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WMO Bulletin for Marks 75 Years Delivering Science for Action is attached herewith for kind information.

Dr. R.K. Giri
Sc.–F (Head Org.)
for DGM

WORLD METEOROLOGICAL ORGANIZATION

1950-2025 SCIENCE *for* ACTION

BULLETIN

Vol. 74 (1) – 2025

WEATHER CLIMATE WATER

WMO Marks 75 Years Delivering Science for Action

WMO Bulletin

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Contents

The WMO Mandate – A Call for Funding

WMO is central to global safety, security and development, with a mission that drives the collection, analysis and dissemination of vital climate and weather data worldwide. This core mandate underpins national and regional climate action, enabling effective early warning systems, enhancing resilience, and building capacity within Member States and Territories. However, as climate risks intensify, WMO faces urgent funding shortfalls that threaten the continuation and growth of these indispensable services. In 2025, the year that WMO celebrates 75 years as a specialized agency of the United Nations, the Organization calls for both public and private sector engagement to meet the goals and targets in the WMO Strategic Plan 2024-2027.

In 2024, voluntary contributions generated 29.4 million Swiss francs (CHF) of additional – extrabudgetary – funding for WMO. Public institutions, mostly WMO Members, provided CHF 13.5 million (46%) of that amount, while various multilateral agencies – CREWS, Adaptation Fund, World Bank, etc – provided CHF 15.8 million (54%) from for projects. In the full year of 2024, WMO signed CHF 39.7 million in new project commitments with funders, while in just five months – from January-May 2025 – an additional CHF 42.2 million has already been signed, with the total new commitments for 2025 expected to exceed CHF 100 million. While private sector income – from foundations, philanthropists, businesses and others – amounted to less than 1% of the Organization's voluntary contributions in 2024, over 20% of the new 2025 commitments are from philanthropic and corporate foundations. Support from such private sector partners is more essential than ever for WMO to deliver on its mandate.

Despite this encouraging trend in commitments, WMO faces growing challenges in securing predictable, flexible, and sustainable funding. With growing demand for early warnings, climate services, and data infrastructure, the gap between ambition and available core resources remains a critical concern that will require continued and diversified resource mobilization efforts.

This Bulletin looks at some of WMO's major achievements over its first 75 years and underscores the critical need for sustained investment in its normative functions at a key juncture in the climate crisis. Five key areas of WMO normative work will be addressed:

- **Global observation networks**: The essential infrastructure for all weather prediction, climate monitoring, and early warning systems, providing the data backbone for climate security.
- **Climate data standards and coordination**: WMO protocols ensure the collection of accurate, interoperable and globally accessible climate data, facilitating informed decision-making across borders.
- **Capacity building for National Meteorological and Hydrological Services (NMHSs)**: WMO equips developing countries with the infrastructure, training and technology necessary to deliver reliable, timely climate data to their communities.
- **Framework for global cooperation**: The WMO Earth system approach integrates meteorological, climatological and hydrological data, uniting weather, climate and water systems across nations for the collective good.
- **Early Warnings for All**: WMO drives the scientific, infrastructural, and collaborative backbone needed to bring universal early warning systems to fruition, providing timely climate information that protects lives and livelihoods.

Climate change is the defining crisis of our time and its impacts , including through severe weather events, are already being observed – much more quickly than feared. We are not powerless, WMO science is the basis for sustainable action. Today, that science needs funding.

An Investor Forum - Weathering the Change: Investing in WMO's Impact - is being organized in the latter half of the 2025 with an aim to:

- Mobilize capital for critical WMO-led initiatives that strengthen early warning systems, climate and water services, and the capacity of National Meteorological and Hydrological Services;
- Raise awareness of WMO's global value as a provider of trusted, science-based data and services that inform climate resilience, risk management, and long-term planning;
- Foster new partnerships with public and private actors to scale impact through innovation, co-financing, and shared solutions.

An investment in WMO is an investment in a sustainable future for all for the decades ahead.

Prof. Celeste Saulo
WMO Secretary-General

WMO at 75: A Shining Example of the Benefits of International Cooperation

By Michel Jarraud, WMO Secretary-General Emeritus

The First World Meteorological Congress took place in Paris, France, in March/April 1951.

Weather and climate conditions have been key factors in almost all aspects of human evolution, from the development of agriculture to the rise and decline, and sometimes even collapse, of several civilizations as well as the major migrations that have shaped the world as it is today. Weather, and its prediction, has held fascination for humanity. For most of prehistory to just a few centuries ago, it was closely associated with gods or religion. The development of meteorological instruments in the 17th and 18th centuries – particularly, the barometer and thermometer – provided the foundation for a scientific approach, based on observations and analysis, to derive the fundamental laws of nature. This brought a major change. It soon became clear that systematic measurements with standardized instruments were essential to understand the behaviour of Earth's atmosphere. Since weather and climate ignore national borders, international collaboration is a sine qua non requirement to achieve success in this endeavour.

The first international observation networks were established in the 17th and 18th centuries. Invention of the electric telegraph by Morse in 1843 was a key technical development which allowed for the first time real-time exchange of meteorological observations, an essential element to enable predictions. This was followed by the establishment of several national weather offices in the 19th century and eventually the foundation of the International Meteorological Organization (IMO) in 1873. The work of IMO underlined the need for a comprehensive network of standardized observations and for the exchange of such data in real time on a global scale, both of which are still the core of WMO's approach in the 21st century.

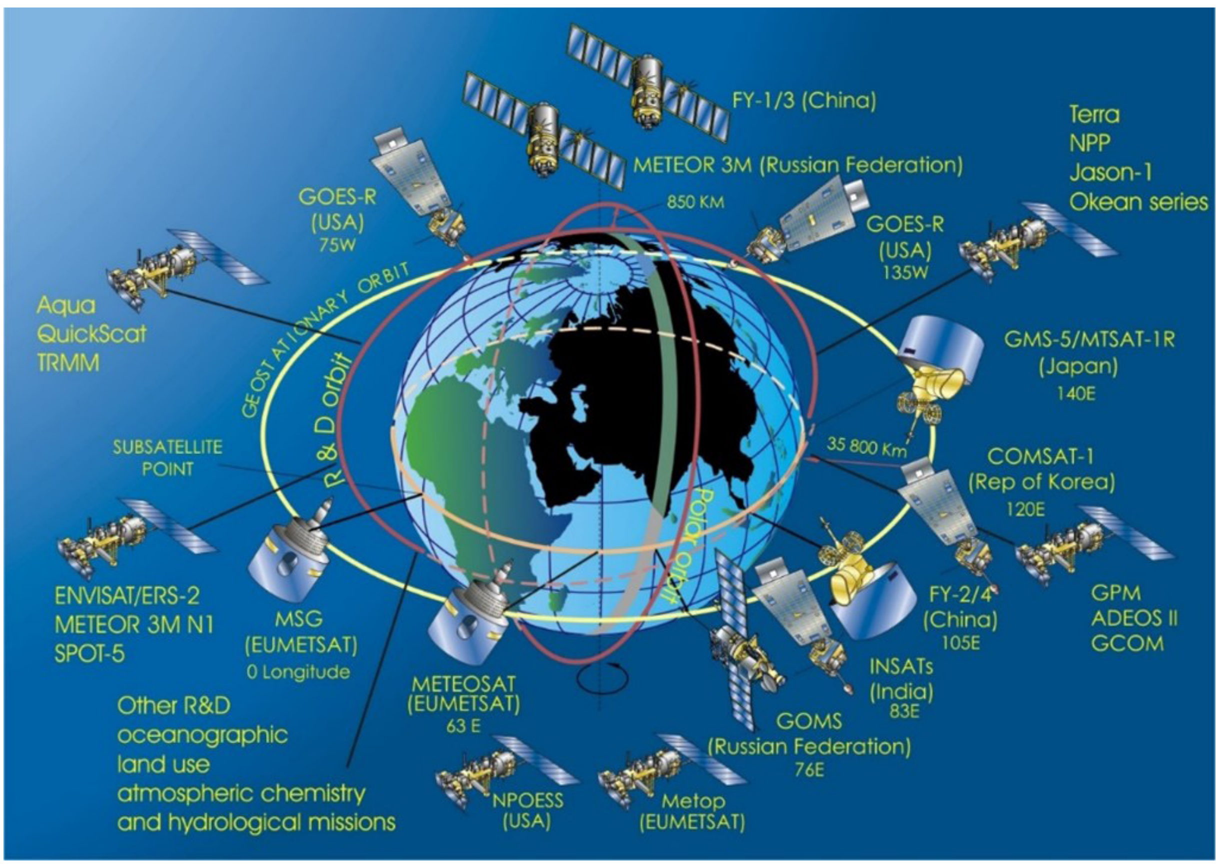
Except for in its initial years, IMO was based on a non-governmental approach, but that progressively became a major limitation. The Berlin meeting of Directors in 1939, proposed radical changes, including the transformation of IMO into an intergovernmental organization. Nothing happened in the following years due to the outbreak of World War II. In 1947, the proposals were adopted in Washington by the signing of the Convention of the new World Meteorological Organization (WMO) by 31 States. After its ratification by 50 States, WMO was established in 1950 on 23 March – now celebrated every year as the World Meteorological Day. In 1951, WMO became a specialized agency in the United Nations System.

The early years

The work of WMO is based on an elaborate global infrastructure of observational, telecommunication and computing facilities, owned and operated essentially by the National Meteorological and Hydrometeorological Services (NMHSs) of its Members. WMO guides and facilitates cooperation among its Members by organizing the exchange of data and information and by providing technical assistance.

During its early years, WMO focused on supporting the standardization and exchange of observations through technical regulations and guides. A key initiative was the development, at the peak of the Cold War, of the World Weather Watch – the original WWW – in response to a UN resolution in 1963, supported by both the United States of America (USA) and the Union of Soviet Socialist Republics (USSR), on the peaceful use of outer space. This initiative confirmed meteorology as a model of international cooperation despite extreme political tensions. As a result, weather observations have since been exchanged without restrictions between all WMO Members.

WWW is one of the crowning achievements of WMO. It has subsequently expanded to encompass other observations – hydrological, climate, chemical composition of the atmosphere and more – as part of the WMO Integrated Global Observation System (WIGOS). This international cooperation has made it possible for today's six-day forecasts to be as reliable as a two-day forecast was 30 years ago. It is also at the core of the major improvement in the accuracy of early warnings which have contributed to the saving of millions of lives and the avoidance of losses in the trillions of US$, due to infrastructure damages and economic setbacks, over the last decades.



Constellation of satellites contributing to the WMO Global Observing System (2015)

These achievements would not have been possible without the overall multilateral coordination spearheaded by WMO. All countries, without exception, even the largest ones, get much more from the free exchange of observations and research coordinated by WMO than what they contribute. The principle that is the basis of this is that all countries contribute to the best of their capabilities and in return get the benefits of achievements in all other countries. It has been a founding principle of WMO and it remains as valid today as it was 75 years ago. It is a clear win-win-win for all players, probably one of the largest one in any socioeconomic domain. The replacement of such a global multilateral system by bilateral agreements, is unimaginable: in view of the interactions between all the countries involved, it would require over 18 000 bilateral agreements. That would be a sure recipe for the collapse of the system, leading to a dramatic increase in loss of lives and economic damages in almost all countries, developing and developed.

All countries, without exception, even the largest ones, get much more from the free exchange of observations and research coordinated by WMO than what they contribute.

In response to the scientific progress in meteorology in the last 75 years, the interest of the public and its confidence in weather forecasts has grown considerably. Everyone has a weather app on their phone that they consult throughout the day. Weather bulletins remain among the most popular programming on television and radio. Weather forecasts are part of everyone's daily routine. But this extraordinary progress has raised expectations, that is the price of success.

Early warning systems

Recurrent droughts in the Sahelian region, devastating tropical cyclones – Cyclone Bhola, in 1970 in what is now Bangladesh, caused more than 400 000 deaths – and many other weather-, climate- and water-related catastrophic events led WMO to prioritize "natural" disaster prevention, particularly by improving early warning systems, in the 1970s. Disasters are often the result of a lack of early warnings for those at risk and a lack of preparedness: statistics show that countries lacking effective early warning coverage experience eight times higher disaster mortality rates than those with comprehensive systems.

Following the adoption of The Sendai Framework for Disaster Risk Reduction 2015-2030 in 2015, WMO urged its Members to develop Multi-hazard Impact-Based Early Warnings, which could be more easily understood and acted upon by those at risk. Further, as the frequency and intensity of weather, climate and water extremes is significantly aggravated by anthropogenic climate change, WMO together with the Presidency of the 15th Conference of Parties (COP15) to the United Nation Framework Convention on Climate Change (UNFCCC) in Paris (2015) promoted the Climate Risk and Early Warning Systems (CREWS) as major initiative to support the development and strengthening of effective early warning systems in vulnerable countries. This was further reinforced since the call for Early Warning for All issued by the UN in 2022.

