"Capacity building for climates services is best achieved through drawing together local and regional knowledge, user-provider engagement, national commitment and global partnerships"

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COMMISSION FOR CLIMATOLOGY

GUIDELINES FOR NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES ON CAPACITY DEVELOPMENT FOR CLIMATE SERVICES

WORLD METEOROLOGICAL ORGANIZATION

CONTENTS

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Foreword

Communities have always been exposed to climate variability and climate extremes, but the expected increase in frequency and severity of these events due to a changing climate poses new challenges for societies worldwide. Reducing risks and maximising climate-related opportunities requires appropriate science-based information and the necessary institutional framework, infrastructure, and human capacity to transform and communicate this information for decision-making and improved stakeholder outcomes.

Many countries lack the resources needed to provide high-quality climate services, particularly in the developing and least developed countries. To support the provision of climate services, the Global Framework for Climate Services (GFCS) was established in 2009 at the World Climate Conference-3. The GFCS seeks to enable societies to better manage the risks and opportunities arising from climate variability and climate change through incorporating climate information and prediction into planning, policy and practices, particularly in climate-sensitive areas such as agriculture, water, health, disaster risk reduction and energy. This is achieved through five GFCS supporting pillars, namely, the User Interface Platform; Climate Services Information System; Observation and Monitoring; Research, Modelling and Prediction; and Capacity Development.

Capacity development is a cross-cutting GFCS pillar focused on investing in people, practices and institutions to develop capacities to provide and use climate information for decision-making. The WMO Capacity Development Strategy recognizes four types of capacity: institutional, infrastructural, procedural and human resources. These capacities must be considered collectively to achieve sustainable capacity development of National Meteorological and Hydrological Services (NMHSs). These guidelines are intended to provide NMHSs and other climate service providers with up-to-date information on available resources, strategies, procedures and best practices available to help develop their capacities in the provision and use of climate services.

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Executive Summary

The demand for actionable climate information and tools to inform decision-making is increasing in response to increased frequency and severity of climate impacts and the changing nature of the climate. In order to be able to provide timely and quality climate services in response to these increasing demands, current and potential climate service providers need to assess and develop their capacities.

These guidelines are intended to provide National Meteorological and Hydrological Services (NMHSs) and other climate service providers with up-to-date information on available resources, strategies, procedures and best practices to help develop their capacities in the provision and use of climate services at the global, regional and national level. The guidance focuses on enhancing capacity of NMHSs in four key capacity areas: **institutional, infrastructural, procedural and human resources**. These four areas must be considered together to achieve sustainable capacity development.

Capacity development activities to support climate services should not be assessed or undertaken in isolation. Effective and sustainable capacity development for climate services should align with the climate service provider's general capacity development requirements, including established modernization plans.

These guidelines draw on a number of existing frameworks and guidelines, including the GFCS Implementation Plan and associated Annexes; the WMO Capacity Development Strategy and Implementation Plan. Section 1 reviews the central importance of capacity development to the development of climate services, with specific reference to the GFCS. We discuss the WMO Capacity Development Strategy and Process in Section 2. The Infrastructural capabilities and the procedures for actionable climate products are discussed in sections 3 and 4, respectively. Institutional framework and human resources are presented in section 5 and 6, respectively. Finally, section 7 describes the full value chain of climate services including socio-economic assessment.

1. An Introduction to Capacity Development for Climate Services

Climate services involve the production, translation, transfer, and use of climate knowledge and information in climate-informed decision making and climate-smart policy and planning[1].

1.1. The Global Framework for Climate Services

The GFCS was established to recognize the need for interaction amongst hydrometeorological and non-hydrometeorological stakeholders in order to complete the value chain for climate services, with a vision "to enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale."

As the GFCS aims to develop technically and scientifically sound capacity to apply and generate climate information and products at national, regional and global levels, capacity development is a central component to climate service development. In fact, the Capacity Development component of the GFCS Implementation Plan can be seen as a foundation that links and supports the four other pillars of the GFCS (Figure 1). The full scope of all these pillars is described in the GFCS Implementation Plan[2].

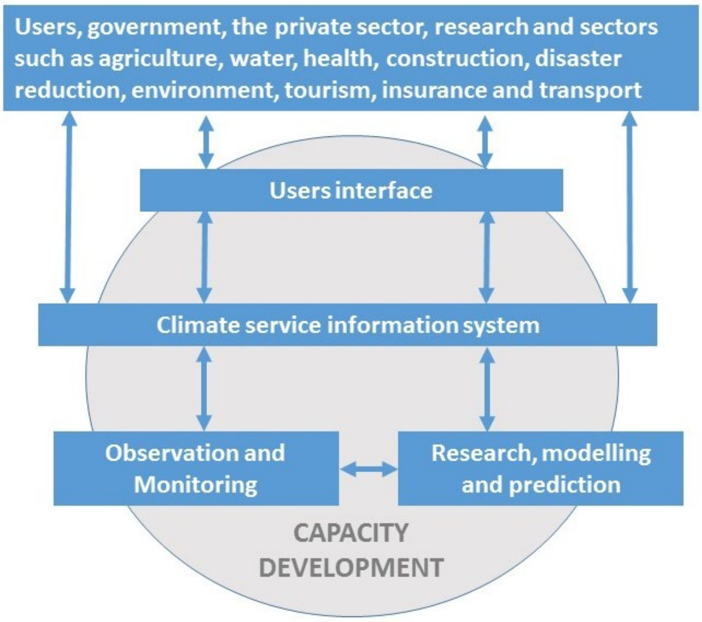

Figure 1: A schematic illustration of the GFCS pillars, illustrating that the Capacity Development pillar encompasses and supports all other pillars

User Interface Platform (UIP): provides a structured means for climate service users, user representatives, researchers and service providers to interact in order to ensure that the climate and other contextual information, products and communications relevant to addressing user needs are included in climate service development. Involvement of users is critical, in order to develop and appropriate actionable products, identify and address capacity development requirements, influence the direction of research and observation activities, provide feedback and evaluate socio-economic benefits.

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[1] Climate Services Partnership (http://www.climate-services.org)

[2] Climate Services Implementation Plan (https://gfcs.wmo.int/sites/default/files/implementation-plan//GFCS-IMPLEMENTATION-PLAN-FINAL-14211_en.pdf)

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Climate Services Information System (CSIS)*:* is the principal GFCS mechanism through which information about climate (past, present and future) is routinely collected, stored and processed, enhancing the capacity of national and regional centres to effectively use global and regional inputs to generate of products and services that inform decision-making across a wide range of climate-sensitive sectors. A set of top-level functions of CSIS can be defined as (i) climate data management, (ii) climate monitoring, (iii) climate prediction and (iv) climate projection. These functions include processes of analysis, re-analysis, diagnostics, interpretation, attribution, verification, delivery and communication. The CSIS[3] comprises a physical infrastructure of global, regional and national institutes, centres and computer capabilities that, together with professional human resources, develop, generate and distribute a wide range of climate information products and services to inform complex decision-making processes across a wide range of climate-sensitive activities and enterprises. Therefore capacity development considerations for the CSIS include institutional, infrastructural, procedural and human resources.

Observations and Monitoring*:* ensures that climate observations and other data necessary to meet the needs of end-users are collected, managed and disseminated. Climate data (and associated meta-data) provide the fundamental building block for climate research, modelling and prediction (for example, for detection and analysis of climate variability and change; for initializing climate models used for seasonal to interannual forecasts and their verification, and to generate simulations of future climate) and the development of climate products, applications, and services. Data rescue of past meteorological records is a recognised activity of this pillar, ensuring the sustainability and use of historical data for climate monitoring. At the global level, gaps in observations and monitoring are being addressed via the Global Climate Observing System (GCOS) implementation plan[4]. In addition to climate data, effective climate services require the availability of high-quality socio-economic, biological, and environmental data, which must be effectively integrated with climate data in order to develop and provide users with climate services to manage impacts in climate sensitive regions, socio-economic settings and sectors.

Research, Modeling and Prediction*:* provide an evidence base for the impacts of climate variability and climate change and for the cost-effectiveness of using climate information. This pillar aims to continually improve the (a) scientific understanding and predictability of the climate system at all time scales, (b) the quality of climate information through modeling, and (c) the development of tools that address gaps in prediction and data analysis. Key to meeting the objectives of this pillar is the World Climate Research Programme[5] (WCRP), which addresses aspects of climate science that are too large and too complex to be tackled by a single nation, agency or scientific discipline. This pillar also fosters interdisciplinary research and modelling related to natural sciences, including social sciences and humanities and other relevant disciplines, to develop solutions-focused climate services. Climate information is more likely to be used if it is credible, timely, and its value can be demonstrated in decision-making.

Capacity Development*:* is the process of strengthening the abilities or capacities of individuals, organizations and societies to solve problems and meet their objectives on a sustainable basis. This all-encompassing pillar addresses capacity development requirements identified in the other pillars and, more broadly, the basic requirements for enabling all GFCS-related activities to occur. Effective implementation of the GFCS

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[3] Workshop on Strategy for Implementation of Climate Services Information System (CSIS) (WMO 2011)

[4] Global Observing System for Climate – Implementation Needs (GCOS, 2016).

[5] https://www.wcrp-climate.org

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requires strong linkages between all of the above pillars, leading to the creation and strengthening of continuously improved operational systems which respond to demand and deliver relevant services.

1.2. Climate Services Delivery Value Chain and User-engagement

Climate service benefits derive from a value chain, which links the production and delivery of services to user decisions. It encompasses climate services enabled by hydrometeorological infrastructure and processes (i.e. the CSIS, primarily implemented by NMHSs at the national level with support from other regional and global centers and entities), services provided by intermediary and boundary organizations user actions, and the outcomes and value resulting from those actions (Figure 2).

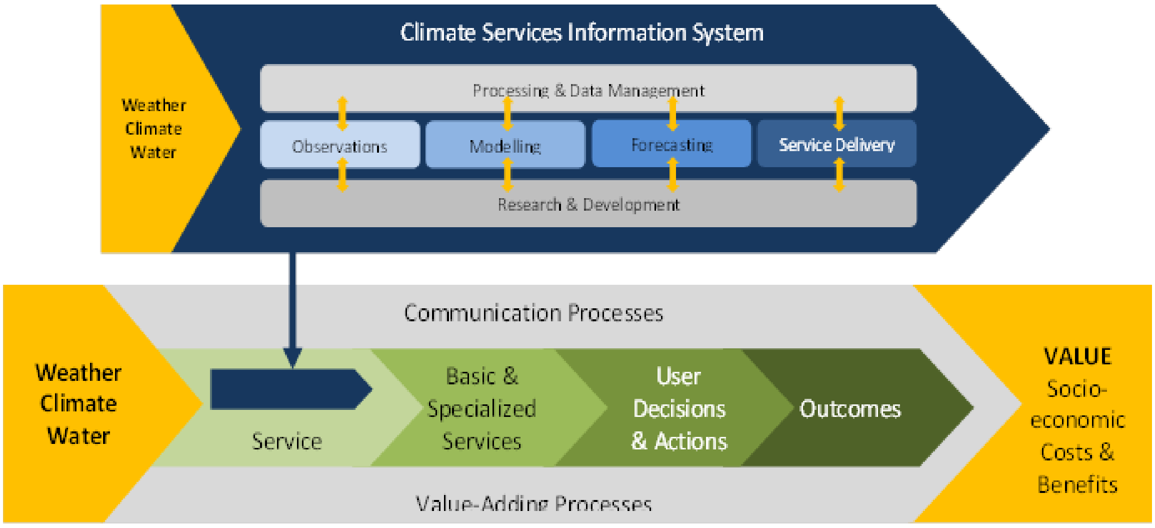

Figure 2: Climate Service Delivery Value Chain. Source: WMO No. 1153, Adapted from WMO et al., 2015[6]

Establishing relationships with these stakeholders across the value chain, through strong and effective engagement, is crucial to successful climate service development and delivery.

1.3. Co-development of climate services

Relevant and usable climate services are likely to require integration of other contextual data and information, such as socio-economic information, with climate information. These data requirements will be identified, defined and refined through engagement with climate-sensitive stakeholders throughout the climate service development process. The concept of co-development is the continuous two-way user-provider engagement throughout the whole service delivery value chain, to enable the generation of climate products and the delivery of services that make use of the best available climate science and technology, while supporting user decisions.

2. Capacity Development

2.1. The WMO Capacity Development Strategy

Capacity development is a strategic priority within WMO, as it is critical to enhancing the capabilities and capacities of NMHSs to improve the quality and delivery of services. The need for capacity development assistance is founded on the WMO Convention, which recognizes that Members need to work with each other and with other organizations to coordinate, standardize, improve and encourage efficiencies in the exchange of

[6] Valuing Weather and Climate, WMO No. 1153 (https://library.wmo.int/doc_num.php?explnum_id=3314)

information to align their application to the needs of society. The WMO Capacity Development Strategy and Implementation Plan (CDSIP) (WMO-No. 1133)[7] aims to provide effective capacity development assistance to Members and facilitate sustainable development of their NMHSs. The CDSIP focuses on enhancing capacity of NMHSs in four key areas: **institutional, infrastructural, procedural, human resources**, which represent the major components of an integrated capacity development programme (CCl-17/Recommendation 9)[8]. These four areas are the main focus of this guideline document to enhance the capacity of NMHSs to improve climate services. They are explored in further detail in sections 3, 4, 5, and 6 respectively.

