Technology Executive Committee

02 April 2024

Twenty-eighth meeting

16–19 April 2024 (19 April TEC-CTCN Advisory Board Joint session)

Draft joint knowledge product on innovation for risk knowledge in the context of the TEC and GEO engagement with the Early Warnings for All initiative

I. Background

1. As per activity A.3.1 of the rolling workplan, the TEC is to publish a knowledge product in 2024, informed by its engagements with relevant partners in 2023 on identifying and analysing emerging and transformational adaptation technologies (e.g., early warning systems and disaster risk management), including the role of finance and the private sector in supporting their deployment.

2. At TEC 26,[1] the TEC agreed to focus the work under this activity on early warning systems and requested the activity group to continue engaging with relevant partners and produce a scoping note for consideration at TEC 27, containing appropriate next steps towards producing a knowledge product in 2024.

3. At TEC 27,[2] the TEC decided to embark on a collaborative partnership with the Group on Earth Observation (GEO) and produce a knowledge product focused on 'innovation for risk knowledge' in the context of engagement with the Early Warnings for All initiative.[3] At the same session, the TEC agreed on the key elements of the knowledge product and appropriate steps for its development, and requested the activity group to prepare a first draft of the knowledge product for consideration at TEC 28.

4. Pursuant to the guidance provided at the TEC 27, the activity group with support from the secretariat and in collaboration with the GEO successfully implemented the envisaged next steps in accordance with the agreed timeline,[4] i.e.:

(a) Launched the work shortly after the conclusion of the TEC meeting in September 2023, and finetuned the scope of the knowledge product in consultation with the Early Warnings for All partners, in particular those supporting the Pillar 1 of the initiative on risk knowledge and management;

(b) Engaged in bilateral engagements with relevant bodies and entities, including the UNFCCC constituted bodies and Early Warnings for All partners, to gather relevant information and insights on technology-related needs and priorities of countries for improving risk knowledge;

(c) Participated at the GEO Week 2023, held in Cape Town November 2023, and highlighted the collaboration of the TEC and GEO, as well as the key elements of the joint knowledge product in various settings at the session (i.e. the plenary, a flash-talk, a workshop and bilateral engagements), as appropriate;

(d) Presented the joint work of the TEC and GEO on the knowledge product at COP 28, including at events and meetings convened by the Adaptation Fund and the UNFCCC's Research and Independent NGOs constituency (RINGO) in December 2023;

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[1] See TEC/2023/26/08 and TEC/2023/26/20.

[2] See TEC/2023/27/06 and TEC/2023/27/21.

[3] More information available at: https://www.un.org/en/climatechange/early-warnings-for-all.

[4] More information on TEC engagements and participation in invited events and meetinsg is available on TT:CLEAR, at: https://unfccc.int/ttclear/events/participation.

(e) Engaged in bilateral engagements with relevant partners including the CTCN and members of the GEO community to identify country examples and good practices, taking into account a set of criteria and considerations agreed by the activity group;[5]

(f) Agreed on the annotated outline of the knowledge product in February 2024;

(g) Solicited written feedback from representatives of the Adaptation Fund, the Global Environment Facility (GEF) and the Green Climate Fund (GCF) on the outline of the draft knowledge product, and exchanged views on its content at a meeting of the activity group, convened in March 2024;

(h) Prepared the draft knowledge product for consideration at TEC 28 (see Annex).

II. Scope of the note

5. The annex to this note contains the first draft of a joint policy brief on innovation and technology in support of risk-informed climate resilience policy and action, developed in the context of the TEC and GEO collaboration under Pillar 1 of the Early Warnings for All initiative.

6. The current draft does not contain a section on ‘conclusions’. To initiate and inform the development of ‘conclusions’ from this work, which may contain key messages and policy recommendations, a presentation of ‘preliminary findings’ is expected at TEC 28.

III. Expected action by the Technology Executive Committee

7. The TEC will be invited to consider the draft knowledge product (contained in the annex) and provide guidance to the activity group for further work on this matter, with a view to finalizing the knowledge product by TEC 29, in particular:

(a) Discuss potential amendments for the finalization of the content of the draft contained in the annex of this note;

(b) Consider preliminary findings from the work, presented at the meeting, and discuss appropriate next steps for the development of ‘conclusions’ from this work, including potential key messages and policy recommendations;

(c) Discuss potential avenues to promote the ongoing work on this topic (e.g. during the 60th Sessions of the UNFCCC Subsidiary Bodies in June 2024) and exchange views on potential entry-points and areas for cross-fertilization between the work on EWS and relevant activities of the TEC that may be utilized.

[5] The criteria and considerations for the selection and development of country examples are: 1) ensuring regional balance, with a focus on the experience of SIDs and LDCs; 2) showcasing the application of a combination of hardware-software-orgware technology measures; 3) integrating cross-cutting issues such as gender considerations and indigenous and local knowledge; 4)tapping into the expertise and good practices in the GEO community and EW4All partners; 5) including relevant insights from the support of climate funds and providers of technical assistance; 6) identifying good practices from the inclusion of climate information and EWS in national climate policies and plans, and the role of non-state actors; 7) benefitting from findings of country roll-out efforts under EW4All, and insights of the TEC members from the national/regional context; 8) taking into account potential synergies and complementarity with other activities of the TEC/Technology Mechanism (e.g. the work on AI, digital technologies and oceans) and relevant efforts under the UNFCCC.

Annex

Realizing Early Warnings for All: Innovation and technology in support of risk-informed climate resilience policy and action

Draft joint policy brief

Realizing Early Warnings for All:
Innovation and Technology in support of Risk-Informed Climate Resilience Policy and Action

A joint policy Brief by the UNFCCC Technology Executive Committee and the Group on Earth Observations

Credit: Faith Kathambi Mutegi (2023). Available at: Loss and Damage in Focus: 10 Years of the Warsaw International Mechanism.

Contents

Abbreviations and acronyms

AF	Adaptation Fund
AI	Artificial Intelligence
ARD	Analysis Ready Data
CREWS	Climate Risk and Early Warning Systems
CZMAI	Coastal Zone Management Authority & Institute
DE	Digital Earth
EO	Earth Observations
EW4ALL	Early Warning for All
EWS	Early Warning Systems
GCF	Green Climate Fund
GDP	Gross Domestic Product
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IoT	Internet of Things
IRNSS	Indian Regional Navigation Satellite System
ITU	International Telecommunication Union
LDC	Least Developed Country
LDCF	Least Developed Countries Fund
LLDC	Landlocked Developing Country
LTIK	Local, Traditional, and Indigenous Knowledge
MHEWS	Multi-Hazard Early Warning System
ML	Machine Learning
MMS	Maldives Meteorological Services
NAP	National Adaptation Plan
NavIC	Navigation Indian Constellation
NDC	Nationally Determined Contribution
PNT	Positioning Navigation and Timing
SCCF	Special Climate Change Fund
SFDRR	Sendai Framework for Disaster Risk Reduction
SIDS	Small Island Developing States
SMS	Short Message Service
SOFF	Systematic Observations Financing Facility
SOP	Standard Operating Procedure
TNA	Technology Needs Assessment
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
UNOSAT	United Nations Satellite Centre

[placeholder for further additions]

[Placeholder for foreword(s) and acknowledgements to be added upon the completion of the policy brief]

Why this brief?

Climate and disaster risk knowledge and information is a foundational element of multi-hazard early warning systems (MHEWS) and key for realizing the Early Warnings for All (EW4All) initiative[1] by 2027, meeting the targets of the Sendai Framework for Disaster Risk Reduction (SFDRR), and achieving goals of the Paris Agreement by 2030 and beyond.

Leveraging technology and innovation for improving climate information[2] and disaster risk knowledge is widely recognized as both an enabling and catalyzing condition for supporting risk-informed decision-making and policy uptake for climate adaptation and climate-resilient development. Yet globally, the access to and application of innovation and technology for climate and disaster risk information and assessment suffers from significant shortcomings, particularly in the least developing countries (LDCs) and small island developing States (SIDS). These countries face a paucity in accessible and relevant disaster risk information, with only 17% of LDCs and 24% of SIDS reporting the existence of disaster risk knowledge for MHEWS[3].

Part of a long-running series produced by the Technology Executive Committee (TEC) to foster policy discussions on climate technology and innovation, and building on the expertise of the Group on Earth Observations (GEO) and EW4All partners[4], this joint policy brief will provide useful policy insights and options for advancing climate information and disaster risk knowledge to support the implementation and scale up of MHEWS in response to context-specific needs and priorities of most vulnerable communities, and bolstering risk-informed adaptation and mitigation outcomes. The brief provides:

- An overview of technology policy and implementation needs/priorities of countries for advancing climate information and EWS, as reflected in multilateral processes;
- A number of proven technology solutions with transformational impacts for improving risk knowledge and information and examples of their application in different contexts;
- Key findings and recommendations for various actors across the early warning value chain.

Drawing from the latest available information and insights from multilateral processes on climate change and disaster risk reduction and featuring proven solutions applied in the Earth observations community, this brief aims to inform a range of stakeholders in the early warnings value chain in their actions, particularly policy-makers at the national levels who are involved in the formulation and implementation of DRR, climate adaptation, and climate technology plans, policies and actions.

[1] Read more about the Early Warnings for All initiative (>Link).

[2] Climate information refers to observed, historical data on past climate-related disasters and future changes in climate derived from climate models.

[3] See thevSendai Framework online Monitoring tool (>Link).

[4] The initiative is co-led by the World Meteorological Organization (WMO) and, United Nations Office for Disaster Risk Reduction (UNDRR), with support from the International Telecommunication Union (ITU), International Federation of Red Cross and Red Crescent Societies (IFRC), and other partners.

Introduction

With the increasing frequency and intensity of disasters, further fueled by the climate crisis, MHEWS have emerged as a potentially transformational adaptation technology and a proven and effective climate adaption measure to protect lives and livelihoods, and reduce the economic impact of natural hazards (UNDRR and WMO, 2023).

Between 2015-2021, global average economic losses corresponded to 1 percent of reporting countries GDP (WMO, 2022). Yet, LDCs, SIDS and LLDCs that form only 2.2 percent of reporting countries' GDP, accounted for 11.3 percent of reported economic losses (WMO, 2022). These losses highlight the significant impact that disasters can have on societies and economies and the importance of EWS in mitigating climate and disaster risks. With only 24 hours' notice, damages from hazardous events can be reduced by 30%, and an investment of $800 million in developing countries' EWS could prevent annual losses of $3-16 billion (Global Commission on Adaptation, 2019).

