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Making Society Climate Resilient

International Progress under the Global Framework for Climate Services

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ABSTRACT: There is growing awareness among governments, businesses, and the general public of risks arising from changes to our climate on time scales from months through to decades. Some climatic changes could be unprecedented in their harmful socioeconomic impacts, while others with adequate forewarning and planning could offer benefits. There is therefore a pressing need for decision-makers, including policy-makers, to have access to and to use high-quality, accessible, relevant, and credible climate information about the past, present, and future to help make better-informed decisions and policies. We refer to the provision and use of such information as climate services. Established programs of research and operational activities are improving observations and climate monitoring, our understanding of climate processes, climate variability and change, and predictions and projections of the future climate. Delivering climate information (including data and knowledge) in a way that is usable and useful for decision-makers has had less attention, and society has yet to optimally benefit from the available information. While weather services routinely help weather-sensitive decision-making, similar services for decisions on longer time scales are less well established. Many organizations are now actively developing climate services, and a growing number of decision-makers are keen to benefit from such services. This article describes progress made over the past decade developing, delivering, and using climate services, in particular from the worldwide effort galvanizing around the Global Framework for Climate Services under the coordination of UN agencies. The article highlights challenges in making further progress and proposes potential new directions to address such challenges.

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There is growing awareness around the world among governments, businesses and the general public of risks arising from changes to our climate. Some climatic changes could be unprecedented in their harmful socioeconomic impacts, while others, with sufficient forewarning and planning, could offer benefits. To help manage potential impacts, decision-makers need to have access to, and use, high-quality, timely, relevant, up-to-date, and credible climate information about the past, present, and future. Such climate information includes data, knowledge, and sectoral information on impacts and risks. We refer to the provision and use of such information as climate services.

Three World Climate Conferences (WCCs; summarized below) held over the past 40 years have each led to landmark global climate initiatives of key societal significance laying the foundation for the development of climate services, based on the activities and leadership from a number of programs, initiatives, and individuals (Fig. 1).

WCC-1, held in 1979, led to the establishment of the World Climate Programme (WCP), the World Climate Research Programme (WCRP), and the Intergovernmental Panel on Climate Change (IPCC). The goal of WCP is to improve our understanding of the climate system and to apply that understanding for the benefit of societies in coping with climate variability and change. The WCRP aims to determine the predictability of climate and the effect of human activities on climate. The IPCC serves to provide governments with rigorously assessed scientific information to inform mitigation and adaptation policies, as well as to inform international climate change negotiations. Even though the IPCC produced their first assessment report in 1990 conveying the risks posed by a changing climate (Fig. 1), the institutional capacities and capabilities to respond to such risks are still not adequately in place, particularly on regional and national scales. The recent IPCC Special Report on the impacts of global warming of 1.5°C (IPCC 2018) has renewed the urgency to step up efforts to mitigate the risks associated with climate change in line with the commitments outlined in the Paris Accord. In particular, article 7 of the Accord calls for the strengthening of scientific knowledge on climate, including research, systematic observation of the climate system, and early warning systems, in a manner that informs climate services and supports decision-making.

WCC-2, held in 1990, led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Climate Observing System (GCOS). The UNFCCC is an intergovernmental platform to facilitate the response to the threat of climate change worldwide (e.g., UNFCCC 2015). GCOS ensures that the observations and information needed to address climate-related issues are obtained and made available to users, and underpin adaptation measures. The WCP has evolved since WCC-2, and is now composed of the GCOS, the WCRP, the World Climate Services Programme, and the World Adaptation Science Programme.

