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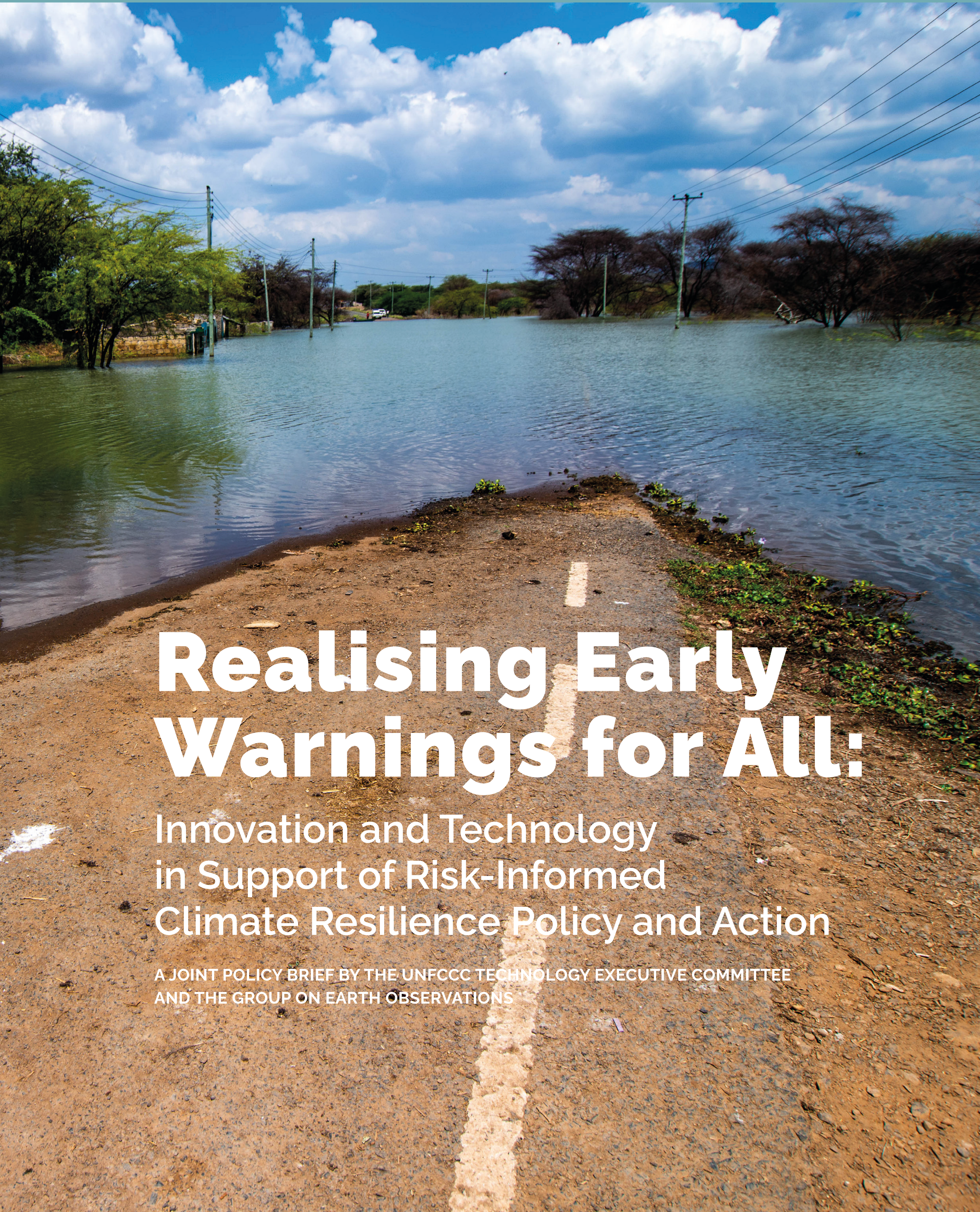

Realising Early Warnings for All:

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

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Abbreviations and acronyms

Acronym	Name
AF	Adaptation Fund
AI	Artificial intelligence
API	Application programming interface
ARD	Analysis ready data
CIEWS	Climate Information and Early Warning Systems
CREW	Climate Risk and Early Warning Systems
CTCN	Climate Technology Centre and Network
DRR	Disaster risk reduction
EO	Earth observations
EW4All	Early Warnings for All
EWS	Early warning system(s)
GCF	Green Climate Fund
GEF	Global Environment Facility
GEO	Group on Earth Observations
GIT	Geospatial Information Technology
GIS	Geographic Information System
GNSS	Global Navigation Satellite System(s)
IFRC	International Federation of Red Cross and Red Crescent Societies
ITRF	International Terrestrial Reference Frame
IoT	Internet of Things
IPCC	IIntergovernmental Panel on Climate Change
ITU	International Telecommunication Union
LDC	Least developed country
LDCF	Least Developed Countries Fund
LiDAR	Light Detention and Ranging
MHEWS	Multi-hazard early warning system(s)
ML	Machine learning
NAP	National adaptation plan
NLP	Natural language processing
NDC	Nationally determined contribution
PPPs	Public-private partnerships
R&D	Research and development
SCCF	Special Climate Change Fund
SFDRR	Sendai Framework for Disaster Risk Reduction
SFM	Sendai Framework Monitor
SIDS	Small Island Developing States
SMS	Short message service
SOFF	Systematic Observations Financing Facility
TEC	Technology Executive Committee
TNA	Technology Needs Assessment
TRF	Terrestrial Reference Frame
UAVs	Unmanned aerial vehicles
UNCCD	United Nations Convention to Combat Desertification
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
UNOOSA	United Nations Office for Outer Space Affairs
UNOSAT	United Nations Satellite Centre
WMO	World Meteorological Organization
WIM	Warsaw International Mechanism

Foreword

Climate-related disasters are increasing in frequency and intensity, placing immense pressure on vulnerable communities worldwide. Small Island Developing States (SIDS) and Least Developed Countries (LDCs) are particularly at risk, and are already facing devastating impacts such as storms, floods, droughts, and rising sea levels. These communities bear the brunt of climate crises, and the need for risk-informed policies and disaster risk reduction measures has never been more urgent. As multi-hazard early warning systems (MHEWS) are among the most effective tools to safeguard communities, the Early Warnings for All (EW4All) initiative has been under way with the aim of ensuring that everyone on Earth is covered by MHEWS by 2027.

Technology and innovation are critical to implementing the EW4All initiative, driving climate adaptation and disaster resilience. However, significant disparities exist among countries in access to and availability of technology and hence the data on and knowledge about disaster risk – particularly in areas most vulnerable to climate disasters. This policy brief, jointly produced by the UNFCCC Technology Executive Committee (TEC) and the Group on Earth Observations (GEO), addresses these challenges. It highlights the essential role of climate technology policies and scalable fit-for-purpose technology solutions in improving climate information and disaster risk knowledge, enhancing the effectiveness of MHEWS.

The TEC plays a pivotal role in supporting Parties to the Paris Agreement by identifying policies that accelerate the development and transfer of climate-resilient technologies. The Committee has been producing a series of knowledge products to stimulate policy discussions on climate technologies, aiding countries in integrating technology into their national adaptation plans and fulfilling their climate commitments. In partnership with the TEC, the GEO, as an established intergovernmental organisation advancing the use of Earth observation data to deliver transformative 'Earth Intelligence' solutions, brings its innovative use cases and extensive network of scientists and technical experts from public and private sectors, to ensure the robustness of this policy brief.

To scale up MHEWS technology innovations effectively, it is crucial to strengthen the technology capacity of relevant stakeholders in developing countries. This includes Indigenous Peoples, youth, female-led and community-based groups, who are vital in generating and using local data on vulnerabilities and exposure to hazards. Empowering these groups with the digital and mobile technologies and tools to engage in climate resilience efforts ensures that local contexts and needs are met, and that the climate information and risk knowledge can be trusted and actionable, and therefore deliver effective 'last mile' early warning systems.

Achieving the vision of the EW4All initiative will require scaled-up innovation, international cooperation, and long-term financing. As supporting implementing partners of EW4All initiative, the TEC and the GEO are committed to working with Parties, EW4All partners and other stakeholders to foster the integration of fit-for-purpose technology solutions in developing countries, and particularly in SIDS and LDCs.

We call on Parties, international organisations and all stakeholders to join us in accelerating risk-informed, data-driven climate resilience policies and actions. Together, we can leverage the power of technology and innovation to create a future where people, properties and the environment are better protected and empowered to respond to climate-related disasters.

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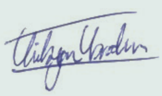

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This joint policy brief of TEC and GEO, Realising Early Warnings for All: Innovation and Technology in Support of Risk-Informed Climate Resilience Policy and Action, is part of a long-running series of publications by the TEC. It is also positioned as one of the flagship reports under the global work of EW4All Pillar 1, led by the United Nations Office for Disaster Risk Reduction (UNDRR), and used as part of the EW4All Implementation Toolkit towards country rollouts.

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Executive Summary[1]

Key Messages

1. The Technology Executive Committee (TEC) highlights the following key messages drawn from the findings in a policy brief on this issue prepared jointly with the Group on Earth Observations (GEO):

(a) **Scaling up early warning innovations and technologies is essential** to enhancing risk-informed climate resilience policies and actions;

(b) **Climate information and disaster risk knowledge provide the foundation for the multi-hazard early warning system value chain**, which saves lives and protects property and the environment. Yet, significant differences exist among countries in access to and availability of data and knowledge on disaster risk; in particular, the LDCs, SIDS and African countries experience poor access and availability. Challenges in relation to risk knowledge, including in its monitoring, status reporting, production, use and accessibility, persist globally, but in particular for these countries;

(c) **A wide array of scalable technology measures, platforms and services have already demonstrated their effectiveness** in boosting climate information and disaster risk knowledge for countries in need. These technologies are most effective when integrated: for example, by combining hardware, software and 'orgware' measures; approaches based on Indigenous and traditional knowledge; and high- and low-technology open solutions that leverage low-cost sensors, mobile and digital technologies, AI and Earth observation satellites, for example;

(d) **Parties have underscored the importance of early warning systems to realising their climate agendas in their national action and planning documents:** about 50 per cent of NDCs, about 40 per cent of NAPs and more than 90 per cent of adaptation communications submitted under the Convention and the Paris Agreement mention early warning systems. However, there is limited recognition of the role of technology applications in improving climate information and multi-hazard early warning systems in these policies and plans or in country programme documents and funding proposals submitted to climate funds: only about 25 per cent of NDCs, 30 per cent of adaptation communications, 12 per cent of the adaptation-related components of TNAs and 10 per cent of GCF funding proposals based on NAPs highlight technologies for this purpose;

(e) **Long-term financing**, both domestic and international, supported by a coordinated multisectoral approach is key to sustaining project outcomes and scaling-up integrated technological solutions that address multiple hazards across multiple sectors, including the building of resilient infrastructure and the assessment of loss and damage;

(f) **Technology can empower citizen scientists and other local stakeholders to produce and use local data on vulnerability and exposure to hazards,** allowing countries to identify their most vulnerable populations, communities and groups. Such local data and knowledge enable evidence-based decision-making and enhance people-centred multi-hazard early warning systems with effective 'last mile delivery', which remains a key challenge.

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[1] This executive summary is what was agreed at the 29th meeting of TEC as its key messages and recommendations for the Conference of the Parties at its 29th session (COP29) and the sixth Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA6). This is included on pages 25 and 26 in the joint annual report of the TEC and the Climate Technology Centre and Network (CTCN) for 2024 (>Link).

