knowledge as intended and do not fall back into old habits. Achieving sustainability requires institutional change, which is often a challenge for public sector organizations. It is not only about building capacity in existing staff; it is also about examining where investment is really needed to make a sustainable difference in organizational capacity. This could include recruiting additional staff, building new physical or technological infrastructure, embracing accompanying changes in mindset, and being open to new ideas and practices. Essentially, it involves changing the management framework.

## Engaging the private sector

Involving the private sector as one of the three components of the Global Weather Enterprise (GWE) is a key to transformational development through implementing the strategic initiatives. The term GWE has been coined to describe the totality of activities by individuals and organizations in the public (NMHSs and other related government organizations), private (weather services providers, broadcasters, equipment manufacturers, weather satellite operators) and academic (universities and research organizations) sectors to enable weather information to be created and provided to society (Thorpe and Rogers 2018). It is fundamentally global because not only is weather ubiquitous, but the creation and use of weather information also require the efforts of all nations.

Forging opportunities for MSMEs in national processes will help reach the last mile and strengthen inclusion by enabling business owners to define their needs while also doing their part in building the impact-based MHEWS. It is also important that these efforts reflect the gender perspective, as women are more likely to participate in the economic sectors that are most vulnerable to disasters, in the informal economic sector, which is particularly vulnerable to disasters, and in MSMEs characterized by informality. Leveraging private sector capabilities without jeopardizing public hydromet service provision is key for maximizing socioeconomic benefits (World Bank 2019). The participation of larger enterprises as both contributors and beneficiaries at the regional level will strengthen demand for sustaining impact-based MHEWS while also potentially shouldering some of the responsibility for continuity of maintenance and continual improvement to ensure needs-responsiveness over time.

## An inclusive approach

Efforts to ensure the regional impact-based MHEWS takes an approach that is inclusive of gender and vulnerable groups are vital, as the impact of an EWS lies in its ability to reach the people, sectors, and businesses that are most at risk. The implementation of this roadmap must reflect this approach in its proposed strategic initiative design, acknowledging the role of different groups and maximizing their involvement. This would not only provide opportunities for them to participate, but also ensure the process benefits from their key knowledge and experience.

The region needs to strengthen the availability of sex- and age-disaggregated data<sup>73</sup> to understand the severity of the impact of disasters on different genders.<sup>74</sup> Region-specific gender analysis on how different gender and vulnerable groups receive, interpret, and respond to alerts is also needed.

Gender-transformative EWS means addressing the root causes and structures that lead to gendered impacts. Different from a superficial headcount, this requires proactively designing and redesigning practices to reduce inequalities to meet all people's needs. Similar consideration should be given to including vulnerable groups. People with disabilities face more danger during any hazard, yet common warning alerts and response measures are not always adequate for them. An inclusive approach in EWS design and implementation would improve outcomes for vulnerable people and create accessible products that also benefit others in their communities (Stough and Kang 2015).

A transformative gender and inclusion methodology examines who is most at risk, who has access to the information required for generating early warnings, how and to which population groups early warnings are issued, whether preparedness and response measures adequately respond to alerts, and which groups should contribute to disaster preparedness, response, and recovery.<sup>75</sup> These considerations need to be an integral part of all strategic initiatives, and particularly SI9.

A core process toward impact-based MHEWS is to build more end-user knowledge to target locally tailored early action, link the actors that have this knowledge to MHEWS, and more systematically link academic knowledge and practical action.

### BOX 5.1. THE ONE-SIZE-FITS-ALL EWS: A LIFE-THREATENING ASPECT OF STRUCTURAL EXCLUSION

Data not only describes the world; it is used to shape it. For reasons once understood as logical within the historical context, the world was designed for the needs of men. Those who built it did not consider women's needs, as they were traditionally at home, not outside working and interacting in the public space. Once built, structures remain. Cars, for example, continue to be designed to the dimensions of an average man, including crash dummies used in research to improve safety. As a result of gender-biased car safety, women are 47 percent more likely to be seriously injured in a car crash than men—even though men are more likely to be involved in a crash (Criado Perez 2019). Similar examples can be found throughout society and in our daily lives.

What does this mean for impact-based MHEWS? As women and girls continue to be underrepresented or overlooked in data collection and analysis, EWS are often designed for the average man. As a result, alert communication, technology, urban planning, and medical facilities all have a gender bias. For socioeconomic reasons, women and girls continue to be more vulnerable to disasters, but the data treat men as the default and women as atypical. For example, although women and children are the main users of shelters in the Caribbean, their shelter protection needs continue to be marginalized, reflecting that an average shelter user is considered to be a man.

The good news is that what has been constructed can be reconstructed. The norms of a society can change, if we understand the bias of their construction. So, making MHEWS gender-sensitive is not enough. To address all those who are at risk, impact-based MHEWS must be gender- and inclusion-transformative, by using a methodology that understands the structural inequalities and reshapes all pillars to ensure true equal access to all warning services, equity and better fulfilment of human rights, and improved results in terms of lives saved and livelihoods and assets protected.

**73** Some countries report that they collect sex- and age-disaggregated data but do not make it available. In these cases, it does not serve its purpose for studies or designing actions based on needs.

**74** The Enhancing Knowledge and Application of CDM initiative, which supported the implementation of the CDM Framework in enhancing the mainstreaming of gender-sensitive decision-making in the public and private sectors (particularly MSMEs), found that data on directly affected populations had generally not been provided by gender.

**75** Globally, the connection between EWS and the rights of vulnerable groups stems from interaction of the Sendai Framework, Beijing Declaration and the Platform for Action and the Convention on Human Rights of People with Disabilities.

## The long-term goal: building a system-of-systems

Building an end-to-end impact-based MHEWS in the Caribbean will involve developing a Concept of Operations that links the four pillars of end-to-end EWS and encompasses the strategic initiatives outlined in this roadmap. Although developed individually, each initiative will eventually need to be interoperably linked or integrated into a system-of-systems. This will likely be a phased approach, with separate systems initially linked through a workstation server until the it is possible to integrate the systems. The timeline will likely take 10–15 years as each hazard component is implemented and included in the multisystem workstation environment where the NMHS forecaster can analyze and assimilate data to produce forecast and warning products. This is the operational underpinning for the roadmap vision that needs to be realized.