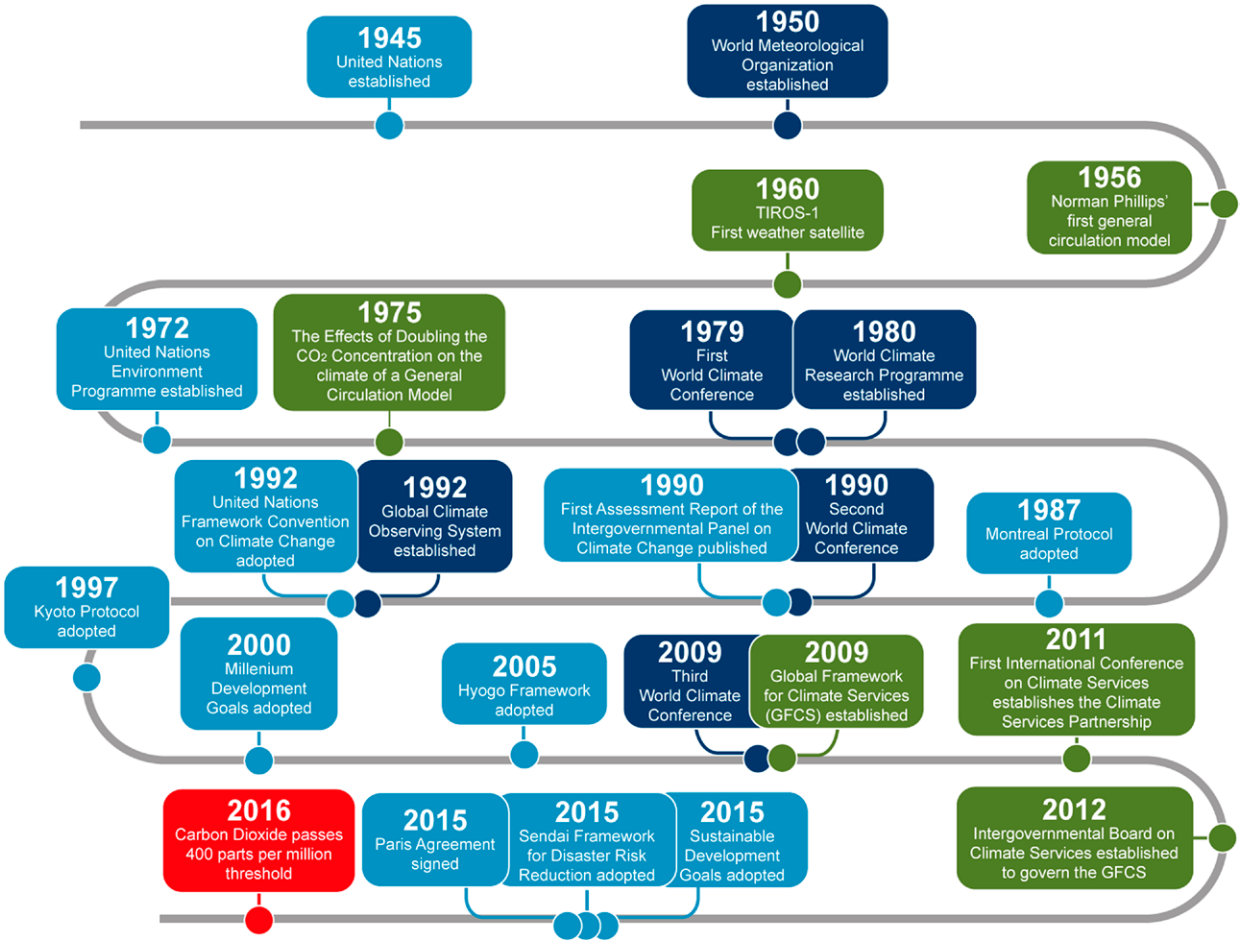

Fig. 1. Schematic of key events relating to the development of climate information for decision-making.

In addition to the entities described above that arose out of WCC-1 and WCC-2, other programs of activities were established to provide improvements in observations and climate monitoring, better understanding of climate processes, climate variability and change, and improvements in predictions of the future. However, the delivery of the resulting climate information in a way that is usable, useful and sustained for decision-makers (viz., the climate services) was receiving far less attention and society was therefore not benefitting sufficiently from the available information. While weather services from a wide range of weather service providers routinely help weather-sensitive decision-making from a few hours to several days ahead, similar services for decisions on longer time scales from monthly to multidecadal were much less well established.

Recognizing this gap, the World Climate Conference-3 (WCC-3) in 2009 focused on empowering decision-makers with appropriate climate information to meet society's climate-related challenges. It brought together heads of states, government ministers, industry representatives, and scientific and technical experts from many fields of practice to discuss the needs for enhanced development and delivery of climate services, and improved coordination between relevant actors. The conference concluded with strong recommendations that existing initiatives needed to be coordinated and strengthened and new infrastructure needed to be developed (WMO 2009). The conference called for the establishment of a Global Framework for Climate Services (GFCS; www.wmo.int/gfcs) to enable better management of the risks of climate variability and change, and adaptation to and mitigation of climate change, through the development and incorporation of science-based climate information and prediction into planning, policy, and practice.

Parallel to the establishment of the GFCS, and following up to WCC-3, the first International Conference on Climate Services (ICCS-1) was held in 2011. A key objective of ICCS-1 was to establish a network of climate service practitioners, with support from an international set of partners with experience in the design, implementation, and use of climate services. An informal international Climate Services Partnership (CSP; www.climate-services.org) was established after ICCS-1 to serve as a platform for collaboration and knowledge sharing among a wide range of actors, and to advance climate service capabilities worldwide. The CSP has been organizing the ICCS in different locations around the world, with the most recent ICCS-5 held in 2017 in South Africa. The CSP also facilitates working groups that advance discussion on topics of interest to the partners, such as socioeconomic benefits of the climate services, and ethics for climate service providers (Adams et al. 2015).

Significant progress developing, delivering, and using climate services has been made in the 10 years since WCC-3 and its call to establish a Global Framework for Climate Services. Many organizations, companies, and national institutions are now actively developing climate services, and a growing number of decision-makers are keen to benefit from such services from a range of climate service providers. This paper highlights the role of the GFCS in this worldwide effort to advance climate services, and describes successes, challenges, and potential solutions to further advance climate service development, provision and use.

Progress under the global framework for climate services

Following the recommendations arising from WCC-3, an intergovernmental process established a taskforce of high-level independent advisors to make recommendations on the priorities and proposed elements of the GFCS and the next steps for its implementation. In 2012, an Extraordinary Session of the World Meteorological Congress established the Intergovernmental Board on Climate Services (IBCS) as the governing body of the GFCS, and subsequently the Partners Advisory Committee (PAC) of key stakeholders. The World Meteorological Congress adopted the GFCS's implementation plan defining deliverables and targets to be realized over 2-, 6-, and 10-yr horizons starting in 2013. In 2019, as part of a reform of WMO governance, the World Meteorological Congress decided to dissolve the IBCS and adopt a new Climate Coordination Panel as the oversight and implementation mechanism for the GFCS (WMO 2019).

From the outset, several key challenges and guiding principles were recognized for this global effort (Hewitt et al. 2012). The key challenges included inadequate availability and quality of climate data in many parts of the world, a need to create or improve access to climate services by potential users in almost all countries, and limited climate literacy and capacity to deal with climate-related risks in many countries and climate-sensitive sectors. Furthermore, users and providers of climate services had limited experience collaborating, and needed to interact more effectively if the quality of future climate services were to match user requirements.