Many tens of thousands of lives are saved every year as a result of these improved early warnings systems which are also being better integrated into disaster prevention management.

Expansion of services and applications

WMO, as the UN's specialized agency responsible for operational hydrological activities, started coordinating the development of hydrological observing networks worldwide in 1972. This led the launch of the World Hydrological Cycle Observing System (WHYCOS) in 1993, the development of drought and flood forecasting and water resource management services.

In 1986, the Chernobyl Nuclear Power Plant accident led to the development of a system for predicting atmospheric trajectories of radioactive or chemical substances, coordinated by WMO in close cooperation with the International Atomic Energy Agency (IAEA). The efficiency of this system was demonstrated during the Fukushima Nuclear Plant accident.

More generally, the number and variety of weather and climate applications has exploded over last decades: the traditional applications still remain at the core of missions of NMHSs, such as services for agriculture to decide on planting, irrigation and harvesting as well as advice on treatments, and aviation services to optimize fuel planning and in-flight safety. But the growth in new sectors, such as health, energy, tourism, retail industry, sporting events, transportation, etc, is exponential. The list is almost endless, since almost all socioeconomic activities are to a significant extent weather-sensitive and as such benefit from increasingly accurate predictions and warnings.

Research

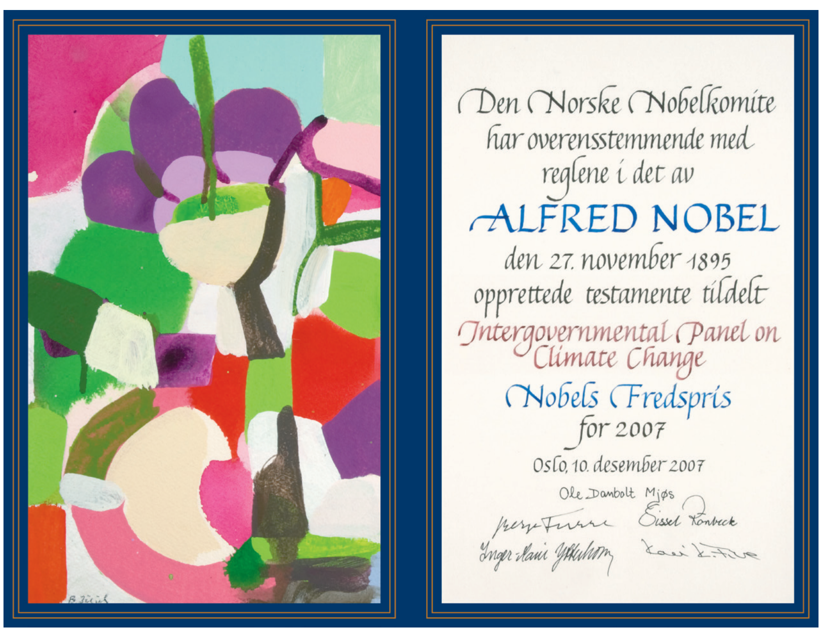
None of this progress would have been possible without a strong support for research activities. In the area of atmospheric science, WMO has been coordinating research activities in the fields of atmospheric composition, weather modification, numerical weather prediction, and urban issues.

In particular, WMO has been providing essential information on the depletion of the ozone protective layer. The first assessment of the state of global ozone was published in 1976 and led to the Vienna Convention on the protection of the ozone layer (1985) and its Montreal Protocol (1987). As a result, today the ozone layer is on a path to recovery, though a few more decades will be required to fully achieve it. This is an outstanding demonstration of the effectiveness of a multilateral approach on global issues and of political decision-making based on solid scientific information.

In 1967, the decade-long Global Atmospheric Research Program (GARP) was launched. Led by WMO and the International Council of Scientific Unions (ICSU), now the International Council for Science (ICS), this program was perhaps the largest global scientific experiment of all times in all disciplines. It organized several field experiments that contributed to a better understanding of the role of the tropics and of global atmospheric circulation, and its interactions with the oceans, and to a spectacular development of numerical weather prediction and climate modelling.

The World Climate Conferences

Climate – the average weather conditions over long periods of time – is an essential element for life on our planet and, of course, for human beings. WMO took a major initiative when it organized the 1st World Climate Conference (WCC-1) in 1979 in Geneva. WCC-1 led to the launch in 1980 of the World Climate Programme – to facilitate the analysis of Earth system variability and change,



The 2007 Nobel Peace Prize was jointly awarded to the IPCC and Albert Arnold Gore "for their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundation for measures that are needed to counteract such change" for use in a range of practical applications – and the World Climate Research Programme (WCRP), co-sponsored by ICSU (now the International Science Council (ICS)) and UNESCO. WCRP has played an essential role in coordinating and supporting global research on the climate system and the effects of human activities on climate. The magnitude of the challenge was such that no country could have achieved the same outcome in isolation. Global cooperation has been key to the progress made. Without WCRP's contribution, our understanding of the impact of human activities on climate would be much more limited and would not suffice to inform decision-making with respect to both mitigation and adaptation.

WCC-1 also led to the creation of the Intergovernmental Panel on Climate Change (IPCC), by WMO and United Nations Environment Programme (UNEP), in 1988, at the request of their Member States. About every six years, IPCC provides decision-makers with authoritative scientific assessments of climate change. IPCC reports go through an extremely rigorous review process, arguably the most thorough ever in such a complex multi-disciplinary scientific context. The Panel received the Nobel Peace Prize in 2007 for its contribution to building-up greater knowledge about climate change, and thereby contributing to a better, safer world. Thanks to successive IPCC assessment reports, there is now overwhelming scientific consensus with respect to climate change.

The scientific evidence is so strong that it is no longer possible, in good faith, to deny it, nor the role of human activities. WMO is proud to have contributed to and supported IPCC since its creation.

The second World Climate Conference (WCC-2), organized by WMO in 1990, launched the Global Climate Observing System in 1992, to provide better observations of the climate system with a strong space-based component. Observations involve physical, chemical and biological properties, covering atmospheric, oceanic, hydrological and terrestrial processes.

Despite considerable progress in Earth observations and in scientific understanding of the climate system, practical application of this knowledge to inform decision-making was limited in a very large number of countries, including in most developed countries. Thus, the third World Climate Conference (WCC-3) in 2009, again led by WMO, unanimously approved the establishment of a Global Framework for Climate Services (GFCS) to develop climate

prediction and services, based on the best scientific information, for various socioeconomic sectors. The initial focus of the GFCS was on agriculture and food security, water management, energy, health and disaster prevention.

The new context

When the UN system developed in the late 1940s and early 50s, specialized agencies were set up with very specific sectoral mandates: FAO for food and agriculture, WHO for health, WMO for meteorology and so on. Counterpart organizations were also in place at the national level. Such an approach served society well for several decades. However, many issues are trans-disciplinary and that sectoral approach created formidable silos, with fierce competition for visibility and resources. WMO was not immune: for example, even within WMO, different observing systems had been developed independently for traditional weather observations, for the chemical composition of the atmosphere, for the hydrological parameters, for the cryosphere, and for climate data. Also, activities linked to disaster prevention were scattered across several WMO programmes.

To address these structural shortcomings and to put its own house in better order, WMO developed cross-cutting approaches. The WMO Information System (WIS) provides an integrated approach in the area of data management and telecommunications for WMO programmes to share weather, climate and water information.

Regional activities, education and training and, more generally, technical cooperation are cross-cutting by nature. It is a significant challenge for experts to get out of their box to dialogue and cooperate with other disciplines. In particular, more bridges are required between physical sciences, social science and economy.

At the UN system level, the trend towards cross-cutting approaches has gathered considerable momentum over the last 25 years. In order to accelerate progress on the Millennium Development Goals (MDGs), the Secretary-General of the UN, Ban Ki-moon, promoted the concept of the various parts of the UN "*Delivering as One*".

Despite a number of practical obstacles, significant progress has been achieved. The development by WMO and key partners of the GFCS (see above) was an important contribution. In that context, 2015 turned out to be an exceptional year in terms of international cooperation, with the adoption of the UN Agenda 2030 with its associated Sustainable Development Goals (SDGs), the Sendai Agreement, the Addis Ababa Agreement on Financing Sustainable Development and the Paris Agreement of the UNFCCC. All of these are inter-connected and cannot be solved in isolation. For example, development will only be sustainable if the impacts of "natural" disasters are reduced and climate change is kept at a minimum. Furthermore, all SDGs are connected and have therefore to be addressed in a cross-cutting manner. No organization can successfully address any of them by itself. This represents new challenges for all actors, at the international level of course, but also at the regional, national and local levels. All UN agencies have been revisiting their modus operandi and are developing new forms of partnerships, involving not only governments, but also other key actors, including regions, cities, civil society and the private sector.

WMO contributes to almost all SDGs and has developed special partnerships on various nexus: climate and health, water and food security, water and energy, disaster reduction and development. WMO is using its unique experience to make significant contributions. It also has an outstanding record as a strong and reliable partner. A successful example is UN-Water, the UN mechanism to ensure coordinated action across the UN system in all water-related issues, including 36 Agencies and Programmes, as well as more than 30 other major partners.

Concluding comments

WMO is a small UN specialized agency placed in a central position for addressing key global challenges from poverty reduction, food security and water resource management to environmental protection and saving lives, among many more. There has been remarkable success in the areas of WMO´s core responsibilities – weather, climate and water – as well as when operating in a cross-cutting and collaborative fashion. But for WMO to address the societal challenges ahead more effectively, further evolution will be required. New partnerships, across varied disciplines are needed at the international, regional, national and local levels. New forms of governance, with a place for non-traditional actors, are also required.

Ultimate success will also require significant change in decision-making approaches at all levels, from individuals to governments: short term considerations and experience will no longer be sufficient or even appropriate for taking decisions on some key issues. In a fast-changing context – for example in relation with climate change – the predictive value of the past is getting weaker and is sometimes even misleading. Furthermore, the decisions taken now – or worse, the decisions not taken now – will have irreversible consequences for decades or even centuries. Decision-makers at the highest levels need to take a longer-term perspective. We now have the knowledge, ignorance is no longer an excuse for inaction.

Over the last 150 years, IMO and then WMO, despite periods of extreme international tensions, and wars, have been outstanding examples of global cooperation, for the benefits of all. Kofi Annan referred to WMO as "the original networker" and expressed his conviction that "the role of WMO will be even more important in the future". IMO and WMO have always promoted the importance of science, which transcends cultural and political differences. In view of the current and emerging challenges facing humanity, international cooperation will be more essential than ever in the next 75 years. A continuously evolving WMO will be more relevant than ever!

Happy 75th anniversary WMO!

WMO Systems for Global and National Benefit

By Dr Anthony Rea, Independent Consultant, former WMO Director of Infrastructure

(AI generated image)

Midnight approaches in the United Kingdom. In London, the gears of Big Ben grind their way to the hands of the clock pointing directly upwards. Unbeknownst to the last tourists making their way back to their accommodations, the arrival of midnight in this location, or more precisely in Greenwich, is the signal for a flurry of activity around the world, activity that underpins something that we all take for granted: the predictability of the weather.

Out in the street, a tourist glances at her phone, the weather app tells her that tomorrow will be fine, with a chance of showers in the afternoon. Perfect weather for morning activities but it might be prudent to pack an umbrella. This kind of weather information is so commonplace that we do not give it a second thought. But how does this information get to her phone? The data comes from somewhere, but where?

As the clock chimes midnight in London, it is a sunny morning in Giles, in central Australia. The weather observer on duty presses the button that releases a weather balloon that will take measurements of temperature and humidity as it ascends more than 20 kilometres into the atmosphere. As it is taken by the wind, the onboard GPS tracker allows its movement to be tracked in real time, giving a precise measurement of the wind speed and direction during its ascent. A small radio transmitter sends the observations back to the ground station where they are recorded in a data file.

After more than an hour ascending into the atmosphere, the balloon bursts and the small instrument package safely falls to Earth, arrested by a parachute. The data file, now complete and containing observations of temperature, humidity and wind every two minutes – an atmospheric profile – is dispatched via the Internet to the Bureau of Meteorology's central systems. From there, it is immediately placed on the WMO Information System (WIS), where it is accessible to every meteorological service with a WIS connection.