The significant overarching goal is to build and develop IBF capability (**SI1**) for each hazard, with SOPs created to assure impact forecasts reach communities (**SI8**), and to ensure people at risk can convert impact warnings into effective actions (**SI9** and **SI10**). This relies on interoperable

links or a system-of-systems that is linked to geospatial data (**SI2**) and uses rainfall data that are shared from radar, satellite, and country rainfall observations (**SI3**). Hazard models need to use high-resolution data to predict multiple sources of flooding (**SI4**) and threatening weather and climate extremes, global, regional, and local numerical weather prediction modeling systems linked into a single environment, capable of high-resolution predictions over land and ocean, and a multi-hazard Caribbean operational plan (**SI7**) developed to deliver accurate and timely warning services from highly trained forecasters.

Developing a MHEWS begins with weather, water, and climate hazards but continues evolving to progressively address emerging hazards such as ocean threats from outbreaks of sargassum and atmospheric hazards such as dust (**SI6**). Volcanic eruptions, earthquakes and tsunamis are extremely high-impact but low-frequency events that need to be assessed for inclusion in the end-to-end MHEWS, as this could provide maximum lead time, accuracy, and impact in terms of reducing the risk of catastrophic losses. The first step is to prioritize the hazards to address; the second to develop a concept of operations, and the third to develop a strategic plan that describes how the operational system will be built.

# 6

## RECOMMENDATIONS



**The region needs to further harmonize activities aimed at strengthening the regional MHEWS.** Developing a regional MHEWS strategy or roadmap was among the recommendations of a 2016 desk review of EWS in the Caribbean region. The roadmap vision statement – *“a regional model for inclusive and reliable multi-hazard, impact-based EWS that are effective in protecting lives, livelihoods and increasing resilience in the Caribbean”*— defines the focus on achieving a people-centered, sustainable regional impact-based MHEWS (evolving from MHEWS) through an approach that is inclusive of gender, community leaders, and vulnerable groups, and involves the private sector.

**Further synchronization of regional and international cooperation should be viewed as essential for societies to get timely access to high-quality, actionable information.** Although ever important, a stronger emphasis on hurricanes can mask the significance of other hazards to which the region is exposed, while donor activities do not always align with national and regional priorities, leading to further fragmentation and inefficiencies.

**It is important to focus on impact when building the regional MHEWS.** The ability to understand and respond effectively to warnings through appropriate anticipatory action is central to a resilient society. But a warning for any hazard—no matter how accurate—is not enough. To take effective early action, authorities and the general population need to understand the potential impacts of any hazard and efforts to direct people and society to take appropriate action should be systematized, and the outcome of review after events, of both hazard impacts and the effectiveness of anticipatory actions, should be incorporated for continual improvement of the MHEWS. This roadmap recognizes the fundamental distinction between a general hazard warning and an impact-based warning by including the specific vulnerability of people, their livelihoods, and the exposure of assets, property and critical infrastructure at risk. Thus, bearing in mind that vulnerabilities in different groups and sectors are compounded by recurrent disasters, the roadmap emphasizes people-centered impact-based MHEWS service delivery, by providing a framework for harmonizing complementary strategic initiatives. Focused regional, national, and local government efforts, in coordination with the private sector, through a phased approach, need to be a priority across the region to reach

achievable results in the near to medium term.

**Climate-related health impacts, including those from extreme heat, should be integrated into impact-based MHEWS.** Caribbean countries have recognized that rising climate-related health risks require public health collaboration in managing disaster risk and strengthening preparedness, surveillance, and response capacities. To succeed, decision makers at all levels need to have access to the most relevant and reliable climate and health information available. Heatwaves have only recently been recognized as a significant threat to environment and society. Caribbean countries can manage heat-related health risks by developing a Heat Health Warning System (HHWS). The impact-based MHEWS should therefore include developing a Heat Health Action Plan (HHAP) that fully integrates an HHWS, the outputs of which are used to operationalize a set of heat intervention strategies from the individual to societal level.

**The policy and regulatory environment will need to progress together with technical advances in implementing the roadmap to build a stronger impact-based MHEWS.** Underpinning the roadmap is the need for all CDEMA participating states to implement its Model National MHEWS Policy. Legislative support for a regionally harmonized approach is also essential to streamline interagency data sharing and develop crucial applications and modeling for the IBF transition. Policy and legislative support can facilitate the expansion of private sector collaboration along the entire EWS value chain.

**Data policy development is challenging yet it is crucial to impact-based MHEWS delivery and should therefore be pursued relentlessly.** The roadmap acknowledges opportunities building on the considerable capacity and existing initiatives to overcome the significant challenges facing the region. Chief among these are sharing data on weather, water, climate, and geophysical hazards, exposure, and vulnerability; mainstreaming EPS for probabilistic forecasting; and developing risk-based warnings for communities and sectors. Countries' inability or unwillingness to share data affects institutional ability to understand the environmental processes that drive disasters and to produce continually improving impact-based services for multihazard risks. Opportunities to use, coordinate, and share geospatial information and satellite

data can enhance national observation networks, and some state-of-the-art components are already in place in the region. Standardizing data for interoperability across the Caribbean is a key priority that will facilitate data sharing.

**Efforts to strengthen the regional impact-based MHEWS should take an inclusive approach for all gender and vulnerable groups**, as the impact of an EWS lies in its ability to reach the people, sectors, and businesses that are most at risk. Roadmap implementation should therefore reflect this approach in SI design, acknowledging the roles and maximizing the involvement of different groups. This will provide opportunities for them to participate, and for the process to benefit from their key knowledge and experience.

**The private sector, in its multiple forms, is a key stakeholder in the impact-based MHEWS process.**

Private sector involvement is crucial for leveraging new technologies, reaching the last mile through more effective dissemination and locally tailored communications, and enabling the application of IBF for anticipatory action and business continuity planning to make communities and businesses of all sizes more responsive to shocks.

**The academic sector is an important vehicle for growth in the hydromet domain and its contributions to the global weather enterprise should be actively pursued.**

Research and development ensure the ability to innovate and push the boundaries of the Global Weather Enterprise, which encompasses public, private, and academic sectors (Thorpe and Rogers 2018). Taking advantage of scientific advances and applying them to strengthen EWS and build new technologies to address community, national, regional, and global challenges is a critical enabler for bringing about many of the changes proposed in this roadmap.