2.2. Climate Services Capacity Categories

The extent to which an NMHS can deliver services will depend on its capacity to access and process observational data, to manage and analyse climate data, to convert the data into relevant and usable information and products, and to contribute to the development of a range of products to support decision-making. Based on these criteria the capabilities of national climate services can be classified as: (1) basic capacity; (2) essential capacity; (3) full capacity; and (4) advanced capacity. The purpose of this classification is to help countries better understand the capabilities required to provide climate, weather and hydrology services, and identify what is needed in their own NMHS to ensure the desired service level. A description of the capabilities expected of a NMHS at each level is provided in Table 1 at the end of this document. Members monitor their progress on climate services implementation through the WMO Community Platform[9] to identify areas where support is needed, based on a Country-focused results-based framework to support the implementation of WMO contributions to the GFCS[10].

2.3. Capacity Development Process

The sections below draw from the general outline of the WMO Capacity Development Strategy and Implementation Plan (CDSIP), applied to the specific issue of capacity development for climate services. The CDSIP was designed to assist all Members, especially NMHSs of Least Developed Countries (LDCs) and Small Island Developing States (SIDS), to coordinate, standardize, improve, and encourage efficiencies in the exchange of weather, water and climate information, and foster its application to the needs of society.

Capacity development is not a one-off intervention, but an on-going continuous improvement process with feedback mechanisms, encompassing activities, approaches, strategies, and methodologies. An eight-step capacity development process was developed in the CDSIP, adapted from the five-step approach of the United Nations Development Programme (UNDP) and others, to better reflect the steps required for NMHS development (Figure 3). These steps are iterative, and each step can be used to review past performance and provide directions for future actions and improvements. All capacity development activities should consider each of these eight steps for their effectiveness and sustainability. Detailed information on these steps is found on the CDSIP manual[11]. To carry out the capacity development of NMHSs holistically, the eight-step process should encompass the four key capacity areas, identified previously: institutional, infrastructural, procedural and human resources.

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[7] Refer to WMO Capacity Development and Implementation Plan (WMO, 2015)

[8] Integrated Capacity Development Process for Climate Services Information System (CSIS) (CCl-17)

[9] https://contacts.wmo.int/

[10] WMO Abridged Report EC-68 (pp 82-92, WMO, 2015)

[11] WMO Capacity Development and Implementation Plan (WMO, 2015)

Figure 3: The CDSIP eight-step capacity development process for sustainable NMHS improvements

3. Institutional Capacity Development

Institutional capacity refers to the institutional arrangements, roles and responsibilities, including legal mandates, for developing and delivering climate services. A National Framework for Climate Services (NFCS) is a typical example for institutional arrangement for national climate services. The timely, credible, and actionable development and delivery of climate services requires close communication, coordination, and liaison between government agencies, multiple institutions and stakeholders at different levels.

Assessment of institutional capacity is specific to each country and must be undertaken incrementally in a national context. Common institutional challenges which hinder proper functioning of effective national climate services include[12]:

1. Potential mismatches between national institutional arrangements and clear legal mandates;
2. Lack of visibility of NMHSs within the community and government, including awareness of climate information generated by NMHSs;
3. Limited technical, financial and human resources;
4. Lack of mechanisms for exchange of information between government agencies;
5. Limited climate knowledge within the government structures.

This section on institutional capacities addresses two broad sets of institutional relationships that can strengthen NMHSs institutional competencies and positioning. The first set focuses on institutionalization of climate services within a country to enhance institutional capacity for both basic systems operations as well as for service delivery. The second set concerns the institutional relationships between NMHSs and other entities whose cooperation is needed for operationalization of the Climate Services Information System (CSIS) on regional scales, using regional forums as a vehicle for strengthening the institutional architecture for CSIS operationalization.

[12] Global Framework for Climate Services Adaptation Programme in Africa (GFCS-APA; Yanda et al., 2015)

Strategic vision for Capacity Development in NMHSs

NMHSs need strong visionary leaders who can see the big picture and think strategically to bring about innovative changes to develop institutional and infrastructural capacity and to sustain it. The director of the NMHS must ensure the following:

1. Participation in leadership and management training workshops to update leadership skills and to be better prepared to tackle emerging challenges. Strong leaders at multiple levels are needed to engage every NMHS staff member in the daily activities of the NMHS;
2. Seek opportunities to work with funding agencies to propose sustainable projects that can help build the infrastructure of the NMHS to enable effective use of climate information. In particular, this can help leverage government funding to maintain an optimal staffing level necessary to meet the demands of society for timely and reliable climate information;
3. Promote the use of climate information through constant dialog with stakeholders in all climate sensitive sectors through government Ministries, the private sector and NGOs. The establishment of a sectorial climate board may be useful as it will provide a mechanism to oversee the use of climate information in the country and to ensure that stake holders are fully engaged with NMHSs in the kind of information they need, and that NMHSs have the resources to meet the requirements of the user sector;
4. Promote research and development and transition from research to operations by encouraging collaborative work between NMHSs, universities, and other research and scientific institutions that will advance science and the use of climate information.

3.1. Institutional capacity at national level

3.1.1. NMHS status within the government

Given that meteorology touches so many sectors of the economy, placement of the NMHSs within the government institutional structure is an important consideration. Optimal placement will help achieve high visibility of hydrometeorological services to enable government policies that will lead to sustained capacity development. Figure 4 shows the institutional placement of NMHSs within national governments in 2018.

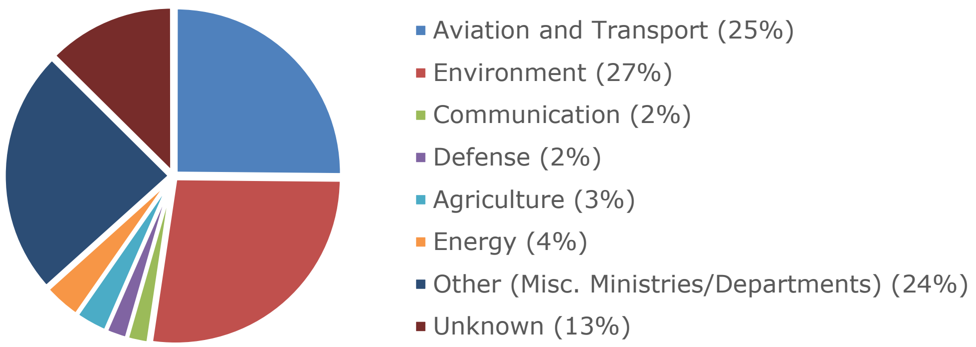

Figure 4: Institutional authority over NMHS (as reported to the WMO Secretariat in 2018)

3.1.2. Promoting NMHS institutional interaction with other stakeholders: National Frameworks for Climate Services

A National Framework for Climate Services (NFCS) is an institutional mechanism to coordinate, facilitate and strengthen collaboration among national institutions to improve the co-production, tailoring, delivery and use of science-based climate predictions and services by focusing on the five pillars of the GFCS. NFCSs have already established or are being established in many countries and need government mandate through participatory national agency agreement with clearly articulated terms of reference and action plans for each of the institutions involved.

A step-by-step Guide for establishing a National Framework for Climate Services[13] explains in detail how to initiate, develop, endorse and launch a functional NFCS that will serve as a key coordination mechanism to bring together the local, national, regional and global stakeholders needed for the successful generation, tailoring, communication, delivery, communication and use of co-designed and co-produced climate services with and for users.

NFCSs may be initiated and led by the NMHSs, which are the government mandated providers of hydrometeorological services in most countries. The NMHS should engage all relevant national stakeholders involved in the five component pillars of the GFCS, taking stock of national institutions providing climate related information, and major on-going climate-related programmes and activities in the country, as part of a Baseline Assessment. The NMHS should also use the stakeholders established through the baseline assessment to convene and lead a National stakeholders consultation process to establish an NFCS configuration, governance structure and a process to operationalize the NFCS.

3.1.3. Intra-institutional arrangements within NMHSs

The division of responsibilities for climatological activities within NMHSs is also an important consideration for climate service capacity building. Some NMHSs have a single division responsible for all climatological activities, while others may have assign responsibilities for different climatological activities (such as observing, data management and research) to different units, or even area or branch offices (WMO-No. 100[14]). Responsibilities may also be assigned to another institution altogether. Therefore, it is essential that a close liaison exist between those applying the climatological data in research or services and those responsible for the acquisition and management of observations.

3.2. Regional and global institutional support

NMHSs are part of a global institutional architecture for climate service delivery, involving exchange of data and products with regional and global centres (Figure 5).

Institutions contributing to this system at each level have different functions and these functions, and the automated exchange of the necessary data and products needed to perform them, must be coordinated in order to achieve effective and efficient operationalization.

Demand for products and services drawing on historical data, climate predictions and projections, is identified through stakeholder interactions at country level. NMHSs also make important contributions in terms of their own data, both historical and from on-going observations.

Resolution 60 (Cg-17) states that GFCS-relevant data and products should be exchanged on a free and unrestricted basis among members. This allows national data to be accumulated at the regional levels and provided to global centers, where it can be integrated with satellite and reanalysis data. These enriched data sets are made available to all Members including countries within the region.

In addition, these data are used to develop improved forecast models, optimized to obtain the highest possible skill for the regional domain. NMHSs can use statistical

[13] Step-by-step Guide for establishing a National Framework for Climate Services (WMO, 2018)

[14] Guide to Climatological Practices (WMO, 100)

techniques to correct biases in the outputs of these models and use the output fields to predict variables of relevance for users, such as reservoir inflow, vegetation soil moisture and others. These products can be developed through regional processes, such as regional climate forums, coordinated by Regional Climate Centres.

By drawing on the shared data and knowledge with in the region and from global entities, advanced services can be provided by NMHSs. This involves interaction among the institutions at the different levels, typically through regional forums, to link all of the elements together to create the full value chain needed to meet the specific needs of particular stakeholder groups, such as farmers, energy planners, health authorities, water resource managers and national disaster management offices.

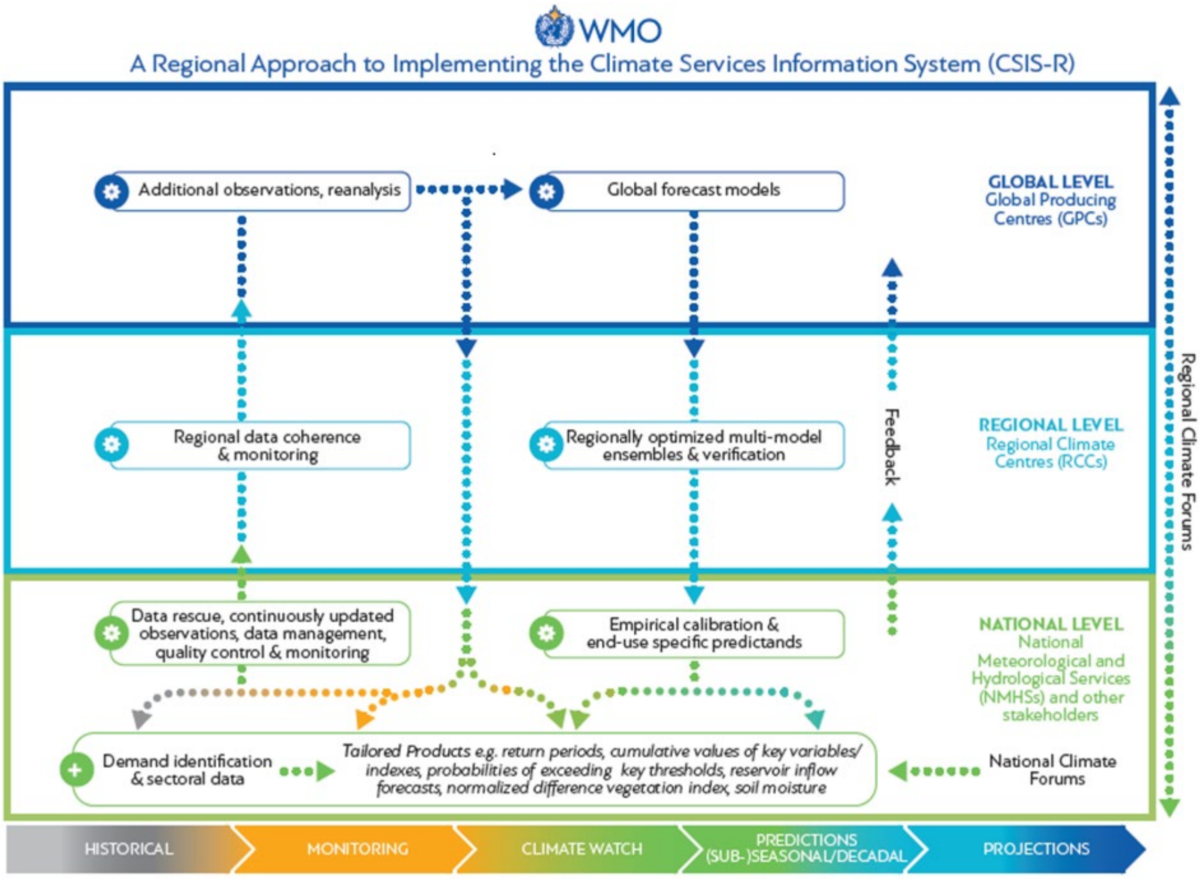

Figure 5: Climate Services Information System operationalized on sub-regional scale with country-level service delivery

Regional Climate Outlook Forums (RCOFs) are key mechanisms for defining institutional roles and coordinating CSIS operationalization. As many of the key stakeholders needed to operationalize the exchange of climate data and products—NMHSs, RCCs, and selected GPCLRFS—participate in these forums, they provide key platforms for planning and coordinating operational, full value-chain, country-level service delivery.