The guiding principles included prioritizing capacity development in developing countries vulnerable to climate impacts, promoting the free and open exchange of climate relevant data where possible, providing climate services primarily for the public good, and facilitating and strengthening existing activities and not duplicating. A cornerstone of these principles is to build partnerships involving all stakeholders. This is essential for developing, delivering, and using climate services, and for creating a market of organizations delivering, investing in, and using the services.

Ensuring active engagement from key organizations has proven challenging, with such a broad range of actors including UN agencies, international organizations, climate service-related programs, users, providers, donors, governments, nongovernmental organizations, private sector organizations, and national meteorological and hydrological services (NMHSs). A GFCS activity with dedicated responsibility to engage key international organizations has

been the creation of the PAC. The PAC currently consists of 22 international organizations and has provided valuable perspectives from the user community. The PAC has given direction to the GFCS implementation, but the broader engagement of the organizations required to enable efficient coordination on national-level activities has been somewhat limited.

The GFCS has focused on climate services for agriculture and food security, disaster risk reduction, health, water resources, and energy. These climate-sensitive areas present pressing and immediate opportunities for bringing benefits to human safety and well-being through climate risk management, including climate adaptation and mitigation. The GFCS has completed two phases–the first (start up) phase in 2013–14, and the second (scale up) phase in 2015–18. These first two phases have focused on: establishing governance, management and reporting frameworks, developing regional and national capacities, engaging user communities, and implementing high-priority proof-of-concept projects, such as Assessing Sustainability and Effectiveness of Climate Information Services in Africa (https://gfcs.wmo.int/Sustainable_CIS), and the GFCS Adaptation Programme in Africa (https://gfcs.wmo.int/GFCS_APA_II).

Important contextual changes have occurred since the GFCS was formally established in 2012. Three global landmark processes are the Paris Agreement of the UNFCCC, the Sendai Framework for Disaster Risk Reduction 2015–30, and the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development. In 2015 the Green Climate Fund (GCF) became operational and is the main financial mechanism for supporting climate action under the Paris Agreement. Numerous projects funded by a range of national and international development agencies (such as the World Bank, the U.S. Agency for International Development, European Commission, the U.K. Department for International Development, the Norwegian Agency for Development Cooperation, Environment and Climate Change Canada) have been actively supporting climate resilience, climate risk management, and climate change adaptation. To succeed, these agreements, frameworks and projects require scientific data, knowledge, and timely and accessible services to support effective climate action.

More than 40 developing countries have identified developing weather and climate services as a key action for their resilient development planning and as a pillar of their ability to commit to the Paris Accord under their nationally determined contributions (World Bank 2019). The number of actors that include climate services in their climate adaptation, climate resilience, and disaster risk reduction programs is growing. This growth in demand for services requires an increase in sector-tailored and end-user-focused climate service capabilities, as well as coordination to avoid fragmentary, contradictory, and piecemeal implementation. The GFCS is intended as a much-needed mechanism for providing a credible, accessible, and integrative platform for enhancing coordination, guiding, and supporting climate services activities worldwide. It has been an effective catalyst for establishing and strengthening regional and national capacities and structures. The following section provides some examples of the successes.

Examples of GFCS success at the regional scale

While the GFCS is a global mechanism, it is typically at the regional, national, and local scales that the societal benefits are realized. Early climate service design principles at these different scales were developed by the GFCS through a series of exemplars and consultative strategic documents (Hewitt et al. 2012) informed by earlier work (e.g., NRC 2001, among others). More recent research has reinforced many of the earlier conclusions on building capacity, particularly within NMHSs to transform them into national climate service centers (such as Mahon et al. 2019), the benefits of coproducing user-oriented climate information (Vincent et al. 2018), opportunities and challenges associated with commercializing climate services (Webber and Donner 2017), and the role of different actors and different approaches in the design of climate services (Christel et al. 2018).

To bring together national, regional, and international climate experts, the WMO, NMHSs, regional institutions, and other international organizations initiated an approach of Regional Climate Outlook Forums (RCOFs) in the late 1990s to produce consolidated regional climate outlooks based on climate predictions through expert assessment in several different regions of the world (Buizer et al. 2000; Ogallo et al. 2008; Gerlak et al. 2018). The early RCOFS were primarily focused on seasonal time scales as modulated by El Niño–Southern Oscillation events and were not yet focused on longer-term variations and changes. Through interaction with users in the key economic sectors of each region, extension agencies and policymakers, the RCOFs support access to credible climate information, and assess the likely implications of the climate outlooks on key sectors in the given region and explore the ways the outlooks could be used by the regional stakeholders. The process typically includes the following components:

1) meetings of regional and international climate experts to develop a consensus-based regional climate outlook for the coming season, typically in a probabilistic form based on a range of credible climate predictions;
2) interactive sessions involving climate scientists and representatives from the user sectors, for the identification of impacts and implications and for the formulation of response strategies;
3) a training workshop on seasonal climate prediction to strengthen the capacity of the national and regional operational climate experts; and
4) special outreach sessions, involving media experts, to develop effective communications strategies.