**Building and retaining capacity should be prioritized at all levels to ensure sustainable impact-based MHEWS implementation and effective change management.**

Capacity building underpins institutional development and the human resources required to sustain it. Introducing new techniques or technologies into MHEWS implementing organizations, especially NMHS and NDMOs, builds sustainable capability to deliver needs-responsive services and effectively manage the requisite changes to enhance

capabilities over time. This requires appropriate training design and delivery, competencies needed to achieve this training, the required level of existing capacity of staff, as well as adequate resourcing to support expanding capability. This systematic approach allows countries to identify gaps between existing capacity and a future state of adequate capability and includes a tailored capacity development plan. Showing governments the socioeconomic benefits of an end-to-end system with sufficient capacity and capability in the organizations responsible for delivering impact-based MHEWS has encouraged them to resource the system.

**Providing early and actionable information through impact-based MHEWS to protect lives, assets, and livelihoods should be regarded as a critical requirement for alleviating fiscal shocks from the compound effects of multiple hazards.** The Caribbean is impacted every year by multiple shocks, caused by hydromet, seismic, environmental, or health-related events. Given the costs associated with the increasing impacts of natural disasters contributing to the deterioration of the fiscal situation in many Caribbean states, developing impact-based MHEWS should be closely aligned with national disaster risk financing strategies.

**Regional roadmap investments are economically more efficient than a patchwork of parallel national investments and should therefore take priority.** To justify the public and donor investments needed to fund the initiatives and activities presented in this roadmap, it is important to compare their socioeconomic benefits and costs. A CBA performed in preparing this roadmap shows that a regional approach would generate national cost savings and reduce overall costs across all countries and would therefore be more economically efficient than countries investing individually in an uncoordinated manner. The BCR for a regional approach would generate twice the benefits per dollar invested than a series of parallel national investments. Confidence in the economic efficiency of the proposed investments is also higher for a regional than a national approach.

**Successful implementation of the roadmap is contingent on the region taking ownership, as the strategic initiatives will require collaboration and resourcing at international, regional, and national levels.** Regional organizations and

member state agencies will need to provide direction, leadership, and commitment. The roadmap is not a project. It should serve a strategic document to guide regional actions for progressively implementing a robust, cascading, national-regional impact-based MHEWS. Implementation will therefore be largely at the national level, requiring strong national and local operational coordination and interoperability to be sustained and remain relevant. Regional expertise must be leveraged in all activities, and to ensure sustained adequate resourcing, the products delivered through the SIs must be systematically integrated into existing platforms, programs, and institutional and investment strategies.

**The roadmap offers a framework for widening medium-term actions that are achievable through a phased approach.**

It offers a common framework to optimize the benefit-cost ratio and encourage coherence in both national expenditures and donor investments. Operational impact-based MHEWS in all CARICOM member states will require major investment in institutional, legislative, infrastructural, technical, and human resources, and in regional and national coordination mechanisms. A phased approach to implementing various activities in the roadmap aims to capitalize on quick and easy short-term wins, building new and sustainable capacities in the medium term, in order to harness emerging opportunities over the longer term.



## Annex 1

**Summary of the Situation  
Analysis of the Caribbean  
Multi-Hazard End-to-End  
Early Warning System**

As part of preparation of the Roadmap, a situation analysis of the Caribbean Early Warning System was carried out by the World Bank in 2019-2020 in collaboration with key regional stakeholders—CDEMA, CMO Headquarters, CIMH, and the Caribbean Community Climate Change Centre (5Cs), in consultation with members of the REWS Consortium. The analysis and findings were organized along the four interrelated elements or “pillars” of EW systems and services: (1) disaster risk knowledge based on the systematic collection of data and disaster risk assessments; (2) detection, monitoring, analysis and forecasting of the hazards and possible consequences; (3) dissemination and communication by an official source of authoritative, timely, accurate and actionable warnings and associated information on likelihood and impact; and (4) preparedness at all levels to take timely action to respond to the warnings received. Key summary takeaways are presented further.

A foundational building block of the regional multi-hazard system is the architecture and capacities of regional organizations such as, for example, CMO HQ, CIMH, CDEMA, CCCCs. Strengthening the capacities of these organizations, including the dynamics of coordinating, cooperating and collaborating more fully will in turn help them to support countries with strengthening regional MHEWS. Consultations and analysis on MHEWS at the regional and national levels revealed common gaps that need to be addressed.

## Pillar I: Risk Knowledge and Information

This pillar of the assessment investigated the necessary components of risk knowledge, the strengthening of organizational arrangements, identification of natural hazards, analysis of community vulnerability and the storage and accessibility of risk information.

Organizational arrangements are generally very limited due to a lack of well-defined standards, roles, and responsibilities around the collection and management of risk information. SIDS-specific limitations due to small size and lack of economies of scale, also hamper the ability of Caribbean countries to adopt new technologies which can streamline the creation of risk information. Legislation and policies are required to define roles, responsibilities, and standards and various model legislations exist for CDM and data management which are in various stages of adoption by CARICOM countries. The issue of economies of scale can be addressed through regional cooperation

around the procurement of software and technologies. Cooperation arrangements with the private sector are also lacking with respect to the collection of risk information, which should be leveraged, in particular for risk information on exposure and vulnerability.

Information on certain hydro-meteorological (drought, tropical cyclones) and geological hazards is readily available at a regional level and several online platforms exist for the dissemination of information. However, information on the other hazards and the elaboration of fuller risk information related to hazards is generally lacking. The information on hazards at a national and community level are not maintained consistently across the region, which hinders the creation of risk information. Being able to regularly document and record hazard and risk information is tied to the general information management infrastructure. CDEMA and CIMH have assisted in the standardization of policies and procedures on risk information, but the national structures, laws, and capabilities of their partners vary significantly. Funding sources for the identification of natural hazards are often sporadic which has prevented the regular collection of hazard information. Assessment of community vulnerability, in particular, is reliant on funding from external agencies which is not provided regularly.

Risk assessments are more often conducted at a regional and national scale while community level analysis is rarely conducted. Risk assessment is conducted using both quantitative (numerical and statistical) and qualitative (community consultation driven) methods. These assessments are mostly focused on physical vulnerabilities, such as building construction type and materials, rather than social vulnerabilities, such as number of persons living in poverty. Societal structures that influence gendered vulnerability have been considered in risk assessments only in minor ways. There is a lack of identifying who is most at risk, and how gender-differentiated roles, vulnerabilities and social norms determine risk-related behavior and vulnerability. The participation of women and vulnerable groups in the collection of data (interviews, statistics, etc.) has not been ensured systematically and faces privacy challenges if it is to be done well, and there is often no general recognition in the studies and assessments that women, men and children interact with their world differently, which can influence their access to different types of information and knowledge.