Evidence suggests that a high-functioning early warning value chain facilitates timely action by individuals, communities, and organizations to respond to- and reduce the risk and impact of disasters. Climate information and disaster risk knowledge play a crucial role in advancing all elements of people-centered, end-to-end, and impact-based MHEWS, by providing essential data and critical insights useful for anticipating, preparing for, and responding to natural, weather and climate-related hazards. Moreover, such insights are key for enabling impact-based decision-making and risk-informed adaptation planning and action.

Multi Hazard Early Warning Systems

MHEWS are integrated systems of disaster risk assessment, hazard monitoring, forecasting and prediction, communication and preparedness activities systems and processes that enable individuals, communities, governments, businesses, and others to take timely action to reduce disaster risks in advance of hazardous events. The MHEWS framework is structured along four key components (see Figure 1):

- Pillar 1: Disaster risk knowledge
- Pillar 2: Detection, observations, monitoring, analysis, and forecasting of hazards
- Pillar 3: Warning dissemination and communication
- Pillar 4: Preparedness to respond to warnings

Figure 1 - Four pillars of MHEWS (Source: EW4All Executive Action Plan)

All four pillars are closely interconnected, and climate information and risk knowledge (Pillar 1) is the foundational basis for creating actionable information for the entire MHEWS framework. For example, understanding hazards, exposed populations and assets, and impact sectors is necessary for: determining which parameters to monitor (Pillar 2), ensuring that warnings reach at-risk communities and are understood by them (Pillar 3), and that response plans at the national, local and community levels -including related capacities, systems and procedures - are risk-informed and up-to-date (Pillar 4). This cross-cutting and interactive nature of MHEWS activities have the potential to increase co-benefits of adaptation actions when combined (UNDRR and WMO, 2023). That said, failure in one pillar can have cascading effects in other interlinked areas, rendering MHEWS ineffective.

The Early Warnings for All Initiative

Launched by the United Nations Secretary-General in 2022, the Early Warnings for All (EW4All) initiative aims to ensure that everyone on Earth is covered by an EWS by the end of 2027, adopting the MHEWS framework.

The initiative aligns with the priorities of the Paris Agreement (see Box 1) and has the potential to accelerate progress on MHEWS by assisting countries around the world to reduce disaster risk and adapt to a changing climate (WMO, 2022; UNDRR and WMO 2023; UN, 2023). It also supports key provisions of the Sendai Framework for Disaster Risk Reduction and contributes to delivering the targets of the 2030 Agenda for Sustainable Development on poverty, hunger, health, water, clean energy, climate action, resilient infrastructure, innovation, and sustainable cities.

Box 1- EWS and climate information in the Paris Agreement

The Article 7 of the Paris Agreement, emphasizes the significance of improving scientific knowledge on climate, research, systematic observation of the climate system and EWS, with the view to guide climate services and support decision-making. Subsequent decisions under the Paris Agreement[5], including the outcome of the first global stocktake, call for enhanced action and support to increase access to useful and actionable climate information for mitigation, adaptation, and EWS, as well as the implementation of the EW4All initiative. The UAE Framework for Global Climate Resilience[6], which will guide the achievement of the global goal on adaptation, includes a target on impact, vulnerability and risk assessment that stipulates: 'by 2027 all Parties have established MHEWS, climate information services for risk reduction and systematic observation to support improved climate-related data, information and services'.

This Policy Brief

This joint policy brief by the TEC and GEO, aims to offer policy-relevant insights for advancing risk-informed climate planning and action, and highlights innovations and technology solutions for improving disaster risk knowledge in support of the overall MHEWS framework and the implementation of EW4All initiative, especially in LDCs and SIDS.

Section 1 highlights technology needs and priorities of countries for improving climate information and disaster risk knowledge, as communicated through their climate and DRR plans. Section 2 provides a list of fit-for-purpose technologies and innovative solutions (hardware, software, and orgware[7]), and their applications for improving risk knowledge and information in advancing MHEWS in different country or regional contexts. Lastly, policy-related key findings and recommendations are presented, useful for various actors across the early warnings value cycle. This policy brief may be used together with various technical guidance and knowledge products made available by EW4All partners and other relevant actors to assist countries in their planning and policy-making processes for improving climate information and risk knowledge capabilities.

[5] 1/CMA.4 and 1/CMA.5

[6] 2/CMA.5

[7] Hardware refers to so-called 'hard' technologies such as capital goods and equipment. Software refers to the capacity and processes involved in the use of the technology and spans knowledge and skills. Orgware relates to the ownership and institutional arrangements of the community or organization where the technology will be used.

Section 1: Understanding technology policy for advancing risk knowledge and early warnings systems through the lenses of multilateral processes

Key takeaways for policy makers from this section: informed by insights from multilateral processes, the findings presented in this section have the potential to inform the process of updating countries' NDCs and NAPs and facilitate the systematic inclusion of technology measures for climate information and risk knowledge in national climate and development plans.

1.1 Global Status of multi-hazard early warning systems

Challenges and opportunities for improving risk knowledge and information

The latest report of the *Global Status of Multi-Hazard Early Warning Systems 2023,* shows that only half of the world (52 percent) is covered by an EWS (UNDRR and WMO, 2023). Although a positive trend in coverage has been observed over the past decade, less than half of the LDCs, and only one-third of SIDS, have reported existence of MHEWS (UNDRR and WMO, 2022). Of the 101 countries that reported on the existence of MHEWS, as of March 2023 only 42 countries (22% of countries) have confirmed availability of accessible, understandable, usable and relevant disaster risk information and assessments at both the national and local levels (UNDRR and WMO, 2023).

The global disparity in the availability of disaster risk knowledge for MHEWS is glaring, particularly among LDCs and SIDS (UNDRR and WMO, 2023). These countries face limited access to relevant disaster risk information, with only 17% of LDCs and 24% of SIDS reporting the existence of disaster risk knowledge for MHEWS. This is further compounded by their limited adaptive capacity, demonstrated by constraints on technology, financial and human resources, and skills.

Broadly-speaking, Pillar 1 on disaster risk knowledge made the least progress, revealing significantly low scores across all regions, with the Arab States reporting the lowest score and the least progress[8]. This reinforces the urgent need to increase global production of disaster risk knowledge, with a particular emphasis on LDCs, SIDS and the Arab States. To accelerate progress on MHEWS implementation, the Executive Action Plan of the EW4All indicates early actions to be taken to achieve its goal. It requires new targeted investments of about USD 3.1 Billion across the four MHEWS components to advance early warnings for all within five years, with USD 374 million allocated to Pillar 1 on disaster risk knowledge (WMO, 2022).

Beyond this, progress on Target F[9] of the SFDRR, which focuses on the role of international cooperation to enhance climate and disaster resilience, revealed 2,203 instances of capacity development reported by 15 recipient countries from 2005 – 2020 and 1,800 programmes and initiatives dedicated to the transfer of science, technology, and innovation between 2005 – 2022 (UNDRR, 2021, complemented with information from SendaiMonitor). New and existing technology and innovation measures present

[8] Out of 5 LDCs in the Arab States, 4 of them are among the initial group of countries that EW4All initiative are focusing its implementation efforts: Djibouti, Comoros, Sudan, and Somalia.

[9] Target F involves the transfer of international financing (i.e., official development assistance (ODA) and other official flows), technical skills, ideas, and technology from developed to developing countries.

significant opportunities to address data gaps and enhance the understanding of risks that will inform decision-making for climate adaptation and resilience, including through EWS.

Challenges for improving climate information and risk knowledge within the MHEWS framework

The coverage of risk knowledge elements within the MHEWS framework remains consistently low, particularly in SIDS and LDCS from the Arab States and Africa, suggesting that efforts to scale up global good practices in developing and managing risk information and risk assessments should remain a top global priority (UNDRR and WMO, 2022 and 2023).

Even where EWS exist, challenges such as the lack of quality, timely, relevant, standardized, interoperable and up-to-date risk information (UN, 2023) may hamper effectiveness of early warnings and on-the-ground decision-making for disaster risk reduction (UNDRR and WMO 2023). Globally, there are persistent data gaps at both subnational and national levels, with limited reporting on gender, sex, age and disability disaggregated data (UN, 2023) (see Box 2 for more information).

Despite advances in technology, especially connectivity, some communities remain hard to reach (UNDRR and WMO, 2022). Mainstreaming people-centered and locally-led approaches across all elements of the early warning value chain (i.e. engagement of end-users through various stages of planning, design, implementation, and evaluation) remains a challenge and priority (UNDRR and WMO, 2023) to ensure MHEWS and related services meet local needs and preferences.

Besides data-related challenges, inadequate technical capacity to interpret data and generate risk information impedes risk-informed decision-making and policy adoption. This calls for enhanced international cooperation, including in the form of capacity development.

It is important to highlight the gender disparity in benefitting from trainings and capacity-building opportunities related to risk knowledge and management. Preliminary gender statistics from participants in a range of trainings, conferences, workshops and webinars (on topics such as disaster management, climate action, and space technology) organized by the United Nations Office for Outer Space Affairs (UNOOSA) in 2023 shows that despite efforts to encourage female participation, the funded trainees are predominantly male, with roughly 70 per cent of all attendees. The United Nations Satellite Centre (UNOSAT) reports similar challenges related to participation of female candidates in trainings on geospatial applications, and roughly the same share of 70 per cent male trainees.

Box 2 – Promoting gender-responsive and inclusive risk knowledge and information by improving the data landscape

In most countries, marginalized groups are typically excluded from early warnings, and there is limited disaggregated reporting on demographic factors such as sex, age and disability at the subnational and national level (UN, 2023). Considering that all forms of inequality and marginalization are mutually reinforcing, and the intersectionality across vulnerable groups, demographic factors must be analyzed and addressed in parallel to prevent one form of inequality from reinforcing another.

Data disaggregation is crucial for analyzing demographic factors and determining differentiated disaster impacts within communities and across countries. It is also essential for understanding and responding to the current vulnerabilities and disaster and climate risks that could be addressed through gender-responsive and inclusive policies. Data disaggregation could be improved through various means, including administrative data (e.g. census, civil registration, education and health systems) (UNICEF, 2022), as well as data collected by non-state actors (e.g. academic and research institutions, NGOs, and private sector) and international entities (e.g. UN agencies, multilateral funds, regional and initiatives). Ultimately, such data should be integrated within the larger data ecosystem in the country to be useful.