The GFCS builds upon the RCOF approach, which forms an important component of regional implementation of the GFCS. Under the GFCS, the core concept of the RCOFs has remained unchanged—namely, the delivery of consensus-based, climate outlook products in real time through regional cooperation and partnership. However, the implementation has been tailored to adapt to the local context. In support of the RCOFs are the WMO-accredited Regional Climate Centers (RCCs), such as the Caribbean Institute for Meteorology and Hydrology (see "Regional collaboration: Caribbean" sidebar). The RCCs leverage data, information, products, and engagement across countries within their respective domains of responsibility, and provide examples of success and standards of good practice for climate service engagement, development, and delivery.

In 2017, the WMO undertook a review of the RCOF process. The review examined the interpretation, creation, and dissemination of regional climate outlooks. The review also considered the high expectations and requirements of stakeholders for more actionable climate information tailored to their needs (WMO 2017a). The review provided recommendations toward a new generation of RCOFs characterized by a transition to objective forecasting approaches to regional climate outlooks, identification of end-use priorities, codesign and operationalization of tailored products, user feedback, systematic evaluation of socioeconomic benefits, and the introduction of training workshops that address specific competencies across regions. The new generation of RCOFs will help enhance the core capacities of providers as well as users of climate services and will facilitate two-way linkages between them.

Examples of GFCS success at the national scale

National Frameworks for Climate Services (NFCS) provide an effective way to establish institutional mechanisms to coordinate, facilitate and strengthen collaboration among national institutions and other key stakeholders, to improve the production, tailoring, communication, delivery, and use of climate services for national and local communities. Development of an NFCS typically includes the following steps (see WMO 2018):

Regional collaboration: Caribbean

Platform for exchange. In 2010 the Caribbean Institute for Meteorology and Hydrology (CIMH) and Caribbean Community Climate Change Centre (5Cs), in partnership with NOAA and the WMO, relaunched the Caribbean Regional Climate Outlook Forum (CariCOF). The CariCOF brings together meteorologists and decision-makers from various climate-sensitive sectors in the Caribbean region to build capacity to improve forecasts and tailoring for climate-sensitive sectors. Since 2012, there has been at least one forum a year, typically ahead of the wet and the dry seasons.

Political anchoring. The Caribbean has a regional strategy for coping with climate change, approved by Caribbean Community (CARICOM) heads of government. In 2013, Trinidad and Tobago launched the Caribbean GFCS. Regional workshops and consultations on climate services at the national level were convened in Belize, Trinidad and Tobago, Dominica, Suriname, and Guyana. The Caribbean Council for Trade and Economic Development endorsed the GFCS in 2015. These were important steps to integrate climate services into regional trade and economic communities and champion sectoral buy-in of climate services at the highest levels [Fourth National Climate Assessment (NCA4); Gould et al. 2018].

Partnerships. CIMH has pursued the signing of formal agreements for collaboration in the development and integration of climate services in decision-making (WMO 2018). It formalized the coordination partners for the Early Warning Information Systems across Climate Timescales (EWISACTs) to bring together the regional agencies with a lead responsibility in climate-sensitive sectors. These partners are Caribbean Agriculture Research and Development Agency, Caribbean Public Health Agency, Caribbean Water and Wastewater Association, Caribbean Disaster Emergency Management Agency, Caribbean Centre for Renewable Energy and Energy Efficiency, Caribbean Tourism Organization and the Caribbean Hotel and Tourism Association, and the Caribbean Institute for Meteorology and Hydrology.

EWISACTs focuses on integration between climate information and early sectoral decision-making related to climate risk management. The integration includes an assessment of climate-related vulnerabilities for end users, codevelopment of products and services to address vulnerabilities, and codelivery of user-defined climate-impact prediction products and services at spatial and temporal resolutions required by end users. The 5Cs play a central role in developing the enabling capabilities for linking operational action to long-term adaptation and sustainability goals. These capabilities include facilitating the outputs from global climate models for application at the scale of small islands, and provision of analytical tools, policy, guidance for mainstreaming climate change considerations into regional development activities, preparation of a regional strategy for achieving development resilient to climate change and its accompanying implementation plan (Gould et al. 2018).

Investment. Agreed priorities enable national governments to prioritize resources accordingly and to enable cooperation among regional and local partners on joint fundraising for key activities.

1) assess the baseline on climate service capacities at the national level, to identify key stakeholders (including developers, providers, investors, and users of the services), map existing services, and establish capacities;
2) organize a national consultation workshop to bring together the stakeholders, and identify gaps and key elements for the development of a plan of action for NFCS implementation;
3) develop and endorse a national strategic plan and costed action plan for establishment and operation of the NFCS; and
4) launch the NFCS, implement the national action plan, and monitor and evaluate.

In 2012, the GFCS conducted pilot projects to develop NFCSs in several countries (Burkina Faso, Cameroon, Chad, Ivory Coast, Madagascar, Malawi, Mali, Niger, Senegal, and Tanzania). As these NFCSs have developed, interest has grown from other countries. For example, in 2018 the economic community of West Africa partnered with the GFCS to support its member states in establishing their NFCSs. As a result, Benin, the Gambia, Guinea-Bissau, Guinea, and Togo have conducted their national consultations and are formulating their strategic and costed action plans. Cabo Verde and Ghana are now starting to pursue the same process. One of the benefits of the NFCS process is to enable NMHSs to evaluate

their current capacity to support decision-making and map the activities and resources needed to bridge the gap in capacity.