Storage and accessibility of risk information has been

increasing over the past decade due to the proliferation of regional and national data portals. However, these portals are often created using project funding and not regularly updated. There also seems to be lack of coordination and communication across regional organizations (for example CDEMA's CRIS and CIMH's DEWETRA) resulting in the development of separate uncoordinated data bases. A lack of defined standard, including privacy protection safeguards for information relating to individuals, has made it difficult to gauge the quality of information on portals and led to the creation of systems which are difficult to maintain and integrate. Harmonizing standards and associated technologies would allow training of persons to be focused and capacity in the region built around the storage and dissemination of risk information.

## Pillar II: Monitoring, Forecasting and Warnings

Limited availability of weather, climate and especially water data in the Caribbean curbs the ability for national hydrometeorological services to provide essential forecasts and warnings for the occurrence of extreme events such as river flooding, flash flooding, coastal flooding and severe weather. All countries share an agreed set of meteorological information for use by international aviation, shipping and for the preparation of national extreme weather warnings. In addition to the meteorological data that are shared regionally, there are many more observations (especially those from automatic weather stations, that are retained nationally for specialized purposes (e.g. for climate analysis or agricultural-related decision making). All countries collect and use river and other hydrological data with varying levels of sophistication, but rarely are these data exchanged regionally. The radar network in the region has a huge potential for providing rainfall data to almost all countries, but data sharing policy restrictions and limitations such as common data formatting, protocols and complexity for calibration prevent availability of this much-needed data.

In addition, amongst the CARICOM States and Associate Member States there are ten with functioning National Meteorological and Hydrological Services (NMHSs) or NMSs and eight States that do not have NMHSs/NMSs but rather, through regionally coordinated arrangements, receive forecast and warning services from their neighbors. Supporting existing regional organizations in

identifying and operationalizing the most efficient and effective ways of providing essential forecast and warning services is recognized as key in the situation analysis.

Some state-of-the-art components are already in place in the Caribbean. The WMO Flash Flood Guidance System (FFGS) is operational in Haiti and the Dominican Republic, and Saint Lucia is currently in the process of implementing it. The WMO Severe Weather Forecasting Program for the Eastern Caribbean (SWFP-EC) is now in full implementation based on a regional operational center in Météo- France Martinique and the CMO/CIMH regional training center. All the NMSs from Trinidad to Haiti are involved and are taking advantage of the process to strengthen their own capability. The NOAA National Hurricane Center (NHC) Storm Surge Forecasting System has been successfully established in Haiti and the Dominican Republic and will be expanded throughout much of the Caribbean in the next years.

At the same time, there is a strong view in the region that the heavy emphasis on hurricane EWS needs to be balanced with improvement in overall MHEWS. A regional operations plan for severe weather an initial set of key hazards is needed to create regional CONOPS and SOPs, building on the nucleus of the region's MHEWS already in place and in doing so creating a regional MHEWS Operational Plan. This is required to strengthen the regional MHEWS framework, upon which existing and further hazard models can then progressively build and be integrated. A key hazard to be considered is tsunami and strengthening the Caribbean Tsunami Warning system should be a focus in the short- medium-term.

Although some countries are advancing IBF and tailored messaging to communicate risk clearly and provide advice on actions that can be taken to reduce risks, it is not yet well understood in the region and is interpreted quite differently between countries. Recent assessment of hurricane forecasting performance by the WMO revealed that forecasts and warnings are generally accurate. However, as highlighted in the context of pillars III and IV below, the public and private sector are not always able to translate forecasts and warnings into actions to protect their homes or businesses. CIMH has begun supporting an IBF initiative together with the Barbados Meteorological Service (BMS), the Barbados Department of Emergency Management (DEM) among others to pilot the Weather and Climate Ready Nations approach in the region. Advancing and strengthening IBF in the Caribbean is clearly a key strategic initiative to pursue.

Current radar coverage is fairly comprehensive, yet gaps exist as it is largely ad hoc, lacking the consistency and interoperability which would be required to deliver rainfall data with accuracy across the region. Improving the regional radar network, combined with regional data-sharing arrangements, is a key to unlocking the power of rainfall data to inform rapidly developing water, weather and climate modelling and forecasting capability for the entire region.

### Pillar III: Warnings Dissemination and Communication

According to stakeholder consultations, although all countries have mechanisms in place for alert and warning dissemination, with strategies for that purpose facilitated by CDEMA and CIMH, in general, these are far from being optimal and barely take advantage of all the technological possibilities that exist today. In fact, the use of newer technologies - such as the Common Alerting Protocol (CAP), Cell Broadcast, social media, etc. is quite limited. Additionally, communication disruptions, during and in the aftermath of extreme events, have been a common experience in recent years.

With respect to responsibilities for warning dissemination, roles are not always formalized nor backed by legislation, policies or budgets, while uncontrolled warning dissemination on social media from non-authorized sources are a growing concern. There is a lack of harmonized communications SOPs for early-warning services, a scarcity of gender-transformative messaging and means of communication which recognizes that men and women access, process, interpret and respond to information in different ways. For delivery to be effective, the means of transmission as well as the messaging require tailoring, so they are readily understood and acted upon, and are specifically tailored to women, youth and vulnerable groups. On the other hand, insufficient communications skills as part of public weather services have been identified, especially for probabilistic forecasts, preventing available information from fully informing the decision-making process. In addition, public sector involvement in this area is largely ad hoc. Currently, the messaging is designed for an estimated average user, which tends to favor only a certain strata of society.

For the delivery of public warnings, while the CAP offers a consistent notification standard for warning messages, no single solution has been implemented in the region

that fits all the requirements for the timely notification of an emergency incident or situation that is resilient to all contingencies. Thus, an Emergency Alert System (EAS) ought to be a blend combining sufficient redundancy with the best attributes of the existing technologies and adapted to the particular demands of the countries or territories served. However, EAS solutions also involve the acquisition, installation and configuration of hardware/software platforms, which can be costly and may be beyond the means of many Caribbean states.

A regional EAS platform is much more cost effective with a sole (redundant) regional platform for the use of every Caribbean country instead of each country deploying their own platforms. Some of the counterparts already operate at a regional level. Such a platform needs to be connected to Mobile Network Operators (MNO). Since two major MNOs are operating in most Caribbean countries, this connection (or interface) with them could offer a means to begin with. For these reasons a regional approach, that takes advantage of economies of scale, is proposed for implementing EAS to strengthen and streamline MHEWS in the Caribbean.