Global frameworks

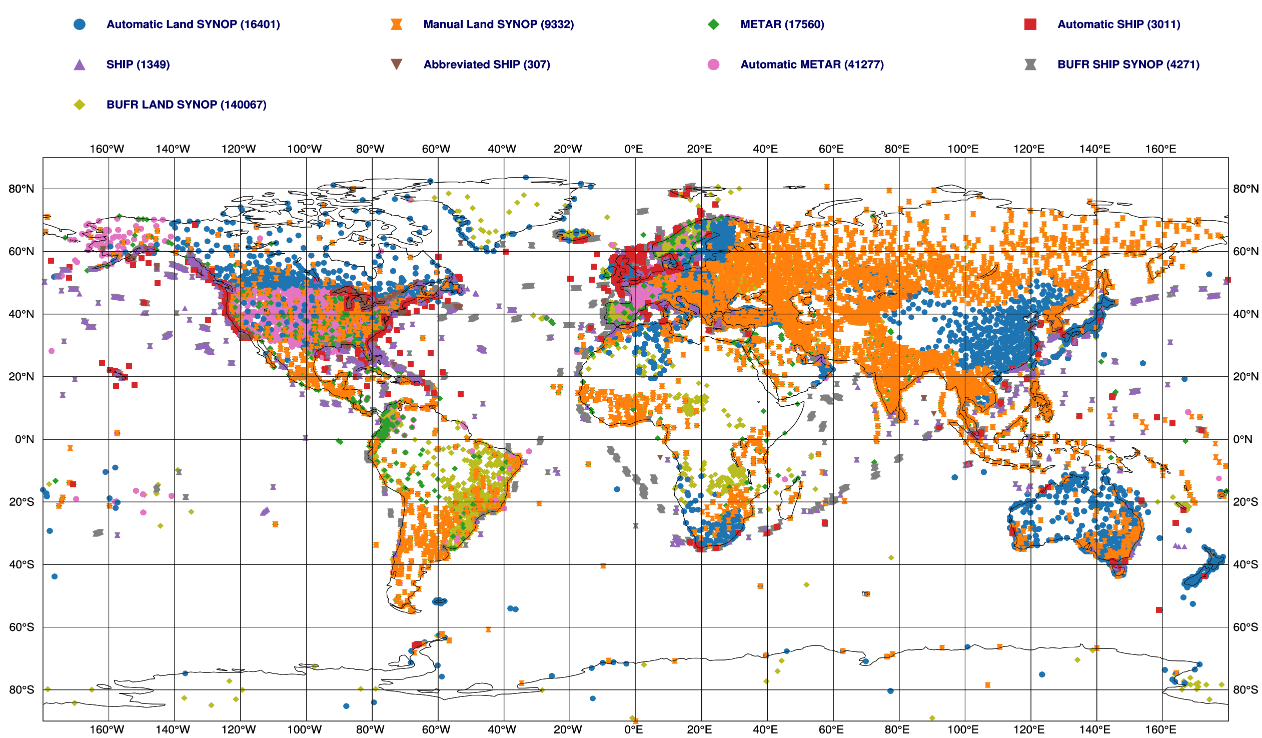
The data arrives at the European Centre for Medium Range Weather Forecasts (ECMWF), where it is checked for errors and then placed in the real-time observations database. This alone is quite

Giles Weather Station balloon release 20 February 2025 (Copyright: Emma Lewis) remarkable: an observation taken in remote Australia is available to a modelling centre on the other side of the globe, in near-real time, with a trusted level of data quality and in a standard format that can be readily understood and decoded. This same process occurs at other numerical weather prediction centres in Australia, Canada, China, France, Germany, Japan, the Russian Federation, the United Kingdom, and the United States of America. These centres, designated World Meteorological Centres under the framework of the WMO Integrated Processing and Prediction System (WIPPS), are at the heart of weather forecasts all around the globe.

What is even more remarkable is that, at the same time as the balloon was launched at Giles, similar launches took place at over a thousand locations around the globe, on every continent including Antarctica, and on many small islands dotted across the oceans. Surface observations – temperature, humidity, pressure, rainfall and wind – from automatic weather stations and from human observers, are also simultaneously recorded and transmitted. Drifting buoys and ships provide measurements at the surface of the ocean, and aircraft, during take-off and landing, provide measurements of wind and temperature. All the data from these observations also end up in the data repositories of World Meteorological Centres.

Complementing these in situ observations, a global fleet of satellites, in both low Earth orbit (500–800 km) and geostationary orbit (32,000 km) provide continuous, real-time observation of a range of meteorological and climate variables. The Coordination Group for Meteorological Satellites harmonizes orbits, sensors, data formats and data downlinks to best meet the needs of the international community. As full member of this group, WMO has a pivotal and unique role in representing the needs of the broader meteorological data user community.

It is this global coordination and free exchange of observational data, under the banner of WMO Integrated Global Observing System (WIGOS), together with the protocols and technology for real-time transmission though WIS, that makes weather prediction possible. Without this framework, global



ECMWF data coverage (all observations: Synop-Ship-MetAr) 1–2 June 2025, total number of observations 233 575 coverage would be patchy at best. Global models require global data. To take this a step further, weather forecasting for more than a day or two ahead requires data covering the whole planet. The dynamic and seemingly chaotic nature of weather requires global models to deliver the forecasts we all depend on.

The dynamic and seemingly chaotic nature of weather requires global models to deliver the forecasts we all depend on.

Global benefits

Weather forecasts are often termed a non-excludable public good: once it's broadcast, it's difficult to prevent anyone from accessing it, and one person's use doesn't diminish its availability for others. As a result, they are available to everyone, all the time, free of charge.

Today, forecasts are ubiquitous on radio, television, print media and, increasingly, on mobile devices. So much so that they can easily be taken for granted. But it is important to remember that, regardless of where you are on the Earth, which country you are in, whether you are on the ground, in the air or on the open ocean, the forecasts you are using are based on information from one of the World Meteorological Centres. And, that every weather, climate or water-related forecast you receive is reliant on the free and open exchange of observational data orchestrated by WMO.

WMO, as the specialized United Nations agency with responsibility for weather, climate and hydrology, can therefore make a unique and unusual claim. The systems that it puts in place benefit every person on Earth who has direct or indirect access weather forecasts and warnings. Perhaps that is not every person on Earth, as there are some who have no access to weather information at all, but it can be said that the overwhelming majority of humans derive benefit from the activities of WMO.

The benefits are distributed to wealthy and poor countries alike, regardless of alliances or geopolitical forces. The frameworks of WMO provide the foundation of all weather services, around the globe. And conversely, the dependency on the data exchange brokered by WMO is also there for all countries – the nature of weather and climate, and the data requirements of global models, mean that no country can "go it alone". A country that would, for example, attempt to run models based only on its national data, would be extremely limited in terms of forecast accuracy and lead time.

Returning to the late-night tourist and her phone, most users of the weather app on their mobile device would have little understanding of the immense global infrastructure that, collectively, delivered the forecast to their device. To put things in perspective, a conservative estimate of the cost of global weather infrastructure, per year, is around USD $10 billion. Comparing this to other global science infrastructure, such as the International Space Station at around $3 billion per year or the CERN's Large Hadron Collider at $1.3 billion per year, it is apparent that, taken as a whole, the global weather forecasting infrastructure is probably the largest science endeavour on the planet. And while this might seem expensive, it is outweighed multiple times by the economic benefit of the services provided, which was estimated in a 2015 WMO report at $160 billion per year, with an average return on investment (ROI) of 1:10 in high-risk regions.

Regional and national benefits

While this is a significant benefit for many countries, in particular Least Developed Countries and Small Island Developing States, the benefits of WMO far exceed the basic foundation of global data exchange and global numerical weather prediction products. There are a wide range of supporting structures and systems that provide supporting capability, capacity development and oversight for WMO Members.

The Severe Weather Forecasting Programme (SWFP) strengthens the capacity in developing countries to deliver improved forecasts and warnings of severe weather to save lives and livelihoods and protect property and infrastructure. SWFP currently involves around 98 developing countries in nine sub-regions of the world including Southern Africa, Eastern Africa, West Africa, Central Africa, South-East Asia, South Asia, Central Asia, Eastern Caribbean , Central America, Oceania and South Pacific, with support from development partners and donors. SWFP builds on data and products made available through

WMO's cascading forecasting process, building additional detail and context on data provided from global producing centres.

For example, for the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), WMO membership brings significant operational benefits, particularly through access to advanced forecasting and data systems. PAGASA uses the SWFP platform as a key tool in its weather forecasting processes, benefiting from multi-model outputs that improve accuracy and aid decision-making. These systems are integral to daily operations at PAGASA's regional forecasting centres.

WMO-sponsored tools like OSCAR, WMO's metadata repository, and the WIGOS Data Quality Monitoring System (WDQMS) enable improved data validation, metadata management, and monitoring of observational network performance. This helps PAGASA to align its practices with international standards and to deliver high-quality meteorological and climate data. PAGASA is also actively implementing the latest implementation of WIS, WIS 2.0, with technical assistance from Indonesia and Japan, ensuring seamless data exchange via both primary and backup systems.

Beyond operations, WMO plays a key role in capacity building and innovation. PAGASA staff regularly participate in WMO-sponsored training programs, including workshops on data systems, radar use, and satellite meteorology. WMO also supports strategic transitions such as the shift to impact-based forecasting (IBF), currently being piloted in Metro Manila and Metro Cebu. Long-term initiatives like data rescue, supported by WMO since 2017, ensure the preservation of historical climate records and support future-ready services.

In Chile, WMO systems have also directly contributed to reducing loss of life and economic damage from extreme weather, climate and water-related events. Agroclimatic warning systems now provide timely alerts for frost, heatwaves, hail and heavy rainfall, while real-time monitoring portals support rapid response to wildfire risks and other hazards. By encouraging and facilitating the exchange of meteorological data across institutions through WIGOS – especially within the agricultural sector – WMO frameworks have helped end users plan more effectively and make informed decisions that protect both people and livelihoods.

Through access to WMO's global network of expertise, and frameworks like WIGOS and WIS, the Chilean

Meteorological Service has significantly improved the accuracy and timeliness of its data and forecasts. This has enabled the development of advanced early warning systems and climate services that support sectors ranging from agriculture to emergency management, particularly in response to prolonged droughts and extreme weather events.

In South Africa, WMO membership has played a vital role in strengthening the delivery of meteorological and climate services by promoting international collaboration, standardizing practices, and supporting sustainable development. Frameworks such as WIGOS and WIS provide access to essential global data and systems, while also offering capacity development and technical assistance – benefits that are particularly valuable to less-resourced countries. This integration with the global weather infrastructure ensures that the South African Weather Service can more effectively carry out the responsibilities under its mandate.

With WMO's support, South Africa has been effective in reducing disaster risks and improving public safety. The promotion of the Common Alerting Protocol (CAP) has enabled warnings to be disseminated widely across multiple platforms, reaching more people, especially in vulnerable communities. Programmes such as the SWFP and the Southern Africa Region Flash Flood Guidance System (SARFFGS) have significantly enhanced the country's ability to deliver accurate, timely warnings for extreme weather events, including flash floods – the most destructive and sudden form of flooding.

In Cambodia, WMO membership has been transformative in enhancing the country's meteorological and climate resilience, particularly in a region highly exposed to seasonal flooding and tropical cyclones. Access to global data and forecasts through frameworks such as WIGOS, WIS, and SWFP has strengthened the country's ability to deliver accurate, timely and actionable warnings. During *Tropical Cyclone Soulik* in 2024, WMO's coordination enabled Cambodia to issue early evacuation alerts and forecasts that significantly reduced casualties compared to previous events. SWFP provided critical guidance, while WIGOS and WIS facilitated the rapid exchange of observations and warnings. These systems, paired with targeted capacity building programs and real-time collaboration with regional centres, have helped modernize Cambodia's disaster risk reduction efforts.

Beyond emergency response, WMO's support has also advanced long-term resilience in sectors such as agriculture. In the Tonle Sap region, for example, WMO's Global Framework for Climate Services (GFCS) has helped farmers adapt to increasingly unpredictable seasonal patterns. By tailoring forecasts to local needs, providing training, and ensuring the delivery of clear, accessible climate information, Cambodian authorities have empowered communities to make better-informed decisions – such as shifting planting schedules or choosing resilient crop varieties. Collaboration with partners, like SERVIR-Mekong and the Mekong River Commission, has further strengthened flood forecasting tools, with alerts now disseminated via SMS and radio to vulnerable populations. This integrated approach has improved food security, reduced economic losses and deepened public trust in national weather services.