Within the tailored products , Global Data-processing and Forecasting System (GDPFS), WMO has designated, certain NMHSs as Regional Specialized Meteorological Centres (RSMCs), which provide forecast products to all other NMHSs. The range of specializations includes geographical considerations, tropical cyclones, emergency response and atmospheric transport models. In addition, WMO has designated Global Producing Centres and Regional Climate Centres, which focus on longer-range predictions. (See box, section 3.2). The climate predictions and information provided by Global Producing Centres and Regional Climate Centres are useful tools for planning and

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developing activities in climate-sensitive sectors, such as agriculture, water resources, energy and health.

The NMHSs can utilize products from RSMCs to develop forecasts and warnings of severe weather and extreme climate events for their respective countries to support socioeconomic development activities, including in sectors such as aviation, agriculture, marine safety, transport, tourism and energy. In addition to using global and regional products, many NMHSs run their own national numerical weather prediction models at various levels of sophistication.

The definitions and mandatory functions of GPCs and RCCs are contained in the Manual on the Global Data Processing and Forecasting System[15] (WMO-No. 485 Vol I) and are part of the WMO Technical Regulations. In addition, WMO has established the Lead Centre for Long-Range Forecast Multi-Model Ensembles and the Lead Centre for the Standardized Long-Range Forecast Verification System, which provide added value to the operational services of GPCs.

One method of promoting NMHS capacity development is through “twinning” or “pooling” services, training and support, through regional cooperative entities (such as RCC-Networks described below), or by partnering with other NMHS(s) or specialist institutions to share capabilities, skills, data and/or resources. Such international support is most effective and sustainable, there is an existing national framework under which the support is provided. WMO facilitates Member NMHSs to support others by transferring funding to them through Letters of Agreement.

[15] Refer to the Manual on the Global Data Processing and Forecasting System (WMO, 2017)

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WMO Global Producing Centres for Long Range Forecasts (GPCLRFs)

To strengthen NMHS capabilities in generating and delivering climate information and prediction products for climate services, in 2006 WMO began a process to designate centres producing global seasonal forecasts as Global Producing Centres for Long-Range Forecasts (GPCLRF). These form an integral part of the WMO Global Data-Processing and Forecasting System (GDPFS) underpinning the generation of climate information products by the NMHSs. The GPCLRFs follow a strict designation process according to which the Centres adhere to certain well-defined standards to ensure consistency and the usability of output. These standards include a fixed forecast production cycle, a standard set of forecast products and the WMO defined verification standards. Currently there are 13 WMO designated GPCLRFs.

WMO Regional Climate Centres (RCCs)

Regional Climate Centres (RCCs) are Centres of Excellence designated to support and strengthen the capacity of WMO Members in a given region to deliver climate services. WMO RCCs have been recognized as key elements of the Climate Services Information System. To date, there are eight RCCs and three RCC-Networks, providing climate services and products to NMHSs on an operational basis. The provided services include data and data management, monitoring, long-range forecasting, training and capacity building. Each of the WMO regional association has at least one RCC or RCC-Network designated or in demonstration phase.

An RCC–Network is a group of centres performing climate-related activities that collectively fulfil all the required functions of an RCC. Each centre in a designated WMO RCC-Network is referred to as a Node, which will perform, for the region or subregion defined by the regional association, one or several of the mandatory RCC activities.

Regional Climate Outlook Forums (RCOFs)

Regional Climate Outlook Forums (RCOFs) began in 1997, to produce consensus-based, user-relevant climate outlook products by adapting large and regional scale forecasts to the national context. RCOFs bring together national, regional and international climate experts to produce regional climate outlooks based on climate prediction products from GPCLRFs, RCCs, and NMHSs. Following Decision 18 (EC-69), on sub-seasonal and seasonal forecasting systems, WMO and its Regional Climate Centres have begun using RCOFs to coordinate the operationalization of objective regional seasonal and sub-seasonal forecasts for which the skill is routinely verified and communicated to users. The regional forums provide platforms for reaching agreement on, and documenting in Standard Operating Procedures, the selection of models to be used in generating the regional forecasts, metrics for evaluating and documenting forecast skill, procedures for operationalizing data exchange, specifications for key tailored products widely needed across the countries in the region, capacity development needs, and research needs to improve forecasts and tailored products. As part of this operational scheme, NMHSs can use statistical methods to correct biases in the regional forecast outputs and generate tailored forecasts of specific variables relevant for different stakeholder groups.

3.3.Public Private engagement

One of the WMO's focus areas, approved by the eighteenth World Meteorological Congress (Cg-18), is to establish principles and guidance for successful public-private engagement, and facilitate a continuous dialogue between players and stakeholders based on collaboration and mutual reinforcement.

Realizing the ultimate need for a new culture of partnership among the public, private and academic sectors, articulated in the Geneva Declaration 2019 (Resolution 80 (Cg-18)), Building Community for Weather, Water and Climate Actions, WMO initiated an Open Consultative Platform (OCP) to coordinate and streamline a high-level dialogue between the sectors The OCP nurtures collaboration and innovation for the new generation of weather and climate intelligence, embracing new information and technology across the whole value chain and enabling greater benefits for society.

The aspiration of the OCP, as a vehicle for sustainable and constructive dialogue between the sectors, is to help articulate a common vision for the future of the weather enterprise in the coming decade and beyond. By fostering a spirit of mutual respect and trust, the platform activities enables all stakeholders in the enterprise to recognize challenges and embrace opportunities, both institutional and technological, to incentivize win-win approaches and help remove any barriers where misunderstanding or mistrust could jeopardize the shared goals of our community. The main objective of the OCP is to foster cross-sectoral, transdisciplinary and long-term approaches in identifying and addressing collaboratively the top challenges facing the weather enterprise, particularly the protection of life and property from disasters and improvement of quality of life, in an open, constructive and participatory way.

An Example of the Public-Private Engagement

The use of seasonal forecasts for water management to identify periods of stress to the supply-demand balance

The UK Met. Office in partnership with the water industry explores the application of seasonal forecasting to identify periods of stress to the UK supply-demand balance. These seasonal signatures highlight chronic or acute periods of stress many weeks out, which will affect the operational management of the water system and the experience of the consumer through supply restrictions.

The United Kingdom (UK) water supply market operates within the private sector comprising of a number of autonomous water companies. The sector is overseen by the Office of Water Regulation (OFWAT), which focuses on consumer regulation. The water businesses constantly balance supply of raw water with demand. Both supply and demand have a significant dependency on the weather.

By regular monitoring of the essential climate variables, such as temperatures, rainfall, sunshine hours and soil moisture deficit, the UK Met. Office explores whether it is possible to secure customer supply and optimize operational costs for private sector.

The project will use existing models that incorporate the dependency of demand on weather out to 12 days ahead. Several water companies in the UK use these models and the case studies will evaluate the use of seasonal forecast information for catchments with distinct climatology. The water demand models developed using observed weather data may not require additional calibration to utilize seasonal forecast data.

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Resolution 80 (Cg-18) recognizes:

- **The need to strengthen the entire weather, climate and water services value chain –** from acquisition and exchange of observations and information, through to data processing and forecasting, and service delivery – to meet growing societal needs;
- **The evolving capabilities and growing engagement of the private sector** in contributing to all links of the value chain and accelerating innovation;
- **The heterogeneous business models** of the diverse stakeholders and differing legislative frameworks of the Members;
- **The persistent capacity gap between developed and developing countries** in the provision of essential services that impedes resilience to natural hazards;
- **The pressure on public funding** which inhibits the ability of some National Meteorological and Hydrological Services (NMHSs) to sustain and improve requisite infrastructure and services;
- **The crucial need for WMO to work more closely** with development and funding agencies, the private sector and the international finance community in designing and guiding development assistance aimed at closing the capacity gap;
- **The need for innovative approaches and incentives** to enable fair and equitable access to data, including to the rapidly growing non-traditional data from all sectors;

It further calls on all Governments to give due consideration to the statements expressed in Geneva Declaration 2019 (WMO-No. 1236, p. 254) to:

- **Foster structured dialogue** between public, private and academic sectors at both national and international level;
- **Safeguard and strengthen the authoritative voice of NMHSs** for the issuance of warnings and relevant information to support critical decisions related to natural hazards and disaster risks, in collaboration with national disaster management authorities;
- **Endeavour to put in place appropriate legislative and/or institutional arrangements** to enable effective cross-sector partnerships and remove barriers to mutually beneficial cooperation and collaboration;
- **Ensure the fulfilment of international commitments,** including those stemming from the WMO Convention, for sustainable operation of the international infrastructure and exchange of required data;
- **Promote uptake of and compliance with WMO standards and guidance by all stakeholders** to enhance interoperability and the quality of data and products;
- **Engage with civil society** to extend the outreach to communities and citizens in particular to enhance public understanding and response to warnings of natural hazards;
- **Encourage stakeholders from all sectors** to facilitate international data sharing and make their data available as needed for essential public purposes, such as disaster risk reduction.

4. Infrastructural Capacity Development

As describe in the previous section, WMO has established new infrastructure within the WMO Global Data Processing and Forecasting System (GDPFS) to improve access to climate information and products for its Members. This three-tiered worldwide structure includes the NMHSs acting on a national scale, Regional Climate Centres (RCCs) and other regional centres providing sub-regional, continent-wide climate information and services, and the Global Producing Centres (GPCs) of Long-Range Forecasts that deliver global-scale information and services. Currently more than 200 global and regional centres offer specific support to NMHSs and play a key role in capacity development.

At the national level, NMHSs own and operate most of the infrastructure required for providing the weather, climate, water and related services, including observation systems, data management and exchanges, prediction, and communication. The NMHSs also use telecommunications networks, for exchange of climate data and access to global information and products, to fulfill their national mandates as climate services providers.

The infrastructural requirements for data management, climate monitoring and forecasting at NMHSs are as follows:

- A strong and reliable observational network, including maintained automatic weather stations, radar, buoys, and hydrological measurements;
- Instruments to calibrate measurements;
- A reliable telecommunication network;
- Access to high speed internet to benefit from GPC data stream;
- Access to high quality data and improved dataflow from the observing stations to the NMHSs computer network;
- A database management system including data rescue;
- Access to high quality historical station datasets or satellite rainfall estimates;
- Access to forecasts and reforecast data and from Global Producing Centers (GPCs);
- Access to computers equipped with adequate hardware and software for data processing and the generation of products (Windows or Linux computers);
- Access to statistical tools for calibrating or downscaling model forecasts, including regression methods, canonical correlation analysis, singular value decomposition, etc.;
- Implementation of tools to quality control data;
- Implementation of graphical and statistical tools to analyze the data and to generate climate monitoring and forecasting products;
- A Geographical Information System to create raster files and shape files for further use in sector application of the climate information;
- Ability to package and disseminate climate data and products in a way that is understandable to the stakeholders to enable decision making in various socioeconomic sectors.

4.1. Data

A strong observational network is required to improve current climate monitoring and forecasting systems, and it is even more critical for NMHSs, RCCs, and GPCs to constantly have access to reliable data in order to improve the end-to-end process of climate services from the gathering and processing of the data to the delivery of climate products that inform socio-economic decision making.

An effective Climate Data Management Systems (CDMS) is essential to address the needs and requirements of NMHSs for delivering improved climate services[16]. A CDMS requires considerable resources and both infrastructure and human resource capacity to design, develop and implement it. Basic requirements for CDMS include:

- Computer systems (database and web servers), network infrastructure;
- Application program developers at different levels;
- Policies and permissions regarding data exchange across organizations (nationally, regionally and internationally);
- A plan for an optimized configuration based on constraints and budget;
- A detailed plan for infrastructure and human resource needs;
- Definition of the type of data to procure, store and disseminate. Typical data types are: text, binary graphics, shape files, raster files. Binary data include GRIdded Binary (GRIB), Network Common Data Format (NetCDF), Hierarchical Data Formant (HDF), etc.
- Sufficient storage: hardware and software;

[16] Climate Data Management System Specifications

- Sufficient mechanisms in place for data transfer from stations to Climate Data Management Systems (CDMS): architecture of data input, such as by manual, internet or General Packet Radio Service (GPRS) technology;
- Sufficient mechanisms in place for data transfer, such as through a client/server architecture
- A mechanism for transfer initiation (manual or automated
- Server-side application programs (Fortran, GrADS, etc.) to process and transfer data
- A decision regarding one-way or two-way transfer (pull/push). Implementation for pulling data is relatively easier than that for pushing the data
- Restrictions and caveats: Business rules, policies and permissions, internet security constraints, etc.
- Plans for an optimized implementation i.e. robust initial configuration that is scalable to satisfy future requirements, maintenance, and upgrades of computer systems
- Quality control processes for data
- Extraction programs that can extract data in specific formats.