Countries have also highlighted the issue of fragmentation within the MHEWS value chain, with operations often taking place in silos. For example, in Papua New Guinea soft and hard disaster resilient infrastructure have been established in Manus Province and Milne Bay Province. However a lack of integrated data collation has hindered critical risk knowledge required to determine the percentage of the coastline that is prone to coastal flooding or shoreline erosion (UNDRR and WMO, 2023).

Development, maintenance, and operation of MHEWS is another persistent challenge with calls for long-term sustainable financing (both domestic and international) supported by a coordinated multi-sectoral approach to achieve coherence between various investments and financial instruments. For example, in Malawi[10], an assessment of funding needs for strengthening climate information and EWS revealed a lack of funding for operation and maintenance (e.g. a shortage of paper for mechanical recording of temperature and humidity) that led to obstacles to the utilization of weather stations. A thorough valuation of annual operating, maintenance, and replacement costs for infrastructure assets, covering an initial period of five to seven years should be integrated in funding strategies and project that support related technology implementation efforts.

Opportunities for improving climate information and risk knowledge within the MHEWS framework - technology and innovation (hardware-software-orgware) in the spotlight

When bolstering the technological base for MHEWS, a combination of hardware (e.g. observation technologies), software (e.g. knowledge and skills trainings for technologies) and orgware measures (e.g. policies, institutional settings, regulation and governance structures) should be utilized, in a mutually supportive manner, to ensure complementarity and effectiveness in the planning and implementation of adaptation and disaster risk reduction efforts (TEC and WIM Executive Committee, 2020).

Equally important is the consideration of the full spectrum of "low-tech" solutions together with indigenous and traditional knowledge and openly available "high-tech" solutions (UNDRR and WMO, 2023) to support risk knowledge generation/dissemination and anticipatory action in remote and hard-to-reach areas in a timely and effective manner. Considering that risk knowledge capabilities are built through a combination of local, traditional, and Indigenous knowledge, embedding these forms of information with scientific evidence in the MHEWS framework increases the effectiveness of early warnings (UNDRR and WMO, 2023).

Enhanced international cooperation in MHEWS, for example through the EW4All Initiative, also supports countries with limited capacity to build their risk knowledge as a basis to create, communicate, and act upon reliable forecasts tailored to local contexts and needs. Maldives -the first country to adopt and publish a national roadmap for achieving EW4All- has a long history of international cooperation for improving its risk knowledge capability (See Box 3).

Box 3 – Maldives: enhancing climate information and risk knowledge capability through international cooperation on technology action and support

The need for strengthening the risk knowledge capability, including through expanding the meteorological and oceanographic observation systems and network to cover all the communities of the Maldives, has been a recurring priority of the country in its climate change agenda, as communicated through Maldives' various planning and reporting instruments under the UNFCCC and Paris Agreement, namely its: national communications (2001 and 2016); National Adaptation Programme of Action (NAPA) (2006); nationally determined contributions (2016 and 2020); as well as the ongoing national adaptation plan process (2022-ongoing).

[10] Lessons learned from the implementation of the an LDCF-financed project in Malawi: 'Strengthening Climate Information and Early Warning Systems in Malawi to Support Climate Resilient Development and Adaptation to Climate Change' (GEF ID 4994)

Tracing the priorities of Maldives pertaining to technology-related measures for improving climate information and systematic observation over the years reveals valuable insights for utilizing international cooperation towards bolstering climate observation and risk knowledge in vulnerable contexts like Maldives, guided by climate policy processes and outcmes:

- **Mobilizing bilateral support on technology transfer for improving climate information and risk knowledge**, e.g. as a response to the objectives set in its first NDC, the Maldives has benefitted from the support of the Italian government (2017-2019) to expand its observation networks, with the installation of 27 Automatic Weather Stations as well as trainings of local technicians. The Italian government is also identified as a support provider for the expansion of the radar network currently in existence under the national roadmap for EW4All (2023-2027);
- **Participating in international cooperation networks and initiatives to improve access to climate risk information and benefit from technical exchanges and capacity-building opportunities**, e,g, Maldives is a member of the Regional Integrated Multi-Hazard Early Warning System (RIMES) for Africa and Asia since 2009 and was the first country to convene national consultations and undertake a gaps analysis of the core capability for MHEWS under the EW4All in 2023;
- **Using multilateral financing windows to utilize technical and implementation support for identifying and formulating risk-informed adaptation measures**, e.g. Maldives has been able to establish its national adaptation priorities informed by climate information and risk analysis developed through a range of projects and programmes funded by the Green Climate Fund (GCF, e.g. see the ongoing work on the NAP process), Global environmental facility (GEF), Least Developed Countries Fund (LDCF), Adaptation Fund, and Global Climate Change Alliance (GCCA);
- **Mobilizing private-public partnerships to improve availability and access to climate information and risk knowledge, including data and information on loss and damage:** e.g. as a part of the new effort on the Global Ecosystems Atlas spearheaded by GEO, Maldives is exploring a pilot project involving a rapid ecosystem mapping activity of the 33 IUCN global ecosystem typologies that have been pre-identified for the country, leveraging high-resolution satellite imagery provided for free by Planet Labs, one of the commercial partners of the initiative. Such critical data is available in the context of the Loss and Damage Atlas project, under which Planet Labs and the UAE Space Agency partnered to extend technology and expertise to developing countries.

Regional cooperation has been another effective policy used by countries across all regions in improving their risk knowledge capability and climate observations. For instance, in 2022, the African Union Commission initiated the Africa Multi-Hazard Early Warning and Early Action System (AMHEWAS) programme to increase the availability and access of disaster risk knowledge for early warning and early action. The goal is for the African Union Commission to eventually support Member States in setting up similar interoperable situation rooms at the county level.

Many developing countries have reported on the participation in regional initiatives as resource-efficient means of capacity- building for implementation of their national climate plans while advancing the climate agenda at the global, regional and/or transboundary levels (UNFCCC, 2022), including for improving availability and application of climate information and tools (e.g. establishing regional web-based knowledge management platforms and data centres) and benefitting from regional training and networks related to hydrometeorological services, forecasting and early warnings.

Climate information and disaster risk knowledge can be also improved by harnessing technology to enhance data collection, analysis and sharing/integration of diverse data sources (UN, 2023), highlighting the co-benefits of the four MHEWS components that lead to more robust EWS. To facilitate greater interoperability, crowd-sourcing and complex risk analytics, countries and relevant stakeholders could invest in data-sharing infrastructure in the information technology sector, and support improved digital field data collection, online reporting, historical records digitization, loss accounting and multi-hazard risk mapping at all administrative levels (UNDRR, 2023).

Globally agreed regulatory frameworks are an effective means for improving the landscape of climate information and risk knowledge globally. For example the World Meteorological Organization (WMO)'s Global Basic Observation Network (GBON), provides a regulatory framework, guidance and tools to enable the generation and international sharing of fundamental weather and climate observations in a sustainable manner.

Leveraging technology and innovation can also advance 'open policies' on climate information and risk data as public goods. By accessing open data and open-source software solutions, policymakers and relevant stakeholders can enhance their decision-making capabilities and communities can effectively respond to climate and disaster risks. These are just some of the ways that technology solutions could strengthen the effectiveness of the MHEWS value chain globally, through better risk information.

1.2 Mapping technology needs and priorities for improving climate information and early warning systems in national climate agendas

Insights from the planning/reporting instruments under the UNFCCC and Paris Agreement

The following subsection highlights practical insights from multilateral processes, including information communicated by Parties under the UNFCCC and Paris Agreement (i.e. NDCs, NAPs and TNAs) on the ways in which risk information related to climate adaptation and early warnings is being enhanced through technology solutions. As country-specific experiences are communicated on a voluntarily basis through these reporting and planning tools, the findings highlighted here are not intended to be exhaustive or reflect the experiences of all countries, regions, or even groups of countries with special needs. Rather, this subsection features a few salient examples on the current state of play of technology-related needs, priorities, and trends at the national, regional, or global level.

1.2.1 Nationally Determined Contribution Insights

Nationally Determined Contribution (NDCs)[11] are central to the Paris Agreement and contain commitments by each country to mitigate and adapt to the impacts of climate change. The NDCs offer meaningful perspectives into the technology needs and priorities of countries, including those that pertain to EWS.

Approximately 1 in 2 countries have included measures related to EWS in their NDCs, and 1 in 4 countries[12] emphasize harnessing technology and innovation to enhance EWS. Some Parties connect the technologies for climate observations and EWS to issues beyond adaptation such as loss and damage, biodiversity, food security, energy systems and infrastructure.

Most technology measures for climate observations and EWS refer to specific technology applications (e.g. hydro-meteorological monitoring systems, modeling technologies, information management systems), with much less focus on 'policy, regulatory and legal instruments', 'institutional strengthening and coordination' or 'innovation, research and development (R&D)'. The water and agriculture sectors, are the most frequently cited as sectors with the most need for climate observations and EWS technologies.

[11]NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive NDCs that it intends to achieve. Information on submitted NDCs is maintained on the NDC registry platform (> Link).

[12] Countries include United Arab Emirates, Oman, China, Myanmar, Sudan, Syria, Vietnam, and Vanuatu

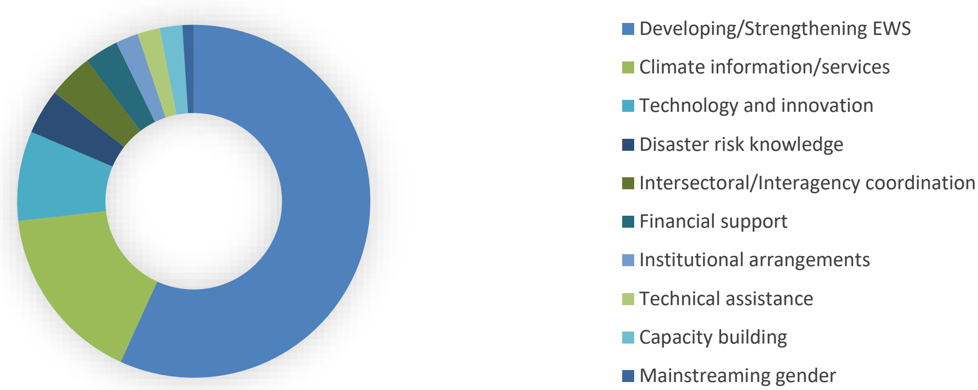

Figure 2- Countries priorities related to MHEWS Pillar 1 as indicated in their NDCs, by themes and cross-cutting areas

Figure 2 depicts countries' priorities related to MHEWS Pillar 1 as indicated in their NDCs, by themes and cross-cutting areas. An inductive method was used to construct the categories represented in the chart, based on the frequency with which they were highlighted in the NDCs. As such, country-level priorities were identified along multiple themes, with the size of each piece representing the share of each category.