In Kenya, WMO membership has provided crucial support for building and maintaining standardized meteorological infrastructure, including observing systems, data exchange platforms, and operational procedures. Through initiatives like WIGOS, WIS, WIPPS, and SWFP, WMO has helped establish the foundational pillars of the country's early warning systems. It has also facilitated access to advanced forecasting models and expertise from global centres such as ECMWF and National Centers for Environmental Prediction (NCEP), enabling Kenya to produce reliable early warnings and benefit from harmonized training and capacity building efforts.

This support has directly improved the quality and reach of severe weather forecasts, contributing to a measurable reduction in loss of life. Kenya's disaster risk authorities, aviation and maritime sectors, and local communities now receive timely, impact-based forecasts through coordinated dissemination channels like CAP and SWFP web portals. A notable example is the response to El Niño-induced heavy rainfall events, where early advisories – enabled by SWFP products – helped prevent fatalities and protect livelihoods and infrastructure across multiple regions.

A vital role

As these examples strongly demonstrate, WMO holds a vital role in providing the underlying framework for advancing global meteorological, hydrological and climate services. From improving the accuracy and timeliness of severe weather warnings to strengthening resilience in climate-vulnerable sectors like agriculture and disaster risk management, WMO frameworks and initiatives consistently translate science into action.

Through systems like WIGOS, WIS, WIPPS, and SWFP, WMO Member States and Territories – regardless of economic status – gain access to critical data, technologies and capacity building that enable them to better serve and protect their populations. As the effects of climate change intensify extremes and the demand for reliable early warning systems grows, WMO leadership in fostering international cooperation, standardization and innovation will become ever more important in the 75 years ahead to the turn of the century. Its enduring commitment to leaving no country behind ensures that the benefits of meteorological science are shared widely and equitably around the globe.

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Celebrating Success in Fostering Regional Collaborations and Coordination – Perspectives from Regional Association V

By Ms KOH Li-Na, Director-General of the Meteorological Service Singapore (MSS) and Permanent Representative of Singapore to the WMO

"I must repeat the meteorological mantra: weather, climate and water know no borders." – WMO Secretary-General, Prof. Celeste Saulo

National Meteorological and Hydrological Services (NMHSs) know that the global nature of weather, climate and hydrological system requires international real-time collaboration to gather and exchange data and make forecasts and predictions, and that there are huge benefits to the collective development of meteorological capabilities. Thus, they welcomed the establishment of WMO in 1950 with its mandate to facilitate international coordination among NMHSs – a mandate that has continuously expanded to cover many emerging priorities over the last 75 years.

NMHSs can point to many essential WMO frameworks for international meteorological cooperation among its Member States and Territories. WMO's establishment of highly ambitious programmes during the Cold War – in 1951, the Global Telecommunication System (GTS), which came to underpin the free and unrestricted exchange of meteorological observations and data, and in 1963, the World Weather Watch (WWW) and the Global Observing System (GOS) – is hailed among the most successful examples of multilateral cooperation. The sharing of data, expertise and resources through the WMO permitted the international meteorological community to develop sophisticated Numerical Weather Prediction (NWP) systems that are continuously refined to support the provision of ever more accurate forecasts

The six WMO Regions, each with its own Regional Association and early warning services down to today. Such advancements would have been impossible for any single nation to attain on its own.

Complementary to its global frameworks, WMO has placed great emphasis on regionalization to support NMHSs in developing capacity for the provision of quality weather, climate and hydrological services. Closer regional and sub-regional cooperation improves the operations of many NMHSs by enhancing capacities through technology exchange, the sharing of resources and cost-effective regional services. In celebration of the WMO's 75th Anniversary, this article reflects on WMO's efforts in regionalization since its inception, with perspectives on how WMO Region V, the South-West Pacific and the Southeast Asian sub-region, have benefitted.

From global frameworks to regional action

From the beginning, WMO recognized that global frameworks would be insufficient to enhance the operational capabilities of NMHSs. Given the unique needs and contexts of NMHSs in each region, it would be equally important to establish regional frameworks to support Members with the implementation of global initiatives, while allowing tailored solutions that addressed regional priorities and needs. It was in this spirit that the very first World Meteorological Congress in 1951 established the six WMO Regional Associations (RAs). These RAs became responsible for translating WMO's strategic priorities and global frameworks into regional action.

To this day, the RAs serve their fundamental missions as platforms for Members to coordinate regional meteorological activities and interests. They allow regions to discuss and pool together expertise and resources for tackling region-specific challenges. Through the RAs, Members are also able to elevate regional priorities and concerns to WMO's global platforms for greater attention.

In support of the regional governance frameworks, the WMO Secretariat created "Regional Offices" in the 1960s to support respective RAs with the implementation of the WMO Strategic and Operating Plans. These Offices were later decentralized from WMO headquarters in Geneva to strategic locations worldwide to strengthen WMO's regional presence and deepen its relationship with regional development partners.

Today, WMO operates four Regional Offices[1] and several Representative Offices (RROs), each serving a distinct geographical area with a unique hydrometeorological context. As the WMO Secretariat's "frontline" in the regions, the RROs support the RAs in a variety of ways such as by facilitating regional information-sharing, supporting the development of NMHS capacities, promoting regional cooperation, and translating Members' needs back to WMO headquarters. With the support of the RROs, RAs are better able to interface with the WMO Technical Commissions to identify regional priorities, access resources and technical expertise, and drive initiatives that address regional needs.

Benefiting from WMO's regionalization efforts

RA V covers a vast area as it comprises the countries of Southeast Asia as well as Australia, New Zealand and the Pacific Islands. The Region faces a wide array of weather and climate-related hazards, ranging from heatwaves and vegetation fires to tropical cyclones, extreme rainfall and floods. With such diverse challenges, and Members at different levels of development, WMO coordinated regional initiatives in specialized areas have been critical in strengthening the service delivery capacities of the individual NMHSs.

Most prominently, WMO Regional Specialized Meteorological Centres (RSMCs), coordinated through the WMO global operational network, have been crucial in strengthening RA V's operational capabilities for service delivery. These RSMCs form an essential backbone in the RA V operational infrastructure, providing each NMHS with clear, accessible region-specific operational information across a broad spectrum of hazards. The products and services provided by RSMCs empower NMHSs with limited forecasting capacities to deliver quality services to their stakeholders despite resource constraints. Space only permits us to highlight a sample of RSMCs services in the region:

- RSMC Darwin (Australia) has served the region for over 50 years, providing tropical analysis, prognosis and diagnostics, as well as tropical cyclone and volcanic ash advisory services.

1 The Regional Office located in Addis Ababa, Ethiopia, serves RA I (Africa), the one in Singapore serves both RA II (Asia) and RA V (South-West Pacific, the one in Asuncion serves RA III (South America) and RA IV (North America, Central America and the Caribbean), and one remains at WMO headquarters in Geneva to serve RA VI (Europe)

- The Tropical Cyclone RSMCs in Melbourne (Australia) and Nadi (Fiji), together with the Tropical Cyclone Warning Centres in Jakarta (Indonesia) and Wellington (New Zealand), track tropical cyclones within their respective watch areas, and work closely to ensure coordinated warnings where necessary. Given the South-West Pacific's vulnerability to tropical cyclones, their advisories and warnings have been critical in reducing the loss of lives and livelihoods across in the region.
- RSMC Wellington issues marine information, advisories and warnings for the South-Pacific and Southern Oceans, including broadscale guidance for expected severe weather over the South-West Pacific.
- RSMC Singapore, designated in 2024, specializes in vegetation fire and smoke pollution forecasting in Southeast Asia, providing advice that supports decision-making in emergency response, fire management, environmental protection, etc.

Other WMO regional centres and mechanisms also serve RA V's wide-ranging needs:

- Supporting observing systems and networks: With the support of RROs, RA V is in the process of developing a Regional Basic Observing Network (RBON), a crucial step towards regional WIGOS implementation. In parallel, a Regional WIGOS Centre (RWC) has been established in pilot mode with nodes hosted by Fiji and Indonesia. The RWC will control the quality, and ensure the timely availability, of meteorological observation data collected by Members in the region. It will support follow-up on data compliance issues, ultimately delivering more and improved observations to stakeholders in RA V. To ensure the accuracy of monitoring instruments, and thus the integrity of observational data, Regional Instrument Centres (RICs) in Manila (Philippines) and Melbourne (Australia) provide specialized facilities to assist Members with calibrating instruments.
- Supporting NMHSs in delivering higher-quality climate services: Coordination between RA V subsidiary bodies and WMO Technical Commissions led to the establishment of two WMO Regional Climate Centre (RCC) Networks: one the Southeast Asian, the other for the Pacific Island sub-region. The Networks comprise nodes that collectively provide regional climate products such as climate datasets, climate monitoring tools and long-range forecasts and training. Both are still in the demonstration phase but will soon be fully operationalized and formally designated. The Networks facilitate the organization of Climate Outlook Forums (COF) to review sub-regional climatic conditions and collaboratively generate regional climate outlooks. The inaugural Association of Southeast Asian Nations (ASEAN) Climate Outlook Forum (ASEANCOF) was held in 2013 while the Pacific Island Climate Outlook Forum (PICOF) commenced in 2015.
- Training and capacity building: The Regional Training Centres (RTCs) in the Philippines and Indonesia provide specialized training – for postgraduate diplomas and degrees in meteorology and for meteorological technicians – to enhance the competencies of NMHS personnel in RA V. RTCs training solutions are cost-effective for smaller NMHSs with limited local training resources.

This limited overview of RA V initiatives and mechanisms established under WMO frameworks show how the Organization's regional approach has created an ecosystem of expertise and resources for the region to leverage. They also demonstrate the value of the regional cooperation and coordination that augment individual Members' capacity to deliver critical weather services, ultimately protecting lives and livelihoods.

Pursuing collaborations with other regional platforms

Beyond its internal coordination mechanisms, WMO is also known for its success in building enduring partnerships with regional and sub-regional intergovernmental organizations. Within Region V, WMO has used these partnerships to advocate for the visibility and development of the NMHSs. For example, WMO used its longstanding relationship with the Pacific Meteorological Council to support the Weather Ready Pacific Programme, which mobilizes resources for strengthening NMHS capacities in climate resilience.

Within Southeast Asia, WMO has also actively engaged with ASEAN for more than three decades to champion the development of the sub-region's meteorological capabilities. Despite its vast geographic spread, Southeast Asia shares common weather patterns that are influenced by large systems such as the Asian monsoon and El Niño-Southern Oscillation (ENSO). While the whole

Inauguration of the ASEAN Specialized Meteorological Centre in Singapore in September 1994 by former Minister for Communications and Minister for Environment Mr. Mah Bow Tan.

WMO Secretary-General Prof. Celeste Saulo, Minister for Sustainability and Environment Ms. Grace Fu, and Director General of MSS Ms. Koh Li-Na at the launch of the RSMC Singapore during the ASMC-WMO Regional Forum.

region is susceptible to monsoon-related floods and ENSO variability, local geography creates distinct weather-related challenges. Maritime countries such as Malaysia and Singapore frequently encounter sea-breeze induced thunderstorms, while countries at higher latitudes – the Philippines, Myanmar, Viet Nam and parts of Indonesia – are vulnerable to tropical cyclones. Attuned to this vulnerability but with relatively limited meteorological capabilities in the post-colonial era of the 1970s, NMHSs in Southeast Asia embraced collaboration with each other as a bulwark against the common risks of floods, drought and tropical cyclones. This was primarily undertaken through the ASEAN Sub-Committee on Climatology (SCC), which was established in the mid-1970s, and supported by WMO. It was renamed the Sub-Committee on Meteorology and Geophysics (SCMG) in 1989.

Further, in the late 1970s and early 1980s, WMO and United Nations Development Programme (UNDP) supported the Malaysian Meteorological Department's pioneering SCC projects: "ASEAN Climatic Atlas" and "ASEAN Compendium of Climate Statistics." Completed in 1982, these initiatives provided five ASEAN Members[2] with access to vital regional climate data, a remarkable achievement in an era before Internet.

WMO also played a pivotal role when the ASEAN Specialised Meteorological Centre (ASMC) was established in Singapore in 1993. In response to interest from ASEAN Members, WMO had led a feasibility study for a Southeast Asian RSMC, however, when ASMC was instead established under the SCMG framework, WMO provided much-needed financial and technical support to the fledgling Centre. For instance, WMO funded training on NWP models for ASEAN NMHSs experts at the ASMC between 1993 and 1997.

Over the last three decades, ASMC and WMO have fostered a close partnership to deliver on a shared vision: the bolstering of NMHS capacities region-wide. The collaborative relationship continues today through joint regional training programmes and capacity building workshops for ASEAN NMHSs and stakeholders.