4.2. Hardware and Software

A range of software products have been developed to assist countries in making high quality climate monitoring products and downscaled and tailored forecast products for a range of timescales, including sub-seasonal, seasonal to interannual, and climate projections. WMO RCCs and RCOFS also assist countries in their domains with downscaling. The Climate Services Toolkit (CST) has the potential to provide access to best practices in accessing, mining, and using information for improving climate services and supporting climate-sensitive societal challenges (WMO-No.49[17] and WMO-No.485[18]).

[17] Refer to Technical Regulations Volume II – Meteorological Service for International Air Navigation (WMO, 2018)

[18] Refer to Manual on the Global Data-processing and Forecasting System (WMO, 2018)

NMHS hardware and software requirements

Based on several training workshops delivered by global, regional, and national climate centers, in particular the training offered by NOAA, a minimum set of hardware and software requirements for NMHSs to implement best practices in climate monitoring, forecasting and verifications, impact-based-forecasts, etc. are suggested:

Hardware requirements:

- **Hardware:** Windows (64 bit, Windows version 7.0 or above)
- **Memory:** 4GB or more (if possible)
- **Free diskspace:** 50GB or more
- **Internet connection**
- **Windows winzip or 7-zip utility to unpack a tar file**

Software Requirements (open source/freely available):

- Cygwin: https://cygwin.com/install
- GrADS (v2.0.x), V2.02 for windows users : https://sourceforge.net/projects/opengrads/files/grads2/2.0.2.oga.2/Windows/
- GNU precision calculator (bc): https://gcc.gnu.org/wiki/GFortranBinaries
- Notepad ++: https://notepad-plus-plus.org/download/v7.7.1.html
- Wget: https://eternallybored.org/misc/wget/
- Curl: https://develop.zendesk.com/hc/en-us/articles/360001068567-Installing-and-using-cURL
- Image Magick: https://imagemagick.org/script/download.php#windows
- Gdal: https://sandbox.idre.ucla.edu/sandbox/tutorials/installing-gdal-for-windows

There are several online facilities hosted by global analysis and data centers[19] which collaborate with WMO on climate data and monitoring activities. NMHSs can access these centers' websites for either downloading climate data or making use of their online tools to download graphics. Example data made available through the NOAA International Desks at the Climate Prediction Center: *ftp://ftp.cpc.ncep.noaa.gov*; or *www.cpc.ncep.noaa.gov*; or through the IRI data library: *https://iridl.ldeo.columbia.edu/index.html?Set-Language=en*.

NMHSs are encouraged to establish collaboration with global and regional centers for further instructions on how to access and download data to improve climate monitoring. The infrastructural requirements for operational sub-seasonal-to-seasonal (S2S) forecasts at NMHSs include:

- Access to high quality historical station datasets or satellite rainfall estimates;
- Access to forecasts and reforecast data and from Global Producing Centers (GPCs);
- Access to statistical tools for calibrating or downscaling model forecasts, including regression methods, canonical correlation analysis, singular value decomposition, etc.;
- Access to Windows or Linux computers.

4.3. Geographical Information System

[19] https://www.ncdc.noaa.gov/sotc/global/201710, https://www.esrl.noaa.gov/psd/data/, http://ds.data.jma.go.jp/tcc/tcc/products/climate/index.html, https://www.metoffice.gov.uk/hadobs/, https://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html, http://www.cpc.ncep.noaa.gov/products/wesley/reanalysis.html, https://climate.copernicus.eu/resources/data-analysis/average-surface-air-temperature-analysis/monthly-maps/, https://www.dwd.de/EN/ourservices/gpcc/gpcc.html

Many NMHSs lack Geographical Information System (GIS) capability. However, GIS is extremely useful in various socioeconomic sectors, for example planning for agriculture, water management, food security, land use, surveying, and community development. A GIS license can be expensive for NMHSs. However, there are now free and open source GIS that can easily be downloaded to a computer, for example QGIS, which has many of the capabilities available in the commercial ArcGIS.

5. Procedural Capacity Development

Technical regulations and guidance have been developed by WMO to provide the foundation for standardized and quality assured procedural operation of NMHSs. A quality management system (QMS) is essential for overall procedural capacity development. A QMS is an end-to-end system encompassing all activities from raw measurements and observations to services delivered to end users. It seeks to improve quality and performance so that customer expectations can be met or exceeded, taking into account the NMHS context as well as interested party expectations and requirements. The Commission for Climatology (CCl) has published Guidelines on Quality Management for Climate Services in 2018 (WMO No. 1221). The readers may refer to it for further detailed information[20].

Operating the necessary systems for generating useful products, communicating those products to users, and assessing the resulting user outcomes and benefits entails successful implementation of multiple types of procedures. A detailed treatment of all of these specific functions is beyond the scope of this guide. The following section focuses on giving an overview and recommendations for establishing a basic end-to-end system for the delivery of improved climate services based on successful implementation at a number of NMHSs, RCCs, and GPCs. References to relevant detailed procedures are provided where available. In this section, procedures to generate climate monitoring and forecasting products, and the dissemination of these products to inform socio-economic decision making are outlined.

5.1. Climate Monitoring

Through continuous monitoring of the climate system, NMHSs can provide timely and relevant information regarding climate trends, including temperature and precipitation. This information must be made available in the form of graphics, bulletins, climate watch and advisory, that include descriptions of the evolution of the most recent climate anomalies i.e., over the past week, ten days, month, season, six months to one year. Climate monitoring reports may also include updates from global centres on large scale climate conditions such as El Niño–Southern Oscillation (ENSO), Northern Atlantic Oscillation (NAO), Indian Ocean Dipole (IOD), Southern Annular Mode (SAM), and the Madden Julian Oscillation (MJO). This information is essential for sector applications, including developing and ongoing droughts, onset and cessation of dry and wet spells, flooding, extreme weather conditions related to heat and precipitation, etc. Below is a minimum set of analyses that NMHSs can produce and update with climate summaries including explanatory text, time-series and graphs on a regular basis:

- Weekly or ten-day total precipitation and anomalies;
- Monthly total precipitation and anomalies;
- Ninety-day total precipitation and anomalies;
- Time series depicting the evolution of rainfall over the past month, 90 day and up to a year at any given station or grid point;
- Number of rain days or dry days
- Number of consecutive days or weeks of rainfall surpluses or deficits

[20] Guidelines on Quality Management in Climate Services

- Number of consecutive days of rainfall exceeding threshold percentiles depicting extreme events
- Standardized Precipitation Indices one, three, and six month time scales;
- Weekly or ten-day mean maximum and minimum temperatures and anomalies;
- Monthly mean maximum and minimum temperatures and anomalies;
- Number of consecutive days of temperature exceeding threshold percentiles depicting extreme temperature events
- Daily or three-day heat indices;
- Monthly updates of soil moisture and runoff and vegetation indices to monitor drought conditions.

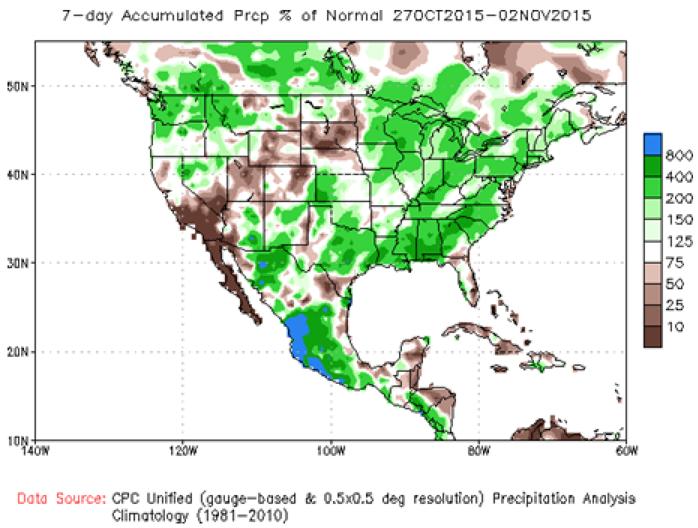

Figure 6: Example of monitoring of weekly rainfall accumulation over North America as a percent of normal for the corresponding seven day period (from NOAA's CPC)

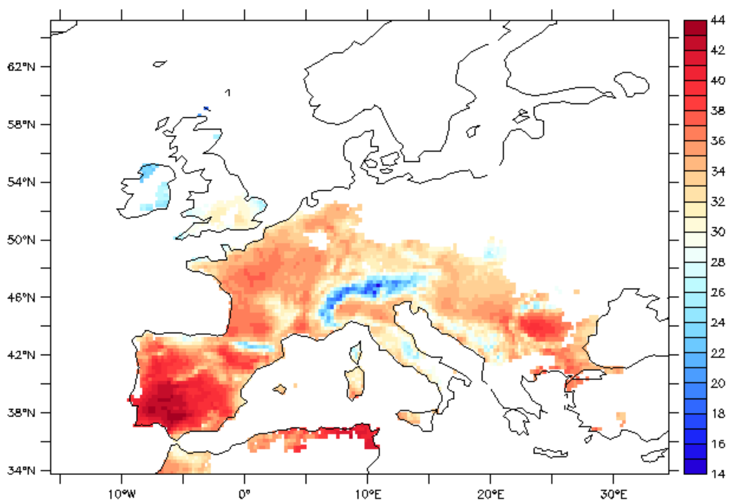

Figure 7: Example of monitoring an a large scale heat wave event over Europe, June 2017 showing maximum values of the daily maximum over the affected area (daily maximum temperatures in parts of Spain reached to well over 40°C) (from KNMI, Netherlands)

In addition to their use at national level, climate monitoring information delivered by the NMHSs is also essential for the WMO Statements [21]on the State of the Global Climate. It is therefore important that reporting and international exchange of climate monitoring information should be done in a consistent manner, so that information can be comparable across the borders and be easily aggregated for use in regional and global

[21] WMO Statement on the Status of the Global Climate

monitoring activities. WMO recommends the use of set of six standard National Climate Monitoring Products (NCMPs)[22].

NMHSs are encouraged to use WMO standards for establishing baselines for computing averages and departure from the averages based on consistent methodology that allows spatial comparisons and providing historical context for climate monitoring information. WMO recommends to compute climatological standard normals to compute most recent long term averages and update them each ten years. The current period for computing is 1981-2010. The next period will be 1991-2020 (WMO No. 1203[23]).

For regional and international climate activities, WMO recommends a set of Data and Climate Monitoring Products that can be produced systematically by the National Meteorological and Hydrological Services and exchanged. These include the World Weather Records (WMO *Guidelines for the Submission of the World Weather Records 2011+*)[24] and the provision of national climate monitoring information based on countries' data processing and analysis (WMO *Guidelines on generating a defined set of National Climate Monitoring Products*, WMO-No.1204)[25].

There are several online facilities hosted by global analysis and data centres[26] which collaborate with WMO on climate data and monitoring activities. NMHSs can access these centres websites for either downloading climate data or making use of their online tools to download graphics. Example data made available through the NOAA International Desks at the Climate Prediction Center: *ftp://ftp.cpc.ncep.noaa.gov*; or *www.cpc.ncep.noaa.gov*; or through the IRI data library: *https://iridl.ldeo.columbia.edu/index.html?Set-Language=en*. NMHSs are encouraged to establish collaboration with global and regional centers for further instructions on how to access and download data to improve climate monitoring.

Work is ongoing at WMO to produce specific guidance[27] on characterizing the location, timing, duration and magnitude of high impact extreme weather and climate events such as heat waves, cold waves, extreme precipitation and drought. Such guidance will be provided to NMHSs when available.

5.2. Climate Forecasting[28] [29]

Operational short-term climate forecasting is an essential component for the delivery of climate services. Short term climate forecasting is defined as forecasting on sub-seasonal to seasonal (S2S) time scales up to one year and is hereafter referred to S2S climate forecasts.

[22] Refer to Guidelines on Generating a Defined Set of National Climate Monitoring Products (WMO, 2017)
[23] Refer to Guidelines on the Calculation of Climate Normals (WMO, 2017)

[24] Refer to Guidelines for the Submission of the World Weather Records 2011+ (WMO, 2017)

[25] Refer to Guidelines on Generating a Defined Set of National Climate Monitoring Products (WMO, 2017)
[26] https://www.ncdc.noaa.gov/sotc/global/201710,
https://www.esrl.noaa.gov/psd/data/,
http://ds.data.jma.go.jp/tcc/tcc/products/climate/index.html,
https://www.metoffice.gov.uk/hadobs/,
https://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html,
http://www.cpc.ncep.noaa.gov/products/wesley/reanalysis.html,
https://climate.copernicus.eu/resources/data-analysis/average-surface-air-temperature-analysis/monthly-maps
https://www.dwd.de/EN/ourservices/gpcc/gpcc.html

[27] A proposal on standardized identifiers for cataloguing hazardous events will be presented for consideration by the WMO Executive Council in March 2018. Refer to International Workshop on Cataloguing and Managing Information on Extreme Weather, Water and Climate Events (WMO, 20-23 November 2017)

[28] Guidance on Verification of Operational Seasonal Climate Forecasts (WMO, 2018)

[29] Manual on the Global Data-processing and Forecasting System Annex IV to the WMO Technical Regulations (WMO, 217-2018)

Sub-seasonal forecasts include forecasts for weekly precipitation and temperature at one or two to three weeks lead time and the forecasts of monthly precipitation and temperature with at least one-month lead time. See for example the WCRP/WWRP S2S project[30].