### Pillar IV: Planning and Preparedness at all levels to respond to early warning

According to the consultations and analysis of the current MHEWS situation at a regional level, there is a very significant body of institutionalization, knowledge and experience in terms of disaster preparedness and response, at the regional, national and local levels. These include many robust elements such as CDEMA's Regional Response Mechanism (RRM), existing standards and materials for preparedness and response, community resilience frameworks, regional drill and simulation exercises, just to mention some.

However, the region is not exempt from weaknesses in this area, such as out of date legislation and plans, a focus on hurricanes with insufficient attention to other hazards, low community engagement and ownership, with risk assessments lacking community involvement and sufficient sex- and age-disaggregated data collected in cooperation with women and men. Moreover, response plans (where they exist) are rarely drilled with communities and no assessments to determine community capacity for forecast-based action are undertaken. Finally, there is an overall lack of reliable and adequate financing for early action, with little systematic engagement of the private

sector, among others.

Based on this analysis of the situation, the region is presented with a great deal of opportunity to improve planning and preparedness, as well as some opportunities that could easily turn into threats if not diligently addressed. For example, building on the development of risk forecasting capability, disaster management stakeholders emphasize the need for people-centered early warning services that effectively reach the last mile. To achieve this, a regional architecture for emergency alert systems needs to be established to ensure that resilient delivery capacity for reaching all people is mandated and maintained.

Investment in EWS has historically – and necessarily – been heavily weighted on hard infrastructure and related data management and modelling systems for monitoring and detection, and to ensure robust “push” capacity to disseminate warnings produced. Investment in the requisite soft infrastructure required to fully exploit warnings, investments in strengthening relationships as infrastructure, and in building the uptake capacity of people at the community level can be characterized as a missing link. To meet this need, support is required to enable community action planning processes to involve people in forecast-based action planning.

To ensure sustainability, stakeholders underlined the need to normalize regular drills and simulation exercises, and to address the necessity for reliable, adequate and timely financing (e.g. “forecast-based financing”). After-action assessment is also essential to enable continual improvement in the effectiveness of forecast-based action planning and implementation at the community level. Therefore, developing and piloting a comprehensive community-based early warning early action approach should aim not to develop “a plan,” but rather to engender the transformation required “to make the last mile the first mile.”

## Gender and Vulnerable Groups integration – reaching the people at risk

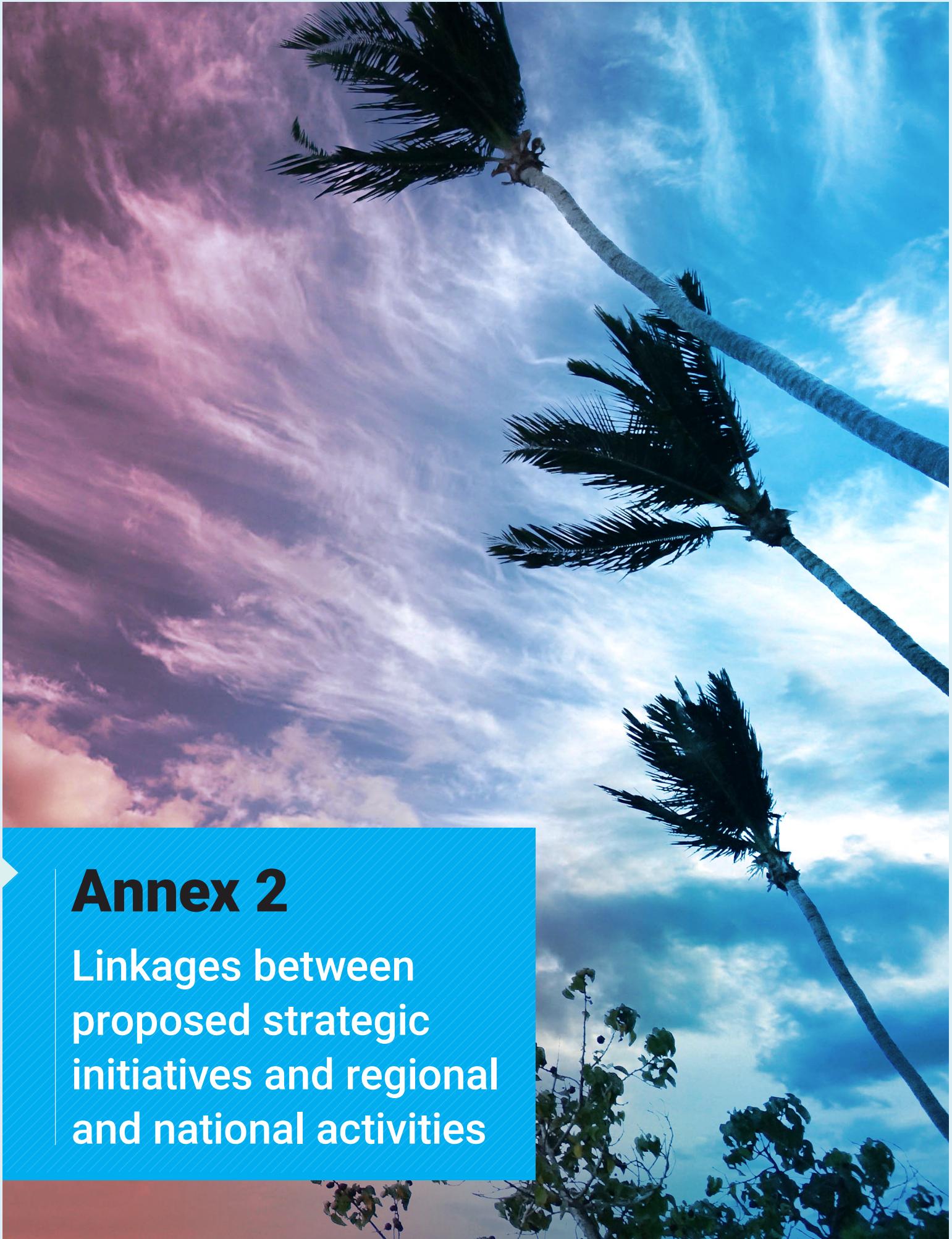
Caribbean governments and regional organizations have taken significant steps in order to guarantee that legislative frameworks affirm the equality of men and women. While this is much needed and a significant strength, it is also evident that in practice structural gender inequalities exist in the society at large. Based on the results of the literature review and workshops, the Caribbean is currently in a gender aware phase, which is the 2nd phase of a 4-step scale in progressing towards gender transformative EWS (Brown et al. 2019; details in Annex 1). In this phase, the region recognizes the importance of gender and vulnerable groups in EWS but makes only minor adjustments to address it. When starting to evaluate the situation on gender and vulnerable groups in EWS through a literature and data review, the first observation was that the region has only some previous materials on the theme and does not have sufficient availability of sex- and age-disaggregated data in regard to disaster effects, which is needed to understand the severity of the gendered effects of disasters.