The ASEAN–WMO Memorandum of Understanding (MoU) in 2002 reinforced WMO's commitment to the region and highlighted its commitment to the pursuit of new opportunities for collaborations and partnerships to benefit its Members. Today, the RRO continues to participate in SCMG meetings, providing insights into technical priorities and advising on possible synergies between SCMG projects and WMO regional initiatives and programmes. This has enabled closer regional coordination that is particularly valuable as ASEAN spans two WMO regions: II and V. WMO also supports technical projects in key areas of interest for SCMG. For example, the WMO Severe Weather Forecasting Programme for Southeast Asia, with its Regional Forecasting Support Centre, hosted by Viet Nam. WMO also supports activities jointly led by SCMG and its Dialogue Partners, such as the ASEAN radar data exchange initiative led by the Thai Meteorological Department (TMD). This experimental radar data exchange initiative aims to demonstrate the benefits of sharing data for specific needs, such as for monitoring rainfall, and contributes towards the WMO Regional Basic Observing Network (RBON) framework.

2 Indonesia, Malaysia, Philippines, Singapore and Thailand

WMO Deputy Secretary-General Ko Barrett has reiterated WMO's commitment to the Weather Ready Pacific – a major ten-year programme endorsed by Pacific Islands Leaders in 2021 – which aims at reduce the human and economic cost of severe weather events and thus protect Pacific Island communities and livelihoods on the frontline of climate change

WMO challenges to serve Members in the years ahead

WMO's facilitation of cross-border and regional collaboration is more critical than ever as climate change impacts are already being felt in many regions through an increase in the frequency and severity of extreme weather events. Emerging technologies like Artificial Intelligence (AI) present new opportunities for cooperation. AI-driven NWP models could revolutionize weather forecasting, but the accuracy of such forecasts will only be as reliable and accurate as the data they ingest, thus the continued importance of international standards, the calibration of instruments and data-sharing mechanisms – all the work of WMO.

It is also more urgent than that WMO pursue regional and international collaboration to advocate for NMHSs at the national, regional and global levels. Engagements between WMO and key regional platforms, such as ASEAN and the Pacific Island Forum, can be enhanced. New areas of synergy can also be found with other regional workstreams, which could benefit WMO's capacity building efforts and disaster risk reduction activities.

Beyond regional frameworks, WMO must continue to work with global frameworks, such as United Nations Office for Disaster Risk Reduction (UNDRR), to further strengthen climate action and disaster risk reduction. WMO could extend its reach and amplify its impact on the ground for the benefit of its Members by integrating more closely with global agendas and platforms. Closer links with regional and global frameworks could also unlock additional resources to help to further bridge persistent capacity gaps between Members. WMO should harness the momentum of the Early Warnings for All initiative and the Systematic Observations Financing Facility (SOFF) to strengthen its advocacy and resource mobilization efforts. WMO requires more resources to translate global ambitions into tangible improvements in regional and national weather services – ultimately building the climate resilience necessary to protect communities.

No Member can be left behind

"Looking back, the success of WMO's regional and international approach lies in how it has democratized access to free and unrestricted data, and meteorological expertise, ensuring that all nations can harness the collective scientific power of the global community to protect their citizens." – Former Permanent Representative of Singapore to the WMO, Ms Wong Chin Ling

In an increasingly complex world, NMHSs are facing existential and operational challenges. WMO's global frameworks and regional coordination mechanisms offer them opportunities to work together to address those challenges and harness emerging opportunities.

The WMO regional strategy has been unique in its ability to unite diverse stakeholders who share a common goal: the safeguard of communities, economies and ecosystems from disaster risks through ever better early warnings and the provision of weather, climate and hydrological services. In an increasingly uncertain world, no Member can be left behind. WMO regional cooperation represents the bedrock for resilience through its continuous improvement of forecasting and early warning services and through disaster risk reductions efforts, which ultimately save lives and protect livelihoods around the globe.

Meteorology in the Caribbean - A Personal Record from Belize Perspective

By Carlos Fuller, Ambassador and Permanent Representative of Belize to the United Nations

In early September 1931, a hurricane was observed by ships moving westward through the Caribbean Sea. The ships tried to avoid the system for their own safety and, as weather observations were sparse at the time, they transmitted the information to the telegraph operator in Belize City who conveyed it to the British governor of British Honduras, as Belize was known at the time. The hurricane was expected to cross the country on the afternoon of 10 September. Belizeans celebrate 10 September as the Battle of Saint George's Caye, a Public and Bank Holiday with citizen parades through the cities and towns. The governor advised local authorities that the parade should proceed as scheduled in the morning but that revelers should return to their homes immediately after to await the passage of the storm.

On 10 September the eye of the Category 5 hurricane crossed Belize City bringing with it a 15-foot (10-metre) storm surge. The hurricane destroyed Belize City and claimed over 3 000 lives. My father was seven years old at the time. The storm surge lifted his home, with him, his father, mother and four siblings inside, and deposited it about 100 yards from its foundation. Fortunately, none of them perished.

Thirty years later, *Hurricane Hattie*, another Category 5 hurricane, crossed Belize City on 31 October 1961, with another 15-foot storm surge. Belize City was destroyed once again, this time 400 lives were lost. WMO had just marked its 10th year and there was now a rudimentary hurricane warning system in place in the region, based a on weather observation stations that were transmitting data to global and regional forecasting centres. Aircraft were dispatched on reconnaissance missions into the Atlantic from bases in Puerto Rico and Trinidad to identify any areas of potential development. *Hattie* was also one of the first hurricanes to be observed by a polar-orbiting satellite. My father evacuated my mother, my sister and me into the interior of the country one day before the hurricane struck. We remained there for six months until the city had returned to some semblance of normalcy and schools had reopened.

I do not recall ever thinking about weather and climate during my childhood and teenage years. However, my Sixth Form mathematics teacher who happened to be the country's Chief Meteorologist offered me a position as a weather observer upon graduation. This was the start of my career in meteorology which lasted 34 years. Subconsciously, did my

The devastation of Hurricane Hattie (left) and of the1931 hurricane (right).
Photos Courtesy: Eric King Collection (with permission from Imagination Factri)

family's experience with these major weather events influence my decision to embrace meteorology and climate change as a career path? The opportunity provided by my teacher certainly opened the door.

These are our stories.

Decolonization

The 1950s and 1960s were exciting but tumultuous years. The world was recovering from the Second World War. New international global governance and financial institutions had been created following the war: the United Nations, the World Bank, the International Monetary Fund (IMF), the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and in 1950, the World Meteorological Organization (WMO). The fervor of nationalism was rampant among colonial peoples; empires were crumbling, and their colonies were clamoring for independence. The British colonies in the Caribbean were no exception, however, the British authorities proposed a different path for them.

The British government of the day believed that their colonies in the Caribbean were too small and had limited human capital, natural resources and potential to succeed as independent states. They proposed that the territories be amalgamated into a federation and become one independent nation. The political leaders of several of the territories agreed and the West Indian Federation was born on 3 January 1958. Federal institutions were formed. The British Caribbean Meteorological Service, which had been established in 1951 became the West Indies Meteorological Service with its headquarters in Port of Spain, Trinidad. Forecast offices were established in the Bahamas, Jamaica and Trinidad. The other territories had weather observation stations that relayed data to the forecast offices, which in turn generated and transmitted weather forecasts and warnings to Members. The forecast offices were manned by personnel from the region. Basic training was provided at the Port of Spain headquarters while the staff went to the British Met Office College for more advanced training as forecasters, climatologists and instrument technicians. However, the federation did not last, it was dismantled on 31 May 1962. The Federal Meteorological Service did not survive either, and the staff were dispersed to their countries.

With no Federal Meteorological Service to provide weather services and warnings, newly independent Caribbean States and self-governing territories formed the Caribbean Meteorological Service (CMS) in 1963. Responsibility to provide weather services was assigned and divided among the Members. But Governments recognized that a more formal institutional mechanism would be required to adequately serve the region. Consultations and negotiations commenced, and the Caribbean Meteorological Council of ministers held its first meeting in 1962. The Caribbean Meteorological Institute (CMI) was established in 1967 as a training centre and an agreement in 1973 established the Caribbean Meteorological Organization (CMO).

One of the former officers of the Federal Meteorological Service was Belizean, Kenrick Leslie. A forecaster in Trinidad in 1961 during the passage of *Hurricane Hattie*, he recalled the pilot of the hurricane reconnaissance aircraft saying in a Texan drawl, "All is gone; all is gone". Upon completing his degree at the University of the West Indies, he returned to British Honduras in 1966 where he was assigned to the Civil Aviation Department, which provided aeronautical and rudimentary meteorological observations to support aviation. Weather forecasts were provided to Belize by Jamaica, which had begun doing so during the period of the Federal Meteorological Service. Recalling his *Hurricane Hattie* experience, the new Chief Meteorologist was determined that Belize should have its own weather service. British Honduras had been granted self-government in 1962, and his aspirations fell on fertile ground: Premier George Price tasked him to develop a full-fledged meteorological and hydrological service for the country.

Former colonies, like Barbados, Jamaica and Trinidad and Tobago, joined WMO as they achieved independence. The Dutch became WMO Members as the Netherland Antilles, however, self-governing colonies like Belize were WMO Members as part of the British Caribbean Territories (BCT). This enabled Mr Leslie to receive technical support from WMO to develop the Service. He brought the diverse weather observing stations operated by the agriculture, civil aviation and forest departments under one umbrella, standardizing the equipment and implementing uniform observing practices and procedures as mandated by WMO. The weather stations were upgraded through the WMO Technical Assistance Programme. Personnel were recruited and received fellowships to the United Kingdom and the United States of America (US) under the WMO Voluntary Cooperative Programme (VCP). By the mid 1970s the name of the country had been changed to Belize and the Belize Weather Bureau had been established as a separate government department – no longer a part of the Civil Aviation Department.

On 21 September 1981, Belize achieved independence and was admitted into the United Nations the following day. On 23 June 1982, Belize became a Member of WMO.

Development

As a Member, Belize could access all the resources of WMO to develop hydrometeorological services for socioeconomic development. The Belize Weather Bureau became the National Meteorological Service (NMS) in 1982.

Meteorological Services in the Caribbean had all developed to provide support to aviation and to provide warnings of severe weather. The threat posed by tropical cyclones to the entire region – including the Caribbean, Central America, Mexico and the US – galvanized their cooperation in the exchange of data, training and the provision of technical assistance. WMO played an instrumental part in this and the WMO Regional Association IV (RA IV) Hurricane Committee was established. It was a major achievement when the region received nine modern 10-cm weather radars in 1970 through a WMO/United Nations Development Programme (UNDP) project funded by Japan. These were deployed in Antigua, Barbados, Belize, Cuba, Guyana, Jamaica, and Trinidad and Tobago and were manned and maintained by local meteorological personnel.

The weather services developed and expanded rapidly during the 1970s. With the support of WMO, more staff were trained at the technical, graduate and post-graduate levels. Automatic weather stations, radio weather facsimile, and satellite Earth stations were procured through WMO technical assistance programmes. Products were developed and provided for the public, agriculture, forestry, tourism and all socioeconomic sectors reliant on the weather and climate. Recognizing the capacity of the staff, their technical expertise and the maturity of the Belize Weather Bureau, the US moved its rawinsonde station and marine broadcasting equipment from Swan Island to Belize in 1978.

CMI was now providing training for weather observers, climatological and instrument technicians, forecasters and, in collaboration with the University of the West Indies, offering undergraduate degrees in meteorology. The radar in Barbados had been installed on the compound of the CMI. CMI also served as an archiving and quality control repository for the region's meteorological data, a regional instrument calibration centre and a warehouse for meteorological instruments and radar spare parts. With the support of the Dutch Government, the Caribbean Operational Hydrological Institute (COHI) was established in 1982 on the compound of the CMI; both institutions were amalgamated in the mid-1980s and officially became the Caribbean Institute for Meteorology and Hydrology (CIMH) in 1999.