As seen in Figure 2, much emphasis is placed on the development and improvement of EWS, with 57% of reporting countries that mentioned EWS in their NDCs drawing attention to the need for standardized approaches and enhanced accuracy of these systems. Community involvement in support of locally relevant solutions is also specified, with countries[13] affirming the importance of end-to-end, people centered MHEWS. Going further, 16% of reporting countries underscored the need for increased production of and access to climate information, including through enhanced and decentralized climate services, especially for countries facing multiple climate-related hazards. Within this priority area, some countries highlighted the need to promote investments in climate information and MHEWS, alongside improvements to delivery models and the legislations that govern climate information.

1.2.2 Adaptation Communications Insights

Many countries integrate both adaptation and mitigation priorities and actions into their NDCs, acknowledging adaptation as an equally critical component of countries climate strategies. As such, NDCs may incorporate specific adaptation policies or measures that correspond to information reflected within adaptation communications. Adaptation communications[14], established through Article 7 of the Paris Agreement, aim to increase the visibility and profile of climate change adaptation on par with climate change mitigation, and enhance adaptation actions and support for developing countries.

EWS are frequently referred to in Adaptation Communications. In fact, more than 90% of the Adaptation Communications submitted by Parties to the Paris Agreement (as at January 2024) include references to EWS, with about one-third of them including associated technology measures. The regional distributions vary considerably with the highest reference to EWS in the Africa region and the lowest in the Middle East and North Africa Region. This is consistent with the Global Status of MHEWS, as described in the introduction of this policy brief. Parties prioritizing technology- and innovation-related measures for EWS are mainly located in the Asia-Pacific region and the Americas.

[13] Countries include Albania, China, Lebanon, Madagascar, Malawi, Mozambique, Nepal, Papa New Guinea, Timor-Leste

[14] Information on submitted Adaptation Communications is maintained on the Adaptation Communications Registry (> Link)

1.2.3 National Adaptation Plans Insights

The UNFCCC's national adaptation planning (NAP) process[15], aimed at reducing vulnerability to climate change impacts by building adaptive capacity and resilience, notably through EWS, supports the objectives of EW4All Initiative (UNFCCC, 2023). By integrating technology measures into adaptation, NAPs support countries to produce, utilize and share risk information more effectively, which leads to better EWS and greater resilience to climate-related disasters.

About 40 per cent of submitted NAPs, as of 30 September 2023 (UNFCCC, 2023), highlight early warning and disaster risk reduction as a key adaptation sector, but only 10 per cent of project proposals submitted to the Green Climate Fund to access funding for implementing the policies, projects and programmes identified in NAPs are focused on EWS.

Adaptation goals identified in this sector focus on "improving EWS and information to respond to extreme climate events", and "preparing and deploying online data integration systems for monitoring, dissemination of information and awareness-raising in relation to the impacts of climate change". Droughts and floods are most frequently cited (by close to 90 per cent of reporting countries) as specific hazard to be addressed through the NAP process, followed by increasing temperature, sea-level rise and land/forest degradation.

1.2.4 Technology Needs Assessment insights

The technology needs assessment (TNA)[16] methodology is a well-established process under the UNFCCC. It follows a participatory and country-driven approach and has evolved over the course of two decades. Countries undertake TNAs to determine their climate technology priorities and needs and develop technology action plans (TAPs) to address those needs, including by examining relevant information on climate mitigation and adaptation technologies. Since the adoption of the Paris Agreement, several Parties have used existing TNAs as a baseline and source of information for their NDCs and vice versa[17].

According to a 2021 report (UNEP-DTU Partnership and Green Technology Center, 2021), about 12% of all technology measures for adaptation identified through the 'technology needs assessment (TNA)' process are related to climate observation and EWS. Similar to the NDCs, water and agriculture sectors are most frequently cited as sectors with the need for climate observations and EWS technologies. When prioritizing different types of technology measures in each sector, the largest share of EWS-related measures is observed in the 'coastal zones' and 'agriculture' sectors. Countries that have prioritized technology measures for climate observations and EWS in their TNAs[18], most frequently aim to address climate risks related to floods, followed by drought and storms.

1.3 Mapping barriers and enablers to technology implementation for climate information and early warnings systems

Insights from technology needs assessmnet process and support of climate funds

Countries and support providers have identified various barriers and enablers that may impede or bolster implementation and scaling up of technologies and innovations for improving climate

[15] Information on submitted NAPs from developing country Parties is maintained on the NAP Central platform (>Link)

[16] Read more about the TNA process under the UNFCCC (> Link)

[17] Read more about the work of the TEC on linkages between TNA and NDCs processes (> Link)

[18] Countries include Antigua and Barbuda, Fiji, Liberia, Malawi and Ukraine from the Phase III of the TNA Global Project, and Somalia, St Kitts and Nevis and Yemen from the Phase IV. For more information about TNA Global Project see the TNA Database (>Link)

information and EWS[19]. An analysis of the the outcomes of the TNAs and lessons learned by the CTCN and funding entities (i.e. Green Climate Fund, Global Environment Facility and Adaptation Fund) in supporting technology-oriented projects and programmes for enhancing climate information and EWS points to a set of common and critical issues, particularly for LDCs and SIDS, that may prove useful in strengthening the impact and effectiveness of such implementation efforts. These include: access to finance, stakeholder engagement, public information and awareness, data quality, technical capacity, legal and regulatory frameworks and institutional arrangements, timeframe, and costing (see Table 1). A more detailed set of information and lessons learned by the funding entities from the EWS portfolio is provided in the annex.

Table 1- Key Barriers and enablers for the implementation and scale up technologies and innovations for climate information and EWS

	Barriers	Enablers
Access to Finance	Changes in public spending patterns (e.g. due to COVID-19), uncertainty in accessing international financing and in sustaining funding for project outcomes in the long run have hindered the implementation of EWSs.	Consistent domestic investment can be used to train technicians, conduct research, risk assessments, and support technology transfer activities. Various form of international cooperation, including mobilization of support from international donors, climate funds and specialized mechanisms[20], could help leverage additional sources of funding for risk assessments and mapping technologies and capacity-building efforts.
Stakeholder engagement	Limited involvement of local community groups/organizations, lack of political will, and entry barriers for the engagement of private sector are among persisting barriers for implementation and scale up of EWS-related technologies and innovations.	Engagement with stakeholders including through: community-based approaches that create ownership; participatory approaches that meaningfully involve local community leaders, decision-makers, and vulnerable groups; and fostering private sector engagement (especially on the last mile support) increases the effectiveness of risk planning.
Public information and awareness	The “last mile” challenge persists, particularly the delivery of actionable climate information to local communities. Moreover, the lack of transparency, misinformation, and limited trust in the system by end users poses barrier to effectiveness and uptake of climate information and EWS.	Among enablers for improved awareness and public participation in the EWS value chain are promoting a transparent approach to building public trust, developing or translating tailored communication strategies and knowledge products for end-users, and improving systems to increase knowledge transfer and adaptive capacity.
Data quality	Benefits of technology, as well as R&D efforts, are underutilized in developing quality long-term historical hazards and exposure/vulnerability/loss and damage data sets for risk mapping. Moreover, in many developing countries insurance systems and financial services do not	Measures for improving data quality for risk knowledge and information though technology implementation include: using international satellite data to address local data gaps; integrating diverse sources of information to develop high-quality assessments and analytics, including risk mapping and scenario planning;

[19] Learn more about the TEC work on:
- Experiences, lessons learned, and good practices from GCF and GEF support for climate technologies (>Link)
- Enabling Environments and Challenges to Technology Development and Transfer - Identified in Technology Needs Assessments, Nationally Determined Contributions, and Technical Assistance provided by the Climate Technology Centre and Network (>Link)

[20] For example the LDCF and Special Climate Change of the GEF, the GCF, the Adaptation Fund, the Climate Risk and Early Warning Systems (CREWS) and the Systematic Observations Financing Facility (SOFF).

	systematically leverage modern technologies for disaster risk assessments.	and tailoring information for different communities to facilitate meaningful action.
Technical Capacity	Limited technical capacity to effectively create and interpret climate risk data including assessments on sectors and community-related impacts and manage operations limits the coverage and uptake of climate information and disaster risk knowledge.	To promote the development and retention of technical capacity, publicly funded research and development initiatives, and training programmes by local and international experts/institutions may be implemented.
Legal and Regulatory Frameworks and enabling environment	Lack of sufficient regulatory framework, policies, and incentives and coherent legislative frameworks leads to fragmented efforts and ineffective policy uptake for advancing climate information and EWS.	National policies and appropriate legal regulatory framework play a central role in fostering an enabling environment for implementation and scale-up of climate information and EWS, including through regulations (e.g by reducing operational risks for the private sector engagement), market creation for EWS related technology, data and services (e.g. through subsidies), promoting international cooperation (e.g. through collaborative research, development and demonstration) and gender-specific support (e.g through quotas).
Institutional Arrangements	Limited coordination and data sharing between government/non-government entities and national/local levels; integration of fragmented interventions lowers effectiveness of support to developing countries.	Establishing cross-sectoral working groups to ensure coordination among institutions to ensure the sustainability of interventions, support existing priorities, and enable buy-in; establishing a central coordinating agency such as the Meteorological Services to manage climate data.
Timeframe	Design and implementation of an EWS typically takes 1 to 5 years, and there are increased public concerns about the length of project timeline, as well as maintenance of the systems and retention of capacities built.	Adopting a programmatic approach may further streamline the process for facilitating linkages and readiness support for improving climate information and EWS through climate technologies, thereby enhancing the efficiency and effectiveness of projects as part of the broader support ecosystem for climate adaptation.
Costing and valuation	There is limited knolwedge and use of quantification methods to assess disaster risk impact (e.g. the number of at-risk houses or businesses), and cost-benefit analysis needed to justify the establishment of EWS for climate impacts.	Quantifying the effectiveness of EWS, for example through evidence-backed estimations of avoided losses and damages is an effective way to garner political buy-in and support for their implementation.