The existence of National Gender Bureaus and the regional Gender Working Group under the CDM Strategy opens an opportunity for the region, as these existing structures can work to ensure regional and national ownership of inclusive EWS. Most of the Gender Bureaus, however, have neither engaged with EWS prior to the workshops conducted as part of this analysis, nor have gender matters been considered in relation to hydromet services. It follows from this that the knowledge base on the importance of gender and vulnerable groups in EWS rests largely within these few bureaus.

Inclusiveness has been defined to target gendered structures, pregnant women, the elderly, children, youth, vulnerable rural populations and persons that are differently abled. In order to strengthen people-centered, end-to-end MHEWS from a gender and vulnerable groups perspective, strengthened political commitment is needed, including to ensure cooperation for capacity strengthening.

## Annex 2

**Linkages between  
proposed strategic  
initiatives and regional  
and national activities**



## SI1

### Supporting the transition to IBF and warning services

The **Caribbean CREWS project** further supports the first effort to bring together NDMOs, NMHS, and national gender bureau experts and practitioners to explore constraints and opportunities together, launched with the virtual IBF and Scenario Planning Workshop organized by Caribbean CREWS institutional and regional partners in 2020.

<https://public.wmo.int/en/media/news/caribbean-workshop-impact-based-forecasting-and-risk-scenario-planning>.

The **Caribbean Weather & Climate Ready Nations program**, which is integral to and fully aligned with the roadmap, continues to support the transition to IBF. <https://www.preventionweb.net/news/new-climate-programme-launched-barbados-and-eastern-caribbean>. It will also need WMO commitment to NMHS operations.

The OECS **Scoping Study on Forecast-based Action** developed initial recommendations for strengthening forecast-based early action with support from the French development agency (AfD) and participation from CDEMA, CIMH, CCCCCs, and others. [https://www.climatecentre.org/downloads/files/Forecast%20based%20early%20action\\_Final\\_11%20June.pdf](https://www.climatecentre.org/downloads/files/Forecast%20based%20early%20action_Final_11%20June.pdf).

The USAID-funded **Strengthening Disaster and Climate Resilience Project**, executed by the CIMH, seeks to strengthen IBF capabilities by expanding IBF tools within the Caribbean DEWETRA Platform, delivering capacity-building workshops and providing low-cost, near real-time hydromet stations. These activities are aligned with the Caribbean Weather & Climate-Ready Nations program. In addition, risk-based forecasting for flooding was piloted to demonstrate the added value of forecasting risk. <https://bb.usembassy.gov/usaid-announces-extension-of-strengthening-disaster-climate-resilience-project-at-the-caribbean-institute-of-meteorology-hydrology/>

The **Expanded Weather and Climate Forecasting and Innovative Product and Service Development and Delivery in the Caribbean** (GA179) project <https://www.caribank.org/publications-and-resources/resource-library/board-papers/grants-capital-and-technical-assistance-contributions-and-use-funds/expanded-weather-and-climate-forecasting-and-innovation-product-and-service-development-and-delivery>

The **Enhancing Weather and Climate Early Warning Systems and Impacts-based Forecasting Platforms in the Caribbean** project (GA176), executed by the CIMH under the ACP-EU-CDB-NDRM<sup>76</sup> facilitated the expansion of the Caribbean DEWETRA Platform and brought together mainly meteorological forecasters and disaster management personnel for training on the Caribbean DEWETRA Platform. [https://www.researchgate.net/profile/Shawn-Boyce-2/publication/318361452\\_Impacts-based\\_Forecasting\\_and\\_Multi-hazard\\_Early\\_Warning\\_Systems\\_in\\_the\\_Caribbean/links/5965e6ca0f7e9b2a36816336/Impacts-based-Forecasting-and-Multi-hazard-Early-Warning-Systems-in-the-Caribbean.pdf](https://www.researchgate.net/profile/Shawn-Boyce-2/publication/318361452_Impacts-based_Forecasting_and_Multi-hazard_Early_Warning_Systems_in_the_Caribbean/links/5965e6ca0f7e9b2a36816336/Impacts-based-Forecasting-and-Multi-hazard-Early-Warning-Systems-in-the-Caribbean.pdf)

NMHS have started implementing different aspects of IBF through various arrangements as they seek to improve service delivery to the general public; e.g. <https://www.barbadosweather.org>

## SI2

### Toward a Caribbean geospatial platform

The **Caribbean Geospatial Development Initiative** seeks to empower Caribbean countries and territories to advance the greater use and sharing of geospatial and statistical information to support improved decision making for sustainable national and regional development. <https://www.cepal.org/en/events/caribbean-geospatial-development-initiative-carigeo>.

CCCCCs has been supporting regional forecasting tools, networks and data—such as **FEWER Fisheries' Early Warning and Emergency Response** app, the **CREWS** network, and the **Caribbean**

<sup>76</sup> <https://europa.eu/capacity4dev/drr-acp/wiki/acp-eu-natural-disaster-risk-management-cariforum>

**Weather Impacts Group** portal (<http://cariwig.caribbeanclimate.bz/#info>)—as well as providing a Lidar system, which is vital for developing bathymetric data to support the development of EWS. <https://www.caribbeanclimate.bz/blog/2018/11/30/cccc-adds-lidar-to-boost-caribbeans-climate-change-fight/>

The **Regional Geospatial Service Development SERVIR** is a joint development initiative between the North American Space Agency and USAID. **SERVIR-Amazonas** will provide training for and facilitate technical engagement with governments, universities, research institutions, and NGOs in the Caribbean aimed at developing sustainable geospatial applications and services related to SI2 and forecast and monitoring hydromet events. <https://servir.ciat.cgiar.org/servir-amazonia-to-engage-with-caribbean-stakeholders-to-foster-geospatial-service-development/>.