Recommendations

2. To scale up innovation and fit-for-purpose technology solutions, the TEC recommends that the COP and the CMA encourage Parties, international organisations and stakeholders, as relevant, to:

(a) **Consider technologies for multi-hazard early warning systems when preparing and updating NDCs, NAPs, TNAs and other national strategies and plans**, where appropriate, integrating a combination of complementary technologies into both existing and proposed systems, plans and processes;

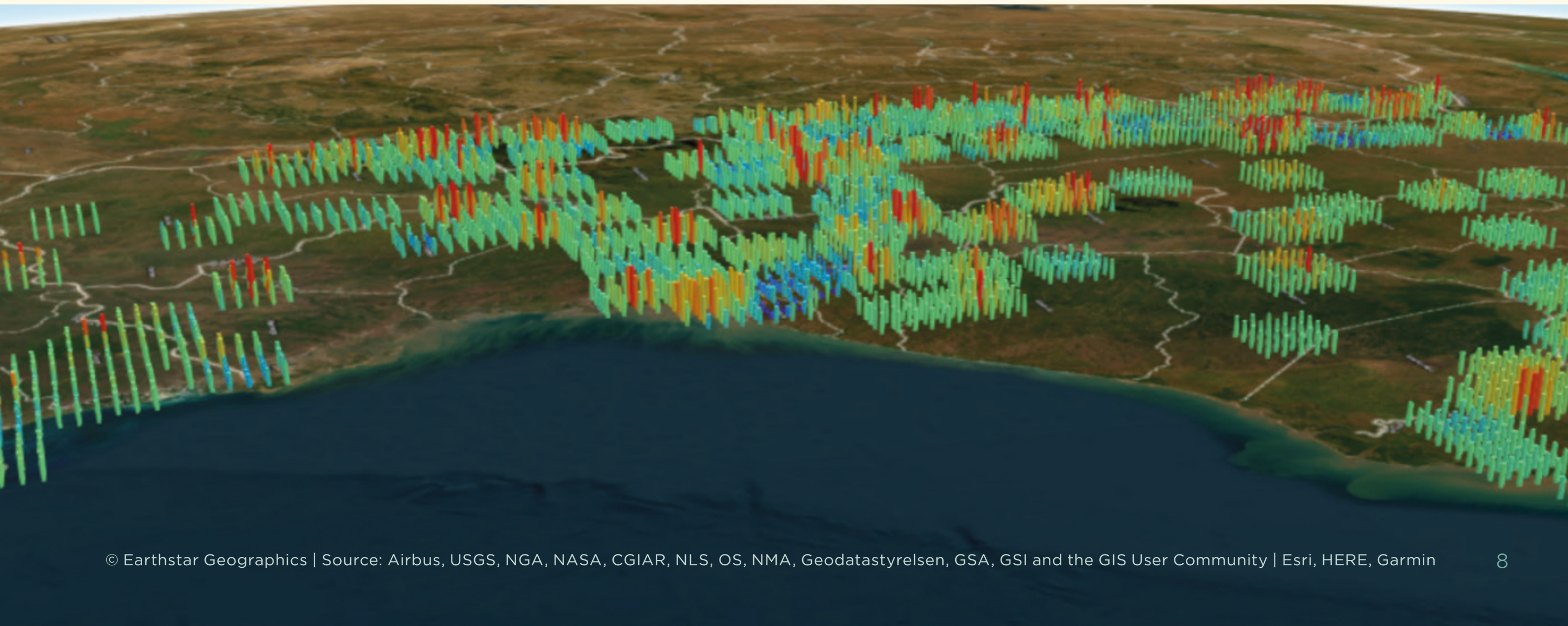
(b) **Invest in multisectoral technology solutions** by leveraging funding from relevant financial mechanisms and other sources, including the AF, the Climate Risk and Early Warning Systems initiative, the Fund for responding to Loss and Damage, the GCF, the GEF and the Systematic Observations Financing Facility, while building on the outcomes of funded projects to avoid fragmentation of efforts, promote longer-term sustainability and maximise impact;

(c) **Leverage international initiatives and public-private partnerships** in order to strengthen the capacity of Governments to understand and mitigate context-specific disaster risks and to reduce the financial and other barriers associated with accessing international capital;

(d) **Support the integration of technologies into projects to promote local stakeholder engagement** such that both low- and high-technology solutions enable the creation and consumption of risk knowledge by Indigenous Peoples; youth; female-led and community-based groups and entities, including local universities, research institutions and start-ups;

(e) **Build the technical capacity of stakeholders** in developing countries for enhancing reporting on, production, use of and access to risk knowledge, including by implementing targeted actions that strengthen the inclusion and build the capacity of women in technology in order to address persisting gender disparity;

(f) **Leverage the global community of scientific experts and innovators**, including GEO, who promote open data, knowledge and solutions as public goods; and who can provide the technical support and knowledge transfer needed for engaging stakeholders and building their capacity; while helping to design fit-for-purpose combined technology measures, including frontier and emerging technologies.



Why this brief?

Climate and disaster risk knowledge and information is a foundational element of MHEWS[2] and key for realising the EW4All initiative[3] 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[4] and disaster risk knowledge is widely recognised as both an enabling and a catalysing 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 LDCs, SIDS and African countries.

Part of a long-running series produced by the TEC to foster policy discussions on climate technology and innovation, and building on the expertise of the GEO and EW4All partners,[5] this joint policy brief will provide useful policy insights and technology 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 multi-hazard early warning systems, 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 system 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 (EO) community, this brief aims to inform a range of stakeholders in the early warning system value chain in their actions, particularly policy-makers at the national levels who are involved in the formulation and implementation of disaster risk reduction (DRR), climate change adaptation, loss and damage, and climate technology plans, policies and actions.

[2] An early warning system is an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events. Multi-hazard early warning systems address several hazards and/or impacts of similar or different type in contexts where hazardous events may occur alone, simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. A multi-hazard early warning system with the ability to warn of one or more hazards increases the efficiency and consistency of warnings through coordinated and compatible mechanisms and capacities, involving multiple disciplines for updated and accurate hazards identification and monitoring for multiple hazards. See A/71/644 (>Link)

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

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

[5] 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, fuelled 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[6] (UNDRR & WMO, 2023).

The occurrence of weather, climate and water extremes has been increasing worldwide. From 1970 to 2019, the number of reported disasters has increased by a factor of 5 (WMO, 2021), water-related disasters being the most prevalent disaster type, and tropical cyclones being the leading cause of reported human and economic losses worldwide (WMO, 2023). Weather-, climate-or water-related disasters in this period are reported to have caused over 2 million deaths and US$4.3 trillion in economic losses. The losses disproportionally impact LDCs, SIDS and landlocked developing countries (UNDRR & WMO, 2023).

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. Implementation of multi-hazard early warning systems (MHEWS) has led to a significant reduction in mortality, evidenced by the nearly three-fold reduction in reported deaths during this 50-year period. (WMO, 2021).. EWS provide more than a tenfold return on investment (WMO, 2022). 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 (GCA, 2019).

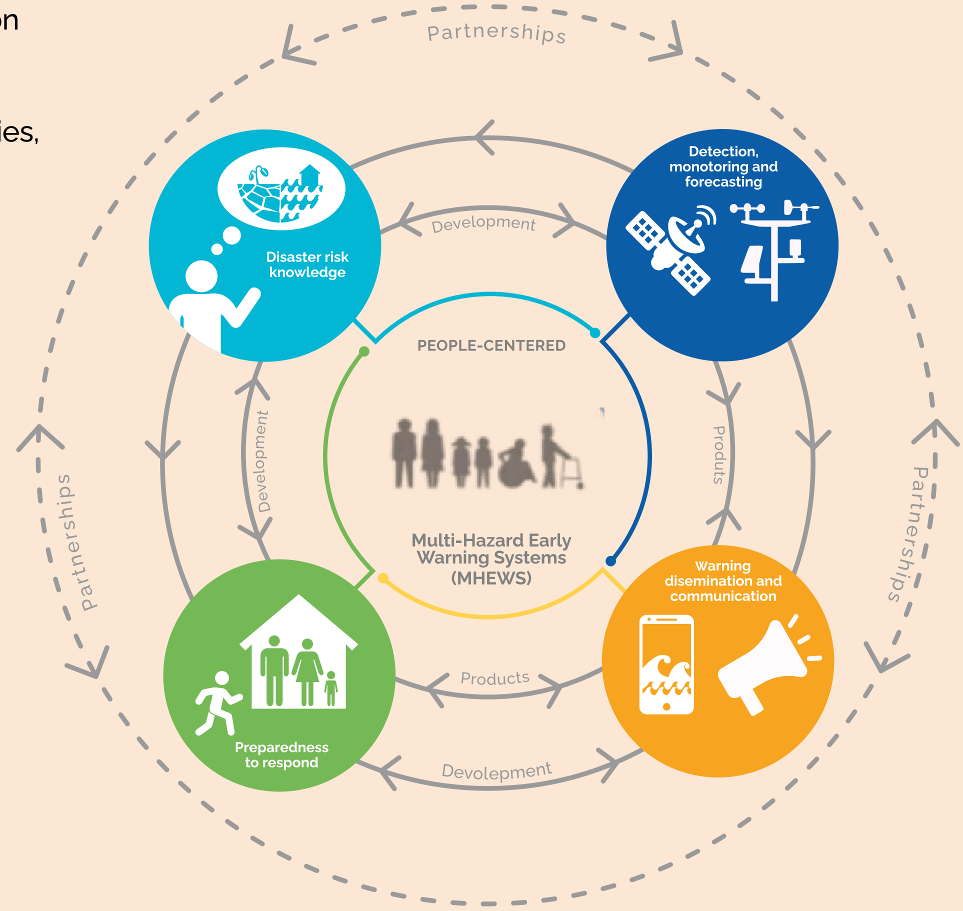
Evidence suggests that a high-functioning early warning system value chain (see Figure i) facilitates timely action by individuals, communities, and organizations to respond to- and reduce the risk and impact of disasters. Climate information and disaster risk knowledge play a crucial role in advancing all elements of people-centred, 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.

[6] According to the United Nations Office for Disaster Risk Reductions (UNDRR)'s Hazard Information Profiles (>Link), 302 hazards are classified into 8 types, such as Meteorological and Hydrological hazards (e.g. floods, droughts, heatwaves), geohazards (e.g. earthquakes, landslide, tsunami), environmental hazards (e.g. wildfires) and biological hazards (e.g. infectious diseases such as dengue and malaria). While Meteorological and Hydrological hazards tend to be a popular focus for countries in implementing the Early Warnings for All (EW4All) initiative, it is important to consider multi-hazard risks of the country's concern as different hazards may occur simultaneously or cascade.

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 i):

Figure i: Early warning system value chain diagram based on four pillars of MHEWS.



Source: (WMO, 2022)

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

Figure ii: Interconnections between the four essential pillars of MHEWS across the value chain.

	RISK KNOWLEDGE	OBSERVATIONS & FORECASTING	WARNING DISSEMINATION & COMMUNICATION	PREPAREDNESS TO RESPOND
RISK KNOWLEDGE		Which hazards to monitor, where and how	Communication strategies to reach vulnerable populations Ability of communications equipment to withstand extreme events	Development of plans and protocols Testing/ optimising comms channels Public awareness/ education campaigns
OBSERVATIONS & FORECASTING	Data and information to quantify hazards and exposure to risk		Warnings as triggers for communication	Warnings provide details on impact and response
WARNING DISSEMINATION & COMMUNICATION	Strengths / weaknesses of communication channels	Agreements on authoritative and consistent warning protocols and language		Plans include communication channels and protocols
PREPAREDNESS TO RESPOND	Feedback and lessons learnt from events and exercises used to update risk knowledge	Feedback and lessons learnt from events and exercises used to optimise monitoring, forecasting and warning	Feedback and lessons learnt from events and exercises used to optimise communication mechanisms/ channels	

Source: (UNDRR & WMO, 2023)

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** (Figure ii). For example, understanding hazards, exposed populations and assets, and impact sectors is necessary for: determining which hazards to monitor, where and how (Pillar 2), formulating communication strategies to reach vulnerable populations and ensuring communications equipment can withstand extreme events (Pillar 3), and developing response plans and protocols 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 & 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 EW4All initiative, which has adopted the MHEWS framework, aims to ensure that everyone on Earth is covered by an EWS by the end of 2027.

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 & WMO, 2023, UN, 2023). It also supports key provisions of the SFDRR 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**

Article 7 of the Paris Agreement emphasises 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 (UNFCCC, 2015). Article 8 of the agreement mentions EWS as an area of cooperation and facilitation to enhance understanding, action and support with respect to loss and damage. Subsequent decisions under the Paris Agreement[7], including the outcome of the first global stocktake, call for enhanced action and support to increase access to useful and actionable climate information services and EWS, as well as the implementation of the EW4All initiative. The UAE Framework for Global Climate Resilience[8], 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[9]), and their applications for improving risk knowledge and information to advance 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, especially for Parties, international organisations and other relevant stakeholders who are involved in policymaking, scoping, designing and implementing projects. 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.