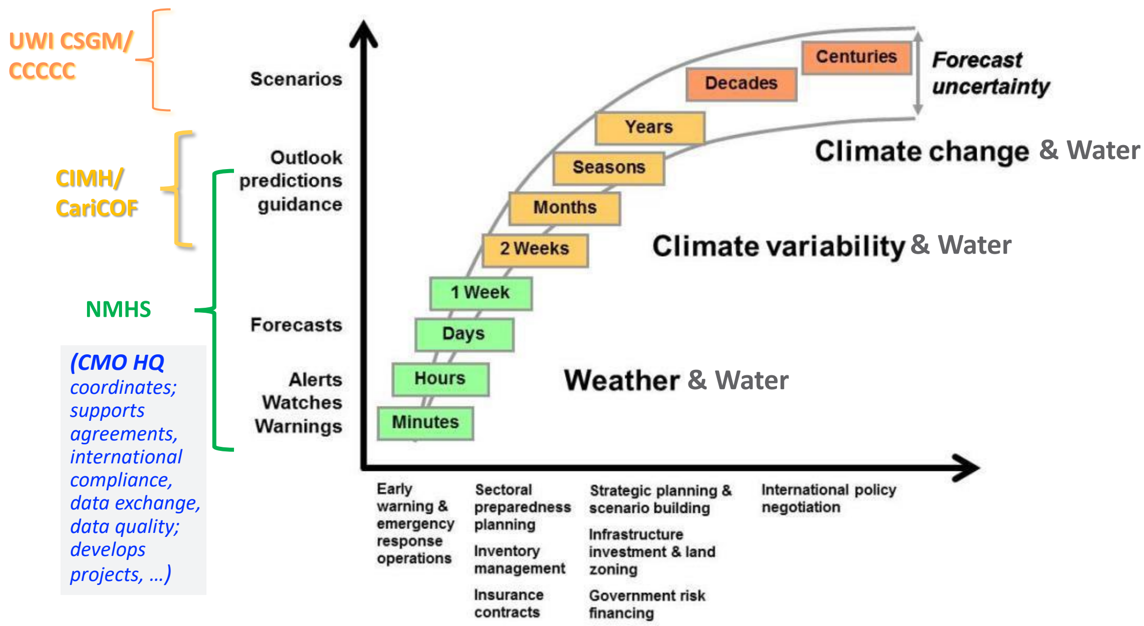
In the 1960s Barbados and CMI had become the node in the Caribbean for tropical research. Florida State University conducted field expeditions utilizing aircraft and ships, and enhanced ground and upper air observations. In 1974 the region contributed to the GARP Atlantic Tropical Experiment (GATE) which studied tropical systems moving across the Atlantic from Africa to the Caribbean. Our understanding of the structure, development, evolution and trajectory of tropical waves and tropical cyclones came through the data gathered in the field experiments conducted in the 1960s and 1970s in the region.

At the international level Caribbean meteorologists joined WMO as staff members. They were elected to posts in the Organization, serving as presidents of RA IV and Vice-Presidents of the World Meteorological Congress and WMO Executive Council.

The New Agenda

In 1962, British Honduras was granted self-government. Local elected representatives assumed responsibility for all the affairs of government except for foreign affairs and defense. This new national government was responsible for the reconstruction of the country following the passage of *Hurricane Hattie*. They decided to move the capital from Belize City into the interior of the country away from the devastating effects of hurricanes, knowing that there would be more threats in the future. A new city, Belmopan, was hewn out of the forest 50 miles inland and 250 feet above sea level in what may have been the first climate change adaptation and retreat project undertaken in the world even before the threat of climate change had been recognized.

The threat posed by climate change and sea-level rise to small island and low-lying developing States convinced the UN General Assembly in 1990 to establish the Intergovernmental Negotiating



Weather, Climate, Water, Prediction in the Caribbean (Source: UKMO/WMO)

Committee to draft a convention on climate change. I had been promoted to the post of Chief Meteorologist by that time and was assigned the task of leading the Belize delegation at these negotiating sessions. The Bahamas, Guyana and Jamaica also had meteorologists either leading or on their delegations and the Caribbean Community (CARICOM), through the Alliance of Small Island States (AOSIS), ensured that the discussions were informed by the science and the best available data. These interventions resulted in projects to enhance the observing networks in Central America and the Caribbean.

The first of these was a project funded by Finland in Central America, which opened the door for Belize. While support to aviation stimulated the development of meteorological services in the Caribbean, it was support to agriculture and hydropower which drove the development of hydrometeorological services in Central America. A Regional Committee of Hydrological Resources (Spanish acronym, CRRH) had been formed to coordinate hydrological and meteorological services. Belize joined CRRH to access all the resources of the FINNIDA project such as meteorological and hydrological monitoring equipment, service vehicles, consultants and training. Through CRRH, Belize undertook its first climate change vulnerability studies in agriculture, coastal zone and water resources. Finland then funded a similar project in the Caribbean, which focused on strengthening the meteorological observing network, the instrument calibration centre at CIMH and capacity building.

Twelve sea-level rise monitoring stations were installed in the region under the Caribbean Planning for Adaptation to Climate Change (CPACC) project, the first regional climate change project funded by the Global Environmental Facility (GEF). The tide stations were upgraded under the successor project, Mainstreaming Adaptation to Climate Change (MACC) which also installed 12 Continuously Operating Reference Stations (CORS) at the sites to monitor changes in elevation.

During this period, the CARICOM Heads of State mandated the establishment of the Caribbean Community Climate Change Centre (CCCCC). As the Chief Meteorologist and the Focal Point to the United Nations Framework Convention on Climate Change (UNFCCC), I was tasked with drafting the proposal and lobbying for Belize to host the Centre. With a final nudge by Prime Minister Said Musa, Belize won the bid, and I was asked to set up the Centre.

Fortunately, the paths of Belize’s first Chief Meteorologist and I were to cross again. Having retired as Chief Meteorologist in 1981, Mr. Leslie had migrated to the US where he went into the LIDAR technology field, achieved a PhD and eventually became a Chief Scientist at Honeywell. He retired and returned to Belize in 2012 as we were looking for the first Executive Director of the CCCCC. Dr Leslie welcomed the challenge, and set about establishing his second institution in Belize, but this time at the regional level.

CARICOM now has several regional weather, water and climate institutions: CMO, CIMH and CCCCC. In 1991, it also created the Caribbean Disaster Emergency Management Agency (CDEMA) and, in 2007, the Caribbean Catastrophe Risk Insurance Facility (CCRIF) to provide insurance coverage to limit the financial impact of hurricanes and other natural hazards.

The global community now recognizes that climate change is producing rapid changes in seasonal patterns, increasing the frequency and intensity of extreme weather events such as droughts, intense rainfall, floods and hurricanes. In response, governments and UN agencies are developing programmes to address these challenges. The Caribbean has the institutions to implement such programmes cost effectively.

CMO continues to coordinate the region's NMHSs through its representation at WMO and other relevant fora while developing project proposals for strengthening the delivery of services by its Member States. CIMH is now a WMO Regional Training Centre and Regional Climate Centre. It runs regional weather models for the NHMSs and wind, rainfall and storm surge models during severe weather events on behalf of CCRIF to validate insurance claims. It executes projects supporting agriculture, flood forecasting and water resource management. CDEMA coordinates the region in mitigating and responding to both natural and manmade disasters; CCRIF provides insurance coverage for hurricanes and flooding, and CCCCC coordinates the region's response to climate change.

The region is thus well poised to access support through initiatives such as the Climate Risk and Early Warning Systems (CREWS), the UN Secretary-General's Early Warnings for All Initiative and the Systematic Observing Financing Facility (SOFF). The five Caribbean regional institutions are making the best use of the resources available to ensure that they are equipped to provide services to foster socioeconomic development and the safety of the Caribbean people.

Unlocking East-West Collaboration for Early Warnings for All in Europe

By Dr Elena Mateescu, Director General, National Meteorological Administration, Permanent Representative of Romania to the WMO, president of WMO Regional Association VI, and Dr Matthieu Kohl, WMO Secretariat

Across Europe, the realities of climate change and extreme weather events are becoming impossible to ignore. The past years have seen a sharp increase in disasters. 2024 alone experienced record-breaking wildfires in Greece, deadly heatwaves across Southeastern Europe, and catastrophic floods in Valencia, Spain (*European State of Climate Report* 2024). Notably, Storm Boris brought exceptional rainfall that led to major inundation across large parts of Central and Eastern Europe. The map below vividly illustrates the scope of this event: between 12–16 September, some areas received more than three times their average monthly precipitation in just five days (Fig. 1). These events reveal the widespread exposure of large parts of the continent to a variety of climate extremes, and the urgent need for timely, efficient and inclusive early warning systems. In this context, resilience to disasters must be embraced as a shared responsibility in the face of a shared risk.

A strong, well-functioning early warning system is one of the most effective tools for reducing disaster risk. When fully operational, such systems provide critical lead time that allows communities to take protective action, emergency services to prepare resources and governments to coordinate responses (*Global Status of Multi-Hazard Early Warning Systems* 2024). Beyond saving lives, these systems strengthen public trust, support economic stability and contribute to broader climate resilience. In a future marked by increasingly frequent and

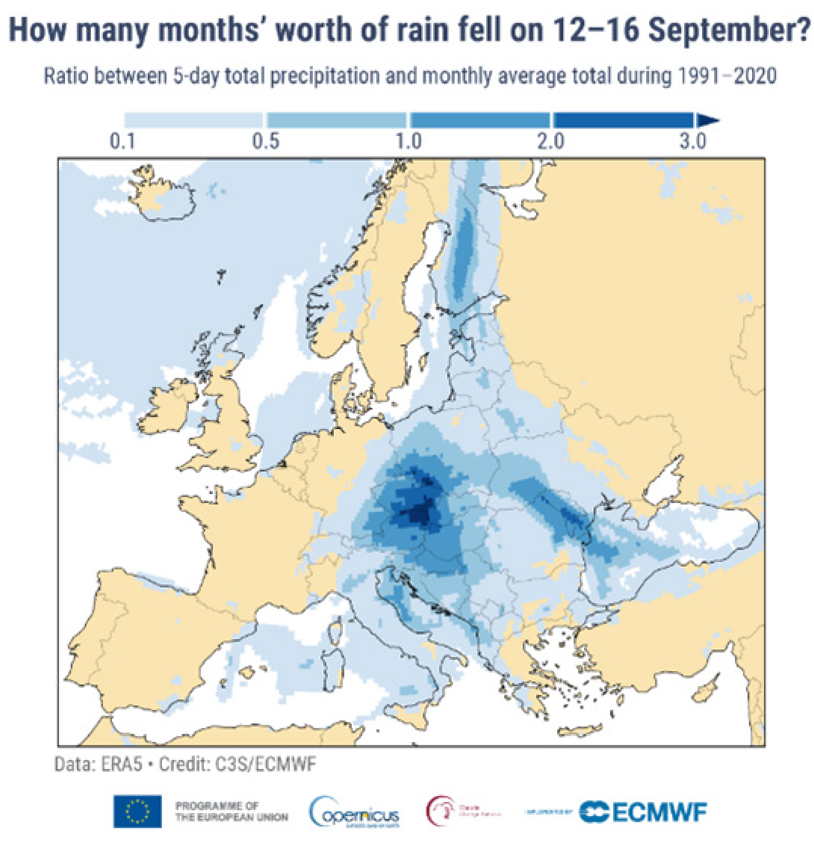


Figure 1. The map shows how Storm Boris brought extreme rainfall over a vast area of Central and Eastern Europe, with some regions – particularly around the Alps and the Balkans – receiving more than three times their usual monthly precipitation in just five days. The spatial extent of the event highlights the scale and cross-border nature of the impact. (European State of the Climate Report 2024, Fig. S1.2)

severe hazards, investing in comprehensive early warning infrastructure is both a humanitarian imperative and a strategic necessity.

Yet, Europe's early warning landscape is characterized by profound contrasts. Many Western and Central European countries boast highly advanced, multi-hazard early warning systems supported by sophisticated institutional frameworks, robust observational networks, and extensive modelling capacities. On the other hand, other parts of Europe – particularly South-East Europe and the South Caucasus – are still working to establish the foundational components of effective warning systems: gaps remain in basic hazard monitoring, risk mapping, data sharing protocols and the ability to deliver timely warnings to communities. This diversity presents both challenges and unprecedented opportunities. East-West collaboration, knowledge transfer and peer-to-peer support can create a powerful momentum for progress. By investing in partnerships, Europe can create a more cohesive and equitable early warning landscape.

Figure 2: Closing the infrastructure gap one station at a time: an automated weather station is being installed to enhance observing and forecasting capabilities. (Armenia's Weather Forecasting Revolution: Navigating Climate Challenges with Innovative Technology | United Nations Development Programme)

The Early Warnings for All initiative offers a unique and timely opportunity to bridge capacity gaps, to promote collaboration between East and West and to strengthen the links in the early warning value chain – from hazard detection to public response. The initiative is led jointly by WMO, the United Nations Office for Disaster Risk Reduction (UNDRR), the International Telecommunication Union (ITU) and the International Federation of Red Cross and Red Crescent Societies (IFRC) with collaboration from other partners. WMO leads the effort to strengthen hazard detection – through monitoring, data sharing and analysis – and forecasting. When implementing hazard detection and forecasting, acknowledging Europe's diversity is essential, not as an obstacle, but as a rich resource for innovation, knowledge sharing and solidarity.