Source: insights extracted from (TEC, 2022a and 2022b), (GCF, 2022), (Adaptation Fund, 2023), (GEF, 2024)

1.4 Trends and key considerations in technology applications for advancing climate information and disaster risk knowledge

The application of the fit-for-purpose innovations and technology solutions for climate information and disaster risk knowledge is critical for the full EWS value chain. Effective risk knowledge is integral to shaping preparedness and response strategies, designing the most probable scenarios for multiple hazards, training early action partners, and producing simulation and drill exercises tailored to the most likely hazards. Such preparation is critical to safeguard lives and livelihoods and prevent, or to a lesser extent reduce, impacts of extreme weather before they occur. With advancements in science, technology, digitalization and other innovations, new tools are being leveraged to reduce disaster risks (UNDRR, 2023).

To-date, sectoral applications of artificial intelligence (AI)[21] relevant to climate change adaptation and risk reduction have largely advanced in the areas of crop yields, EWS and water management, especially around climate modelling and forecasting (IPCC, 2022). Technology applications for better climate information and disaster risk knowledge include the use of AI, remote sensing, Earth observations (EO), and geospatial technologies, and interoperable platforms, which will be covered in more detail in Section 2.

Box 4 provides a summary of observed trends and key considerations in the current landscape of technology policy and implementation, informed by findings of the Working Group II of the Intergovernmental Panel on Climate Change (IPCC) in its 6th assessment report, the mid-term review of the Sendai Framework for Disaster Risk Reduction (SFDRR), and outcomes of the Global Stocktake under the Paris Agreement.

Box 4-Trends and key considerations in technology applications

- Less than 50 percent of the countries reporting on Sendai Framework targets indicate having fit for-purpose, accessible and actionable risk information(UNDRR and WMO, 2023)
- Since 2015, countries have recognized the importance of reliable and interoperable data in capturing various aspects of disaster risk, including for EWS. Moreover, countries are increasingly utilizing widely-accessible technologies such as mass SMS messaging and social media to improve public access to and awareness of disaster risk knowledge.
- 110 countries now have national disaster loss databases and many countries have made efforts to increase access to such databases (UN, 2023).
- The private sector and regional cooperation provide cost-effective avenues for low-capacity, or technologically poor countries to access advances in technology for disaster risk reduction (UNESCAP, 2023).
- There is noticeable improvement in the understanding of risk, and progress on the use of climate risk and GIS tools, including more guided risk assessments, devolution of roles and responsibilities, collection of disaggregated data and the production of risk atlases (UN, 2023).
- New technologies are helping to bridge data gaps to enable better decision-making (UNDRR, 2023; UN, 2023), including by overcoming data disaggregation gaps and challenges.
- Progress across sectors that leverage AI use diverse learning techniques such as supervised and unsupervised learning, multi-modal learning, and transfer learning techniques. These approaches generate predictions that are far more accurate than traditional climate projection methods (IPCC, 2022).
- [placeholder to add more insight that may be emerging throughout the development of this brief]

[21] Learn more about the UNFCCC Technology Mechanism initiative on Artificial Intelligence for Climate Action (>Link)

Section 2: Innovations and technology solutions for risk knowledge in the context of implementing MHEWS

Key takeaways for policy makers from this section: informed by good practices and expertise of the GEO community and EW4All partners, this section provide policy makers with a set of proven technology solutions that may help their decision making when defining national strategies and priorities or designing climate policies, projects, and programmes for improving climate information and disaster risk knowledge-to better examine what works, how and for whom.

2.0 Background

In recent years, technologies for processing, storing, analyzing, and visualizing geospatial data have vastly improved. AI, EO, the internet of things (IoT) and analysis ready data (ARD) are, to a great extent, transforming the ways in which users collect, process and analyze information (WEF, 2024). The Executive Action Plan of the EW4All (2023-2027), serving as a blueprint for the implementation of the initiative, gives a central role to innovation (namely through the use of new and existing technologies), as a key cross-cutting enabler for realizing global coverage of MHEWS, and in particular for driving rapid change in risk knowledge capability (e.g. for production, access and use of risk knowledge) at all scales, for all, and with a whole-of-society approach. Against this backdrop and in line with the MHEWS Checklist (WMO, 2018), Table 2 shows how such technology and innovation-related measures may be utilized for improving disaster risk knowledge, and thereby advancing the entire MHEWS framework.

Table 2- Disaster risk knowledge (Pillar 1) checklist used in EW4All country-level consultations

Steps	Key questions	Examples of technology and innovation-related outputs
Production	Are key hazards and related threats identified?	Hazard profiles (frequency, magnitude, seasonality etc. of top 5 hazards) + hazard maps
	Are exposure, vulnerabilities, capacities, and risks assessed?	Maps of exposed/vulnerable people, critical infrastructures, economic activities (industrial sites, crops, livestock), ecosystems
Use	Is information properly incorporated into the EWS?	Pre-determined hazard thresholds, warning messages, early action plans with safe areas/shelters, evacuation zones and routes
Access	Is risk information consolidated?	Central standardized data depository
Enabling environment	Are roles and responsibilities of stakeholders identified?	Process for for integrating indigenous and traditonal knowledge into EWS; scientific/technical experts to assess and review climate and risk knowledge; international cooperation; capacity development

Source: Adapted from MHEWS Checklist (WMO, 2018) and the work under EW4All Pillar 1

The foundation and starting point of the Pillar 1 of the MHEWS is production of risk knowledge, such as hazard profiling, vulnerability and exposure assessments (see Table 3), and analytics about future risks and possible impacts. Exposure and vulnerability assessments are overlayed with priority hazard(s) to create hazard maps and impact scenarios (i.e. best case, worst case, most frequent/probable) which guides decisions and actions.

The produced climate information and risk knowledge are used as the basis for creating actionable information for across all MHEWS pillars (see Figure 3). The use of risk knowledge can occur through risk knowledge outputs, such as pre-determined hazard thresholds to help the timing and decision of disseminating early warnings (Pillar 2), contents of warning messages (Pillar 2 and 3), options for communication methods and channels (Pillar 3) and early action plans with safe areas/shelters, evacuation zones and routes (Pillar 4).

Table 3 - Examples of exposure and vulnerability

Elements	Exposure	Vulnerability
Population & settlements	Areas of residence, work/study, migration/displacement	Age, gender, disabilities, legal status, special-economic status, access to services
Critical infrastructures	Hospitals, power/electric plants, dams, communication towers or centers, (air)ports, road networks,	Design, materials, age (construction period), level of maintenance, number of floors
Economic activities	Industrial sites, crops, livestock	Level of dependencies on vulnerable infrastructures, locations, diversification
Environmental areas	Protected areas, green infrastructures, cultural heritage	Fragility of ecosystems and species, cultural sites

Source: based on ongoing work of EW4All Pillar 1

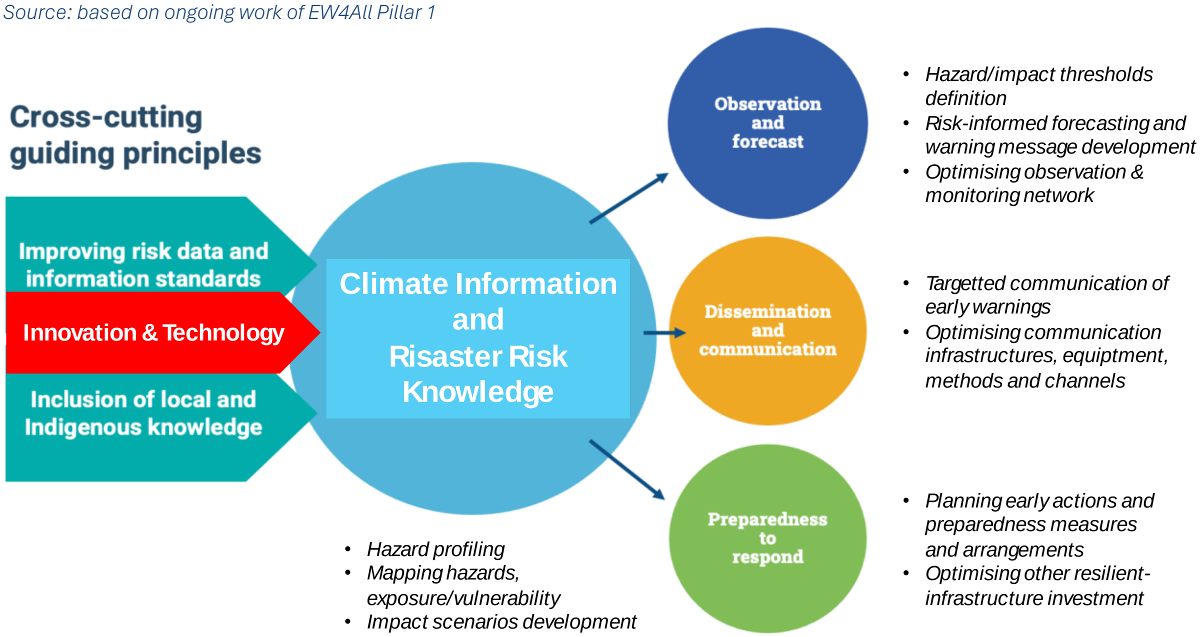

Figure 3 - Climate Information and Disaster Risk Knowledge as the Basis (Source: ongoing work of EW4All Pillar 1)

The remainder of this section presents a selection of technology solutions (including hardware, software and orgware measures) for each key elements of the risk knowledge: production, use, access and enabling environment. The technology measures described below serve as illustrative examples, based on their readiness for immediate use and their contributions to the objectives of the EW4All Initiative and long-term adaptation goals of countries.

2.1 Production of Risk Knowledge

2.1.1 Sensors (surface-, air-, ocean-, and space-based)

Fundamental to the production of risk knowledge is Earth observations (EO), which is the gathering of information about the planet Earth, obtained via sensor technologies. It can be performed through remote-sensing devices on the ground (e.g. weather radars) or mounted on platforms such as drones, airplanes, helicopters, and satellites. EO can also be acquired through direct-contact sensors in surface- and ocean-based platforms and airborne platforms. Basic telemetric observation systems such as automatic weather stations, tide gauges and buoys provide localized and real-time data on essential weather, climate variables i.e. atmospheric pressure, temperature, relative humidity, wind direction and speed, precipitation. These data collected from ground-based and upper air-observation networks complement the remote-sensing data by providing ground-truth information for calibration and validation purposes, and real-time bias correction. They are the backbone of weather and climate models for hindcasting and forecasting.