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[7] 1/CMA.4 and 1/CMA.5
[8] 2/CMA.5
[9] 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 lens of multilateral processes

Key takeaways for policy makers from this section:

The findings presented in this section underscore the global status of MHEWS, revealing the uneven distribution in the availability of disaster risk knowledge, especially in countries with special needs. The discussion covers both the challenges and the opportunities for enhancing climate information and risk knowledge. Additionally, it maps technology needs and priorities for improving EWS, outlines the challenges and enablers for effective implementation and highlights trends and key considerations in technology applications.

1.1 Global Status of multi-hazard early warning systems

The latest report of the Global Status of Multi-Hazard Early Warning Systems 2024 shows that only 55 per cent of the countries in the world are covered by an EWS (UNDRR & WMO, 2024). Although a positive trend in coverage has been observed over the past decade, it has been modest: Only 44 per cent of the LDCs and 38 per cent of SIDS have reported the existence of MHEWS (UNDRR and WMO, 2024). Of the 108 countries that reported the existence of MHEWS, as of March 2024, less than half of countries have confirmed availability of accessible, understandable, usable and relevant disaster risk information and assessments at both national and local levels[10] (UNDRR & WMO, 2024).

As of 2024, the majority of LDCs and SIDS have never reported on the disaster risk knowledge (Pillar 1) under the SFDRR[11], which may be attributed in part to constraints on technology, financial and human resources and skills in SIDS and LDCs to collect relevant data and assess the effectiveness of MHEWS.

Broadly speaking, Pillar 1 on disaster risk knowledge made the least progress over the past decade (UNDRR & WMO, 2023), revealing significantly low scores across all regions. This reinforces the urgent need to increase global production of disaster risk knowledge, with a particular emphasis on LDCs and SIDS. To accelerate progress on MHEWS implementation, the Executive Action Plan of EW4All

[10] The official reporting of countries' progresses on risk knowledge (Pillar 1) within the MHEWS is tracked on the UNDRR Sendai Framework Monitor with indicator G-5: "Number of countries that have accessible, understandable, usable and relevant disaster risk information and assessment available to the people at the national and local levels". In 2024, 49 per cent of the countries reported the existence of MHEWS had positive (non-zero) Pillar 1/SFM G-5 scores, confirming the existence of disaster risk knowledge information. Although the percentage has improved since 2015, the Pillar 1 coverage is still the lowest among the four MHEWS pillars.

[11] For example, as of March 2024, only 8 out of 45 LDCs and 10 out of 39 SIDS, reported some level of the coverage for disaster risk knowledge in the UNDRR Sendai Framework Monitor (SFM) (Pillar 1, SFM Indicator G-5).

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[12] 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 to 2020 and 1,800 programmes and initiatives dedicated to the transfer of science, technology and innovation between 2005 and 2022 (UNDRR, 2024 and 2021). New and existing technology and innovation measures present 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

Reporting coverage and score of risk knowledge elements within the MHEWS framework remain consistently low, particularly in SIDS, LDCs and African countries[13], suggesting that efforts to scale up global good practices for 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, standardised, 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 and 2024). Mainstreaming people-centred and locally led approaches across all elements of the early warning system 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 and knowledge 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 benefiting 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) organised 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, making up roughly 70 per cent of all attendees.[14] 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[15].

[12] 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.

[13] Per inputs provided by the UNDRR in June 2024, the average score for Pillar 1 (Indicator G-5) on the UNDRR Sendai Framework Monitor, as self-assessed by governments, for SIDS is 0.44 and for LDCs is 0.32; and Africa regional score is 0.34, all lower than the average global score of 0.56.

[14] Per inputs provided by the UNOOSA secretariat, in March 2024.

[15] Per inputs provided by the United Nations Institute for Training and Research secretariat, in March 2024.

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

In most countries, marginalised groups, who are particularly vulnerable to the impacts of climate change, are typically excluded from early warnings (UN, 2023). This is compounded by limited disaggregated reporting on demographic factors such as sex, gender, age and disability at the national and subnational levels (UN, 2023). Considering intersectionality across vulnerable groups, whereby all forms of inequality and marginalization are mutually reinforcing, demographic factors must be analysed and addressed in parallel to prevent one form of inequality reinforcing another.

Climate disasters are not gender-neutral. Women and children are 14 times more likely than men to die during a disaster (OECD, 2023), in part because of a lack of information, resources, training and decision-making power to respond to disasters. Data disaggregation is crucial for analysing 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). Disaggregation can also be enhanced through 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) with relevant technology measures (e.g., citizen science, artificial intelligence (AI), models to create exposure/vulnerability). Ultimately, such data should be used as a basis for risk knowledge and integrated within the larger data ecosystem in a given 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 has 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 & WMO, 2023).

Development, maintenance and operation of MHEWS is another persistent challenge that 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,[16] 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 hindered the use 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 projects that support related technology implementation efforts and their sustainability (GEF IEO, 2024).

[16] LDCF-financed project in Malawi: 'Strengthening Climate Information and Early Warning Systems in Malawi to Support Climate Resilient Development and Adaptation to Climate Change.

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 utilised, 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 as crucial as 'high-technology' solutions is the recognition of 'low-technology'[17] solutions (UNDRR & WMO, 2023) alongside Indigenous and traditional knowledge to support the locally led and context-specific generation and dissemination of risk information 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 & WMO, 2023).

[17] Examples of low-technology communication solutions include posters, murals, town criers and runners, flags, whistles and megaphones.

Enhanced international cooperation in MHEWS, such as 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 road map 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 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's climate change agenda. This is communicated through Maldives' various planning and reporting instruments under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, namely its: national communications (2001 and 2016); National Adaptation Programme of Action (NAPA) (2006); nationally determined contributions (2016 and 2020); ongoing national adaptation plan process (2022–ongoing); and the technology needs assessment (TNA) (2020–2024).

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

- **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 and training 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 road map 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 has been 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 gap analysis of the core capability for MHEWS under the EW4All in 2023;

- **Using multilateral financing windows to utilise technical and implementation support for identifying and formulating risk-informed adaptation measuresmeasures** – 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) (for example, see the ongoing work on the National Adaptation Plan (NAP) process), Global Environment Facility (GEF) and its Least Developed Countries Fund (LDCF), and Special Climate Change Fund (SCCF), Adaptation Fund (AF) and Global Climate Change Alliance Plus (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 part of the new effort on the Global Ecosystems Atlas spearheaded by GEO, Maldives is exploring a pilot project involving a rapid mapping of ecosystems based on the International Union for Conservation of Nature Global Ecosystem Typology, leveraging high-resolution satellite imagery provided by Planet Labs and geographic information system (GIS) technology provided by Esri, commercial partners of the initiative. Access to Planet imagery 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 for 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 of and access to 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 their participation in regional initiatives as a 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). Additional benefits include improving the availability and application of climate information and tools (e.g., establishing regional web-based knowledge-management platforms and data centres) and participation in regional training and networks related to hydrometeorological services, forecasting and early warnings.

Climate information and disaster risk knowledge can also be improved by harnessing technology to enhance data collection, analysis, sharing and 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, crowdsourcing 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 frameworks are an effective means for improving the landscape of climate information and risk knowledge globally. For example, the World Meteorological Organization (WMO) Unified Data Policy provides a comprehensive update of the policies guiding the exchange of weather, climate and related Earth system data between its Members with a commitment to free and unrestricted data exchange.[18] Another example is the Global Geodetic Reference Frame, which includes the International Terrestrial Reference Frame (ITRF) and relevant international standards.[19] It ensures compatibility between geolocation of observations and positioning made by national or regional systems and their technologies and therefore facilitates reliable data and knowledge sharing over extended times and distances (see Section 2.2.3).

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 and accessible risk information.

[18] WMO offers a range of supporting frameworks for data sharing. The Global Basic Observing Network (GBON) is a key component of the WMO Integrated Global Observing System aimed at improving the availability of essential surface-based observational data globally to enhance weather forecasts and ensure citizen safety and socioeconomic benefits. The WMO Information System 2.0 (WIS 2.0) facilitates data sharing across disciplines and supports GBON, embracing an Earth system approach and the WMO unified data policy. The WMO Integrated Processing and Prediction System (WIPPS) provides operational products and services for weather, climate, water and environmental applications, leveraging advanced science and technology for more accurate predictions, benefiting operational meteorology, hydrology, oceanography and climatology.

[19] According to the UN-GGIM Knowledge Base (>Link), the Global Geodetic Reference Frame (GGRF) is a generic term describing the framework that allows users to precisely determine and express locations on Earth as well as to quantify changes of the Earth in space and time. Most areas of science and society at large depend on being able to determine positions at a high level of precision. At present the GGRF is realised through International Terrestrial Reference Frame (ITRF) and International Celestial Reference Frame (ICRF).

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

Information communicated by Parties under the UNFCCC and the Paris Agreement provides practical insights on 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 reporting and planning tools such as nationally determined contributions (NDCs) and national adaptation plans (NAPs), 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.

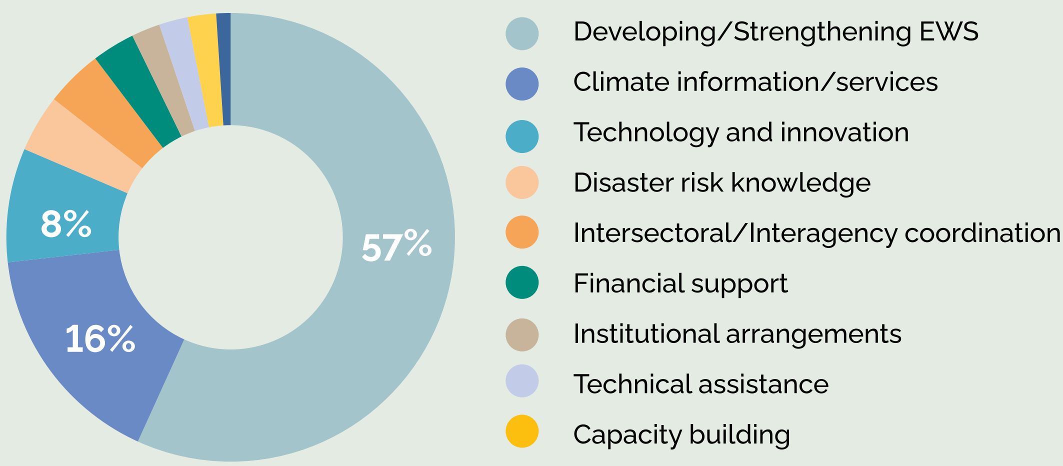
1.2.1 **Nationally Determined Contributions Insights**

NDCs[20] 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 50 per cent of countries have included measures related to EWS in their NDCs, and one in four countries[21] emphasises harnessing technology and innovation to enhance EWS. Some Parties connect the technologies for climate observations and EWS to issues 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, modelling 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 most frequently cited as sectors with the most need for climate observations and EWS technologies.

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



Source: Based on NDCs submitted as of September 2023.

[20] 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).

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

Figure iii 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 iii, much emphasis is placed on the development and improvement of EWS, with 57 per cent of reporting countries that mentioned EWS in their NDCs drawing attention to the need for standardised approaches to and enhanced accuracy of these systems. Community involvement in support of locally relevant solutions is also specified, with countries[22] affirming the importance of end-to-end, people-centred MHEWS. Going further, 16 per cent of reporting countries underscored the need for increased production of and access to climate information, including through enhanced and decentralised 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 legislation that governs 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,[23] established through Article 7 of the Paris Agreement, aims to increase the visibility and profile of climate change adaptation on par with climate change mitigation and also to enhance adaptation actions and support for developing countries.

EWS are frequently referred to in adaptation communication. In fact, **more than 90 per cent of the adaptation communications submitted by Parties to the Paris Agreement (as of January 2024) include references to EWS, with about one-third of them including associated technology measures.** The regional distributions vary considerably, with the most references to EWS in the Africa region and the fewest 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 prioritising technology- and innovation-related measures for EWS are mainly located in the Asia-Pacific region and the Americas.