Seasonal forecasts refer to the forecasts of three-month averages of precipitation, temperature, or any other variable, with at least one month lead time. Climate forecasts are probabilistic in nature as a way to convey uncertainty in the forecasts.

Requirements for operational S2S forecasts at NMHSs include:

- Access to high quality historical station datasets or satellite rainfall estimates;
- Access to forecasts and reforecast data and from Global Producing Centers (GPCs);
- Access to statistical tools for calibrating or downscaling model forecasts, including regression methods, canonical correlation analysis, singular value decomposition, etc.;
- Access to Windows or Linux computers with minimum hardware capabilities as outlined in section 3.

It is recommended that NMHSs develop procedures for operational climate forecasting to include basic understanding of sources of predictability as a requirement to make high quality forecasts. In addition, it is highly recommended that NMHSs use GPC products as guidance for operational climate forecasts. In the following, we outline recommendations for seasonal forecasting and sub-seasonal forecasting. We also discuss impact-based forecasts, and climate projections.

5.2.1. Seasonal forecasting

Procedures to follow when establishing an operational seasonal forecast system include:

Conduct diagnostics studies to document sources of predictability. Physically based statistical models now can be run on WINDOWS platforms and are powerful enough to document sources of predictability. Several sets of diagnostics studies may need to be conducted in order to settle on a relatively optimal forecasting system, where the predictand (variable to be predicted) is the historical station measurement or gridded valued of a given variable of interest to decision-makers, such as temperature, precipitation, streamflow, wind speed, vegetation, soil moisture, etc. and the predictor can be several fields including Sea Surface Temperature (SST), winds, mean sea level pressure, geopotential height, stream function, etc.:

- Determine the predictand of interest in consultation with key stakeholders;
- Force statistical models with an observed field for example SST and determine the strength of the relationship between the predicted and the predictor data;
- Repeat the same procedure using GPC model predicted fields;
- Conduct further diagnostics studies based on preliminary results;
- Make forecasts for at least a 10-year period and verify the forecasts;
- Make forecasts for present day climate and verify the forecasts;
- Prepare forecast bulletins with a discussion of the current state of the climate and the tools used for the forecasts;
- Update the forecasts on a monthly basis;
- Share with the user community and disseminate via a website;
- Verify user outcomes.

For further information please see footnote No 34

[30] http://s2sprediction.net

5.2.2. Sub-seasonal forecasting

Sub-seasonal forecasting is moving from research to an operational phase through work on sub-seasonal to seasonal (S2S) prediction by World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP). Much of the procedure outlined above for seasonal forecasting can be followed for monthly forecasting. However, for weekly forecasts at one to two weeks lead time, statistical methods are yet to be proven relevant and research is being conducted in this area. However, a subjective combination of numerical model outputs and knowledge of the dynamics associated with sub-seasonal variability can improve forecast skill tremendously in some parts of the world (WMO-No. 1192[31] and WMO-No. 485[32]). Western Africa is one region where operational sub-seasonal forecasting is currently being piloted. The MJO is the dominant mode of variability on the intra-seasonal time scale and advances in numerical modelling has improved MJO predictions significantly. Forecasters even in areas that are not strongly influenced by the MJO need to acquire basic knowledge of the MJO and how it impacts climate around the world. NMHSs can determine how strong the MJO teleconnection is for their areas by calculating precipitation and or temperature anomalies based on the eight phases of the MJO in the Wheeler-Hendon diagram.

These are called MJO anomaly composites and are essential tools for making forecasts of seven-day averages at one week or two weeks lead. Several MJO tutorials are now made available on the internet and easily accessible[33].

Similar to seasonal forecasts, sub-seasonal forecasts are probabilistic and often expressed in a two-tail categorization for above or below average conditions. The reason is that the near average category has very low skill and is nearly impossible to predict for. In addition, it is thought that a two-category forecast is easier to communicate to users. Hence, the forecasts simply consist of polygons drawn on a map for above or below average precipitation and or temperature.

The following is a recommendation for weekly climate forecasts at one to many weeks lead time (these steps can also be found in chapter 7 of Meteorology of Tropical West Africa The Forecasters’ Handbook, Parker and Diop-Kane, 2017):

- Visit MJO website to assess the state of the MJO. The following URL is a web portal hosted by NOAA’s Climate Prediction Center, with useful information on MJO monitoring and forecasting: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml
- Several scenarios can be considered when preparing week-2 to week-4 forecasts. Considering a two-category probability forecast for above or below average rainfall or temperature, polygons are drawn to highlight areas where the signals are strong to tilt the odds in favor of one category over another one.
- The MJO is active and is projected to remain active during the forecast period or the MJO is not active but is projected to become active during the forecast period:
- Use MJO based rainfall anomaly composites for guidance as to where to draw wet or dry (or above or below) polygons;
- Examine Numerical Weather Prediction (NWP) outputs from GPCs to ensure consistency between the rainfall anomaly MJO composites and the NWP guidance.

[31] Refer to WIGOS Metadata Standard (WMO, 2017)

[32] Refer to Manual on the Global Data-processing and Forecasting System (WMO, 2018)

[33] http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#educational%20material

- Analyze the predicted circulation features associated with the predicted rainfall anomalies. The following sets of NWP tools can provide useful information:
    - Low and upper level winds;
    - Low and upper level divergence;
    - Mid-level geopotential height;
    - Vertical velocity;
    - Bias corrected precipitation and or temperature forecasts.

There tends to be a high degree of confidence in the forecasts when the MJO anomaly composites are in strong agreement with the NWP. If there are discrepancies, a careful look at the NWP outputs is warranted and use of intuition and experience will guide the forecaster's decision. More weight is usually given to the NWP precipitation outlook tools that are more consistent with the predicted rainfall anomalies.

- The MJO is active but is projected to weaken during the forecast period, or the MJO is inactive and projected to remain inactive during the forecast period. In this case, NWP outputs are the primary tools for guiding the forecasts.
    - Examine NWP outputs from GPCs to ensure consistency between the rainfall anomaly MJO composites and the NWP guidance.
    - Analyze the predicted circulation features associated with the predicted rainfall anomalies. See above for guidance on the most important diagnostics variables.

Upon making the preliminary forecasts, the forecaster leads a forecast briefing to review the forecasting tools and to discuss the forecasts before they are final. The briefing is very important, especially when there are inconsistencies among the prediction tools. Feedback from other forecasters can help refine the forecasts. A GIS tool is then used to draw polygons that indicate high chances for above-average or below-average precipitation as displayed in Figure 8.

In addition, it is recommended to:

- Prepare a forecast bulletin to discuss the forecasts including the reasoning behind the forecasts;
- Update the forecasts at least once a week, but preferably two or three times a week;
- Share the forecasts with the user community and disseminate via a website.
- Verify the forecasts.

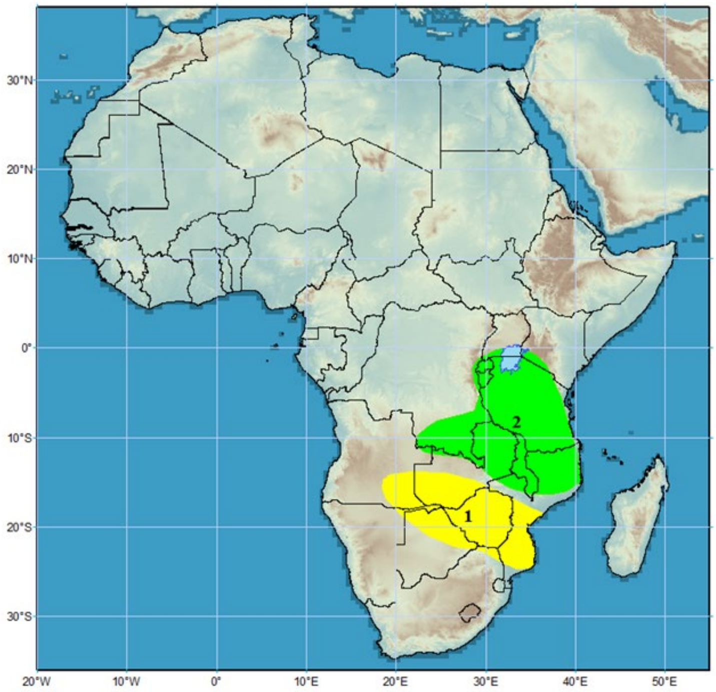

Figure 8: Subseasonal outlooks for Africa for week 2 issued with 7 days lead time. Shaded in green (yellow) are areas of predicted enhanced (suppressed) rainfall. Source NOAA/CPC

5.2.3. Forecasting with tailoring of climatic variables to impacts

Multi-hazard climate forecast systems are critical to increase preparedness for drought, floods, and variability within a season. Climate forecasts refer to the predictions of meteorological variables, such as rainfall and temperature, into the future. Impact-based climate forecasts are multi-disciplinary outlooks that contain information relevant for anticipating what a hazard will do (impact) rather than solely what a hazard will be. Such impacts can include crop damage, water shortages, epidemic outbreaks, food insecurity, etc.

Achieving this requires NMHSs and climate services to increase their emphasis on delivering tailored products risk-based[34] forecast and warning services.[35] The latter can be used as an example to illustrate procedures for impact-based climate forecasts. NOAA's Climate Prediction Center updates regional hazards outlooks for food security for many regions of the world every week. The outlooks are prepared in partnership with government agencies including United States Agency for International Development (USAID), United States Geological Survey (USGS), United States Department of Agriculture (USDA), National Aeronautics and Space Administration (NASA), and the private sector, and draw from expertise in a variety of fields, including meteorology, hydrology, agriculture, remote sensing, environmental and social science. The hazard outlooks feature both long-term (past conditions throughout the season) monitoring of the climate system and outlooks into the near future about one week to a season. The objective is to provide targeted forecasts for areas that are vulnerable to droughts or flooding that might result in adverse impact on crops or pastures. Hence, requirements for the hazards outlooks for food security applications include:

- Rain gauge data and satellite rainfall estimates;

[34] "Risk-based" considers the socio-economic impacts of a hazard integrating hazard uncertainty with vulnerability and exposure information. The terms "risk-based" and "impact-based" are often used interchangeably.

[35] Refer to Guidelines on Multi-hazard Impact-based Forecast and Warning Services (WMO, 2015) and Implementing Multi-Hazard Impact-based Forecast and Warning Services, CMA, Meteo Shanghai, WBG, GFDRR

- Rainfall and surface temperature forecasts up to 16 days;
- Sub-seasonal and seasonal forecasts of rainfall and temperature;
- River flow forecasts;
- Water Requirement Satisfaction Index (WRSI) for crops and rangelands;
- Normalized Difference Vegetation Index (NDVI);
- Vegetation Health Index (VHI);
- Field reports.

The schematic displayed in Figure 9 illustrates a procedure for the preparation of the hazard outlooks. In this case the impact is food security and the user is USAID Famine Early Warning System Network (FEWS NET). A description of the procedure follows:

- Identify areas that exhibit consistent rainfall deficits or frequent flooding through routine in-depth monitoring of the climate system. These areas are often faced with a high risk of food insecurity
- Use model guidance tools to examine both short range and extended range forecasts. The reliability of these forecasts is qualitatively assessed by looking at consistency both within each model and between different models
- Use GIS or other software packages to draw polygons to highlight areas at risk for food security
- Bring the preliminary hazards outlooks to the attention of members of the FEWS NET including the field representatives who have expert knowledge of conditions on the ground to obtain feedback.
- Finalize the hazards outlooks based on the feedback received
- Disseminate the hazards outlooks through a website and email distribution list and provide GIS shapefiles to FEWS NET
- FEWS NET uses shapefiles to integrate the weather and climate information with other food security indicators to issue monthly food security outlooks
- USAID uses the food security outlooks to work with the international community on a contingency plan to move food or safe drinking water to places in need.

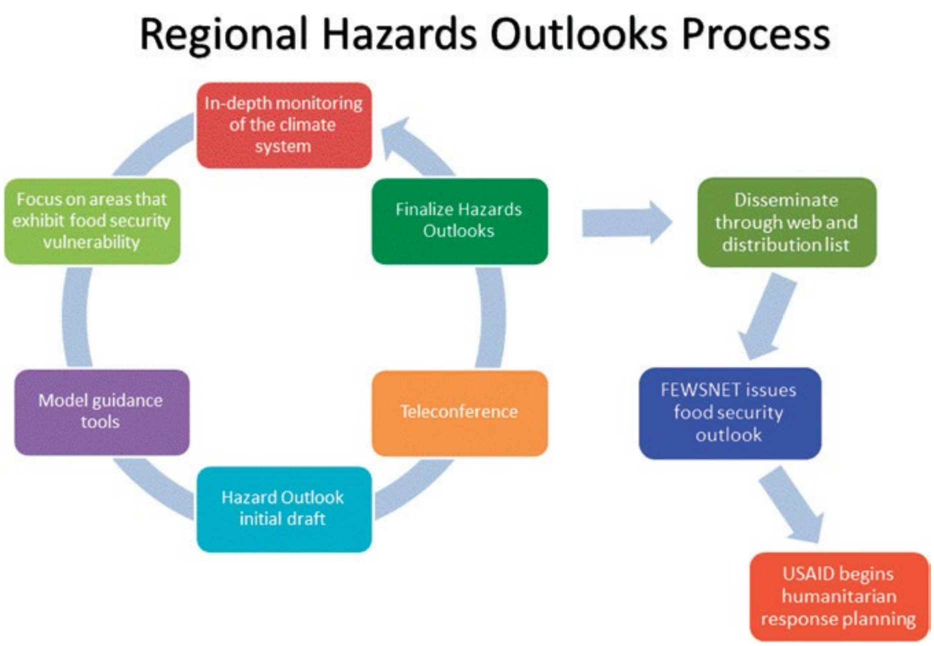

Figure 9: Schematic for the process of the regional hazards outlooks for food security, after BAMS 2015.