Challenges: Barriers to achieving Early Warnings for All

Despite clear imperatives and opportunities, several significant challenges stand in the way of achieving Early Warnings for All in Europe. Chief among them is the chronic under-resourcing of National Meteorological and Hydrological Services (NMHSs) in many parts of South-East Europe and the South Caucasus. These institutions often operate with outdated infrastructure, limited access to observational data and modern technologies, and severe shortages of trained personnel, making it difficult to provide timely and reliable forecasts, let alone evolve into multi-hazard early warning providers.

Cross-border data sharing and technical interoperability present another persistent challenge. While hazards do not respect national boundaries, information systems often do. Political sensitivities, outdated agreements and incompatible technologies hinder the seamless exchange of data needed for regional coordination. Without greater trust and integration, transboundary early warnings in the subregion will remain fragmented and less effective than in the more advanced European countries.

Meanwhile, climate change continues to magnify risks in vulnerable regions, placing even greater strain on already stretched capacities. The prolonged heatwaves, forest fires and drought conditions that affected South-East Europe in 2024 are stark reminders of how climate variability exacerbates vulnerabilities, especially in countries that are least equipped to adapt.

Compounding these technical and environmental challenges is an increasingly uncertain funding landscape. While national governments are encouraged to prioritize investment in early warning systems, budgetary realities often fall short. Some regional initiatives that once benefitted from steady international funding now face existential threats due to the withdrawal or redirection of donor support. Without identifying alternative financing mechanisms, there is a real danger of reversing hard-won progress.

Systemic failures can occur beyond the meteorological domain. The lessons of the Ahrtal floods in Germany in 2021 – where shortcomings in risk communication and institutional coordination led to losses of life, which were avoidable – highlight the critical need to optimize the entire early warning value chain. Forecasts alone are not enough: warnings must lead to effective, timely public action.

Opportunities: Building resilience through collaboration

However, Europe also has strong assets to draw upon, numerous regional initiatives and programmes offer pathways for progress and cooperation.

For example, the Copernicus Emergency Management Service (CEMS) provides timely, reliable geospatial information for disaster risk management, response and recovery. In addition, CEMS supports major upgrades to flood forecasting systems such as EFAS and GloFAS, introduces enhanced drought indicators, and improves wildfire detection tools. Facilitating utilization of the Copernicus framework and tailoring products to local contexts could dramatically expand the reach and effectiveness of CEMS services.

MeteoAlarm exemplifies pan-European collaboration by uniting 38 NMHSs to provide standardized weather alerts throughout the continent. By utilizing a unified colour-coded system and universally recognized pictograms, it ensures that critical weather information is accessible and understandable, transcending language barriers. Its continuing expansion to more countries in Europe, along with the development of impact-based forecasting and real-time flood warnings, could bring even greater cross-border coherence to Europe's early warning landscape.

Regional systems such as the South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A) and the South-East European Flash Flood Guidance System (SEEFGS) offer proven models for cooperation in Southeast Europe.

The essential elements of an effective early warning system

By providing shared access to forecasting tools and fostering cross-border communication, these systems have improved early warning capacities. However, both systems face serious threats as there is an urgent need for new investment and political support to ensure their sustainability.

HydroSOS, a WMO-led initiative, brings another opportunity. By offering standardized assessments of hydrological conditions and short- to medium-term forecasts, HydroSOS empowers national and regional actors to anticipate droughts, floods and other water-related risks. Expanding its implementation in regions with weak hydrological monitoring could greatly strengthen local resilience.

Moreover, peer networking and twinning arrangements between NMHSs, such as those established between Moldova and Sweden or between Finland and Ukraine, show that solidarity can overcome capacity gaps. Sweden and Moldova's partnership permits them to work to enhance forecasting, warnings and disaster communication systems. Finland and Ukraine's partnership focuses on modernizing weather infrastructure and automating services to improve accessibility and responsiveness for all users, including vulnerable groups. Other similar initiatives – like the evolving Regional Agrometeorological Centre for RA VI in Romania – aim to strengthen regional cooperation, develop skills and coordinate research to contribute to broader climate resilience efforts in Europe. These partnerships facilitate knowledge exchange and technical assistance and harmonize service delivery, creating a stronger and more integrated European weather and climate service community.

Emerging technologies offer yet another horizon of opportunity. Artificial Intelligence (AI) and Machine Learning (ML) are beginning to revolutionize forecasting, hazard detection, and early warning dissemination (Artificial Intelligence for Disaster Risk Reduction: Opportunities, challenges, and prospects). As operational applications of AI and ML mature, ensuring that all countries – regardless of their current technological capacity – have access to these innovations will be essential to maintaining equity and maximizing the collective benefit.

Toward a Unified Early Warnings Future

The path to achieving Early Warnings for All across Europe demands determined action. It requires that solutions be tailored to national contexts, reflecting the unique needs and capacities of each country. It calls for deeper and more sustained engagement with development partners to unlock financial and technical resources. Above all, it necessitates strong political will to embed early warning priorities into national budgets, civil protection strategies and climate adaptation plans.

The strengthening of the technical backbone for early warning systems is central to this effort. WMO is working closely with national and regional partners to modernize observation infrastructure, enhance data sharing, and upgrade forecasting capacities. Closing capacity gaps between countries, particularly between East and West, is essential to building a seamless, resilient and equitable early warning architecture across the continent.

Truly effective early warning systems must involve civil society to ensure that alerts reach the most vulnerable groups and that communities are empowered to act on warnings. The protection offered by early warnings must be universal, accessible and actionable.

Europe's diversity is its strength. By embracing collaboration between East and West, sharing knowledge and standing in solidarity, the continent can bridge its early warning gaps. In doing so, Europe will not only protect its people and economies – it will set a powerful global example of collective resilience in the face of a changing climate.

Get Involved: Support Early Warnings for All in Europe

Want to help translate research into operational early warning services? Interested in donating to support Early Warning projects? Ready to bring innovation, data, or technology into the hands of those who need it most? Get involved and become part of the Early Warnings for All movement in Europe—contact the WMO Regional Office for Europe at roe@wmo.int.

Africa's Future Climate: Navigating Extremes through Innovation and Early Warnings

By Fetene Teshome, Permanent Representative of Ethiopia to the WMO and president of WMO Regional Association I (Africa)

The WMO community has seized the occasion of the Organization's 75th anniversary to reflect on decades of progress in advancing meteorological science, climate monitoring and early warning systems towards disaster risk reduction. This reflection has led to the conclusion that Africa as a whole is grappling with more frequent and intense extreme weather and climate events due to climate change and that further investment is urgently needed.

In recent years, droughts, floods, tropical cyclones, and heatwaves have surged in frequency and severity across Africa, undermining livelihoods, disrupting ecosystems and threatening decades of development gains. Yet, amid these rising risks, a narrative of resilience and innovation is emerging driven by the implementation of early warning systems, regional cooperation and informed policymaking. WMO is taking the lead in shaping a more climate-resilient future for the continent, but further regionalization is needed as well as investment.

The escalating threat

Africa is among the most vulnerable regions to climate change, despite contributing the least to global greenhouse gas emissions. The continent's exposure to extreme weather and climate events is exacerbated by a high dependence on rain-fed agriculture, rapidly growing populations, under-resourced infrastructure and limited adaptive capacity. Furthermore, weather and climate information and services have not been fully utilized in supporting effective decision-making for national adaptation strategies, disaster management and planning.

The key climate trends include prolonged droughts in the Horn of Africa and Southern Africa, which have resulted in severe crop failures, livestock losses and mass displacements. Many countries have reported a 2%–5% loss in Gross Domestic Product (GDP) annually and have had to divert up to 9% of their budgets to respond to climate extremes. The 2020–2023 Horn of Africa drought, one of the worst in recorded history, affected over 36 million people. While, in other regions, rapid unplanned urbanization, coupled with inadequate drainage systems, led to devastating floods in cities. In 2022 alone, floods displaced over 1.5 million people in West and Central Africa. Southern Africa has witnessed unprecedented cyclone activity, with Cyclones *Idai* (2019), *Eloise* (2021), and *Freddy* (2023) leaving trails of destruction across Madagascar, Malawi, Mozambique and Zimbabwe. Increasing temperatures are worsening heat-related illnesses, impacting labour productivity, and exacerbating the spread of vector-borne diseases such as malaria and dengue.

The WMO coordinated State of the Climate in Africa reports, published annually since 2010, have highlighted these challenges and stimulated efforts to develop and improve climate services in these areas. Many projects and initiatives, launched by WMO and its partners, are showing impacts on the ground: improved climate services for agriculture and health as well as better early warnings systems.

Challenges to climate resilience in Africa

Despite the growing awareness of climate risks and the many ongoing projects, Africa faces several systemic and operational challenges in adapting to climate change. Over 60% of continent lacks adequate weather and climate observation systems. Many National Meteorological and Hydrological Services (NMHSs) remain underfunded and poorly equipped. There is limited access to early warning information and vulnerable communities, particularly in rural and remote areas, often lack timely and accessible climate information tailored to their local context.

Low institutional capacity, resulting from gaps in training, data analysis and inter-agency coordination, hinder the effectiveness of disaster risk reduction and adaptation planning.

The situation is further compounded by uncoordinated investment and support for climate-related activities. This has resulted in ineffective delivery of climate services as well as weak integration of climate services into national development and disaster risk management frameworks, limiting sustainable adaptation.

Opportunities on the horizon

While the challenges are significant, Africa also stands at a pivotal moment of opportunity to transform its approach to climate risk management. One of the transformative strategies is the Early Warnings for All initiative, which has become a game-changer. Launched by the United Nations in 2022, the initiative aims to ensure that every person on Earth is protected by early warning systems by 2027. Most of the 30 countries prioritized by the UN for Early Warnings for All initiative are in Africa, thus they are at the forefront of implementation. With support from WMO and partners, national roadmaps have been developed to strengthen early warning infrastructure, build capacity and enhance community preparedness. The initiative has provided NMHSs with an opportunity to co-produce people-centred, impact-based weather and climate products and services with diverse socioeconomic sectors and stakeholders. These services are bridging the gap between scientific data and actionable information for end users. The initiative, and services it generates, re-affirms the NMHSs' role as authoritative voice for national forecast, for climate-smart agricultural advisories, for localized flood alerts via mobile platforms, and as a purveyor of community education programmes that integrate indigenous knowledge.

The WMO State of the Climate in Africa reports have provided annual scientific assessments of key climate trends, sectoral impacts and policy responses across the continent, while Early Warnings for All has started to implement solutions to some of the challenges identified. The reports also offer authoritative data that supports the design of National Adaptation Plans (NAPs), Nationally Determined Contributions (NDCs), and climate financing proposals. They shine a light on hotspots of vulnerability to extreme weather and climate events as in Southern Africa, North Africa and Horn of Africa, and stress the importance of urgent mitigation and adaptation measures.

The Road Ahead: A call to action

Africa is witnessing a surge in digital transformation and mobile applications that deliver real-time climate information to farmers, urban planners and emergency responders. Collaboration between African countries is enhancing access to meteorological equipment and training programmes and has stimulated the creation of joint research initiatives, providing an alternative to traditional North-South aid paradigms.

As WMO celebrates 75 years of service, the need for a unified, science-based and inclusive approach to climate resilience in Africa has never been clearer. The continent must build on existing momentum and seize the opportunities presented by global partnerships, digital transformation, and grassroots innovation. Further investments is needed in innovative technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), as well as in hydrometeorological infrastructure and data systems. There is need to ensure that early warning information reaches the most vulnerable in accessible formats and languages for early action. Climate services should be developed for all socioeconomic sectors. Further regional integration is needed as well as of investment. Platforms such as the African Ministerial Conference on Meteorology (AMCOMET) should be encouraged for this purpose.

Africa's climate challenges are vast, but so too are its capacities and aspirations. The continent can be better equipped than ever to forecast risks, protect lives and plan for a sustainable future through the leadership of institutions like the WMO, initiatives such as the Early Warnings for All and reports such as State of the Climate in Africa which outline challenges. As we commemorate WMO's 75 years of service, we must renew the call for action to our governments, communities and partners to ensure that no one is left behind in the face of climate extremes in Africa and around the world.

WMO Research Programmes, Promoting Science for Action

By WMO Secretariat

Over the past decades, WMO programmes have been at the forefront of revolutionary advancements in weather, climate, water and related environmental sciences. The World Weather Research Programme (WWRP), World Climate Research Programme (WCRP)[1] and the Global Atmosphere Watch (GAW) have equipped the world with science, technology and knowledge that can save lives and contribute to sustainable socioeconomic development.