1.2.3 **National Adaptation Plans Insights**

The process to formulate and implement national adaptation plans (NAPs) under the UNFCCC,[24] aimed at reducing vulnerability to climate change impacts by building adaptive capacity and resilience, supports the objectives of the EW4All Initiative (UNFCCC, 2023). By integrating technology measures into adaptation, NAPs support countries to produce, utilise 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.**

[22] Countries include Albania, China, Lebanon, Madagascar, Malawi, Mozambique, Nepal, Papa New Guinea and Timor-Leste.
[23] Information on submitted Adaptation Communications is maintained on the Adaptation Communications Registry (> Link).
[24] Information on submitted NAPs from developing country Parties is maintained on the NAP Central platform (>Link).

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' (UNFCCC, 2023). Droughts and floods are most frequently cited (by close to 90 per cent of reporting countries) as specific hazards to be addressed through adaptation measures identified in the NAP, followed by increasing temperature, sea level rise and land/forest degradation.

1.2.4 **Technology Needs Assessment insights**

The technology needs assessment (TNA)[25] 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 they subsequently develop technology action plans 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.[26]

According to a 2021 report, **about 12 per cent of all technology measures for adaptation identified through the TNA process are related to climate observation and EWS** (UNEP-DTU & GTC, 2021). Similar to the NDCs, water and agriculture sectors are most frequently cited as sectors with the need for climate observations and EWS technologies. When prioritising different types of technology measures in each sector, the largest share of EWS-related measures is observed in coastal zones and the agriculture sector (UNEP-DTU & GTC, 2021). Countries that have prioritised technology measures for climate observations and EWS in their TNAs[27] most frequently aim to address climate risks related to floods, followed by drought and storms.

[25] Read more about the TNA process under the UNFCCC (> Link)
[26] Read more about the work of the TEC on linkages between TNA and NDCs processes (> Link)
[27] Countries include Antigua and Barbuda, Fiji, Liberia, Malawi and Ukraine from Phase III of the TNA Global Project, and Somalia, St. Kitts and Nevis and Yemen from Phase IV. For more information about TNA Global Project, see the TNA Database (> Link)

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1.3 Mapping challenges and enablers of technology implementation for climate information and multi-hazard early warnings systems

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 information and MHEWS[28]. An analysis of the outcomes of the TNAs and lessons learned by the Climate Technology Centre and Network (CTCN) and funding entities (i.e. GCF, GEF and AF) in supporting technology-oriented projects and programmes for enhancing climate information and EWS points to a set of common and critical issues. These issues are particularly relevant for LDCs and SIDS and may prove useful in strengthening the impact and effectiveness of implementation efforts.

Table 1

Key challenges and enablers for the implementation and scale up technologies and innovations for climate information and EWS

	CHALLENGES	ENABLERS
ACCESS TO FINANCE	Changes in public spending patterns (e.g., because of COVID-19) and uncertainty in accessing international financing and sustaining funding for project outcomes in the long run (GEF IEO, 2024) have hindered the implementation of MHEWS.	**Consistent domestic investment** can be used to train technicians, conduct research and risk assessments, and support technology transfer activities. Various form of **international cooperation**, including mobilization of support from international donors, climate funds and specialised mechanisms[29] (Wagner, 2023), could help leverage additional sources of funding for risk assessments, mapping technologies and capacity-building efforts.
STAKEHOLDER ENGAGEMENT	**Limited involvement of local community groups/organisations**, lack of political will and entry barriers for engaging the private sector are among persisting barriers for implementing and scaling up MHEWS-related technologies and innovations.	Engagement with stakeholders including through: **community-based approaches** that **create ownership** (AF, 2023); participatory and co-production approaches that meaningfully involve local community leaders, academia, research centres, decision-makers and vulnerable groups; and fostering private sector engagement (especially on '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 (GEF IEO, 2024). Moreover, the lack of transparency, information, understanding of sociocultural norms and limited trust in the system by end users is a barrier to effectiveness and uptake of climate information and MHEWS.	Among enablers for improved awareness and public participation in the MHEWS value chain are: promoting a transparent approach to building public trust; integrating Indigenous knowledge; developing or translating tailored communication strategies and knowledge products with and 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 underutilised** 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 systematically leverage modern technologies for disaster risk assessments.	Measures for improving data quality for risk knowledge and information through 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 (AF, 2023); and tailoring information for different communities to facilitate meaningful action (AF, 2023).

[28] 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).

[29] For example, the LDCF and SCCF administered by the GEF, the GCF, the AF, the Climate Risk and Early Warning Systems (CREWS) initiative and the Systematic Observations Financing Facility (SOFF).

	CHALLENGES	ENABLERS
TECHNICAL CAPACITY	**Limited technical capacity to effectively create and interpret climate risk data**, including assessments on sectors and community-related impacts. Limited coverage and uptake of climate information and disaster risk knowledge also makes it difficult to manage operations (GCF, 2022).	Publicly funded research and development initiatives and training programmes by local and international experts/institutions may be implemented to promote the development and retention of technical capacity.
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 MHEWS.	**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 MHEWS, including through regulations (e.g., by reducing operational risks for the private sector engagement), market creation for MHEWS related technology, data (including its sharing) 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/nongovernment entities and national/local levels (GCF, 2022); integration of fragmented interventions lowers effectiveness of support to developing countries (GCF, 2022).	Establishing cross-sectoral working groups to facilitate coordination among institutions to ensure the sustainability of interventions, support existing priorities and enable buy-in (AF, 2023); and establishing a central coordinating agency such as Meteorological Services to manage climate data. Furthermore, **modern warning system technology can be combined with existing infrastructure and institutional arrangements** to enable local authorities to issue warnings in a cost-effective and sustainable manner (WIM Executive Committee, 2019).
TIMEFRAME	Design and implementation of an EWS typically takes one to five 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 MHEWS through climate technologies. This would enhance the efficiency and effectiveness of projects as part of the broader support ecosystem for climate adaptation.
COSTING AND VALUATION	There is limited knowledge 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 MHEWS for climate impacts.	Quantifying the effectiveness of MHEWS, for example, through **evidence-backed estimations of existing or avoided loss and damage** is an effective way to garner political buy-in and support for their implementation. Multi-hazard approaches form the basis of a cost-effective EWS, and the costs of using and maintaining the system will be shared (WIM Executive Committee, 2019).

Source: Insights extracted from TEC (2022a and 2022b), GCF (2022), AF (2023), GEF IEO (2024), WIM Executive Committee (2019).

The EW4All initiative has been an ambitious push in mobilizing the support needed to ensure that everyone on Earth is protected by early warnings, including through the operationalization of a specialized financing mechanism of the initiative the Systematic Observations Financing Facility (SOFF). The initiative also calls for increased coherence and alignment of existing and planned investments from international financing institutions to enable accelerated support and scaled-up implementation of MHEWS (WMO, 2022).

There has been a growing momentum in the recognition of needs and provision of support for strengthening climate information and EWS, including by the GEF, GCF and Adaptation Fund. Box 4 provides a glimpse into relevant work and practical insights from the support of these entities to projects and programmes across the early warnings value chain, including through the implementation of innovative technology solutions.

BOX4 **Insights from the support of funding entities to projects and programmes across the early warnings value chain**

Green Climate Fund[30]

As of May 2024, the GCF has financed more than 70 projects related to EWS and risk-informed climate resilience, supporting about 80 countries across the world, with total budget of roughly USD$4.7 billion inclusive of co-financing. The largest share of beneficiary countries is located in Africa (47 per cent), followed by those in the Asia-Pacific region (32 per cent), Latin America and the Caribbean (18 per cent), and Eastern Europe. About 70 per cent of the listed projects are implemented in the Asia-Pacific and African regions, with roughly the same number of projects in each. Thematically, these projects cover a range of topics, including:

• Development and scaling up of EWS and climate information services by expanding meteorological networks, installing automatic weather and hydrological monitoring stations, and improving flood modeling systems; and

• **Integrating climate resilience into infrastructure planning and development**, such as urban flood management and the mainstreaming of climate-resilient infrastructure.

Other areas of focus include strengthening water management and agricultural practices to enhance resilience against climate variability, community-based adaptation and natural resource management projects, ecosystem-based adaptation, disaster risk reduction, and enhancing agricultural and food security practices.

Adaptation Fund (AF, 2023)

As of June 2024, disaster risk reduction and multi-hazard early warning systems projects account for 18 per cent of Adaptation Fund's portfolio, with a budget of US$206.2 million (AF, 2023). The portfolio, as of April 2024, comprises 22 projects, 10 of which are regional projects, and operates in 36 countries across the globe. Though the Asia-Pacific region has the highest number of approved projects (8 out of 22), about 45 per cent of beneficiary countries are located in Africa, 28 per cent in the Asia-Pacific, 19 per cent in Latin America and the Caribbean, and the rest in Eastern Europe. Emerging recommendations from the review and analysis of the Fund's support for disaster risk reduction and EWS recommended that:

• The Adaptation Fund support sustainable systems; increase resources for coordination; **build alignment with other initiatives, such as EW4All**; promote adaptative management and learning; and **explore the link to loss and damage.**

• Implementing entities and countries focus on the 'last mile' to support near- and long-term planning; build capacity of climate services agencies and climate-sensitive sectors; and co-develop disaster plans with communities.

Global Environment Facility (GEF IEO, 2024)

As of March 2024, the GEF has invested nearly US$690 million from its adaptation funds (LDCF and SCCF) in 105 projects, which include support for climate information and early warning systems (CIEWS) in developing countries, with a specific focus on least developed countries and small island developing states. This is nearly 31 per cent of the total adaptation project portfolio funding on average. This amount represents the total funding for these projects, which includes interventions related to CIEWS but not the specific investments allocated solely for CIEWS components. During the current GEF-8 funding period (2022 to 2026), CIEWS is a priority theme for LDCF and SCCF programming. Findings from the review of a sample of projects in the GEF's portfolio in support of the climate information and EWS (GEF IEO, 2024) suggest that:

• More attention needs to be placed on community-level risk awareness and capacity-building linked to appropriate responses;

• There is **uncertainty in sustaining funding for project outcomes** in the long run, as operational and maintenance costs can be challenging, especially in LDCs;

• Despite advancements made in the development of relevant infrastructure and innovative solutions, the **'last mile' challenge persists,** and private sector involvement remains constrained in the early warning value chain;

• There are significant wins in improving the effectiveness of CIEWS by integrating hazards, vulnerabilities and risk reduction measures into existing systems, harnessing technologies and enhancing institutional effectiveness, operational efficiency and public preparedness.

[30] Per inputs provided by the GCF secretariat in May 2024.

1.4 Trends and key considerations in technology implementation 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 MHEWS value chain. Effective risk knowledge is integral to the entire comprehensive risk management approach like 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 AI[31] 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, EO, and geospatial technologies, and interoperable platforms**, which will be covered in more detail in Section 2.

Box 5 provides a summary of observed trends and key considerations in the current landscape of technology policy and implementation for advancing climate information and disaster risk knowledge, 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 SFDRR, and outcomes of the Global Stocktake under the Paris Agreement.

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

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BOX5 **Trends and key considerations in technology implementation**

• Less than 50 percent of the countries reporting on Sendai Framework targets indicate having fit for-purpose, accessible and actionable risk information (UNDRR & 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 Short Message Service (SMS) messaging and social media to improve public access to and awareness of disaster risk knowledge.

• Despite widespread recognition of EWS as a critical component in disaster risk reduction and resilience building within reporting and planning instruments, challenges persist in terms of developing funding proposals for EWS.

• The emphasis on the development and improvement of EWS over technology and innovation in NDCs reflects the specific needs and priorities of LDCs and SIDS reinforced by certain challenges they face such as financial constraints, limited technical expertise, and institutional capacity gaps.

• The water and agriculture sectors are frequently cited as sectors with a critical need for climate observations and EWS technologies due to their vulnerability to climate change. Climate observations and EWS technologies can contribute to the management of climate-related risks, optimize the use of resources, enhance productivity, and promote resilience of climate-vulnerable sectors.

• Findings show that leveraging technology and innovation can advance 'open policies' on climate information and risk data as public goods.

• Since 2021, progress on Target F of the SFDRR, which underscores the importance of international cooperation in enhancing climate and disaster resilience, has shown a lack of reported instances of DRR-related capacity development as well as an absence of transfers and exchanges of science, technology and innovation as reported by recipient countries (UNDRR, 2024).

• Since 2015, global progress on total official international support for DRR capacity-building and for the transfer and exchange of DRR-related technology has been uneven (UNDRR, 2024).