An example of hazard outlooks is displayed in Figure 9 (Thiaw and Kumar, 2015). In real time forecasting, polygon shapes are numbered and show areas of concern for flooding

or drought. The numbering allows for the long-term monitoring of the conditions in the areas of interest. The color shades determine the nature and severity of the hazards. In this example, abnormal dryness, drought and severe drought is featured over Southern Africa and the northern areas of East Africa, while flooding is predicted to occur or persist over equatorial East Africa and over West Africa. GIS shapefiles and raster files of the forecasts are produced. FEWSNET uses the information together with current climate forecasts and trends and other food security indicators to issue monthly food security outlooks. Finally, this information is provided to USAID for informed decision in humanitarian response planning based on the level of food security threats.
The procedures outlined here are analogous to impact-based climate forecasting systems for other socio-economic sectors, provided that NMHSs and stakeholders from these sectors are both involved in the preparation of the forecasts either together or at different stages of the forecasts. Other examples include heatwaves forecasts for heat health early warning, reservoir inflow forecasts for hydropower operations and river-flow forecasts for inland waterway transportation. The WMO Climate Services Toolkit (CST) could serve as an excellent resource for providing NMHSs and RCCs with much of the climate monitoring, forecasting, and climate data management tools that are required to manage data and create graphics for the preparation of impact-based forecasts.

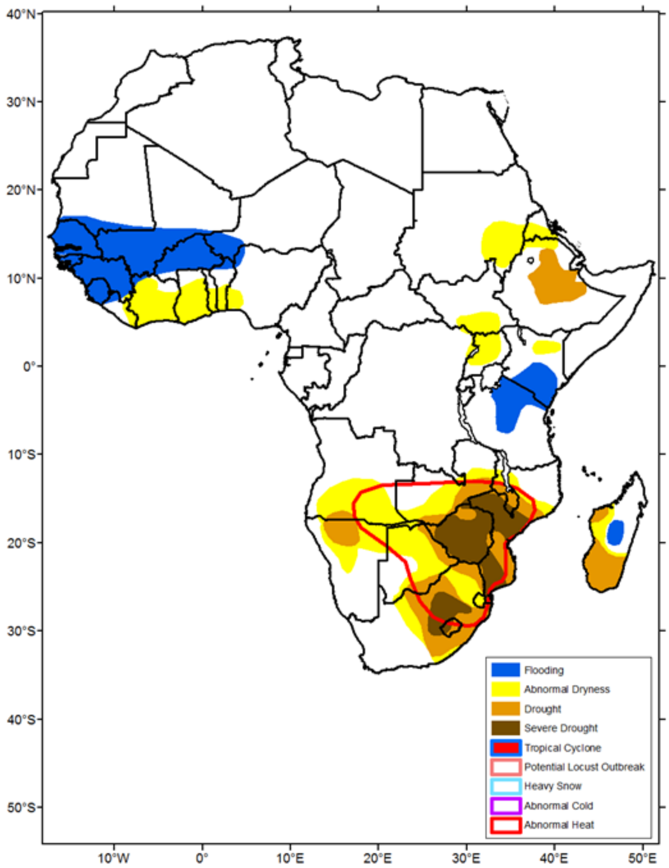

Figure 10: GIS based hazards outlooks for food security: Shaded in brown, yellow, and blue, are areas that exhibit drought, abnormal dryness, and flooding, respectively. Red contour indicates heat hazard. In real time forecasting, polygon shapes are numbered based on the evolution of weather and climate conditions that led to the events. Outlooks are generated in the middle of the week and valid for the coming week. Included in the hazards outlooks are the long-term conditions in the field and the current meteorological and climate forecasts. Source NOAA/CPC

5.2.4. Near Term Climate Predictions and Climate Change Projections

The evolution of climate in the near term, out to a decade or two ahead, is the combination of natural climate variability and human-forced climate change. This combination both determines the shift in the mean climate over the period of interest but also affects the risk of extremes or unprecedented events, which affect human activity and well-being. For example, natural variability can cause changes in storm paths and intensities (and hence weather risk to property and life) or in rainfall and temperature (and hence water shortages, drought and flooding). These changes in natural variability are large enough from one decade to the next to temporarily exacerbate or counter underlying anthropogenic trends.

Near and long term information is important to a broad range of users of climate information who are engaged in planning activities and require regionally-specific predictions and projections as they grapple to address risks imposed by the combination of anthropogenic climate trends and natural climate variability.

5.2.4.1 Near Term Climate Predictions

World climate modelling centres have been seeking to harness global coupled climate models to explore the potential of initialized, multi-year to decadal climate prediction under WCRP's Working Group on the Coupled Model Intercomparison Project (CMIP). A two-fold challenge has been identified in relation to near-term predictions. Firstly, there will be need for further research and development as to improve multi-year to decadal climate predictions and the utility of the associated information. Secondly, fundamental will be the development of organizational and technical processes to underpin the future, routine provision of scientifically-sound, prediction services that can assist stakeholders and decision-makers. The latter will include greater international coordination and the development of recommendations on which conditions should be met prior to the dissemination of forecasts.

These challenges will entail the synthesis of real-time prediction information from multiple existing prediction systems, an assessment of the confidence the scientific community has in the information, and the development of criteria that need to be satisfied before WMO would endorse and advise on how to implement the operational prototype services.

NMHSs will be particularly pivotal on Near Term Climate Predictions (NTCP) as they will support the pursue of the following objectives:

- To improve the quality of decadal climate information and prediction;
- To collect, collate, and synthesize the prediction output and tailor information to form the basis of a service that addresses stakeholders' needs;
- To develop processes to assess and communicate the degree of confidence and uncertainty in the predictions.

More specifically, NMHSs could be involved in the following:

- Develop and comply with uniform protocols and standards for delivery of decadal prediction products;
- Establish and engage with two-way communication with regional and global forecast centres and train forecasters in the use of decadal climate prediction products;
- Invite and engage early career scientists in the production of a Global Decadal Climate Outlook each year.

The Near Term Climate Predictions will fill an important gap in the provision of seamless climate information that is still dominated by seasonal-to-interannual climate predictions on the one hand, and multi-decadal and longer-term climate change projections on the other hand. This will be an important contribution to the provision of a seamless climate service, as recommended by the GFCS.

5.2.4.2. Climate Change Projections

Projections of past and future climate change generally refer to the simulated responses of the climate system to scenarios of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models – numerical tools combining the physical principles governing the climate system and empirical understanding of complex earth system processes, with the aim to account for the evolution of physical, chemical and biological properties of components of the climate system, their interactions and feedback processes[36].

Climate projections are uncertain and not deterministic like weather forecasts and climate predictions. First because they are dependent primarily on scenarios of future anthropogenic and natural forcing that are uncertain and based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. Second, because of incomplete understanding of the climate system and finally because of the existence of internal climate variability[37].

Although it is possible to write down the equations of fluid motion that underpin climate models and determine the behaviour of the atmosphere and ocean, it is impossible to solve them without using numerical algorithms through computer model simulation, similarly to how aircraft engineering relies on numerical simulations of similar types of equations. In addition, many small-scale physical, biological and chemical processes, such as cloud processes, cannot be accurately described, either because we lack the scientific understanding of the mechanisms driving these processes or because we lack computational ability to describe the system at a fine enough resolution to directly simulate these processes. Those processes need instead to be approximated through empirical relations between directly simulated and approximated quantities[38].

Predicting socioeconomic development is arguably even more difficult than predicting the evolution of a climate system. It entails predicting human behaviour, policy choices, technological advances, international competition and cooperation. The common approach is to use scenarios of plausible future socioeconomic development, from which future emissions of greenhouse gases and other forcing agents are derived. The Representative Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs) were developed to cover a wide range of emissions and development scenarios[39].

The term climate projections tacitly implies a cascade of uncertainties and it is not possible to make definitive predictions of how the climate system will evolve over the next century and beyond as it is with short-term climate predictions. Nevertheless, as greenhouse gas (GHG) concentrations continue to rise, we expect to see future changes to the climate system that are greater than those already observed and attributed to human activities. It is possible to understand future climate change using climate models and to use such models to characterize outcomes and uncertainties under specific assumptions about future forcing scenarios.

[36] Climate Change 2013: The Physical Science Basis
[37] Role of Natural Climate Variability in the Detection of Anthropogenic Climate Change Signal for Mean and Extreme Precipitation at Local and Regional Scales
[38] Taking climate model evaluation to the next level
[39] Assessing the impacts of 1.5°C global warming - simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project

The coordination of model experiments and output by the World Climate Research Program (WCRP) led Coupled Model Intercomparison Project (CMIP) has seen the international science community step up efforts to develop a robust framework to assess climate models projections and evaluate the ability of climate models to simulate past and current climate[40].

5.2.4.3 Harmonization of climate change projections on sub-regional scales

The Association of Southeast Asian Nations (ASEAN), comprising Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam, lie in Southeast Asia, a region sensitive to climate variability and change. In the last decade, most countries in the region have developed climate change projections to support national adaptation plans in response to concerns expressed by governments. The projections from these studies, which are conducted at the national level via top-down processes, have a lot in common from one ASEAN country to the next. Therefore, improving coordination and sharing of experience between countries in the region would help develop regionally relevant best practice guidelines.

ASEANCOF is a successful example of regional coordination for the sub-seasonal to seasonal (S2S) times-scale. The RCC-network covering the ASEAN region includes a node dedicated to Climate Change.

Southeast Asia Climate Analysis and Modelling (SEACAM) was initiated and funded in 2011 by Singapore with technical support from UK Met Office Hadley Centre. SEACAM's objectives were to enhance regional scientific cooperation and increase scientific capacity among climate researchers in the Southeast Asia region. The project made use of high resolution regional simulations (25 km) using a single Regional Climate Model (RCM): the UK Met Office's PRECIS model forced with Coupled Model Intercomparison Project (CMIP3) Global Climate Models (GCMs). Southeast Asia Regional Climate Downscaling (SEACLID), established as a collaborative project in regional climate downscaling with collaborators from various countries within the Southeast Asia region. SEACLID has been streamlined and integrated into the World Climate Research Programme (WCRP)'s Coordinated Regional Climate Downscaling EXperiment (CORDEX) and renamed as SEACLID/CORDEX Southeast Asia (CORDEX-SEA). SEACLID/CORDEX-SEA is downscaling a number of CMIP5 GCMs for the Southeast Asia region to a resolution of 25 km through a task-sharing basis among the institutions and countries involved. It represents a step forward as several regional models are used, allowing a more comprehensive description of the uncertainties attached to regional climate change projections.

These coordinated programmes produce regional climate projections by using RCMs to downscale GCMs made available by the international research community through the CMIP programme. The latter programme is in support of the Intergovernmental Panel on Climate Change (IPCC) and its mandate to deliver regular climate change assessment reports. The climate projection scenarios provide future ranges of quantities such as temperature, rainfall, wind, and sea level rise from which national agencies can develop Vulnerability Impact Assessment (VIA) studies.

The benefit of regional coordination across ASEAN NMHSs is now well-established in the delivery of climate services for sub-seasonal to seasonal time-scales. This takes place via the regular Regional Climate Outlook Forum (ASEANCOF), in which relevant scientific

[40] Overview of the Coupled Model Intercomparison Project Phase 6

methodologies and experiences are shared amongst NMHSs as well as regional end-users.

Notwithstanding the width of technical complexity in the delivery of climate change projections, a critical element for success is the early and sustained engagement with stakeholders and intended end-users to 'co-produce' tailored climate products and foster a mutual understanding of model limitations and uncertainties. The quality of the work is achieved by working closely with end-users across a number of regional projects.

Amongst the many technical difficulties encountered during the delivery of climate change projections, some important issues, such as the standardization of the GCM selection criteria and downscaling methodologies need to be addressed. These were seen as essential across the region to consolidate the current wealth of regional climate change information. For the first point, there is a need for quantitative model evaluation metrics, complemented with process studies to understand the sources of model biases and limitations. For the second point, while dynamical downscaling (the use of RCMs) is prevalent, statistical downscaling methods are also used across the region, given the variety of free-to-use analysis software such as SimCLIM.

5.3. Climate Service delivery

The observations and data gathered by NMHSs can be processed to generate products that potentially support decision-making at all times and especially when extreme events occur or are predicted to occur. The latter include tropical cyclones/hurricanes, heat waves, disease outbreaks, flash floods and drought. The quality of the products is dependent on the adequacy of processing facilities and human resources. All NMHSs contribute to these products through the sharing of observations, which are the basis for generating tailored products, forecasts and warnings.