Satellite remote sensing - arguably the most significant among EO, offers the greatest benefits when combined with complementary data acquired through other techniques (STAP, 2021). Basic observation systems (e.g. weather stations) continuously collect data for specific geographic areas whereas remotely sensed data can cover larger areas although with limited frequency (e.g. in the case of satellites, associated with the repeat pass). Together they can complement each other to produce disaster risk knowledge – locally, regionally, and globally – and enable countries to do essential hazard identification and profiling with characteristics of hazards including the location, extent (or severity), and historical occurrences.

The ministry of environment in Colombia uses methodologies that combines remote sensing satellite data with ground-based observations to address the issue of erosion at the national level, which has diminished the effectiveness of essential ecosystem services that mitigate floods and landslides. This data has contributed to knowledge of the underlying drivers of loss and damage, providing valuable input for risk assessments and adaptation planning over the years. The ministry recorded the erosion grade using a map developed with high-resolution satellite imagery to identify the degree of land degradation (GEO, 2023).

Other remote sensing technologies are also becoming increasingly available for developing countries. For example, airborne Light Detection and Ranging (LiDAR) is a remote sensing method that captures very accurate ground height and seafloor information. This data when combined with on-site sea level measurements and ground control surveys is a game-changer. Tuvalu is one of a few places in the world benefitting from LiDAR technology to capture bathymetry and topography to elucidate the relationship between land elevation and sea level rise, supporting adaptation planning into the future.

2.1.2 Citizen Science

Citizen science is a transformative approach to scientific inquiry, which promotes public engagement in research through active contributions by communities (Chari et al., 2021). With the advent of new technologies, scientific knowledge, tools, and methods have become increasingly accessible. Leveraging such tools and principles, communities are investigating, influencing, and informing policy and decision-making alongside professionals in the disaster risk management and climate change communities. Citizen science is facilitated by digital and mobile devices through accessible platforms (e.g. citizen mapping of floods in real-time via social media) for collection and sharing of local geo-spatial data on hazards, exposure, vulnerability, and impacts. Citizen science complements data collected by sensors described above, offering various entry points for public engagement in the EO (Dean, 2020) to help improve the early warnings value chain.

The production of low-cost remote sensors has enhanced the public's contributions to and engagement in scientific research and monitoring (WIPO, 2022). For example, to provide baseline information of key hazards in Fiji (on landslides and coastal flooding), satellite imagery was used together with drone images from the University of Pacific. Citizen scientists contributed to the provision and assessment of exposure and vulnerability data (See storymap), the result of which was incorporated into Standard Operating Procedure for Planned Relocation in the Republic of Fiji, adopted in 2023.

2.1.3 Artificial Intelligence (Machine Learning)

With a set of mathematical and computer science techniques, artificial intelligence encompasses large language models, advanced big data and predictive analytics, machine- and deep-learning, which have emerged as critical tools that play a key role at each stage of the EWS value chain (WEF, 2024). AI is a powerful tool that provides better information by exploiting relationships between existing datasets (e.g. bridging incomplete datasets through techniques such as missing-value inference), alongside its ability to learn from new knowledge (e.g. finding hidden patterns in large, complex datasets i.e. big data), and generating hindcasts and forecasts.

In the context of risk knowledge, AI may be used to process large volumes of raw satellite imagery to create standardized baseline data on exposure, such as built-up areas and population distribution, some of which are available as open and free global data products, for example the Global Human Settlement Layer. The accuracy and reliability of statistical estimation and prediction using AI algorithms and sets of algorithms (i.e. models) relies on sufficient, high-quality training and validation data. More data does not necessarily lead to more useful, informative, and insightful model guidance.

AI models can assist in identifying variables that are essential for capturing a pattern or process, particularly in the presence of spatial variability. Quantifying data and process (model) uncertainty and its propagation may become increasingly important to validate AI models, especially when AI and non-AI approaches are integrated. AI can be applied to all phases of Pillar 1 and the MHEWS value chain. For example, machine learning-based mapping (supported by Microsoft’s Azure platform) was used in Belize to process and integrate a large volumes of data, including high resolution satellite imagery and field data to provide updated estimates of the status of the country’s major coastal and marine ecosystems (i.e. coral reefs and mangroves). The outcomes of this exercise has provided key insights for improving risk knowledge (i.e. on vulnerability and exposure in coastal and marine ecosystems) and informed the NAP of Belize (GEO, 2023).

2.2 Use of Risk Knowledge

2.2.1 Simulation Models

Simulation models in the context of EWS are mathematical models that assist in reducing disaster risks. They play a pivotal role in creating climate and disaster risk knowledge by assessing hazards, exposure, vulnerability and analyzing risks. Simulation models can simulate the past and future occurrence and impact of hazards and provide representations of exposure data, such as populations, assets, critical infrastructure, industrial/agricultural sites, and environmental areas. Models are fed by observations (measured from ground, remote sensors, citizen scientists), socioeconomic data (including census and citizen science), and recently, increasingly used in conjunction with AI/ML. Simulation models are integral to generating risk information, including hazard maps and risk scenarios. The model outputs provide foundational information that help Pillar 2, 3 and 4 of the MHEWS.

For example, in Pillar 2 that deals with observations and forecasts, models based on historical data can inform the hazard and/or impact thresholds to trigger warnings and early actions. To give an example, the government of Uganda leveraged statistical models informed by ground observations and satellite-based data to analyze historical drought-induced crop failures. This assisted the government in setting a predetermined hazard threshold value to trigger a scale-up of disaster risk finance for early and anticipatory action. In Indonesia, the meteorological agency (BMKG) and disaster management agency (BNPB) have jointly developed a system called Signature with various models for weather prediction and analysis to produce and calibrate impact-based forecasts[22] for different hydrometeorological hazards: floods, landslides, land & forest fires, severe weather such as heavy rain. Meanwhile, Mongolia produced flood vulnerability and flood hazard mapping using a flood simulation model for forecasting future climate and flood risks. In Ulaanbaatar city, the map is accessible for public use through a mobile application while the risk information was integrated into development and land use plans. The process was undertaken through co-development that integrated community information with data from different government departments at the municipality, district and khoroo level (Adaptation Fund, 2023).

2.2.2 Internet of Things

The Internet of Things (IoT) increases the accuracy of critical resilience tools such as EWS and improves hydro-meteorological services. It is comprised of networked devices, including sensors and hand-held devices, that collaborate to gather, distribute and monitor localized data across systems (WEF, 2024). IoT essentially combines aspects of the 'physical world and things' with 'virtual world and data', creating an interlinked and distributed web of information. It ensures the early detection of hazardous events, assists in the evaluation of impact, and contributes important data to decision-making (Khan et al., 2023). IoT allows gathering of new data such as temperature and engages in nudge adaptive behaviors by directing people to safety.

An example of this is networked heat sensors to detect hazards such as wildfires and communicate advanced warning to forestry stations, by pushing mobile alerts to individuals in affected areas. IoT can be a powerful especially when it is used in combination with risk information on exposure and vulnerability, including for informal settlers and targeted communication of early warning for them (Pillar 3 of the MHEWS). Such a country example can be found in South Africa where a social enterprise uses mobile-IoT to connect fire sensors inside homes in informal settlements to alert to residents and their neighbors fire risk via SMS instant notifications. The scheme is linked to an opt-in micro insurance.

2.2.3 Global Navigation Satellite System and Terrestrial Reference Frames

Global Navigation Satellite System (GNSS) are a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers on the ground. The receivers then use this data to determine location, and accurately relate this location to all others using a Terrestrial Reference Frame (TRF)[23]. GNSS is a general term for systems like the US Global Positioning System (GPS). Other countries, for example India and China, have launched or are in the process of launching their own systems to provide complementary, autonomous positioning, navigation, and timing capability. Other developing countries without their own GNSS satellites also benefit from this technology.

For example, Thailand is utilizing GNSS data provided by Japan, to enable targeted communication of warning message of tsunami (to those with smart phones and smart watches on the beach or shorelines) and forest fire and air pollution (to people in affected areas). International cooperation on

[22] Impact-based forecasts and warnings (IBF) integrates risk knowledge on hazards and vulnerability to articulate the expected impacts resulting from anticipated weather conditions. IBF aims to provide qualitative descriptions of expected impacts from forecasted hazardous conditions, based on vulnerability considerations (e.g. "on <date> in the lower part of the <river name>, high water levels and consequent flooding are expected to cause traffic disruptions on the road network and affect population and cropland"). EW4All aims to further improve the effectiveness of early warnings with impact forecasts which calls for integration of climate information and risk knowledge on hazard, vulnerability, and exposure to provide detailed and specific impact information at individual, activity, or community levels. Warnings based on impact forecasts can provide detailed quantitative information of impacts, including information on the forecast uncertainty (e.g. "on <date> in the lower part of the <river name>, high water levels and consequent flooding are expected to affect 40'000 people in <region name>, 13 km of roads and 15'000 hectares of cropland"). (For more information, see a Manual for Operationalizing Impact-based Forecasting and Warning Services >Link)

[23] The importance of a Terrestrial Reference Frame is recognized by the United Nations in its General Assembly resolution a "Global Geodetic Reference Frame for Sustainable Development".

GNSS-enhancements to MHEWS, AI-powered protocols for data analysis and sharing, and innovative communications technologies for transmitting real-time GNSS data could ensure the life-saving information on weather and climate risks reaches countries or regions with limited bandwidth capacity and/or limited communications infrastructure.

TRFs are used to model, detect, and understand displacements caused by natural hazards and disasters , and are the positioning backbone of innovations such as data cubes. GNSS and TRFs also provide important information to SIDS experiencing sea-level change and land subsidence. For example, Tuvalu and other low-lying islands rely on the use of GNSS and TRF to understand current and future sea-level rise, and ensure risk-informed early warning, policy, and adaptation.

2.2.4 Advanced Computing (Cloud Computing)

Advanced computing is a crosscutting measure to power intelligence and accelerate the use of risk knowledge. It can employ cloud-based supercomputing to power graphics processing units (GPU)-based climate models and ensure they are accessible. In addressing concerns with access, storage, and processing of vast amounts of satellite EO data, innovative cloud-based infrastructures services are becoming increasingly available, enabling users to access and process images in the cloud without needing to download raw images (Dean, 2020). These technologies combined with others, such as API can help communities improve their preparedness to respond to early warnings (Pillar 4 of the MHEWS) with early action plans and forecast-based financing.