• The EW4All initiative is an ambitious push in mobilizing the support needed to ensure universal coverage of EWS for all, and since its launch, has led to a growing momentum in the recognition of needs and provision of support for strengthening climate information and EWS by financing entities.

• A total of 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 geographic information system (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 such as AI and Machine Learning (ML), remote sensing and EO 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).

Section 2:

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

Key takeaways for policy makers from this section:

Drawing from the collective expertise of the GEO community and EW4All partners, this section provides policymakers with a proven set of innovation and technology solutions covering hardware, software and 'orgware' measures. These solutions aim to enhance risk knowledge capabilities across various domains of production, access, use and enabling environment. This section provides technical and actionable insights by showcasing country-specific, regional and organisation-driven technology applications based on their readiness for immediate use and their alignment with the objectives of the EW4All Initiative.

2.1 Background

In recent years, technologies for processing, storing, analysing and visualising 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 analyse 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 alongside new and existing technologies as a key cross-cutting enabler for realising global coverage of MHEWS. In particular, it helps drive rapid change in risk knowledge capability (e.g., in production, access and use of risk knowledge) at all scales, for all and through 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 utilised for improving disaster risk knowledge, thereby advancing the entire MHEWS framework.

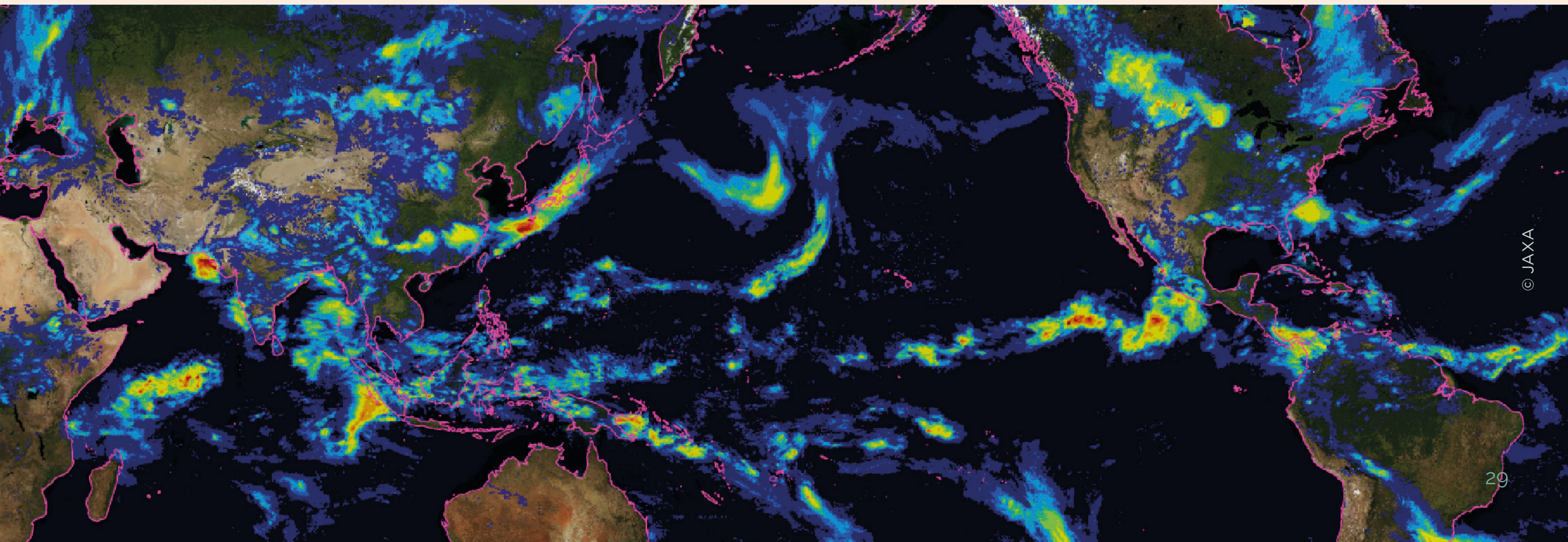


Table 2
Disaster risk knowledge (Pillar 1) checklist used in EW4All country-level consultations

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 repository or federated repository
ENABLING ENVIRONMENT	Are roles and responsibilities of stakeholders identified?	Process for integrating indigenous and traditional knowledge into MHEWS; 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 guide decisions and actions.

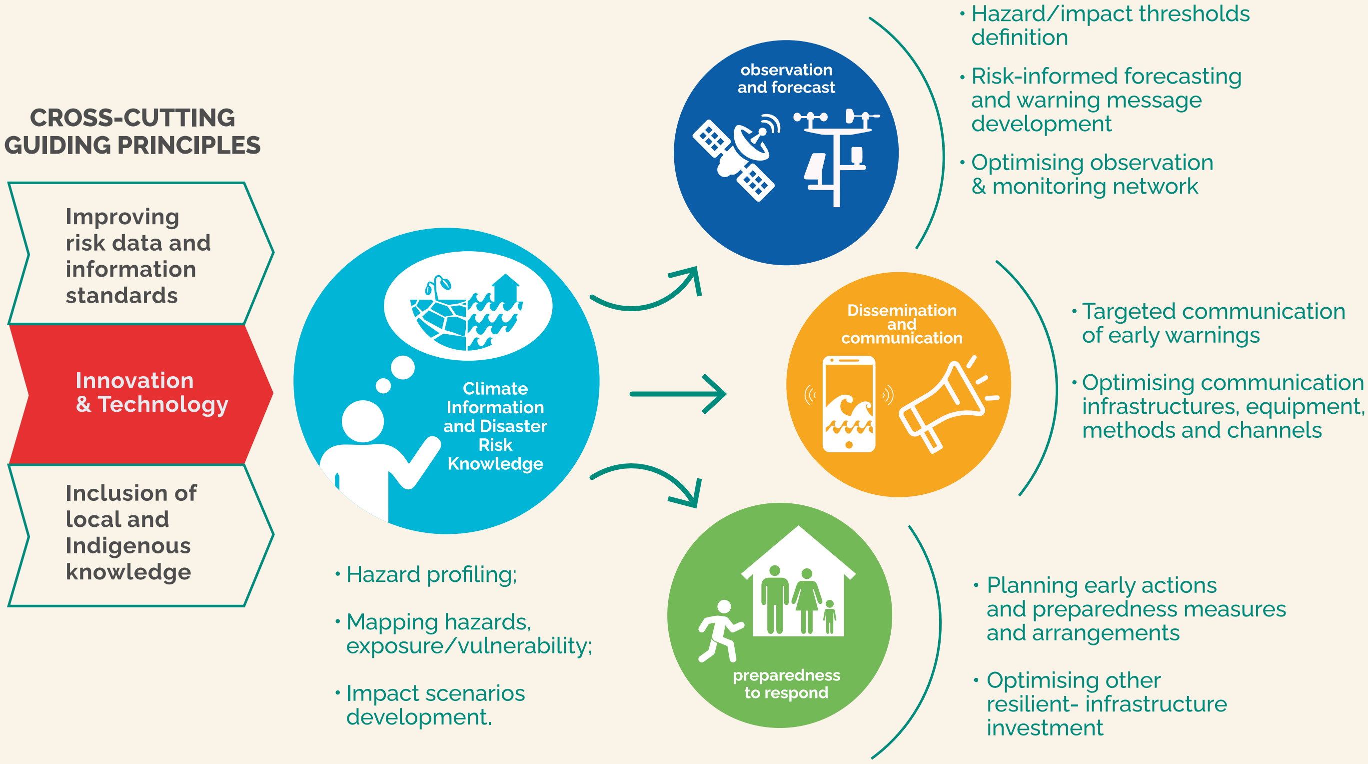
The produced climate information and risk knowledge are used as the basis for creating actionable information for across all MHEWS pillars (see Figure iv). The use of risk knowledge can occur through risk knowledge outputs, such as predetermined hazard thresholds to help the timing and decision of disseminating early warnings (Pillar 2); contents of warning messages (Pillar 2 and Pillar 3); options for communication methods and channels (Pillar 3); and early action plans with safe areas or 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 (i.e., of migrants, refugees, and displaced persons), special-economic status, access to services
Critical infrastructures	Hospitals, power/electric plants, dams, communication towers or centres, (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 iv: Climate Information and Disaster Risk Knowledge as the Basis for MHEWS.



Source: : Adapted based on Handbook on the Use of Risk Knowledge for MHEWS (2024).

The following subsections present a selection of technology solutions[32] (including hardware, software and 'orgware' measures) for each key element of risk knowledge, namely: production, use, access and enabling environment to provide concrete examples of Table 2. 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 the long-term adaptation goals of countries.

[32] See definitions of the following information technology: cloud computing by ITU (> Link) and ISO/IEC (> Link); IoT by ITU (> Link); AI by ISO/IEC (> Link); API by ITU (> w) It should be noted that most technologies can and are applied across various thematic disasters.

2.2 **Production of risk knowledge**

2.2.1 **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 planet Earth obtained via sensor technologies. It can be performed through remote-sensing devices on the ground (e.g., weather radars, hydrological monitoring stations) or mounted on ocean-based and airborne platforms such as ships, drones, airplanes, helicopters and satellites. Basic telemetric observation systems such as automatic weather stations, tide gauges and buoys provide localised and real-time data on essential weather and climate variables (i.e., atmospheric pressure, temperature, humidity, wind direction and speed, precipitation).[33] 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.

Remote sensing can offer the greatest benefits when combined with complementary data acquired through other techniques (STAP, 2021). Basic observation systems (e.g., weather stations) as well as others (e.g., agricultural, ecological monitoring) 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 perform essential hazard identification and profiling with characteristics of hazards, including the location, extent (or severity) and historical occurrences.

For example, Tuvalu took an advantage of a remote sensing method called airborne Light Detection and Ranging (LiDAR) to advance **profiling of the country's top environmental hazard:** sea level rise. LiDAR technology can capture precise ground height and seafloor information therefore bathymetry and topography to elucidate the relationship between land elevation and sea level rise, supporting adaptation planning into the future. This data, when combined with on-site sea level measurements and ground control surveys is a game-changer.

Sensor technology is not only useful for profiling key hazards but also related threats or acerbating factors. For example, the ministry of environment in Colombia used methodologies that combine remote sensing satellite data with ground-based observations to address the issue of erosion at national level, which has diminished the effectiveness of essential ecosystem services that mitigate two top hazards of the country: floods and landslides. This data has contributed to knowledge of the underlying drivers of loss and damage associated with the adverse impacts of climate change, 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).

[33] As of April 2024, there are 55 Essential Climate Variables (ECV) specified by the Global Climate Observing System, that critically contributes to the characterization of Earth' s climate and are required to support the work of UNFCCC and IPCC. Read more about ECV (>Link)

2.2.2 **Citizen science**

Citizen science is a transformative approach to scientific inquiry that 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 apps and devices through accessible platforms – for example, citizen mapping of floods in real-time via social media or through NGOs, youth groups and local experts (e.g., community leaders, agricultural extension workers and local or national meteorological and hydrological services officers). It enables field and household data collection via open data digital survey tools and crowdsourcing, and it supports sharing of local geospatial data on hazards, exposure, vulnerability and impacts. In other words, citizen science is an essential technology to assess exposure, vulnerabilities, capacities and risks. **It is important to note that citizen science complements data collected by sensors described above, offering various entry points for public engagement in EO** (Dean, 2020) to help improve the early warning system 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, in order 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 the Pacific. Citizen scientists contributed to the provision and assessment of **exposure and vulnerability data** (See storymap), the result of which was incorporated into the Standard Operating Procedure for Planned Relocation in the Republic of Fiji, adopted in 2023.