The URISA Caribbean Chapter is the Caribbean geospatial organization, which aims to: be a network of GIS knowledge across the Caribbean; provide a wealth of professional services for its members; assist in the development of innovative professionals prepared for the future of GIS; promote and cultivate the use of GIS to enhance the research, development and expansion of GIS use within the region; promote the development and publication of standards and methodologies; and influence government policy and governance on the effective and efficient use of GIS in the Caribbean region. <https://www.urisa.org/caribbeanchapter>

The **Caribbean DEWETRA Platform** is an online tool that manages geospatial data from near real-time networks, satellite observations, and forecast models to assess hydromet impacts. It was designed to aid decision making by seamlessly fusing data from different sources, including socioeconomic and vulnerability information. It presents ground- and space-based near real-time hydromet observations and numerical weather prediction model outputs alongside flood and landslide hazard maps, population demographics, and geolocated critical infrastructure. The application is maintained by CIMH staff and used to support IBF and early warning. CMO member states and other stakeholders have access. <https://www.coopi.org/en/dewetra-a-real-time-platform-to-predict-weather-related-risks.html>

The **Caribbean Risk Information System (CRIS)** is supported by CDEMA and provides an integrated regional platform for geospatial data, disaster risk management and climate change adaptation information. <https://www.cdema.org/cris/>.

The WMO **Severe weather forecasting Initiative (SWFP)** in the Eastern Caribbean aims to provide reliable forecasts of hazardous weather in support of disaster risk reduction and climate change adaptation. <https://public.wmo.int/en/resources/meteoworld/strengthening-of-severe-weather-forecasting-capabilities-eastern-caribbean>

The **University of the West Indies Seismic Research Centre (UWI-SRC)** is the official source of information on earthquakes and volcanoes in the English-speaking Eastern Caribbean. <https://uwiseismic.com>

The **UWI Mona Climate Studies Group** Mona develops computer-based models to project climate variability and change. *Inter alia*, the **Simple Model for the Advection of Storms and Hurricanes (SMASH)**, the development of which was led largely by Dr Tannecia Stephenson, lecturer in the Department of Physics, allows the user to examine different scenarios of hurricane tracks and intensity and determine the associated rain rates and wind speeds for a given location, allowing users to answer the ‘what if’ questions and investigate multiple scenarios. For example, what a category 5 would have done for an area in terms of rainfall amounts and wind speeds. [https://uwimonanow.com/index\\_view\\_more.php?id=415](https://uwimonanow.com/index_view_more.php?id=415)

## SI3

### Toward a regional multisensory rainfall grid

Since 2004, **CCCCCs** has been seeking financial support, researching, and pooling regional resources to help countries cope with the expected impacts of a changing climate. There is scope to align CCCCCs' recent work introducing regional planners to and training them in applying and using forecasting tools to make countries weather and climate-ready with the development of a regional precipitation grid. <https://reliefweb.int/report/cuba/climate-scientists-use-forecasting-tools-protect-caribbean-ways-life>.

**SERVIR** provides local decision makers with the tools, training, and services they need to act on climate-sensitive issues such as disasters, agricultural security, water management, and land use, which could include building understanding of the benefits of a regional rainfall grid. <https://servir.ciat.cgiar.org/servir-amazonia-to-engage-with-caribbean-stakeholders-to-foster-geospatial-service-development/>.

**CCRIF SPC Excess Rainfall (XSR) Model** and its XSR product models rainfall losses to the built environment in close to real time, enabling swift insurance payouts after a triggering event. CCRIF is continually improving and developing parametric insurance products based on modeled losses, which is faster and can be more objective and accurate than ex-post ground-based verification of actual losses. This approach also builds the foundations for possible future ex-ante payouts triggered by a defined threshold of risk. [https://www.ccrif.org/en/publications/technical-paper/CCRIF-Excess-Rainfall-XSR-Model?language\\_content\\_entity=en](https://www.ccrif.org/en/publications/technical-paper/CCRIF-Excess-Rainfall-XSR-Model?language_content_entity=en).

## SI4

### An integrated approach to flooding

**WMO** is developing an **approach for integrated riverine flood forecasting** (SWFP, FFGS, CIF) and IBF for the Dominican Republic. <https://public.wmo.int/en/events/meetings/approach-integrated-riverine-flood-forecasting-swfp-ffgs-cifi-and-impact-based>.

**OECS countries** have introduced a **methodology based on assessing operational disruptions due to changing climatic factors**, producing marine flood maps for ports and airports for different future scenarios. This applied decision support for critical infrastructure can provide a practical contribution to build on in the OECS countries and include in scaling up an integrated approach to flooding in the wider Caribbean region. <https://unctad.org/es/node/1766>.

**Flood-PROOFS**, (<https://www.cimafoundation.org/foundations/research-development/flood-proofs.html>) the hydromet forecasting chain integrated into the Caribbean DEWETRA Platform, provides a workflow that uses numerical weather prediction outputs and observed data to generate forecasts and nowcasts of discharge and peak flows, respectively, using the Continuum open source hydrological model. The Flood-PROOFS forecasting chain has been piloted in Barbados and Guyana, and discussions are ongoing regarding expansion to other CMO member states. **Continuum** is a continuously distributed, physically-based hydrological model capable of reproducing the spatial-temporal evolution of soil moisture, energy fluxes, surface soil temperature, evapotranspiration, and discharge. (Silvestro et al. 2015, 2019)

**WRF-Hydro®** is an open source community hydrological model that supports flash flood predictions, impact assessments, and seasonal forecasting. The CIMH runs and maintains operational 4-kilometer WRF numerical prediction models over the Caribbean. Model outputs are publicly available and used by NMHS to support forecast operations. WRF-Hydro® may be forced by WRF outputs for the purposes of forecasting peak flows, discharges, and the propagation of flows through hydrological systems. Under the CIMH research and development program, instances of WRF-Hydro® will be developed and implemented across the Caribbean to provide additional guidance to NMHS and further support IBF. This effort is resourced internally. It is expected that this effort will complement any existing forecast products. [https://ral.ucar.edu/projects/wrf\\_hydro](https://ral.ucar.edu/projects/wrf_hydro)

**SI5****Integrating health impacts into the impact-based MHEWS**

The **EWISACTs consortium** has been laying the groundwork to strengthen climate services for inter alia the public health sector. <https://public.wmo.int/en/resources/bulletin/strengthening-climate-services-health-sector-caribbean>.