NFCSs are increasingly being recognized as a useful mechanism for the development and consolidation of national capacities, connection to policy processes, and formalizing partnerships and working modalities with key sectoral organizations. For example, the GCF has recognized the NFCS as a foundational step for the implementation of projects. The World Bank has used the NFCS to inform its hydrometeorological investments in several countries as well as some of the strategic dialogues under the Pilot Programme for Climate Resilience (PPCR). Similarly, the French Development Agency used the NFCS to inform their overseas development investment activities. The Climate Investment Fund's Climate Risks and Early Warning Systems program (CREWS) has used the NFCS approach to identify priorities and costed action plans. In the case of Burkina Faso alone, the NFCS process has guided over $25 million of investment.

National collaboration

National frameworks for climate services: Ivory Coast

Launched. 2016 in joint partnership with WMO and the NMHS [Société d'Exploitation et de Developpement Aéroportuaire, Aéronautique et Météorologique (SODEXAM)].

Funding and support. WMO provided support for local consultant and national workshops.

Benefits. NFCS has 1) enhanced engagement of users in codesign processes through sector-specific working groups and 2) guided development investments of the World Bank, the French Development Agency, African Development Bank, as well as national investment ($20 million).

Challenges. Reaching local levels, funding, delay in signing the policy decree, private sector collaboration viewed as a threat to national budget allocation.

A different example of success at the national scale is the joint GFCS and Copernicus Climate Change Data climate data rescue activities through the International Data Rescue (I-DARE) portal (www.idare-portal.org/) to provide guidance material and support national data rescue in countries with high risk of data loss due to the data being stored on perishable media.

Challenges and potential solutions

At the time of writing, the GFCS is entering its third major phase (2019–23), aiming to better ensure the sustainability, and necessary financial investments of the main components of the GFCS, and to provide further support to institutional mechanisms for climate service delivery and uptake. A focus is to improve those areas of the climate services chain that are less mature, in particular the provider-user engagement and the Climate Services Information System. Focus in these areas will also foster enhanced linkage to other important foundational pillars such as observations, monitoring, and research.

While the GFCS has demonstrated success, a number of challenges impede progress:

- The hub of climate service activities nationally most naturally fits within a NMHS, but many NMHSs are focused on weather-oriented activities (typically for aviation) and have not fully embraced the ethos, business model, or value-chain approach for climate services, nor do all NMHSs have dedicated resources to sustain ongoing engagement with their users.
- Many regions and countries have insufficient capability and capacity to develop and deliver climate services. This can undermine confidence in national service providers, sending users in search of alternative and sometimes less credible services. The ability to build service capacity is often compounded by competition among national bodies for funding. There are also major imbalances regarding access to the essential services, and there is no relationship between the level of climate risks that a country faces and the level of per capita

spending on developing climate information in that country (Georgeson et al. 2017). The lack of resources, capability and capacity is at odds with the growing demand for climate services, and severely hampers proper codevelopment and delivery of sustainable climate services that can help society make effective decisions.

- The gap between the needs of the decision-makers and the scientific and operational capabilities is often large, be it around understanding climate variability and climate change, or climate modeling capability for climate predictions and climate projections, or observational datasets, or downstream applications needed by decision-makers. The scientific capability is often developed to address research questions, but not tailored to an operational setting. Developing science and services of value for societal issues often needs to be multi- and interdisciplinary and to be performed in conjunction with a range of stakeholders.
- There are inherent limits to what science can offer. There will always be unanticipated climate shocks and missed opportunities, there will be anticipated shocks and opportunities that did not materialize, and there will be forewarned shocks whose impacts cannot be completely mitigated either because those shocks are too severe or because of lack of resources to successfully intervene.
- It is challenging to ensure that the beneficiaries of investments in climate services are sufficiently involved in establishing the utility of climate services development. Effective engagement between the users and the providers of climate services is demanding and can be very time consuming depending on what level of engagement is appropriate in each case (Hewitt et al. 2017).
- Obtaining and providing credible, useful, accessible, and timely climate information at spatial and temporal scales that decision-makers find actionable and valuable is difficult. For example, decisions are often made locally, such as at the scale of a farm, a town or a river, and the climate information is often considered scientifically credible at a much coarser resolution.
- The monitoring and evaluation framework for the GFCS was only partially implemented because of a lack of sufficient resource, particularly in terms of monitoring and evaluation personnel and partner engagement. Going forward, a priority should be to ensure the dedicated resource and skills are in place and the monitoring and evaluation framework implemented.

While the above challenges are already evident, the climate service landscape is relatively new, and rapidly evolving, compared to weather services. New issues are anticipated around the need for common standards for the provision of climate services, ethical considerations among climate service providers, common language and terminology for all stakeholders, and whether it is possible and useful to develop seamless services across weather and climate time scales, or, perhaps more ambitiously, to develop decision-relevant services covering time scales crossing weather and climate.

To alleviate the above challenges and accelerate the successful

National collaboration

National frameworks for climate services: China

Launched. 2013 motivated by the need to enhance climate services for improving resilience and disaster risk reduction.

Funding and support. Financial resources prioritized through funding the NMHS [China Meteorological Administration (CMA)] as well as the Ministry of Water Resources and the Academy of Sciences to improve forecasts (national government) and technical support collaborating with the Met Office.

Benefits. NFCS has 1) enhanced collaboration with other agencies on climate services and 2) mobilized additional resources through projects.

Challenges. Demonstrating the value, skill, and reliability of seasonal forecasts, and trust of users.

development of climate services, we highlight the following suggestions as key strategies for transforming climate services.