Hazard and risk profiling and mapping are crucial outputs in the process of producing risk knowledge, useful for risk zoning, spatial and resource sectoral planning, and informed decision-making. A salient example of this is a project in Georgia that produced hazard and risk maps of seven climate-induced hazards (i.e., floods, landslides, mudflows, drought, hailstorm, windstorm and snow avalanche) for 11 major river basins.[34] Following the hazard mapping, **vulnerability and risk assessments** were conducted within these same river basins. These assessments were then overlaid with the **hazard maps** to generate **risk maps**. A combination of technology measures were used, namely: sensor data (hydrometeorological equipment, geological monitoring equipment), geographic information system (GIS), models, high-performance computer and citizen science (i.e., social media, mobile app, survey tools). As a result, more than 100 of the most vulnerable communities across the 11 river basins were identified in 45 (in western Georgia) implementing community-based DRR measures.[35]

[34] GCF- financed project in Georgia: 'Scaling-up Multi-Hazard Early Warning System and the Use of Climate Information in Georgia' (> Link)
[35] Per inputs provided by United Nations Development Programme (as an implementation agency of the project) in May and September 2024

2.2.3 Artificial intelligence (machine learning)

With a set of mathematical and computer science techniques, AI encompasses large language models, advanced big data and predictive analytics, and machine- and deep-learning, which have emerged as critical tools that play a key role at each stage of the MHEWS value chain (WEF, 2024; Kuglitsch et al., 2022). AI is a powerful tool that provides better information by exploiting relationships between existing data sets (e.g., bridging incomplete data sets through techniques such as missing-value inference) alongside its ability to learn from new knowledge (e.g., finding hidden patterns in large, complex data sets, i.e., big data), 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 (e.g., built-up areas and population distribution), some of which are available as open and free global data products, such as 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, ML–based mapping was used in Belize to process and integrate 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 (coral reefs and mangroves). The results of this exercise have yielded valuable insights for improving risk knowledge, particularly regarding **vulnerability and exposure of environmental areas**, specifically in coastal and marine ecosystems, and have informed Belize's NAP (GEO, 2023). Furthermore, under the UNFCCC Technology Mechanism Initiative on AI for Climate Action, a series of activities are underway that explore the role of AI as a tool for advancing and scaling up transformative climate solutions in developing countries, with a focus on LDCs and SIDS. This includes the AI Innovation Grand Challenge which has attracted ideas for AI-powered climate action, around 20 per cent of which are on EWS.[36]

[36] According to the progress of the AI Innovation Grand Challenge reported to the 29th Meeting of TEC in September 20, 22 out of 114 submissions were on EWS. (> Link).

2.3 **Use of risk knowledge**

2.3.1 **Simulation models**

Simulation models in the context of MHEWS 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 analysing 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 or agricultural sites, and environmental areas. **Models are fed by observations (measured from sensors and/or citizen scientists), socioeconomic data (including census and Citizen Science), and of lately, 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 are incorporated into pillars 2,[37] 3 and 4 of the MHEWS.

For example, in Pillar 2, which deals with observations and forecasts, models based on historical data can inform about hazards and/or impact thresholds to trigger warnings and early actions. To give an example, the government of Uganda leveraged statistical models fed by ground observations and satellite-based data as well as citizen science to analyse 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**[38] for different hazards: floods, landslides, land and forest fires, and severe weather such as heavy rain.

Mongolia has 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 is 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 levels (AF, 2023).

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[37] Read more about WMO's Integrated Processing and Prediction System, which provides operational products and services that are generated using Numerical Weather Prediction and Earth System modelling (>Link).
[38] Impact-based forecasts and warnings (IBF) integrate risk knowledge on hazards and vulnerability to articulate the expected impacts resulting from anticipated weather conditions (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 warnings with impact forecasts that call for integration of climate information and risk knowledge on hazard, vulnerability and exposure (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'). See Manual for Operationalizing IBF and Warning Services (>Link)


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2.3.2 **Internet of Things**

The Internet of Things (IoT) increases the accuracy of critical resilience tools such as MHEWS and improves related services. It is comprised of networked devices, including sensors and handheld devices, that collaborate to gather, distribute and monitor localised data across systems (WEF, 2024). By leveraging connectivity (i.e., data integration across multiple IoT devices) and ensuring interoperability (i.e., data exchange across diverse sources to enable comprehensive risk management), MHEWS can increase its accuracy when reducing disaster risks. IoT combines aspects of the 'physical world and things' with 'virtual world and data', creating an interlinked and distributed web of information. **When AI and data analytics are applied as core components of an IoT network, this ensures the early detection of hazardous events and the rapid evaluation of impact, and it contributes recommendations for human decision-making** (Khan et al., 2023) when directing people to safety. An example of this is networked heat sensors that 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 tool, especially when it is used in combination with risk information on exposure and vulnerability, including **targeted communication** of early warning for informal settlers (Pillar 3 of the MHEWS). In South Africa, for example, a social enterprise uses mobile-IoT to connect fire sensors inside homes in informal settlements to alert residents and their neighbours to fire risk via SMS instant notifications (GSMA & UKaid, 2021). The scheme is linked to an opt-in micro insurance plan.

IoT as a data gathering and AI analysis mechanism works well in supporting predictive disaster analysis and safety planning. For example, with support from the CTCN, a new irrigation insights project is planned to leverage IoT and other technologies such as AI, application programming interface (API), GIS, ARD/data cubes and sensors to build an open database of climate information as a part of flood and drought early warning system in Tanzania. It is planned that IoT-based sensors will gather real-time local environmental health measurements, such as surface water and groundwater movement, soil moisture, gas, pollutant levels and species impact analysis, and it will be cross-correlated with historical climate events for the provision of recommendations on course-correction actions.[39]

2.3.3 **Global Navigation Satellite Systems and Terrestrial Reference Frames**

Global Navigation Satellite Systems (GNSS) are a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers on the ground (EUSPA, 2024). The receivers use this data to determine location and then accurately relate this location to all others using a Terrestrial Reference Frame (TRF). TRFs are effectively a gridded mesh that covers a country, region or, in the case of the International Terrestrial Reference Frame (ITRF), the entire globe. TRFs enable the description of every location on the Earth with three coordinates and accurately relate this to any other location. Through GNSS data, users are able to align their position, as well as the position of Earth observation data sets, to a TRF.[40] GNSS is a general term for systems like the US Global Positioning System (GPS). Other countries, including India and China, have launched or are in the process of launching their own systems to provide complementary, autonomous positioning, navigation and timing capability. Developing countries without their own GNSS satellites also benefit from this technology: For example, Thailand is utilising GNSS data provided by Japan to enable targeted communication of warning messages of tsunamis (to those with smartphones and smartwatches on the beach or shorelines) and forest fire and air pollution (to people in affected areas).[41] International cooperation on GNSS-enhancements to MHEWS, AI-powered

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[39] Per inputs provided by the Enterprise Neurosystem in April 2024.
[40] The essential role of the ITRF is recognised by the United Nations in its General Assembly resolution on a 'Global Geodetic Reference Frame for Sustainable Development' (See >A/RES/69/266). .
[41] Per inputs provided by the Cabinet Office of Japan in April 2025 (see >Link).

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 serve as critical tools for modelling, detecting, and understanding displacements caused by natural hazards and disasters (Sahagian et al., 2009), **and constitute the fundamental positioning infrastructure supporting innovations such as data cubes** (Angermann, 2024). GNSS and TRFs also provide important information to SIDS experiencing sea-level change and land subsidence, as the combination of GNSS and TRFs are essential for authoritative data to understand the changes in an island's shape, elevation, and its position relative to points over the horizon. For example, Tuvalu and other low-lying islands rely on the use of GNSS and TRFs to understand current and future sea-level rise, and ensure risk-informed early warning, policy, and adaptation. Aligning a national TRF to regional and international TRFs ensures conclusive data sharing, improving the accuracy and reliability of risk data.

2.3.4 Cloud computing

As a form of advanced computing, cloud computing is a cross-cutting measure to power intelligence and accelerate the use of risk knowledge. While enabling users to rent processing power and storage space on demand, cloud-based supercomputing can power climate models and ensure they are readily accessible. **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)**, addressing concerns with access, storage, and processing of vast amounts of satellite EO data**. These technologies combined with others, such as open access through API and analysis ready data (ARD), can help communities improve their preparedness to respond to early warnings (Pillar 4 of the MHEWS) with early action plans and forecast-based financing. Cloud computing allows countries with limited IT infrastructure and the capacity to manage it to analyse large quantities of data for risk assessments and actions.

The CGIAR AWARE platform, for example, leverages an open-source model and algorithm that are fed by cloud-based data. The analysis done and stored on the cloud gives local communities early warnings and supports them in planning proactive climate action (Amarnath, 2023). 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 on reducing disasters and building 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 global hydrologic model using satellite data on the cloud. Because of cloud computing, users and beneficiaries were able to harvest the hydrological information without having to download massive amount of data and run a complex model at a local server. 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).

2.4 **Access to Risk Knowledge**

2.4.1 **Geographic Information System**

A geographic information system (GIS) is a system designed to create, store, manage, analyse, 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, United Nations Office for Disaster Risk Reductions (UNDRR) and International Organization for Migration have supported the strengthening of a national digital risk information management system as a **central standardized repository** 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. An example of a **federated repository** that leverages GIS comes from the Philippines where weather updates from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA), seismological activities from the Philippine Institute of Volcanology and Seismology (PHILVOLCS), and health and disease information from the Central Visayas Electronic Health Referral System (CVeHRS), among other critical sources of information, are assembled to provide decision-makers with a systemic overview of risks.

2.4.2 **Application Programming Interface**

Application Programming Interface (API) represents software components that link subsystems and actors in digital environments by sharing data between applications, systems and devices. API is commonly used for web access to resources (e.g. AWARE platform described in 2.2.4) and increasingly used in IoT devices (e.g. AI4Climate Action work described in 2.2). 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 (Posada Sanchez 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**, who can visualise, analyse 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 regional project.

Similarly, APIs play an important role in facilitating integration of 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. DIAS platform utilises several types of APIs, within its system e.g., converting and reformatting data into meaningful forms in preparation for data integration and analysis within its vast storage and analytical space with numerous applications. 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 three to six months in advance. It can then issue warnings to a local Malaria Centre in Tzaneen, South Africa, and to the national infectious disease MHEWS bureau for relevant actions, such as planning to spray insecticide.

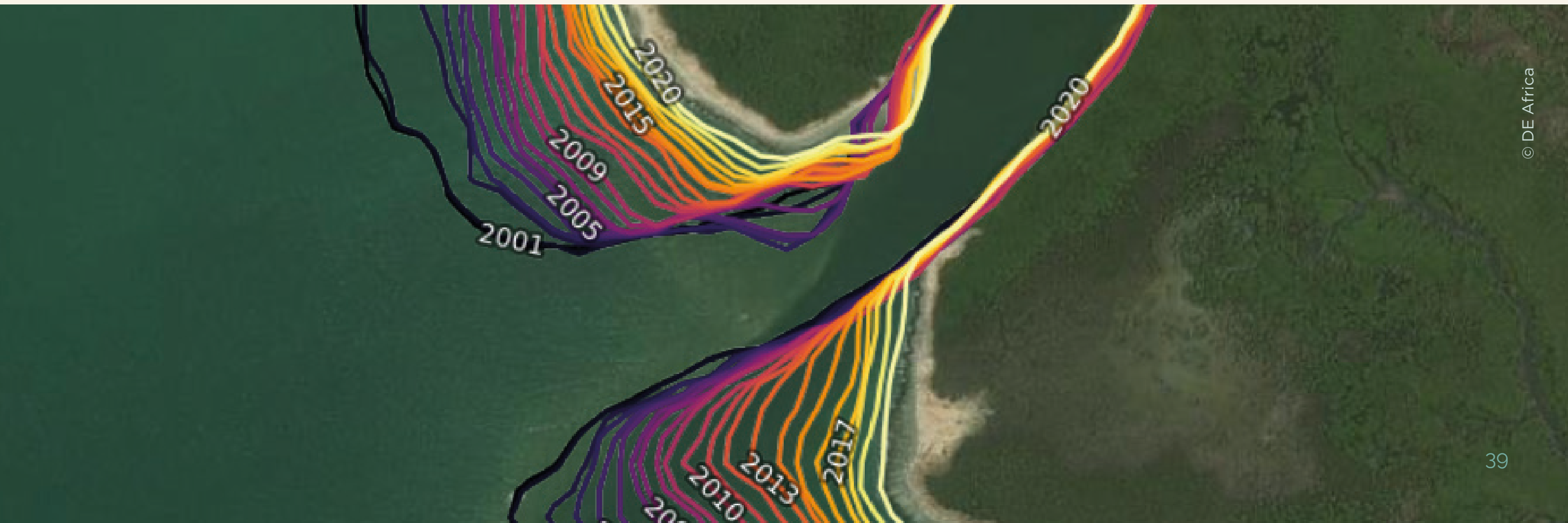
Another example of the use of API is the Montandon - Global Crisis Data Bank, hosted by IFRC, which uses APIs to access data from numerous applications and databases from different sources to **bring together current and historical data on hazards, their impacts and post disaster-responses** by government and humanitarian organisations. This system aims to reduce disaster risks by anticipating future events based on analysis of similar cases of past hazards. It covers several decades to optimise learning and facilitate analysis of key trends, and it aims to eventually be used to forecast hazard impacts, including potential loss and damage.