The **Caribbean Health-Climatic Bulletin** is a climate-smart tool developed and disseminated by CARPHA, PAHO, and CIMH to help the health sector manage climate risk. <https://rcc.cimh.edu.bb/caribbean-health-climatic-bulletin/>.

CIMH has been researching **heat-health forecasting**, promoting understanding, and developing outlooks and products for heat early warning in the region. [https://ghhin.org/wp-content/uploads/VanMeerbeeck\\_Herrera.pdf](https://ghhin.org/wp-content/uploads/VanMeerbeeck_Herrera.pdf).

The Barbados Meteorological Service and Ministry of Health and Wellness have developed a modeling approach that combines the dengue prediction model with climate indicators. Routinely monitored and forecast by the CIMH Regional Climate Centre, probabilistic dengue outlooks could be included in the quarterly Caribbean Health-Climatic Bulletin to provide climate-smart decision-making guidance for Caribbean health practitioners. This flexible modeling approach could be extended to model the risk of dengue and other arboviruses in the Caribbean region. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6049902/>.

**SI6****Air quality**

**WMO Pan American Node Sand and Dust Storm Initiative** and its **Sand and Dust Storm Warning Advisory and Assessment System** enhance countries' ability to deliver timely, quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities. The Pan American Node established its Regional Steering Group at the CIMH in 2017. <http://sds-was.cimh.edu.bb>.

**CAHN** is primarily a network of health and environmental agencies whose mission is to improve the understanding of the impacts (on air quality, health, climate, weather, ecosystems, and so on) of atmospheric particles. Although regional in focus, extra-regional participation is encouraged. One output of this collaboration is the NASA ROSES-funded **Caribbean Air-quality aLert and Management Assistance System – Public Health (CALIMA-PH)**, which integrates ground-based observations (in situ and remotely sensed), satellite remote sensing, and dust forecast models to better understand the impacts that African dust incursions—such as the historic “Godzilla” mega dust event in June 2020—have on the air quality of the Greater Caribbean Basin (and southern United States). <https://www.nccs.nasa.gov/news-events/nccs-highlights/field-campaigns>

**SI7****Toward a Caribbean multi-hazard operational plan**

WMO has developed a **concept for an efficient, adaptable MHEWS** that integrates FFGS, CIFI, and SWFP. <https://community.wmo.int/mhews-concept-reference-material-et-mie>

**WMO Region IV (North America, Central America, and the Caribbean) Hurricane Committee** was established to improve the region's hurricane warning systems and its hurricane operational plan is available to all. [https://library.wmo.int/?lvi=notice\\_display&id=13696#.YX9TzdbML9E](https://library.wmo.int/?lvi=notice_display&id=13696#.YX9TzdbML9E).

**SI8****Regional emergency system**

CIMH has provided **training on the benefits of integrating the CAP into IBF**. <https://preparecenter.org/wp-content/uploads/2020/04/cap-workshop-2019-weather-and-climate-ready-nations.pdf>.

**WebAlert** is a web-based application within the Caribbean DEWETRA Platform that supports alert generation and dissemination. The CIMH is leveraging platform functionality to develop an application that generates and publishes CAP alerts that consider IBF concepts and collates and

publishes available CAP feeds for Caribbean countries.

WMO offers an **online CAP basics course**. <https://etrp.wmo.int/course/view.php?id=163>.

**CAP offers an annual workshop**, attended in 2021 by delegations from Grenada, Barbados, Jamaica, and Trinidad and Tobago, and participants from Belize, British Virgin Islands, Curaçao, Dominica, France, Guyana, St. Kitts and Nevis, St. Vincent and the Grenadines, Saint Lucia, Turks and Caicos, Sint Maarten, and the UWI. <https://cap-workshop.alert-hub.org/2021/training.pdf>.

A linked **2021 CAP workshop for the Red Cross** offered follow-up support to national Red Cross Societies on the CAP, public awareness and engagement, and early warning early action, regionally coordinated by IFRC/Red Cross Caribbean Disaster Risk Management. <https://preparecenter.org/site/ifrcalerthubinitiative/rcrc-cap-workshop-2021/>.

## SI9

### Community-based action planning

The **French Red Cross READY Together project** has been supporting MHEWS awareness and promoting early warning early action since 2020. <https://www.interreg-caraibes.com/news/ready-together-launches-its-awareness-campaign>.

The **OECS Commission** has engaged with regional experts and researchers to develop an initial forecast-based action and financing plan. [https://cdn.odi.org/media/documents/odi\\_oecs\\_rfba\\_action\\_plan\\_final1603.pdf](https://cdn.odi.org/media/documents/odi_oecs_rfba_action_plan_final1603.pdf).

## SI10

### Sectoral impact-based MHEWS, the private sector and BCP

The **Caribbean Society for Agricultural Meteorology agroclimatic bulletin** prepared by CIMH highlights agricultural impacts from the previous month's climate as well as provides climate smart information to the stakeholders. Climate products from the Caribbean Regional Climate Centre drought monitoring products; rainfall, temperature, and drought forecasts) are embedded within the bulletin. <http://carisam.cimh.edu.bb/>.

CARICHAM, the Caribbean Chambers of Commerce network, offers a BCP toolkit. Across the region, universities, chambers of commerce, and organizations such as the UNDRR ARISE network, help entrepreneurs put **BCPs** in place. UNDRR has run workshops with CARICHAM to help small business owners use its tools to better prepare for disasters. <https://www.caribbeanchambers.net/caricham-bcp>

**UNDRR's COVID-19 Small Business Continuity and Recovery Planning Toolkit** is designed to help firms protect their employees, customers, and operations; its online Quick Risk Estimation tool helps entrepreneurs gauge their risk exposure. <https://www.undrr.org/news/battered-caribbean-businesses-set-hopes-resilient-recovery>.

In the framework of the READY Together project's Business Disaster Preparedness initiative, the **French Red Cross Regional Intervention Platform for the Americas and the Caribbean**, supports workshops and coaching for small businesses in Guadeloupe, Martinique, and St. Lucia to help them assess the impact of natural hazards on their activity and develop BCPs. <https://pirac.croix-rouge.fr/en/our-missions/disaster-preparedness/>

**The IFRC'S Global Disaster Preparedness Center** features a BCP helpdesk. <https://preparecenter.org/toolkit/business-continuity-planning-help-desk/>.

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