Develop (applied) science to better match scientific capability to societal needs. The decision context and needs of the decision-makers lie at the heart of effective climate service uptake. Information often needs to be tailored to reach the right person or institution in the right form at the right time (Hov et al. 2017). This tailoring requires multidisciplinary science that considers the complexity of the systems within which climate information is produced and delivered, the contexts within which users work and use it, the specific questions that need to answered, and the many contextual factors driving users' decision-making. Inclusion of different types of social science expertise to improve understanding of climate service needs, effectively engage stakeholders, and broker knowledge and understanding are essential. Climate information often needs to be integrated and layered with socioeconomic data to develop a product or to provide the context required to support decision-making for development and sustainable livelihoods.

Fostering interdisciplinary teams of researchers and communication specialists can bring a wide range of expertise and competences to all stages of climate service design and implementation (Pulwarty et al. 2009; Huard et al. 2014; Buontempo et al. 2018). With this objective, the Caribbean Community Climate Change Center, the Caribbean Institute for Meteorology and Hydrology, and the University of the West Indies have developed an applied master's level degree program that has built a cadre of professionals across the region, capable of conducting analyses of climate risk, vulnerability, and capacity while engaging stakeholders at the regional, national, and community levels.

Enhance information management at the global, regional, and national scales. One of the key pillars of the GFCS is the Climate Services Information System (CSIS; Fig. 2). The CSIS is

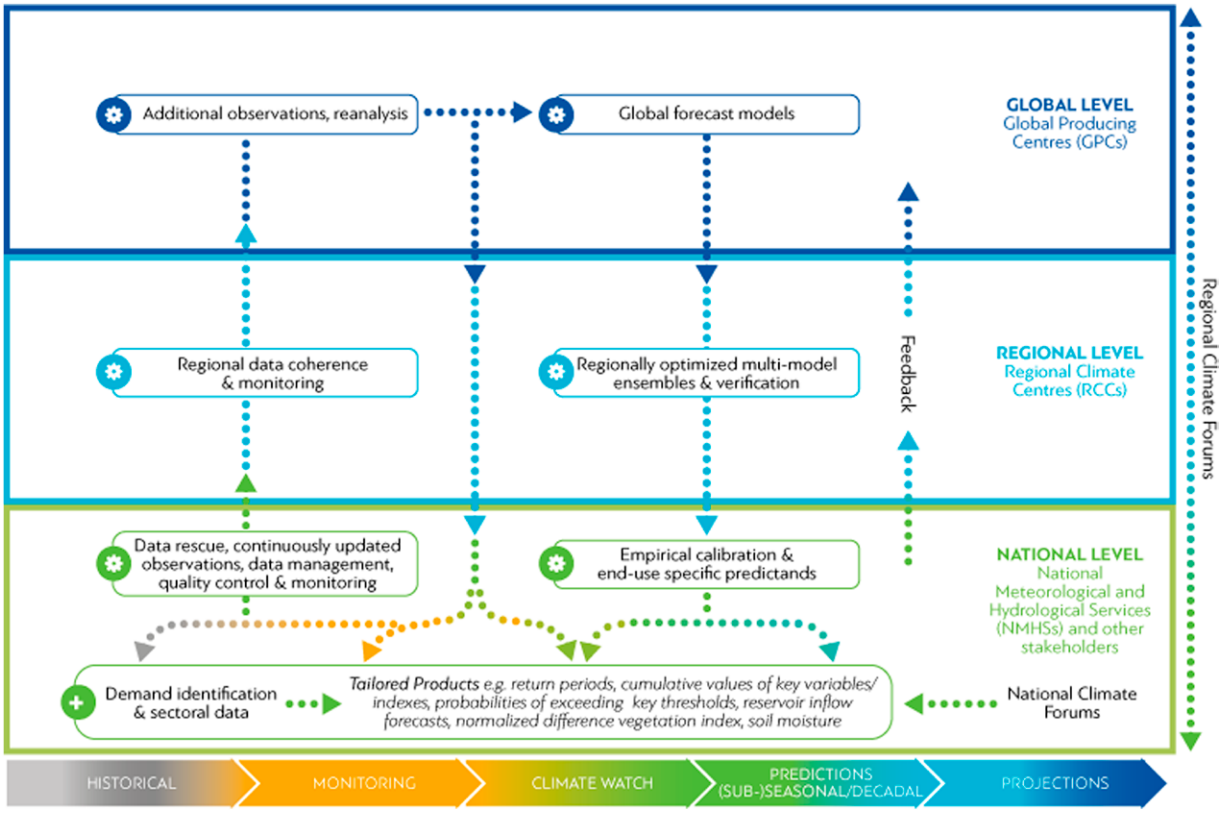

Fig. 2. A regional approach to implementing the Climate Services Information System.

the principal mechanism through which information about past, present, and future climate is archived, analyzed, modeled, exchanged, and processed for use. Regional and national entities currently have access to multiple sources of climate information, but they must identify the most robust signals, assess the reliability of the information, and likely future states of the climate in their respective locations on their own. The CSIS provides expert guidance and training in interpreting and using the information to help regional and national users identify the information of most use for their areas of interest, including in applying the information in developing products.

The CSIS has facilitated climate service development by regional and national providers, expanded the RCC, RCOF, and National Climate Outlook Forum (NCOF) operations, and developed a prototype climate services toolkit. This toolkit includes knowledge, software tools, datasets, and training materials to enable scientific and technological advances to be used in the provision of climate services. For example, in the health community, the development of tailored climate products begins with integrated climate and epidemiological data to analyze how, where, and when the occurrence of disease may be influenced by climatic conditions. Integrated climate and health surveillance systems are useful to health authorities to enable retrospective analysis, the real-time monitoring of climate-sensitive disease risks, and the development of early warning for climate-sensitive diseases such as dengue or cholera (Shumake-Guillemot and Fernandez-Montoya 2016).