2.4.3 Analysis ready data and data cubes

ARD[42] refers to data that has been organised and processed to meet a set of requirements, which allows for immediate analysis and ensures interoperability with other data sets. This offers simplicity in the development of applications with the data, and databases can run queries with minimal effort. ARD is valuable as many users of EO data generally commit considerable time and effort to data preparation. A large portion of satellite data users also lack the technical capacity, infrastructure and internet bandwidth to effectively access, organise and process increasingly large volumes of space-based data for decision-making. ARD is often disseminated in form of a data cube with continental, regional and thematic focuses.[43]

A data cube refers to a data structure in which satellite imagery data sets are organised for a specified geographic area and time period. Data cubes provide a framework for organising and analysing multi-dimensional geospatial data, including ARD, along dimensions such as time, spectral bands, 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 trends to be identified. Together they are revolutionising the way vast geospatial and EO data sets are handled while leveraging faster, cost-effective ways to facilitate the analysis of remote sensing imagery at scale. They **drive data straight into the hands of wider audiences** and policymakers to support decision-making, including on climate change and disaster risk. The use of ARD in combination with data cubes in LDCs and SIDS in the Africa region has 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 coastlines of the seaside resort of Saly Portudal in Mbour, assessing location and patterns of coastal retreat and erosion.

[42] 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.
[43] Learn more about the work of the CEOS on ARD (>Link) and Data Cubes (>Link); More Data Cubes use cases on UN-SPIDER (> Link)



2.5 Enabling environment for improving risk knowledge

2.5.1 Capacity-building

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 proven and emerging technologies and ensuring the safety and protection of users. Given differences within and among countries and regions, there is no standardised approach to capacity-building; as such, evidence on the most effective capacity-building approaches is required, taking into account the political, economic and social contexts of countries (UN, 2020). One approach is better coherence and coordinated action, and a focus on scaling up solutions remains crucial to addressing digital capacity-building challenges.

A successful case of capacity building is in Haiti – in the aftermath of Hurricane Matthew, a series of **capacity development** activities were initiated **for a public GIS agency.** Their staff were trained to use open GIS software to analyse open data satellite imagery and to produce and maintain a yearly national landcover map, which became a critical layer for all change-related products. It was also used for a post-disaster needs assessment in Macaya Park following the 2021 earthquake as a way 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.

As covered in the previous chapter, **gender disparity in benefiting from technology training and capacity-building is a persistent challenge. To address this gap, several institutions have been implementing targeted actions to enhance the inclusion and capacity of women in the technology sector for climate and disasters.** Measures taken by UNOSAT includes collecting gender-disaggregated training data, organizing training and awareness-raising events targeting only female participants. While engaging with universities, UNOSAT also encourages the participation of young women in its project activities by providing training opportunities and facilitating networking with women in the geospatial sector[44]. UNOOSA has also been addressing the gender gap issue through its programs such as UN-SPIDER and the Programme on Space Applications to promote the use of space-based EO and GNSS technologies. Supporting conferences, workshops, webinars and other training opportunities, these programmes utilise open application processes and select participants based on a strong emphasis on both geography and gender. As a result, they frequently achieve a higher proportion of female applicants being selected compared to their representation among all applicants.[45] Meanwhile, SERVIR has been running a dedicated initiative called "Women in Geospatial Information Technology (GIT)" in the Hindu Kush Himalaya region where the gender disparity is particularly stark. Aiming to provide substantial growth opportunities for women professionals to advance their careers and assume leadership positions in EO and GIT, 12 training programs has been organised, tailored to young and early-career women in GIT, benefiting 1,490 women across the region since 2018.

[44] As per inputs provided by the UNITAR secretariat, in April 2024.
[45] As per inputs provided by the UNOOSA secretariat, in March 2024.

2.5.2 **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 (OECD, 2019). 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 are the roles of small and medium enterprises, including start-ups and youth in academia, in creating risk knowledge with the set of technologies described above. Under CREWS in West Africa, community-led mapping, drones, aircraft image analysis, modelling mobile apps and satellite imageries were used for improved flood-risk knowledge in Niger. Community mappers[46] leveraged GeoODK, an open-source mobile application, to build a database of people and assets exposed to flood risk in Niamey, Niger, and collected over 15,000 locations and data points.[47] 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 (OpenDRI, 2018). The images were analysed to improve resolution of digital elevation models and flood modelling.

Recognising the transboundary and cascading nature of hazards and climate risks, **regional cooperation** frameworks and mechanism among countries that share common river basins and mountain ranges help address shared risks. 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 other things, the countries created and shared climate services for the Andean glaciers. This regional cooperation initiative, while leveraging these technologies, required a re-examination of the legal frameworks and institutional structures governing data and knowledge sharing, as initially each country operated under its own arrangements (AF, 2023).

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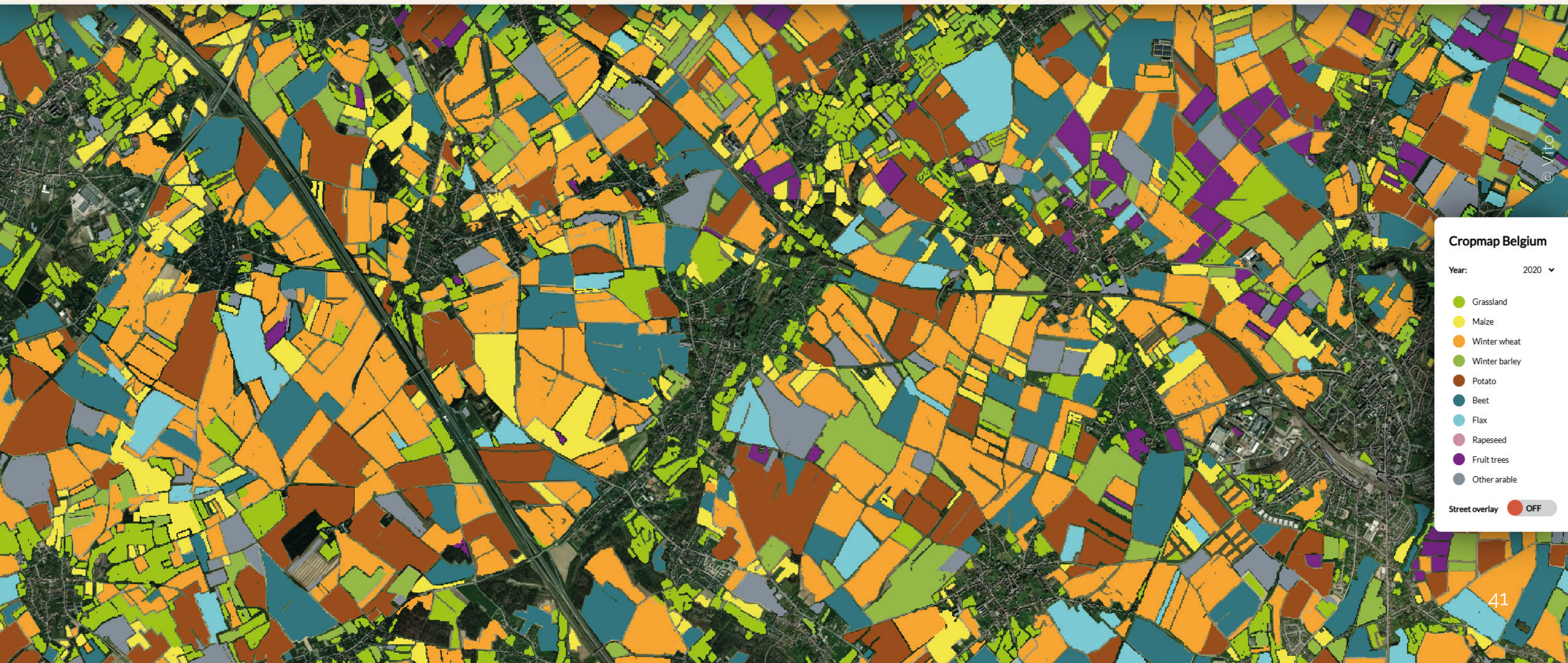
[46] 20 university students and young professionals from Niger's OpenStreetMap community.
[47] Data points on the type of building, number of people in the household, preferred contact channel in case of emergency, type of crops, characteristics of key infrastructure elements such as culverts and streetlights, description of drainage and sewage, etc.



2.5.3 **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 addresses 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[48]. 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 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 consultations 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 data sets 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. **Indigenous, local knowledge is a critical cross-cutting element throughout the value chain of risk knowledge and can support the use of and access to risk knowledge in addition to the production** as the two cases as described in the afore-mentioned cases.

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

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

This chapter showcased some practical examples of how developing countries including SIDS and LDCs have been empowered by proven technology solutions to improve their climate information and disaster risk knowledge in MHEWS. T**he review of these country experiences (see Table 4) illustrates that innovations and technology solutions are often used in combination.** Hazard profiling and mapping with a comprehensive coverage of a country would be based not only on satellite imageries but also on hazard and exposure data taken from surface-based sensors and Citizen Science for ground-truthing. Integrated with hazard and exposure information, vulnerability data comes from statistics and census data complimented by Citizen Science. Additional elements such as patters of human movement and rising sea levels and changing shorelines can be captured by GNSS, TRF and LiDAR. IoT offers powerful data gathering, integrating and interoperability capabilities. All of these are used as input data to be fed into simulation models for risk assessment, risk mapping, impact scenarios development and thresholds definitions. To process, store and facilitate access to big data, use of cloud computing is becoming increasingly common. AI/ML is also crucial to produce and use risk knowledge based on big data with efficiency. GIS links data to maps, which is a popular way to delineate climate information and risk knowledge. ARD and data cubes lower barriers for people with GIS skills to integrate and analyse growing volume of satellite data for individual hazard and context-specific needs. APIs link and integrate varieties of data, products and applications within a single hazard as well as multi-hazard context, for planning early actions and preparedness.

As these technology measures have complementary features and work together effectively in combinations, single, isolated use of one particular technology may hinder unleashing the power of innovation. There is no rigid rule and pattern of technology combination and the application of technology measures. Combination of hardware, software and 'orgware' should be flexible and guided by context-specific factors and needs.

Moreover, **technology measures for climate information and disaster risk knowledge can often provide benefits to multiple sectors at once** (including water, health, as well as infrastructure, agrifood and energy systems, as illustrated in Table 4) **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 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.

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. **EO techniques with data sharing mechanisms 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 digitise tacit traditional knowledge for recording and sharing, present new opportunity to facilitate the integration of traditional knowledge with scientific analysis (i.e., hindcasts out of models) into the comprehensive MHEWS in a systematic manner.

Technology measures can also help extend the benefits of risk knowledge to the local level to reach the 'last mile'. **The use of readily available technologies (e.g., mobile 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 MHEWS and consequently facilitate wider access and use of them.

For vulnerable countries and regions aiming to achieve early warnings for all their citizens, utilising public-private partnerships can lower the cost of governments to access international capital to ensure increased investment in risk reduction. Participation of private sector as well as academia and research institutions can also bring more data, cutting-edge technologies and collective expert knowledge, all of which in combination make international cooperation effective. This is because data, as public goods, needs to be trusted and verifiable for beneficiaries, including policymakers and end-users to have confidence in implementation. Expert communities and global partnerships like GEO play a key role in ensuring data quality and validating data and building consensus (e.g., coordination with over 50 expert partners to produce risk knowledge). The outcomes of such efforts are made available as open to the public so that they can be further validated and replicated while being disseminated.