To give an example, the AWARE platform operates on an open-source model and data and uses Amazon cloud computing for storage to promote early warning and support local communities to plan early actions. Community-led early action empowers at-risk communities to identify risks and develop action plans for potential disaster events. Sri Lanka was selected for the pilot project after it was identified as being particularly vulnerable to floods and landslides. Community focus group discussions were held to create an Anticipatory Action Plan, followed by simulation exercises to test the effectiveness of the plan, using a combination of preparedness, readiness, and activation triggers. The simulation demonstrated the impact of such initiatives to reduce disasters and build community-based resilience. Another example of the use of cloud computing stems from a remote drought-prone area of Azuay in Ecuador where analysis of hindcast historical streamflow and water level data was done based on a ML-fed web-based model using satellite data. Using these, siphons for a new irrigation system were designed for a project led by women – primarily mothers or heads of household whose sons, husbands, and fathers had emigrated for economic reasons (GEO, 2023).

2.3 Access to Risk Knowledge

2.3.1 Geographic Information System

A geographic information system (GIS) is a system designed to create, store, manage, analyze, and map various types of data. By linking data to a map, GIS integrates location data with descriptive information. This serves as a basis for mapping and analysis across various industries and fields. The benefits of GIS include better communication, management, and decision-making. Using GIS, the global Risk Information Exchange (RiX) platform provides a living repository of open-source risk data, information, and analytics, that seeks to promote risk-informed decision-making, and facilitates risk analysis by governments, UN agencies, the private sector, and other actors. It could also serve as a template for countries interested in developing their own disaster risk information management systems by effectively streamlining risk information through a common platform to facilitate analysis by different entities and actors.

In Burundi, under the auspices of the CREWS East Africa project, UNDRR and IOM have supported the strengthening of a national digital risk information management system and improving access to high-quality multi-hazard risk data. Important to note is that UN Member States decide where their national risk data will be stored when building and operating their respective digital risk information management platforms.

2.3.2 Application Programming Interface

Application Programming Interface (API) represents software components that link subsystems and actors in digital environments (Monica et al., 2022). They play a pivotal role in data sharing, access, synthesis, control, and coordination of digital exchanges within their environment. What is more, these interfaces determine what data is accessible, how, by whom, and under which circumstances. APIs also offer high flexibility of data use and are easy to scale and monitor (Monica et al., 2022). For users, actionable information on hazards and extreme events tailored to their specific needs is proven to be valuable aspects of API (Kirschbaum, 2016). As such, the Global Precipitation Measurement (GPM) mission delivers near real-time and historical information on rain and snow globally, in thirty-minute intervals. Through an API, this data can be accessed at no cost by consumers, to visualize, analyze, and ascertain the location, timing and amount of rainfall around the world (Kirschbaum, 2016). A GPM-product such as GSMaP provides a global hourly rain rate including in the developing countries, such as Mauritius via a CREWS project. Similarly, API can integrate a variety of different data such as real-time and non-real-time data from satellites and in-situ observations, model outputs as well as statistical data.

For example, by triangulating climate and health data through an ML-based malaria model, EO, and malaria patient count information, the DIAS platform can predict malaria transmission up to 3-6 months in advance. It can then issue warnings to a local Malaria Center in Tzaneen and to the national infectious disease EWS bureau for relevant actions such as insecticide spray planning. Another example of the use of API is the Global Crisis Data Bank, hosted by IFRC, which aims to reduce disaster risks by anticipating future events based on analysis of past hazards, their impacts and post-disaster responses by government and humanitarian organisations. It covers several decades to optimize learning and facilitate analysis of key trends and aims to eventually be used to forecast hazard impacts, including potential loss and damage.

2.3.3 Analysis Ready Data and Data Cubes

Analysis Ready Data (ARD)[24] refers to data that has been organized and processed to meet a set of requirements, which allows for immediate analysis and ensures interoperability with other datasets. This offers simplicity in the development of applications with the data, and databases can run queries will minimal effort. ARD is valuable as many users of EO data generally commit considerable time and effort to data preparation. What is more, a large portion of satellite data users lack the technical capacity, infrastructure and internet bandwidth to effectively access, organize and process increasingly large volumes of space-based data for decision-making. ARD are often disseminated in form of a data cube with continental, regional and thematic focuses[25].

A data cube refers to a data structure in which satellite imagery datasets are organized for a specified geographic area and time period. Data cubes provide a framework for organizing and analysing multi-dimensional geospatial data, including ARD, along various dimensions such as time, spectral bands,

[24] While specific definitions of ARD have varied across user groups, limiting usefulness, Open Geospatial Consortium (OGC), International Organization for Standardization (ISO), and the Committee on Earth Observation Satellites (CEOS) are actively creating a new global ARD standard.

[25] Learn more about the work of the CEOS on ARD (>Link) and Data Cubes (>Link)

and spatial dimensions. ARD and data cubes work together to streamline the process of geospatial analysis and facilitate the extraction of valuable insights from remote sensing data, often over significant periods of time which allows identification of trends. Together, they are revolutionising the way vast geospatial and EO datasets are handled while leveraging faster, cost-effective ways to facilitate the analysis of remote sensing imagery at scale, by driving data straight into the hands of wider audiences and policy makers to support decision-making, including in the area of climate change and disaster risk. Use of ARD in combination with data cubes in LDCs and SIDS in the Africa region have been promoted by initiatives such as Digital Earth Africa. In Senegal, for example, an environmental agency, (CSE), uses the Digital Earth Africa platform to monitor the coastlines on the seaside resort of Saly Portudal in Mbourl, assessing location and patterns of coastal retreat and erosion.

2.4 Enabling Environment for Improving Risk Knowledge

2.4.1 Capacity-building (Data-Sharing and Data-Integration)

There is high demand for digital capacity-building, and achieving tangible and sustainable progress across multiple dimensions of digitalization entails skills development and effective training, especially in developing countries (UN, 2020). This is key to unleashing the benefits of technology, which involves the progressive use of emerging technologies and ensuring the safety and protection of users. Given differences within and among countries and regions, there is no standardized approach to capacity building. As such, evidence on the most effective capacity-building approaches is required, taking in account the political, economic and social contexts of countries (UN, 2020). For one, better coherence and coordinated action, and a focus on scaling up solutions remain crucial to addressing digital capacity-building challenges.

A successful case of capacity building is in Haiti, in the aftermath of Hurricane Matthew, where a series of capacity development activities were initiated for a public GIS agency. Their staff were trained on the use of open GIS software for image analysis, using open data satellite imagery, to produce and maintain a national landcover map on a yearly basis, which became a critical layer for all change-related products (UNDRR, 2022). It was also used for a post-disaster needs assessment in Macaya Park following the 2021 Earthquake, as a means to consistently monitor changes, and as a base layer for the Haiti's National Environmental Information System, thereby contributing to annual reporting for relevant UN conventions. What is more, the capacity building training has been playing a crucial role in enabling the GIS agency to develop risk information products for the National Civil Protection Agency.

2.4.2 Partnerships and International Cooperation

Public-private partnerships (PPPs) involve long term agreements between governments and private entities that can be used to finance, build, and operate projects. In effect, partnerships between the public and private sector can strengthen the capacity of governments to understand their own risk and prepare effective risk strategies that combine global best practices with local knowledge to reduce the risk of disasters, especially in climate vulnerable countries. The Global Risk Modelling Alliance (GRMA) is one such example of a Public-Private Partnership that demonstrates how applying open-source risk models and open data can contribute substantively towards understanding, reducing, and managing countries' current and future risk.

Also worth highlighting is roles of Small and Medium Enterprises including startups and the youth in academia to create risk knowledge with a set of technologies described above. Under CREWS in West Africa, community-led mapping, drones, aircraft image analysis, modelling mobile apps, satellite imageries were used for improved flood risk knowledge in Niger. Community mappers[26] leveraged an open-source mobile application (named GeoODK) to build a database of people and assets exposed to flood risk in Niamey, Niger and collected over 15,000 locations/data points[27]. Building on this risk knowledge, a Nigerien startup (Drone Africa Service) trained the government and the community-mappers to use drones to acquire high-resolution images of areas where exposed people and assets were located. The images were analyzed to improve resolution of digital elevation models and flood modelling.

Recognizing the transboundary nature of hazards and climate risks, it is essential to place regional cooperation frameworks and mechanism among countries that share common river basins and mountain ranges. For example, governments of Chile, Colombia and Peru worked together to create and share climate information to better address climate variability, extreme events and the retreat of Andean glaciers that impact stream flow and water supplies for their cities, agriculture, and hydropower generation. Using sensor technologies and models among others, the countries created and shared climate services for Andes glaciers. This regional cooperation while using these technologies necessitated a re-examination of legal framework and institutional structures for data and knowledge sharing, as each country originally had its own (Adaptation Fund, 2023).

2.4.3 Indigenous and Traditional Knowledge

Indigenous knowledge, rooted in cultural experiences, traditional practices, and localized understanding of specific ecosystems (Bruchac, 2014), contributes significantly to environmental stewardship and addressing climate change impacts. The global community has much to gain from collaborating with and learning from indigenous people to sustainably manage natural resources and build climate resilience[28]. For example, the Secretariat of the Pacific Regional Environment Programme (SPREP) has worked with countries in the Pacific to develop their traditional knowledge monitoring systems. In Niue Island, the yam "ufi" is traditionally considered a climate indicator for tropical cyclones in Niue Island. The Niue Meteorological Services, in collaboration with a local youth group, is currently looking into yam (ufi) growth as a climate indicator for tropical cyclones in relation to the effects of El Niño and La Niña.

Another case example is the Malawi Red Cross Society that conducted community consultation in the northern district of Karonga to gather indigenous local knowledge on the impacts and drivers of flash floods (deforestation and sedimentation), early warning signs (changes in clouds, wind direction, and rainfall patterns), and distinct hydro-meteorological processes that lead to flash flood events (Bucherie et al., 2022). This knowledge was supplemented with traditional knowledge of historical records of disaster events, together with impacts, and perception of frequency were combined with large-scale scientific and global reanalysis datasets to inform EO-fed modelling and hindcasting. Indigenous knowledge was used to: guide the scientific analysis of the factors that contribute to flash floods in the area; improve understanding of flash flood processes within the local context; and contribute to the risk knowledge for flash Flood Early Warnings.