Scientific advancements, satellites and supercomputers, as well as an increase in observational data, have improved our ability to forecast hydrometeorological events with remarkable accuracy and to project future changes in climate with reduced uncertainty. Advances in multi-hazard early warning systems have decreased mortality rates, and new technologies, such as nowcasting, artificial intelligence and high-resolution modelling, are revolutionizing the way we predict high-impact weather and water hazards[2].

This article highlights how WMO-sponsored research, coordinated through GAW, WWRP and WCRP, has led to groundbreaking scientific advancements while also providing support to WMO Members to enhance observations, prediction and applications. It demonstrates how WMO science has informed, and continues to inform, strategies for achieving global goals, such as the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC), the Sendai Framework for Disaster Risk Reduction 2015–2030, the Sustainable Development Goals (SDGs) and the UN Early Warnings for All initiative.

Global Atmosphere Watch

Soon after its establishment, WMO embarked on the development of a programme to monitor atmospheric chemistry and the meteorological aspects of air pollution by creating the Global Ozone Observing System in 1957. In the late 1960s, when environmental protection became an international concern, the Background Air Pollution Monitoring Network was established. Then, the UN Conference on the Human Environment in 1972 drew worldwide attention to environmental problems, including the threat of Chlorofluorocarbons to the ozone layer, transboundary air pollution, and potential global warming caused by the build-up of greenhouse gases (GHGs) in the atmosphere. Each of these issues became the subject of international treaties or conventions and subsequent protocols and agreements. This led WMO, in 1989, to consolidate the Background Air Pollution Monitoring Network and the Global Ozone Observing System into GAW.

1 WCRP is co-sponsored by WMO, the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) and the International Science Council (ISC)

2 World Meteorological Organization (WMO). United in Science 2023: Sustainable Development Edition; WMO: Geneva, 2023

Over the years, GAW has matured considerably to coordinate atmospheric composition observations from global to local scales. About 100 countries participate in GAW, enabling the provision of accessible, high-quality, atmospheric data to the scientific community and enhancing global understanding of atmospheric composition and atmosphere-ocean-biosphere interactions. Some of the major achievements to date include the provision of data to support global conventions through the annual *WMO Greenhouse Gas Bulletin* and *WMO Ozone and UV Bulletin*, the coupling of observations with prediction tools to support services aimed at protecting human and ecosystem health and establishing new initiatives that serve society.

Current GAW activities build on its longstanding success in fostering international collaboration to drive impactful science and services for society. For example, recognizing that air pollution is a global health risk[3] contributing to millions of premature deaths each year[4], GAW established the Global Air Quality Forecasting and Information System (GAFIS), which enhances air quality forecasting and information services to reduce health impacts. By accelerating the implementation of effective pollution control strategies, GAFIS contributes to reducing the health burden of pollution to societies, protecting environmental resources and enabling socio-economic development.

GAW also supports the implementation of Early Warnings for All. For example, its Sand and Dust Storms Warning Advisory and Assessment System (SDS-WAS) is coordinating a global network of research and forecasting centres to enhance operational SDS forecasts through technology transfer. In arid and semi-arid regions, SDS pose a major challenge to sustainable development and are becoming more frequent due to climate change and unsustainable land and water use. In Burkina Faso, for example, SDS-WAS is being used daily by local weather forecasters to assess dust situations quickly and provide warning levels computed using the dust surface concentration predicted by the SDS-WAS Northern Africa Middle East Europe Node multi-model median.

Another example is the Vegetation Fire and Smoke Pollution Warning Advisory and Assessment System (VFSP-WAS), which enhances the delivery of vegetation fire and smoke pollution forecasts, observations, information and knowledge. Vegetation fires release large amounts of particulate matter and toxic gases into the atmosphere, which have impacts on human health and the environment. Recognizing the need for international coordination, GAW has taken the lead to develop and implement the VFSP-WAS in support of early warnings and the prevention of destructive fires.

Finally, GAW activities play a crucial role in the provision of data to support global conventions. From its inception up to the present day, GAW has been one of the pillars of the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol on Substances that deplete the Ozone Layer. GAW plays an essential role in supporting the success of the Montreal Protocol and the expected recovery of ozone, which must be fully measured and understood. GAW activities also support the


3 Lelieveld, J., Pozzer, A., Pöschl, U., Fnais, M., Haines, A., and Münzel, T.: Loss of life expectancy from air pollution compared to other risk factors: a worldwide perspective, Cardiovascular Research (2020) 116, 1910–1917, doi:10.1093/cvr/cvaa025

4 World Health Organization, https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

UNFCCC and its Paris Agreement through the Integrated Global Greenhouse Gas Information System (IG3IS), which has improved the evaluation of GHG sources and sinks. As a result, IG3IS plays an important role in supporting ambitious mitigation actions under the Paris Agreement and, together with provision of GHG concentration through the monitoring infrastructure, contributes to developing the Global Greenhouse Gas Watch.

World Weather Research Programme

Established in 1998, WWRP promotes research to improve weather forecasting, and to provide impact-based forecasts from minutes to months ahead. However, observations show that climate change is increasing the frequency and intensity of extreme weather – heatwaves, heavy precipitation, drought and tropical cyclones – which disproportionately affects vulnerable populations. This is amplifying the importance of WWRP, which focuses on putting science into the hands of those who need it to reduce disaster risks and to drive sustainable development. To accomplish this, WWRP strives to achieve seamless Earth system observations and predictions through increased convergence between weather, climate and environmental approaches as well as interdisciplinary collaboration that links physical and social sciences.

In its early days, WWRP was integrated into The Observing System Research and Predictability Experiment (THORPEX), a 10-year international research and development programme launched in 2003 that accelerated improvements in the accuracy of 1-day to 2-week high-impact weather forecasts. THORPEX was succeeded by three WWRP core projects: Polar Prediction Project (PPP) from to 2013 to 2022, Sub-seasonal to Seasonal Prediction (S2S) Project from 2013 to 2023, and High-Impact Weather (HIWeather) Project from 2014 to 2024. These projects made major advances in weather prediction for capacity building and improved stakeholder engagement.

Highlighted by the Year of Polar Prediction, PPP broke new ground in the coupled atmosphere-ice-ocean system through analysis of novel observations and the advent of kilometre-scale simulations. The S2S project probed the predictability of the atmosphere to seasonal time scales and led to the use of S2S forecasts for applications across a wide range of economic sectors and the creation of a high-quality research database, galvanizing the research community and enabling collaboration and exploration. The HIWeather project explored the value chain of weather forecasts and created a framework for understanding disaster risk reduction by uncovering the reasons behind the unforeseen impacts of extreme weather.

Building on this success, and in response to emerging needs, the current WWRP Implementation Plan (2024-2027) includes six projects. For example, the Sub-Seasonal Applications for aGriculture and Environment (SAGE) Project directly contributes to several SDGs by making sub-seasonal forecasts (from 2 weeks to 1 or 2 months ahead) more useful for decision-making in sectors such as agriculture, energy, health, water and disaster risk reduction. Another project, the Polar Coupled Analysis and Prediction for Services (PCAPS) Project, aims to improve the actionability, impact and fidelity of environmental forecasting for human and environmental well-being in the Arctic and Antarctic regions. As a result, this project will support adaptation and sustainable development in Indigenous communities that face increasing threats to their traditional livelihoods resulting

from dramatic shifts in weather patterns.

WWRP also has numerous projects that contribute to Early Warning for All and the Sendai Framework for Disaster Risk Reduction. For example, the Integrated Prediction of Precipitation and Hydrology for Early Actions (InPRHA) project aims to improve effective warning of flood hazards by integrating precipitation and hydrologic predictions and social sciences. The Urban Production Project, which is just getting started, will contribute to more effective early warnings systems tailored to urban populations. Additionally, the Progressing EW4All Oriented to Partnerships and Local Engagement (PEOPLE) Project focuses on researching the structural and social elements of expanded early warning systems, emphasizing science for and with policy and practice to enhance effective risk reduction. Finally, the Aiding Decision-making in Vulnerable Africa with Nowcasting of ConvEction (ADVANCE) Project encompasses several WWRP endorsed projects – such as the Weather and Climate Information Services (WISER) Early Warnings for Southern Africa (EWSA) project – that harness science and technology to enhance satellite-based nowcasting, or the prediction of rapidly developing events, such as thunderstorms, on timescales up to six hours. As a result, the project aims to not only advance nowcasting technology but also help ensure that everyone receives these early warnings and knows what action to take to reduce the risk of negative impacts.

World Climate Research Programme

In 1979, WMO and partner organizations hosted the First World Climate Conference in Geneva, marking the end of a decade of growing concern about issues related to the human impacts on the climate[5]. Conference deliberations resulted in the *World Climate Conference Declaration*, which called for urgent action to improve knowledge of climate to prevent potential man-made changes in climate that might be adverse to the well-being of humanity. Recognizing the interdisciplinary nature of climate issues, WCRP was formally established in 1980 under the joint sponsorship of the International Science Council (ISC) and the WMO to coordinate climate research. In 1993, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) also became sponsors.

From launching its first initiatives in 1982 to its ongoing work coordinating and facilitating international climate research, WCRP has made important contributions to advancing climate science for society. In particular, WCRP has played a critical role in underpinning the Intergovernmental Panel on Climate Change (IPCC) since it was created in 1988 by WMO and the UN Environment Programme. The WCRP Coupled Model Intercomparison Project (CMIP), which provides climate projections to understand past, present and future climate changes, has been at the core of every IPCC Assessment Report that informs governments about the state of knowledge on climate change. Additionally, CMIP projections inform policymakers in the development of global climate change policies, contribute to national

5 Sommeria, Gilles ; Touzé-Peiffer, Ludovic. Le programme mondial de recherche sur le climat fête ses 40 ans. La Météorologie, 2019, 107, p. 10-13 10.4267/2042/70546. English version available here: https://www.wcrp-climate.org/documents/2019/The%20World%20Climate%20Research%20Programme%20(WCRP)%20celebrates%20its%2040th%20anniversary.pdf

and regional climate assessments and support decision makers across diverse sectors, including the financial and insurance sectors.

Building on CMIP, the WCRP Coordinated Regional Climate Downscaling Experiment (CORDEX) supports effective climate change adaptation by providing projections of how the climate may change in the future at regional scales to support the identification of potential adaptation solutions. For example, the new CORDEX Flagship Pilot Study on High- Resolution Downscaling of Tropical Cyclones in the Caribbean Region, is developing detailed projections of tropical cyclone behaviour and associated impacts in the Caribbean region, where many small islands are not represented in coarser climate models. The information provided by high-resolution projections is essential to inform multi-sectorial adaptation strategies, reduce risks and vulnerabilities, and enhance natural hazard preparedness in line with the Sendai Framework for Disaster Risk Reduction.

Additionally, one of WCRP's Core Projects: the Climate and Cryosphere (CliC) advances understanding of climate-driven changes in the cryosphere to support efforts to mitigate and adapt to their impacts on ecosystems and human society. Changes to glaciers not only contribute to global sea level rise but can also lead to new hazards – such as glacial lake outburst floods – and effect water availability and hydropower, which can significantly impact local communities. As a result, CliC is advancing glacier dynamics research through the Glacier Model Intercomparison Project, which aims to provide – for the first time – a framework for a coordinated intercomparison of global-scale glacier mass change models. Additionally, CliC is contributing to international initiatives, such as the International Polar Year, the 2025 International Year of Glaciers' Preservation and the Decade of Action for Cryospheric Sciences, 2025-2034 to raise global awareness of the critical role of glaciers and the impacts of glacier retreat.

WCRP also recognizes the importance of understanding what climate research, data and information is needed in a regional context and engaging directly with users. The My Climate Risk Lighthouse Activity, for example, aims to develop and mainstream a 'bottom-up' approach to understanding regional climate risk by working with both researchers, especially in the Global South, and the users of climate data, such as farmers, businesses and local communities. Additionally, the Regional Information for Society (RIfS) Core Project leverages existing WCRP activities and expands their scope to provide actionable climate information at regional scales. In particular, RIfS will address the challenges in how to reconcile and integrate multiple lines of climate information (distillation) to produce context-relevant knowledge for decision makers and explore barriers to use this information.

Conclusion

By enabling transformative advances in science through international collaboration and informing global climate policy while supporting achievement of the SDGs, the WMO research programmes are creating lasting global impacts. Moving forward, the importance of research cannot be overlooked as the world confronts increasingly complex challenges that will require new technologies, scientific breakthroughs and innovative approaches to achieve global goals and a better world for present and future generations.

World Meteorological Organization

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