NMHSs should identify their potential users and understand their needs, as well as understand the role of weather, climate, and water related information in their different sectors[41].

NMHSs are encouraged:

- Create and maintain websites where they can provide access to timely weather and climate information that can be accessed by the stakeholders.
- Establish and update a list of targeted stakeholders for specific products relevant to each user group.
- Seek feedback from the user community as a way to improve service delivery.
- Organize frequent stakeholder meetings in the form of National Climate Outlook Forums (NCOFs) or National Climate Forums (NCFs) to assess the quality of the service being provided and the evolving needs of the stakeholders.
- Attend and participate actively in the Regional Climate Outlook Forums (RCOFs) to articulate user demands and promote the operational delivery of relevant products.

Engagement between climate service users and providers[42] occurs at multiple levels, ranging from relatively passive engagement through websites and web tools, to much more active engagement in focused relationships. This is not to say that all climate service providers, or all climate services, need to be targeted and tailored. The level of

[41] Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services (WMO, WB, USAID, 2015 (WMO No. 1153)

[42] Guidance on Good Practices for Climate Services User Engagement: Expert Team on User Interface for Climate Services

engagement should be based on the users' needs, and providers can move up and down the continuum, perhaps in an iterative manner where, for example, further improvements or development of web-based services and tools can be made following learning achieved through interactive group activities and/or more focused and tailored activities.

Websites and online tools: Most climate service providers, including NMHSs, operate a website which is their entry level user interface. It connects the service provider with a large number of users (sometimes hundreds of thousands) within their country and across the world. A good website is well designed as a "shop window", with easy-to-follow links to multiple products and services, such as climatology, data access portals, current conditions, climate outlooks and climate change information. Ideally, the design of the website and the level of content should be informed by consultation and feedback from users. The website should also include links to social media forums, clearly convey how a visitor to the website can contact someone in the organization for more information and, importantly, draw attention (which many do not do) to how a user can request and establish more active engagement with the climate service provider.

Interactive group activities: Interactive group activities, such as workshops and seminars, create a strong dialogue between climate service providers and users. Multiway communication should be encouraged in the workshop process, where co-learning and co-development of products and services is an ideal outcome. In addition, the interactions should build knowledge, understanding, trust and, ultimately, skills to improve climate literacy to support the application of climate information, taking into account its strengths and limitations.

Focused relationships: This type of relationship is often of higher intensity and has a stronger focus on needs than the other forms of engagement discussed above. A key requirement for all involved is to determine very precisely and clearly the key decision points and decision needs of the user. This type of interaction may also require very targeted scoping studies with the user and an associated iterative process between provider and user to ensure the user's decision needs are being fully addressed. There is a strong need for data sharing to ensure appropriate tailoring to the user's exact requirements, together with any associated need to build more specific user-orientated simulation models in, for example, agriculture or water resources modelling. It is important that communications between the climate science provider, associated research teams, and the customer be very targeted and relayed as often as the user demands and as may be appropriate. It is also important in any fully customer-focused relationship to create a strong sense of ownership of, and build trust in, the whole engagement and product development process by the user.

5.4. Assessing the value of Climate Services

Climate services do not generate economic and social value unless users benefit from decisions as a result of the information provided, even if the services are of the highest quality. Climate services of similar quality provided in two countries can vary significantly in terms of their benefits depending on the relative nature of climate-related risks, the number and types of users and their capacity to access the services and to take actions to avoid harm or increase economic output. Assessing the actual or potential value of climate services is essential when determining where effort should focus when prioritizing capacity development activities for climate services development.

A Socio-Economic Benefit Assessment (SEB) may cover verification of service quality, characteristics of service uptake by user communities, the economic cost of producing

Ref.: 24040/2017-1.1 CLW/CLPA

services and economic value of services to user communities. The WMO "Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services"[43] document includes detailed guidance on undertaking socio-economic benefit analysis of climate services. Non-economic social science methods can be applied to assess and understand the uptake of climate services, including the ability and capacity of users to access, understand and apply particular climate services to respond to their needs, or to incorporate climate information into decision-making contexts. However, assessment of the non-quantifiable (qualitative) values and benefits of climate services remains a challenge.

SEB studies are powerful tools through which climate service providers can communicate to funders the likely return on current and/or future investments in climate services. A SEB assessment of climate services may be triggered by the service provider, funder, parent government ministry, board of directors/management of an NMHS or a council of users. The Annex to the Implementation Plan of the GFCS – Capacity Development[44] includes an annex on resource mobilization, including assessing resource mobilization options at the national, regional and global level, and identifying partner organizations and projects to mobilize resources.

6. Human Capacity Development

Building human capacity is an integral part of the process through which organizations build and maintain the capabilities to achieve their developmental objectives over time. With changes in the technological, social, political and environmental landscape, and the additional challenges imposed by a changing climate, the process of building human capacity for climate services needs to be adaptive, flexible and involve people from the supply (information providers), intermediary (government agencies, NGOs, private sector) and demand (information users) side of climate services. This requires a review of the education qualifications, skill requirements and job training required for climate specialists, including those in management positions.

6.1. Human capacity for climate information providers

The provision of effective and usable climate services within a country or region requires input from multi-disciplinary personnel including meteorologists, climatologists, engineers, geographers, statisticians, mathematicians, economists, sociologists, development practitioners, anthropologists, computer scientists and science communicators. Although each institution designates its particular job roles, climate services provision will involve professionals at the managerial level, trainers, communicators and administrators, and those specifically involved in climate services delivery. Therefore, capacity development should involve both managerial and climate specialist personnel.

To develop the Human Capacity for climate service providers, a review of the education qualifications, skill requirements and job training for climate specialists is necessary. Currently most training and capacity building is targeted at meteorology and weather forecasting, although several research institutions have made significant contributions to capacity building in climate forecasting, including through the climate outlook forums, developing skilled personnel to access, interpret and translate climate information into decision-relevant products and services.

[43] Valuing Weather and Climate
[44] Annex to the Implementation Plan of the Global Framework for Climate Services – Capacity Development (WMO, 2014)

Management and leadership skills need to be added to human resource capacities to enable NMHSs to build stronger national political ownership, develop relevant policies and legal frameworks and enhance sustainability by linking regional, sub-regional and national planning processes.

WMO Education and Training Program

The World Meteorological Organization, through its Education and Training Program, plays a leading role in coordinating the development of weather and climate scientist skills by promoting access to training programs, fellowships, technology, manuals, guidance documents, technical papers and workshops. Currently there are 26 WMO Regional Training Centres (RTCs) and a network of cooperating universities and advanced training institutions that contribute to education and training in meteorology and hydrology, as well as to establishing and developing specialised centres of excellence in various regions. The focus of most of these centres, however, is on the technical training of meteorologists for weather forecasting rather than climate specialists. There has been progress made in many parts of the world through the WMO Voluntary Cooperation Program (VCP) and the WMO Climate Information and Prediction Services (CLIPS) training workshops which have helped to create some national capacity to develop and deliver climate information including seasonal outlooks. Furthermore considerable effort has been made by Commission for Climatology in conducting training for meteorological personnel in climate activities for Data Rescue DARE), in data management and the use of CDMS, as well as in development of climate indices for climate change detection.

WMO hosts other climate-relevant training activities, including the Global Atmospheric Watch Training and Educational Centre (GAWTEC) which develops capacity in the specialized field of atmospheric composition monitoring, calibration standards and data quality control. WMO Members such as USA (The COMET Program) and UK provide comprehensive training in basic climatology and in climate statistics through online activities and workshops. The USA also, through NOAA's International Training Desks, supports professional development training in operational climate monitoring and forecasting for NMHSs around the world.
Sources:

1. RTC: http://public.wmo.int/en/resources/meteoworld/wmo-regional-training-centres
2. GAWTEC: http://www.gawtec.de
3. COMET Program: http://www.comet.ucar.edu/index.php
4. MétéoFrance training courses: http://www.enm.meteo.fr/content/liste-des-formations-pour-m%C3%A9t%C3%A9orologistes
5. Educational Resources by Hong Kong Observatory: http://www.hko.gov.hk/education/edu_e.htm
6. TROP-ICSU-WCRP: https://climatescienceteaching.org/
    a. Teaching Tools: https://climatescienceteaching.org/tools
    b. Lessons Plans: https://climatescienceteaching.org/lessons
7. WMO Learn Portal: https://public.wmo.int/en/resources/training/wmolearn
8. Climate Services Toolkit: http://www.wmo.int/cst/guidance
9. WMO Training Resources http://www.wmo.int/cst/content/training-resources
10. European Virtual Org. for Meteorological Training (Eumetcal)- https://eumetcal.eu/
11. EUMETSAT sponsored international training project (EUMeTrain)- http://www.eumetrain.org/ and http://www.eumetrain.org/courses.html
12. University Corporation for Atmospheric Research (UCAR) COMET Training Program- https://comet.training/categories/environmental/05-climate-and-weather.html
13. Integrated Water Resources Management (IWRM)- http://www.un.org/waterforlifedecade/iwrm.shtml
14. Guide to Climatological Practices- http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php
Technical Reports and series- Water Management-
http://www.wmo.int/pages/prog/hwrp/technicalreports.php

http://www.wmo.int/pages/prog/hwrp/manuals.php
http://www.wmo.int/pages/prog/hwrp/trainings.php
15. University of Oklaham- https://janux.ou.edu/index.html
16. United Nations Climate Change Learn- https://unccelearn.org/course/
17. E-Tutorial of the Global Framework for Climate Services (GFCS)- https://gfcs.wmo.int/node/805
https://unitar.org/gfcs-tutorial/story_html5.html

6.1.1. Education and Competency-based Training[45]

Education and professional development training are critical to building the workforce necessary to meet the challenges of climate services. Both academic and professional development training are essential. In that aspect, NMHSs should prioritize both qualification and competency in human resource development plan. Resolution 5 (EC-68) on the *Competencies for provision of Climate Services* can be used as a reference. The competency framework for climate services is designed to help NMHSs and other institutions to deliver high-quality climate services in compliance with WMO standards and regulations, specifically those defined by the CCl and the GFCS.

Its implementation by each organization follows four stages, as described in the *WMO Guide on Competency Framework* (WMO-No. 1205)[46]:

- ***Stage 0***: Awareness of the Competency Framework;
- ***Stage 1***: Adoption and adaptation of the Competency Framework;
- ***Stage 2***: Establishment of a Competency Assessment Process;
- ***Stage 3***: Completion of the Competency Assessment and planning of Competency Oriented Training to fill the identified competencies gaps.

The Competencies Framework is structured in 5 top-level competencies, which are further specified into second levels (Performance Criteria) and suggested Third Levels (Learning Outcomes).

In a given institution the list of the competencies to be met and the associated performance criteria are determined by its infrastructural capacity. Competencies falling in the areas of quality of climate information and services as well as communication of climatological information with users are considered cross-cutting and should be met, at least at basic levels, by all institutions providing climate services.

Appreciation of the competencies framework is conditioned by:

- The organizational mission, priorities and stakeholder requirements;
- The way in which internal and external personnel are engaged in the provision of climate services;
- The available resources and capabilities (financial, human, and technical);
- National and institutional legislation, rules, organizational structures, policies and procedures;
- WMO guidelines, policies and procedures for climate data and products;
- The dominant weather and climate influences and extremes experienced;
- Basic knowledge of user needs and requirements.

6.1.2. Education

In this document, education refers to academic training beyond high school. Currently, there is a huge imbalance in personnel at NMHSs. Often there is a large number of administrative personnel and meteorological assistants for only a handful of professional meteorologists. It is incumbent however to meteorologists and engineers to develop products and services that enable NMHSs to deliver climate services. Meteorologists or physical scientists must possess at least a 4-year university degree in meteorology or related sciences. The following is a priority for NMHSs to strive and develop competencies required for climate services:

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[45] Refer to Guidelines for Trainers in Meteorological, Hydrological and Climate Services (WMO, 2013) and Manual on the Implementation of Education and Training Standards in Meteorology and Hydrology – Vol. 1 Meteorology (WMO, 2012)

[46] Refer to Guide to Competency Framework (WMO, 2018)

- Assess the staffing needs and requirements to meet the challenges for co-developing climate services;
- Invest in inter- and multi-disciplinary higher level education for meteorological assistants who have a high school diploma. Offer a promotion to the newly graduates to positions of meteorologists;
- Hire new graduates from universities;
- Allow the staff to attend post graduate studies (MSc. or Ph.D.) provided that this does not impede upon the delivery of climate services;
- Provide newly hired and returning staff from academic training with a job description and work plan tied to the overarching operating plan of the NMHSs;
- Encourage hands-on sectorial training and training in social science methodologies;
- Engage mid-level managers in the operations of the NMHSs.