Open data and open knowledge on climate information and disaster risk knowledge as trusted public goods are to be co-designed and co-created with stakeholders including the local and indigenous community, private and academic sectors while leveraging combinations of multiple technologies for multiple hazards and cross-sectoral benefits.[49]

Proven technology solutions such as those described in this brief should to be considered together with applications of emerging technologies that may currently be in use primarily in developed countries but would lend themselves to innovative solutions for improving risk knowledge and information for all in the near future. For example, Natural Language Processing (NLP) as a field of AI has a massive potential to broaden the 'last mile delivery' of warning messages. NLP can be used to integrate risk information sources from multiple languages (e.g., where schools are located, areas of cultural significance, community-based vulnerability mapping) and automatically apply that information to a warning exponentially faster than a human would be able to do. NLPs can also translate warnings by designated national authorities in Common Alerting Protocol format and automate posts on social media in appropriate languages in the warning targeted areas, including various local languages.

Also, novel space-based radar technologies, i.e. used in the Surface Water and Ocean Topography (SWOT) mission, will enable the production of unprecedented surface water height data, which in turn have many applications[50]) for assessing water resources on land, tracking regional sea level changes, monitoring coastal processes, and observing small-scale ocean currents. Such high-resolution observations will drastically expand the last mile delivery by generating risk knowledge for everyone on Earth, including for those in remote areas. Fed by such big data, digital twin Earth (DTE) models will visualize what is it that the world we live in, what will it be in days, weeks and months, and what could it be in the future if policy measures are implemented. Through emerging technologies and innovation, there will be enough data to produce and use climate information and disaster risk knowledge for early warning and other decision-makings, including for the benefit of the most vulnerable. The effectiveness and the last-mile delivery depend on whether open data and open knowledge are mainstreamed throughout the process.

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[49] Hurdles remain in open data and open knowledge including proprietary aspects of commercial data, sensitive privacy and security aspects of exposure/vulnerability data, along with legal constrains of data sharing through data privacy laws. According to the UN Report on Digital Cooperation, "addressing the legitimate concerns underlying the need for encryption without undermining legitimate law enforcement objectives is possible, along with human rights-based laws and approaches to address illegal and harmful online content." See more in the Report of the Secretary General: Roadmap for Digital Cooperation (> Link).

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
PRODUCTION	COLOMBIA	**Sensor**s (Satellite), cloud computing	Assessment of erosion and land degradation by flood/landslides; SDG reporting	Flood, landslide	Water
PRODUCTION	FIJI	**Citizen Scienc**e, 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
PRODUCTION	GEORGIA	Sensors, GIS, models, high-performance computer, **Citizen Science**	Multi-hazard risk maps for risk zoning; spatial, resource sectoral plannings and decision/policy making and climate risk management	Flood, landslide, mudflow, drought, hailstorm,windstorm, avalanche.	Water, Climate & weather observations, Agrifood System, Energy
PRODUCTION	BELIZE	AI/ML, satellite, cloud computing	Assessment of coastal & marine ecosystems, e.g. coral reefs and mangroves for NAP	All	Coastal zones
PRODUCTION	UGANDA	**Models**, AI/ML, Mobile App, satellite	Predetermining EW threshold for drought-induced crop failure to trigger disaster risk finance and social safety net program	Drought	Agrifood systems
USE	INDONESIA	**Models**, satellite	Producing and calibrating impact-base forecasts	Flood, landslide, extreme weather	Climate & weather observations
USE	MONGOLIA	**Models**, Mobile App	Local-level vulnerability and hazard mapping for future climate & flood risks for development and land use plans	Flood	Water
USE	SOUTH AFRICA	Mobile-**IoT**, fire sensor	Alerting informal settlements about fire with an opt-in micro insurance	Fire	Infrastructure
USE	THAILAND	**GNSS**	Identifying and targeting vulnerable people for warning about tsunami, forest fire and air pollution	Tsunami, storm, forest fire	Water, coastal zones
USE	SRI LANKA	**Cloud-computing**, API, satellite, AI/ML	Community anticipatory action planning; forecast based financing	Flood, drought, storms	Agrifood systems
USE	ECUADOR	**Cloud-computing**, satellite, AI/ML, models	Analysing hindcast of historical streamflow of remote village for women-led project to design an aqueduct to deliver water to irrigate farmlands	Drought	Agrifood systems, infrastructure
USE	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
ACCESS	MAURITIUS	**API**, satellite	Visualising, analysing historical and real-time rain and snow fall	Flood, drought	Climate & weather observations
ACCESS	SOUTH AFRICA	**API**, models, satellite,	Data integration for malaria predictions and insecticide spray planning	Heat, infection	Health, heat
ACCESS	SENEGAL	**ARD/Data cube,** satellite	Assessing location and patterns of coastal retreat/erosions	Coastal flooding	Coastal zones
ACCESS	HAITI	GIS, satellite	**Capacity development** for updating landcover map as critical layer (basis) for Post-Disaster Needs Assessment, UNFCCC/UNCCD/Rio reporting	Storms, earthquake	All
ENABLING ENVIRONMENT	NIGER	Citizen Science, satellite, mobile App, UAVs, models	**PPPs:** private(startup)-academia-youth collaboration	Flood	Water, agrifood systems
ENABLING ENVIRONMENT	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/ flooding	Water, agrifood systems, energy, infrastructure
ENABLING ENVIRONMENT	NIUE ISLAND	Digital/mobile app	Examine **indigenous** climate indicator in el niño & la niña years	Drought	Agrifood systems
ENABLING ENVIRONMENT	MALAWI	Digital, satellite, (models)	Indigenous/traditional knowledge to guide scientific analysis using EO-fed modelling for flash floods	Flash flood	Water

Section 3:

Key findings and recommendations: Scaling up innovation and technology

Climate information and disaster risk knowledge provide the foundation for the MHEWS value chain, which saves lives and protects property and the environment. Targeted warning messages, optimised monitoring and communication networks and infrastructures, as well as effective evacuation plans all require risk knowledge as the basis. Yet significant differences exist among countries in access to and availability of data and knowledge on disaster risk; in particular, LDCs, SIDS and African countries experience poor access and availability. Challenges in relation to risk knowledge – including in its monitoring, status reporting, production, use and accessibility – persist globally, but in particular for these countries.

A wide array of scalable technology measures, platforms and services have already demonstrated their effectiveness in boosting climate information and disaster risk knowledge for countries in need (see Table 4 for illustrative examples). These technologies are most effective when integrated: for example, by combining innovative (hardware, software and 'orgware') measures, approaches (e.g., scientific processes and Indigenous and traditional knowledge and practices) and solutions (e.g., high- and low-technology open solutions that leverage low-cost sensors, mobile and digital technologies) tailored to context-specific needs.

As Section 2 indicates, the global community of scientific experts can support designing combined technology measures – in hardware (e.g., use of satellite imageries validated by citizen science that are fed into AI-trained model for analysis and made available through API and cloud computing), software (e.g., expert validation of open EO data or improving the interoperability of data sets in the GEO community) and 'orgware' (e.g., enforcing collection of gender-disaggregated administrative data; ensuring alignment to national, regional and international TRFs).

It is also important to note that technology measures for improving disaster risk knowledge and climate information that feed MHEWS can often inform policies, decisions and actions in multiple sectors (e.g., water, agriculture and energy), including the building of resilient infrastructure and the management as well as the assessment of loss and damage.

Yet, such measures, many of which leverage openly accessible data and knowledge, are not well known and are often underutilised in vulnerable contexts. In fact, they are not well integrated in policies, plans, project design and implementation. Parties have underscored the importance of EWS to realising their climate agendas in their national action and planning documents: About 50 per cent of NDCs, 40 per cent of NAPs and more than 90 per cent of adaptation communications submitted under the Convention and the Paris Agreement mention early warning systems, particularly for achieving adaptation goals in the water and agriculture sectors. However, there is limited recognition of the role of technology applications in improving climate information and MHEWS in these policies and plans or in country programme documents and funding proposals submitted to climate funds: Only about 25 per cent of NDCs, 30 per cent of adaptation communications, 12 per cent of adaptation-related components of TNAs and 10 per cent of GCF funding proposals based on NAPs highlight technologies for this purpose.

Having a supportive enabling environment is crucial to unlock the power of innovation in addressing persistent challenges that developing countries face in their implementation of MHEWS, such as access to financing, data quality, stakeholder engagement, public participation and awareness ('last mile' challenges), and technical capacity and regulatory frameworks. Long-term financing, both domestic and international, supported by a coordinated multisectoral approach is indeed key to sustaining project outcomes and scaling up integrated technological solutions that address multiple hazards across multiple sectors, including those mentioned above. As many of the examples in Table 4 illustrate, technology can empower citizen scientists and other local stakeholders to produce and use local data on vulnerability and exposure to hazards, allowing countries to identify their most vulnerable populations, communities and groups. This type of local data and knowledge enables evidence-based decision-making and enhances people-centred MHEWS with effective 'last mile delivery', which remains a key challenge.

It is time to scale up fit-for-purpose technology solutions and good practices for generating and managing risk information through policy development, project planning and implementation. Efforts to promote technology solutions should be accompanied by awareness raising (e.g., under EW4All, UNFCCC Technology Mechanism Initiative on AI for Climate Action), technical assistance (e.g., in the work of the CTCN) and programming guidance for the use of climate funds, taking into account specific needs of vulnerable groups, considering their age, gender, disabilities, legal status, special economic status and access to services.

To scale up innovation and fit-for-purpose technology solutions, the TEC recommends that the COP and the CMA encourage Parties, international organisations and stakeholders, as relevant, to:

1. **Consider technologies for MHEWS when preparing and updating NDCs, NAPs, TNAs and other national strategies and plans**, where appropriate, integrating a combination of complementary technologies into both existing and proposed systems. Consideration should also be given to ongoing and complementary national processes on developing disaster risk reduction strategies and plans and their implementations, which often have synergies with climate change adaptation targets, supported through regional and global cooperation frameworks.

2. **Invest in multisectoral technology solutions** by leveraging funding from relevant financial mechanisms and other sources, including the AF, the CREWS, the Fund for responding to Loss and Damage, the GCF, the GEF and the SOFF. Also, to promote longer-term sustainability and maximise impact, it is important to build on the outcomes of funded projects and to integrate new components in existing systems that may otherwise lack operational and maintenance costs.

3. **Leverage international initiatives and public-private partnerships** in order to strengthen the capacity of Governments to understand and mitigate context-specific disaster risks, including to help quantify the effectiveness of MHEWS at national and international levels. PPPs can also help reduce the financial and other barriers associated with accessing international capital, particularly in climate-vulnerable countries. Support from the private sector may be encouraged through enabling policies (e.g., national coordination mechanisms with private sector participation; policies that link environment and innovation to nurture technology start-ups in developing countries) and leveraging public finance (e.g., co-financing arrangements).

4. **Support the integration of technologies into projects to promote local stakeholder engagement** such that both low- (e.g., low-cost sensors, mobile and digital technologies) and high-technology solutions (e.g., EO satellite, ARD/data cubes and AI) enable the creation and consumption of risk knowledge by Indigenous Peoples; youth; female-led and community-based groups and entities, including local universities, research institutions and local start-ups.

5. **Build the technical capacity of stakeholders** in developing countries for enhancing reporting on, production, use of and access to risk knowledge, while accelerating the above-mentioned local stakeholder engagement. Regional, national and local stakeholders need to benefit from capacity-building activities for effective data and knowledge creation and management. Planning and implementing technology measures for enhanced climate and risk information for MHEWS can be positioned as a response to broader demand and necessity for digital capacity-building in developing countries. Particularly useful is implementing targeted actions that strengthen the inclusion and build the capacity of women in technology in order to address persisting gender disparity (see 1.1, Box 2 and 2.4.1).

6. **Leverage the global community of scientific experts and innovators**, including GEO, who have been promoting open data, knowledge and solutions as public goods; and who can provide the technical support and knowledge transfer needed for engaging stakeholders and building their capacity; while helping to design fit-for-purpose combined technology measures, including frontier and emerging technologies. Regional and international cooperation can be leveraged to enlist such experts to improve the data and technology landscape of developing countries. Success stories in SIDS and LDCs should also be showcased to ensure knowledge transfer through South-to-South peer-learning opportunities.

As the EW4All initiative enters its third year, it is imperative to accelerate the planning and implementation of technology policies that leverage the most effective development and deployment of early warning systems. Scaling up innovations and technologies is essential to enhance risk-informed climate resilience policies and actions for ensuring comprehensive protection for all from hazardous weather and climate events through the deployment of life-saving early warning systems.

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