2.5 Opportunities and considerations in technology applications for advancing climate information and risk knowledge

One of the resounding findings emerging from the review of country experiences in this section (see Table 4) is that innovations and technology solutions are most effective when used in combination,

[26] 20 university students and young professionals from Niger's OpenStreetMap community

[27] Data points on the type of building, number of people in the household, preferred contact channel in case of emergency, type of crops, characteristics of key infrastructure elements such as culverts and streetlights, description of drainage and sewage etc.

[28] Learn more about the Local Communities and Indigenous Peoples Platform under the UNFCCC (>Link)

whether it is a combination of technology types (e.g. citizen science, satellite data and products, mobile applications), or hard, soft and organizational technology measures, and in response to context-specific needs.

Moreover, technology measures for climate information and disaster risk knowledge can often provide benefits to multiple sectors at once (including water and agricultural, as well as infrastructure, urban and energy systems), and inform climate change adaptation and mitigation actions, while supporting knowledge creations to assess the status of biodiversity and loss and damage.

Besides the foundational role of the climate information and disaster risk knowledge in advancing all elements of MHEWS, such insights are key for providing and strengthening the rationale for investments in MHEWS as well as other climate-resilient infrastructures, enabling impact-based decision making and risk-informed adaptation planning and action.

For vulnerable countries and regions aiming to achieve early warnings for all their citizens, utilizing public-private partnerships and international cooperation can lower the cost of governments to access international capital and ensure increased investments in risk reduction.

While in some parts of the world climate observations are available in abundance, in others they are scarce or even non-existent, and may not be exchanged internationally or frequently enough. Remote EO techniques provide the opportunity to improve data availability to observe the planet and monitor potential disasters even in otherwise hard-to-reach communities. Moreover, emerging efforts to digitize tacit traditional knowledge for recording and sharing, present new opportunity to facilitate integration the traditional knowledge with scientific analysis (i.e. hindcasts out of models) into the comprehensive EWS in a systematic manner.

Technology measures can help extending the benefits of risk knowledge to the local level to reach the last mile. Use of readily available technologies (e.g. cell phones and cloud data-sharing platforms) could enable involvement and even active participation of local stakeholders including indigenous peoples, citizen scientists, academic institutions, youth and female-led local groups as well as startup companies in the process to produce disaster risk knowledge. Such co-development and co-creation of climate information and disaster risk knowledge help boost the ownership of EWS and consequently facilitate wider access and use of them.

This brief has focused its attention on proven technology solutions that are available and may be scaled up for wider application in vulnerable contexts, i.e. SIDS and LDCs. However, it is equally important to consider potential applications of emerging technologies that are currently is use primarily in developed countries, but may lend themselves to innovative solutions for improving risk knowledge and information for all in the near future, e.g. digital twin Earth (DTE) models, Natural Language Processing (NLP), Satellite Internet Networks and Surface Water and Ocean Topography (SWOT) satellite.

Table 4 - A summary of country examples from applied technology measures, as presented in this brief

	Country	Technology measure	Technology outputs/outcomes	Hazard type	Impact sectors
Production	Tuvalu	Sensors (LiDAR). GNSS, TRF	Obtaining bathymetry and topography to elucidate the relationship between land elevation and sea level rise	Sea-level rise	Coastal zones, infrastructure
	Colombia	Sensors (Satellite), cloud computing	Assessment of erosion and land degradation by flood/landslides; SDG reporting	Flood, landslide	Water
	Fiji	Citizen science, satellite, social media, crowd sourcing	Risk profiling of possible relocation sites for discussions among communities affected by sea level rise	Sea-level rise	Coastal zones

	Belize	AI/ML, satellite, cloud computing	assessment of coastal & marine ecosystems, e.g. coral reefs and mangroves for NAP	All	Coastal zones
Use	Uganda	Models, AI/ML, MobileApp, satellite	Predetermining EW threshold for drought-induced crop failure to trigger disaster risk finance and social safety net program	Drought	Agrifood systems
	Indonesia	Models, satellite	Producing and calibrating impact-base forecasts	Flood, landslide, extreme we ather	Climate & weather observations
	Mongolia	Models, MobileApp	Local-level vulnerability and hazard mapping for future climate & flood risks for development and land use plans	Flood	Water
	South Africa	Mobile-IoT, fire sensor	Alerting informal settlements about fire with an opt-in micro insurance	Fire	Infrastructure
	Thailand	GNSS	Identifying and targeting vulnerable people for warning about tsunami, forest fire and air pollution	Tsunami, storm, forest fire	Water, coastal zones
	Sri Lanka	Cloud-computing, API, satellite, AI/ML	Community anticipatory action planning; forecast based financing	Flood, drought, storms	Agrifood systems
	Ecuador	Cloud-computing, satellite, AI/ML, models	Analysing hindcast of historical streamflow of remote collage for women-led project to design an aqueduct to deliver water to irrigate farmlands	Drought	Agrifood systems, infrastructure
Access	Burundi	GIS software, EO	Overlying climate info and disaster knowledge, data integration; national disaster risk info management system, institutionalising UN-data base to national government	All	All
	Mauritius	API, satellite	Visualizing, analysing historical and real-time rain and snow fall	Flood, drought	Climate & weather observations
	South Africa	API, models, satellite,	Data integration for malaria predictions and insecticide spray planning	Heat, infection	Health, heat
	Senegal	ARD/Data cube, satellite	Assessing location and patterns of coastal retreat/erosions	Coastal flooding	Coastal zones
Enabling environment	Haiti	GIS, satellite	Capacity development for updating landcover map as critical layer (basis) for PDNA, UNFCCC/UNCCD/Rio reporting	Storms, earthquake	All
	Niger	citizen science, satellite, mobile App, UAVs, models	PPP: private(startup)-academia-youth collaboration	Flood	Water, agrifood systems
	Chile, Peru, Colombia	Sensors, Models	Regional/transboundary/basin-wide cooperation to share climate services of Andes glaciers, facilitating legal framework & institutional structures to share data	Glaciers melt/floodi ng	water, agrifood systems, energy, infrastructure
	Nieu island	Digital/mobile app	Examine indigenous climate indicator in el nino & la nina years	Drought	Agrifood systems
	Malawi	Digital, satellite, (models)	Indigenous/traditional knowledge on to guide scientific analysis using EO-fed modelling for flash floods	Flash flood	Water

Section 3

[Placeholder for conclusion, including any key messages and/or policy recommendations emerging from this work, to be developed after the TEC 28 meeting]

Annex - Lessons Learned of Funding Entities in supporting climate information and early warning systems

A. Green Climate Fund (2022)

- Reliable, timely and effective climate information and early warning systems are essential for achieving objectives outlined in the Paris Agreement and the 2030 SDGs.
- Limited coordination and data sharing between government and non-government entities undermine the effectiveness of climate information and early warning systems.
- Inadequate hard and soft infrastructure limits the coverage and uptake of climate information and early warning systems.
- Integration of fragmented interventions diminishes the effectiveness of existing support to developing countries.
- Limited public funding for National Meteorological and Hydrological Services constrains the operation and maintenance of equipment.
- Significant technical difficulties are experienced by developing countries in building and using national climate information and early warning systems.
- The absence of an enabling environment, including policies, incentives, funding, and entrepreneurial culture deters climate resilient practices.
- There is limited quality of climate data and forecasts, necessary for supporting financial and investment decisions.
- 'Last mile' effectiveness is limited. Despite the existence of climate information and early warning systems, remote communities do not necessarily benefit from early warnings and early actions.

B. Adaptation Fund(2023)

- Higher quality data leads to better decision-making: Understanding future risks calls for detailed hydrometeorological data across temporal and spatial scales. Innovative approaches e.g., using international satellite data are useful for addressing local data gaps. While ground truthing and community engagement are robust data collection and verification tools. Ultimately, integrating diverse sources of information is crucial for building higher quality assessments including risk mapping and scenario planning.
- Improved risk knowledge and communication advances outcomes: The success of early warning systems depends on their capacity to meet the needs of users, giving them enough time to act. Evidence suggests that different communities require tailored information presented in various formats to facilitate meaningful action.
- Institutions fit for purpose ensure success: Projects require technical staff with proper skills and sufficient resources, important for managing emerging data related to early warnings. At the regional level, formal institutions with a legal mandate are important. While at the community and local level, disaster management offices and community groups play a key role in facilitating the collection and use of climate information.
- Community-led interventions are essential for long-term resilience: Community involvement increases the effectiveness of risk planning and renders early warning systems more responsive to community needs. Community-based approaches combine local knowledge with informed decision-making, thereby improving risk knowledge and disaster management processes, and creating ownership.
- Working within existing government structures and policy environments enables scalability: Streamlining projects with policy and government initiatives ensures the sustainability of interventions, support

existing priorities, and enables buy-in. Furthermore, it facilitates the long-term institutionalization of activities within government mandates.

- Partnerships and coordination help achieve goals: Partnerships have been important to the success of projects given that partners provide diverse skills sets, resources, and networks.
- Learning improves capacity and bolsters sustainability: Learning is taking place at various levels across projects, which supports transfer of disaster risk and adaptation knowledge and ensures long-term sustainability of activities. Workshops, training programmes and site visits have increased understanding of climate risks and ensured effective implementation of project activities.

C. Global Environment Facility (2024)

- Findings suggest that although projects have improved their climate information and early warning capabilities, there is still a lack of systematic knowledge transfer for disaster responses. More attention needs to be placed on community-level risk awareness and capacity building linked to appropriate responses. An effective early warning early action value chain depends on complete national and local plans together with communication infrastructure and knowledge for effective response.
- Projects have achieved success meeting the objectives across climate information and early warning systems, such as delivering warning services through infrastructure development and capacity building. That notwithstanding, there is uncertainty in sustaining funding for project outcomes in the long run as operational and maintenance costs of climate information and early warning systems can be challenging, especially in LDCs.
- There are significant wins in integrating climate information and early warning system elements into existing systems, harnessing technologies, and strengthening the results of other interventions that have demonstrated their catalytic potential.
- Advancements have been made in developing infrastructure and building capacity for climate information and early warning systems; however, the “last mile” challenge persists, particularly the delivery of actionable climate information and warnings to local communities.
- Integrating hazards, vulnerabilities, and risk reduction measures enhances institutional effectiveness, operational efficiency, and public preparedness, contributing to the overall effectiveness of climate information and early warning systems.
- Private sector involvement in climate information and early warning system projects remains constrained even though collaborations with private sectors is supported for innovative solutions in sectors such as agriculture and insurance.

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