Many climate services and applications require long-term and high-quality climate data (Brunet and Jones 2011). Climate risk management and adaptation efforts such as risk mapping, impact modeling, forecasting of extreme events, attribution services, and decadal climate prediction activities all require high-quality long-term datasets. Accordingly, data recovery and restoration (including generating dynamical reanalysis products) of climate time series remains a high priority.

Include climate services more widely in planning and policy. Integration of climate change adaptation and low-carbon pathways into development planning requires systematically accounting for climate risks and opportunities in decision-making at every level of country dialogue, policy planning, governance, investment design, implementation, and evaluation. Decision-makers need to have easily available climate services that are relevant to their needs and can guide strategic climate-resilient and low-carbon growth action.

Formalizing mechanisms to connect climate services to decisions and legislative frameworks will enhance the uptake of science in climate-resilient planning processes. Several countries have developed national climate change scenarios as a key basis for climate adaptation and mitigation, issued on a regular basis using the latest scientific knowledge. For example, the Netherlands (van den Hurk et al. 2014), Switzerland (NCCS 2018) and the United Kingdom (Lowe et al. 2018) recently launched

National collaboration
National frameworks for climate services: United Kingdom

Launched. 2013 through a shared intent from the national Met Office, research councils, Environment Agency, and government to enhance coordination on climate services.

Funding. U.K. government and in-kind contributions from collaborating institutions.

Benefits. NFCS has enhanced 1) collaboration between key actors in the climate service landscape; 2) understanding of climate services among climate-sensitive sectors; 3) engagement of users in codesign processes; and 4) investment in research and development, particularly science for service programs.

Challenges. Demonstrating the value of climate services, capacities and capabilities across the climate service value chain, competition versus collaboration.

updated climate change scenarios to underpin government strategy and national adaptation plans.

To support the science and policy link, the RCOF and RCC products are being diversified beyond consensus seasonal climate outlooks. For example, some RCOFs now include a climate change component, monitoring information, reflect on observed trends, review attribution of extreme events to climate change, improve on impact predictions, and help ensure a national consistent approach is followed in understanding and interpreting climate information. However, in many countries, issues such as the governance of climate data, or poor availability of climate data of high quality and long enough record length, are key limiting factors for initiating the process. While multidecadal climate change projections are essential for informing mitigation policy, consideration should be given as to whether such projections target the appropriate time scale needed for adaptation decisions in developing countries (Nissan et al. 2019).

At the national level, the NFCS can serve as the mechanism to coordinate, facilitate, and strengthen collaboration among national institutions and other key stakeholders. Promoting governance arrangements in an NFCS that incorporates representatives of key climate-sensitive sectors and policy-makers to oversee the service development and uptake will further enhance mainstreaming of climate services in planning and policy. Creating transparent systems to monitor the access, usage, and user satisfaction of services will support iterative feedback required to improve services to become more useful and to be used more effectively.

Enhance capacity and governance along the climate services supply chain. Linking capacity and governance along the supply chain from the knowledge generation to service delivery is problematic (Pulwarty and Sivakumar 2014). There can be impediments to the flow of knowledge among the key organizations, for example between the RCCs and the NFCS entities, demonstrating the credibility and value of the service to private and public partners along the supply chain can be difficult, and some organizations involved may have policies and practices that can prevent the creation of an integrated information system.

A recent survey of human resources in NMHSs identified a serious capacity gap in many NMHSs, spanning virtually all professional areas (WMO 2017b) and most NMHSs listed climate services as one of their top five training priority areas. Updating regional and national training strategies in coordination with development partners and recognized centers of excellence (such as WMO Regional Training Centers) offer promising inroads to closing the capacity gap. Enhancing the effectiveness of ongoing training activities, such as those linked to RCOFs, to address specific competences across regions will be important. Developing and maintaining linkages between research communities and operational services to expedite the application of research advances in operational climate services is also important, as these linkages will enhance the offerings of operational services.

While training the climate service providers is important, training the recipients of the climate services is equally important to ensure capacity and capability to translate and incorporate climate services into their decision-making, as well as to refine the set of questions and information that could enhance climate-smart action. User training aspects can be incorporated into the NFCS action plans and priorities discussed at NCOFs.

Enhance monitoring, evaluation, and knowledge management and communication. The concept and common understanding of climate services is not yet widely established. While climate mitigation and adaptation have become common terms in the policy arena, outside the WMO and research community many practitioners have no idea what climate services are or that they are more than simply data or are beyond weather services. Therefore, communication strategies need to be developed for all actors in the climate services arena. In

addition, many actors are asking, "What value do climate services provide for my decision?" Responding to this question requires the monitoring and evaluation of the socioeconomic costs and benefits of climate services, a practice that is complex and is not currently widely undertaken. Nascent efforts have been engaged to evaluate different components of climate services (Gerlak et al. 2018) but more needs to be done to evaluate alignment and effectiveness across all aspects of service design, implementation, and feedback for learning and improvements in services.

Sharing knowledge, approaches, good practice, and tools through a centralized knowledge management system, that could also provide expert-based advice, would provide a useful resource to be utilized by communities of practice and through face-to-face forums, such as RCOFs and NCOFs. The GFCS has a structure in place for monitoring and evaluation with consideration of targets, indicators and a monitoring framework, but the process has not yet been fully and effectively implemented. Doing so would better enable climate service contributions to the Sendai Framework, SDGs, National Climate and Disaster Risks Plans, the Paris Agreement, as well as providing a stronger basis to evaluate the socioeconomic costs and benefits of climate services.

Foster strategic partnerships and catalyze innovation. The international development community already considers climate as a development issue and it is committed to act. In doing so, it is increasingly bringing science and technology together to facilitate climate-resilient and low-carbon development. Strengthening the knowledge base for climate-smart planning through improved access to, and use of, best-available climate data (including recovering historical climate observations), information, and tools is imperative.

There is a need to scale up partnerships between the development community and the climate service community to meet the climate challenge. New models for cooperation should be explored. The GFCS and the CSP are beginning to collaborate closer, for example by bringing their respective communities together in the next International Conference on Climate Services. Initiatives such as CREWS, the World Bank's PPCR and the Africa Hydromet Program, the Global Weather Enterprise and an expanding number of multilaterally funded projects are aiming to make climate services an intrinsic part of climate resilient and low carbon development. Supporting long-term national and subnational climate visions and strategies will inform the type of information that will be required to enhance climate-smart planning.

The private sector is an important and emerging group of actors in the climate services arena. As well as being potential users of climate services, the private sector is already engaged in the development and delivery of climate services. The sector has different knowledge of the needs of users and different approaches to research and development, often with more rapid development cycles than public sector organizations for delivering specific outcomes. However, there are also possible pitfalls to such private sector engagement in development and delivery, including potentially not funding the underpinning climate science capability, and commercial models potentially disadvantaging the developing world (Webber and Donner 2017).

On the other hand, many private companies recognize that using climate services effectively can add value in many socioeconomic sectors, and some private companies are willing to pay for receiving climate services to enhance productivity and reduce reputational risks. While this represents an opportunity as an undertapped market, a lack of resources or capacity means that many climate service providers are unable to respond to the growing and specific demands of the potentially vast and diverse private sector.

Collaboration with the private sector, such as through public–private partnerships, could help address the demand and could be beneficial for sustaining and expanding the

production and delivery of climate services. Collaboration with the private sector offers an exciting challenge and opportunity that could bring greater societal benefit and financial value to climate service providers by building on the experience that the private sector has in innovation and product development, and in opening up new markets and applications. Continued dialogue is needed to ensure alignment between private sector goals and the provision of public goods and services.

Future opportunities for advancing the use of climate services for climate risk management

Given the progress made so far in ensuring that climate services are used more widely and more effectively in decision-making, as well as the challenges highlighted above there are also exciting opportunities. The GFCS and actors engaging in it are ideally placed to serve as a focus for change as this global framework enters its next phase from 2019 onward. The GFCS has helped evolve the regional development, coordination, and delivery of climate service activities, and has created a national service-oriented culture within the context of a NFCS, allowing a range of sectors in the public and private domain to engage in climate services within many countries.

NMHSs are a specific category of organization in national climate service activities, often acting as the nation's hub. The role of NMHSs is becoming more important in the climate change arena through participation in climate change committees, national adaptation plans, and strategies for climate resilience. Climate change data and information derived from observations and modeling is recognized as having significant value (World Bank Climate Change Knowledge Portal; http://climateknowledgeportal.worldbank.org). The NMHSs through the NFCS process have an opportunity to improve collaboration with sectoral partners and other key actors to coproduce tailored services on impacts, risks, and in some cases options for action. Sustained support between NMHSs and other key actors on the specific climate service situation in their respective territories is needed. However, some countries may face similar challenges, and there is an opportunity to share knowledge from developing climate services. It is a testament to the success of the GFCS that so many NMHSs have become actively engaged in climate service development and delivery in recent years, such as through engagement in the Intergovernmental Board on Climate Services, but most tangibly borne out by the fact that to date 47 NMHSs are already engaging in developing their nations' NFCS, 19 of which are already established and 18 more are well underway.

Climate services are steadily and successfully being used by a growing number of decision-makers in both the public and private sectors. Ensuring that the beneficiaries of the services are better involved will drive user-focused development of scientific and technical capability and user-focused development of the climate services built on that capability. Such developments will ultimately enable better risk management and better-informed climate-smart decisions.

Funding and prioritized investment in climate service development is of course essential to support the necessary resources and scientific and technical developments, as well as to influence and drive a service-oriented culture and to engage decision-makers and key influencers. A portfolio of funding from diverse investors (including research funding bodies) would be beneficial but needs coordination to avoid fragmented implementation. Working with donors and development banks will help to ensure resources are targeted to regional and national priorities that will enhance the donor's mission, for example, through the GCF, CREWS, International Finance Institution grants and loans, and bilateral donors. An example of work between international funders, RCCs, and NMHSs is the European Commission's funding of the Euroclima+ program in South America. The RCCs and NMHSs together with various public institutions are working to strengthen the capacity of the NMHSs to deliver

and communicate timely, relevant, and sector-tailored climate information and knowledge focused on drought and extreme events.

To conclude, major progress has been made over the past decade developing, delivering, and using climate services. There are many challenges for improving the development, uptake and use of climate services for climate-smart decision-making and we have provided several recommendations to address such challenges. This paper provides a summary of barriers and opportunities that could be further explored in more detail elsewhere. In particular, we anticipate that new challenges, not yet fully realized, are likely to emerge around the need for some common standards for climate services, ethics, common language and terminology, and seamless services across weather and climate time scales.

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