6.1.3. Professional development training

A well-trained workforce is essential to improving the quality of services. NMHSs must strengthen their human resource capacity in the areas of NWP modelling, weather and climate monitoring and forecasting, research, climate data management, and computing support and maintenance to meet the requirements of a modern hydro-meteorological service. There is a huge investment in training, but these training programs could be made more efficient to reach the goal of developing capacity at NMHSs to deliver climate services. The priority for NMHSs is to develop skills that enable work as defined in the operating plans. On-the-job or hands-on training is the best approach to develop skills in specific areas of interests. NMHSs must set their priorities for training based on their needs and requirements. In addition, professional development training is a long-term process. Often time concepts that are taught at training workshops are new. Repetition and practice are required to cement the knowledge acquired. This represents a huge effort and commitment, but it is essential for the training to be beneficial. Newly hired NMHS meteorologists and returning staff from academic training must undergo rigorous professional development training in line with their job descriptions and work plan in order to contribute to the development of climate services. Professional development training is also a requirement for NMHSs managing staff to acquire critical executive management skills and networking tools to enable vision and execution count in NMHSs. For the training needs and requirements for NMHSs, refer to Table 2 at the end of this document.

6.2. Human capacity for users of climate information

Developing human capacity on the application of climate information in different sectors is essential. This is the most challenging aspect of climate services delivery as often the users are not fully aware of climate concepts or uncertainties, what products are available and how to use them. Similarly, service providers may not have a full understanding of the users' requirements. Capacity building activities should be user-driven and should inform decision and policy making processes directed at national goals for sustainable development.

Translating climate information into decision making "intuitively" is difficult due to inherent uncertainties in climate information and the complexities of the system where decision is to be made. The use of modelling and scenario analysis adds substantial value by enabling information to be much more relevant to the decision in question than the general information contained in the forecast. Therefore, training and capacity development for users of climate information are crucial as the interactions and the insights gained from analysis of expected outcomes and risks provide more relevant information sources for the decision-maker.

There have been numerous initiatives in developing countries supported by international agencies that develop human capacity in scientists, policy makers, technical experts and local communities to enhance resiliency to climate variability and climate change. Some examples include:

- UNESCO works on education and outreach on climate variability and climate change and natural disaster preparedness, targeting the general public, educational systems and youth in SIDs and Africa.
- The Red Cross and Red Crescent Climate Centre interacts with groups including the NMHSs, WMO, International Research Institute for Climate and Society (IRI) and other scientific research groups to develop information products for reducing the impacts of climate change and extreme weather events on vulnerable people[47].
- The Australian Government, through the Australian Bureau of Meteorology, developed Decision Support tools for climate prediction as well training and capacity building workshops for the Pacific Island NMHSs. This program specifically targeted capacity building for the user communities in water, health, hydropower and agriculture in eleven Pacific countries.
- Capacity development programs promoting dialogue between climate services provider and user communities also exist, such as the Climate and Health Working Groups in Africa through the World Health Organization.

Developing human capacity for users of climate information and products both at regional and national levels has also been undertaken through the Regional Climate Outlook Forums (RCOFs) often in coordination with the RCCs. Users from various sectors are invited to participate in these forums as part of understanding the interpretation of the products and how to apply them. This process is translated to the national level where in some countries National Climate Forums and National Climate Outlook Forums are held between providers and users to facilitate interaction on the interpretation of the regional forecasts to national and sub-national scales and the co-identification and co-design of tailored products. The participation of users in these processes from various sectors helps to build their capacities in the application of the information, and to understand the processes and problems involved in developing climate products and information. And as, if not more, importantly, they are essential for informing climate services providers concerning user requirements as a basis for development and operationalization of relevant tailored products for decision-support.

[47] http://www.climatecentre.org/

Gender equality

Gender considerations must be taken into account at all stages of climate service development and delivery, including promoting gender equality for those producing, communicating and using climate services. It is especially important that engagement and training activities do not exclude/favor men or women.

When considering access to climate services and climate-related information, and ability to respond, manage and benefit from that information, the differences in challenges and opportunities due to gender must be considered, so that there is an equal distribution of benefit. Socio-cultural contexts may restrict women's access to training, promotion, ability/acceptability to participate in meetings and engagement activities. Inequalities may be related to childcare and household responsibilities, labor and decision-making roles, financial resources, difference in level of education and literacy, and religious and cultural traditions.

The CGIAR Research Program on Climate Change and Agricultural Food Security (CCFAS) has produced a helpful checklist to guide the consideration of gender issues in climate service projects, highlighting key issues to consider during project design, and good practices to follow to address those issues. It also provides key talking points to share and discuss with partners.

WMO is resolved in its efforts to achieve gender equality, empower women and build climate resilient societies, including providing improved climate services that are responsive and sensitive to women's and men's needs. It is committed to mainstreaming gender in its governance, working structures, programmes and service delivery. It is also determined to attract more women in the fields of science, technology and meteorology. The WMO Policy on Gender Equality was adopted by the seventeenth World Meteorological Congress in June 2015 as Annex to Resolution 59 (Cg-17), to promote, encourage, facilitate and monitor gender equality across WMO. This policy incorporates the outcomes of the Conference on the Gender Dimensions of Weather and Climate Services, and is operationalized through the WMO Gender Action Plan.

Sources:
Checklist: Gender considerations for climate services and safety nets (CGIAR, 2019)
WMO Policy on Gender Equality (WMO, 2015)
Update to the WMO Gender Action Plan (WMO, 2018)

7. Conclusions and Recommendations

The status of climate services varies significantly across the world, with some countries having well-developed services whereas others require capacity development to deal with climate-related risks, particularly in the developing and least development countries. There are a number of reasons attributed to the lack of effective climate service delivery. These include:

- Understanding of user's needs;
- Visibility and mandate of NMHSs as a provider of climate services;
- Institutional arrangements for effective user engagement;
- Human resources, infrastructure and technical capacity;
- National capacity for climate monitoring and forecasting; and,
- Forecast skill and lead time;
- Research to quantify the benefits of climate forecasts in different sectors of the economy;
- Improving awareness among decision makers regarding the local and regional impact of climate variability and climate change.

To address these constraints, the following recommendations are made for achieving improvements in institutional, infrastructural, procedural and human resources capacity development:

Institutional

Institutional arrangements: Effective delivery of climate services requires NMHSs to have mandate and visibility as a provider of climate services. Countries need to be supported to clearly define the terms of reference for climate service responsible structures and this should be guided by establishment of national coordination mechanisms, such as a National Framework for Climate Services (NFCS), to help to ensure that there is mutual understanding and alignment of objectives across different institutions to enable effective co-production of climate services.

User engagement: Capacity development activities should target both climate service providers and users. From an institutional perspective, this includes training of government employees, including the establishment of specific positions across different institutions, in climate variability and climate change. In-country capacity development activities, starting from national dialogues, can be an efficient means of simultaneously developing the capacity of multiple staff members across different organizations in a given country.

Mobilizing regional and global institutional support: International institutional support can be technical or a combination of technical and financial. Institutional capacity development can be gained through "twinning" or "pooling" services, training and support, through global and regional cooperative entities or by partnering with other NMHS(s).

Standard mechanisms for assessment, monitoring and evaluation: A mechanism should be further developed and continued to assess and monitor the progress of NMHSs for climate service delivery over time. This may be achieved through the climate services checklist incorporated in the WMO Community Platform[48] and a process of ISO certification as described in the Guidelines on Quality Management in Climate Services. interfaces such as the Country Profile Database (CPDB).

Infrastructure

Enhancing observation networks and facilities: Building on available, or developing global and regional level infrastructure, effort may be required to: provide new, and upgrade existing country observation networks; improve internet access and bandwidth; enhance computing, communication and data management facilities; and NMHSs access to the Global Telecommunication Systems (GTS).

Data retrieval and integration: Construction of high-resolution datasets by merging satellite and in-situ measurements. Data rescue activities may be required. Access to socio-economic, biological, and environmental data to create climate service information and products relevant for decision making in climate-sensitive sectors, such as agriculture, water, health, and disaster risk reduction.

Integrating observations from diverse sources into WIGOS supplements NMHS observations and ultimately leads to better NMHS services and broader benefits for Members. Yet there must also be incentives for non-NMHS operators to share their observations with an NMHS and potentially with the international WMO community. A key principle of successful and sustained observation partnerships is the recognition of mutual benefit based on common organizational interests and strengthened collaboration.

For climate applications:
(a) All raw data and agreed subsets of processed data should be collected into a documented and permanent data and metadata record following common standards (see, for example, the Guideline for the Generation of Datasets and Products Meeting GCOS

[48] WMO Community Platform

Requirements, GCOS Report No. 143 (WMO/TD-No. 1530)) and archived in a World Data Centre or other recognized data centre,
(b) A sustained operational capability is required to produce and maintain the archived data record throughout and after the life of the observing network,
(c) Resources should be allocated to ensure appropriate reprocessing of observational data to respond to the needs of climate applications. (WMO No. 1165 (edition 2019)-Guide to the WMO Integrated Global Observing System.

Procedural:

Utilization of available WMO regulations, frameworks and guidance: There is a comprehensive set of WMO Technical Regulations and guidance documents providing a sound foundation for the operation of NMHSs, which will also guide effective capacity development of climate services aligned to the framework of the GFCS and the NFCS.

Quality Management Systems: One of the main steps in enhancing procedural capabilities of NMHSs involves implementation of Quality Management Systems (QMS). The provision of climate services by NMHSs can be improved by implementation of a QMS, and it is recommended that the ISO 9001 framework (WMO No. 1221[49]) should be used to achieve this. This external certification audit process will allowing NMHSs to be able to identify and meet the requirements of their customers, monitor and measure their own performance, identify opportunities to mitigate risk and find ways to continually improve their service delivery, while achieving certification of compliance with ISO 9001.

Socio-Economic Benefits Analysis: Climate services do not generate economic and social value unless users benefit from decisions as a result of the information provided, even if the services are of the highest quality. A comprehensive evaluation of the socioeconomic benefit of climate services, via a Socio-Economic Benefit Assessment (SEB) may cover verification of service quality, characteristics of service uptake by user communities, the economic cost of producing services and economic value of services to user communities. Demonstrating value can help to mobilize resources from national government through to international funding mechanism.

Human Resources[50]

Management and leadership development: Management and leadership skills are required to enable NMHSs to build stronger national political ownership, develop relevant policies and legal frameworks, and enhance sustainability by linking regional, sub-regional and national planning processes.

Meteorologist and climatologist training: Meteorologists and climatologists need to be well trained in operational weather and climate forecasting from short range to sub-seasonal, seasonal, and inter-annual time scales. A pool of well-trained meteorologists must be supplemented by another interdisciplinary pool of professionals who understand climate and can work with specific climate-sensitive sectors and societal actors on priority issues, such as food security, water, energy and health.

Impact modelling and scenario-based training: Translating climate information into decision making is difficult due to inherent uncertainties in climate information and the complexities of the system where each decision is to be made. The use of impact-based modelling and scenario analysis can add value by enabling information to be more relevant to the decision in question, rather than relying on the general information

[49] Refer to Guidelines on Quality Management in Climate Services (WMO, 2018)

[50] WMO Integrated Strategic Planning Handbook (WMO, 2016)

contained in the forecast. Training and capacity development for users of climate information is crucial, as the interactions and the insights gained from analysis of expected outcomes and risks can provide a more relevant information source for the decision-maker.

Analytics: Capacity development for climate information and products should not solely focus on climate prediction, particularly in regions where prediction skill is poor. Useful products can be developed from existing data, such as accumulated rainfall, frost frequency, and number of consecutive dry days, which can have enormous value for agricultural sector and other industries. Development of analytical capacity, modelling, simulation, and decisions support systems should be part of all training activities.

User-engagement: embrace the concept of co-development of climate services through continuous two-way user-provider engagement throughout the whole service delivery value chain. This approach will enable the generation of climate products and the delivery of services that make use of the best available climate science and technology, and other contextual data and information, such as socio-economic information, to support user decisions, while allowing services to be continually monitored and refined.

Gender equality: must be considered at all stages of climate service development and delivery, including promoting gender equality for those producing, communicating and using climate services. Engagement and training activities should not exclude/favor men or women. Refer to the CCFAS checklist to guide the consideration of gender issues in climate service projects.

The above recommendations concerning the need to improve infrastructural, institutional, procedural and human resource capacities can make a significant difference to the ability of NMHSs to take full advantage of new and existing regional and global infrastructure and services. The drawing together of local and regional knowledge, user-provider engagement, national commitment and global partnerships will stimulate and establish rigorous dialogue and ensure that targeted actions are taken to reduce climate risks, enhance adaptation, and pursue transition to sustainability locally and globally.

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Table 1: Categorization of NMHSs

Level of service	Weather services	Climate services	Hydrology services	Description of capacity needed to achieve service level
Category 1 Basic	• Weather observations • Weather Data Management • Interaction with users of weather data and products	• Climate observations • Climate Data Management • Interaction with users of weather data and products	• Hydrological observations • Hydrological data management • Interaction with users of hydrology data and products	• Small network of quality controlled observations • Basic data-processing, archiving and communication systems • Little or no backup / offsite storage, or contingency options • Staff: observers and some meteorologists trained to Basic Instruction Package (BIP) • No 24 /7 operation • Rudimentary Quality Management System • No research and development
Category 2 Essential	• Medium-range (synoptic scale) forecasts and warnings • Established links with media and disaster risk reduction (DRR) communities	• Seasonal Climate outlooks • Climate monitoring	• Hydrological data products for design and operation of water supply structures • Water level and flow monitoring • Short-term flow forecasts (low flows) • Flood forecasting	• Able to take and integrate observations from other parties • Well-established protocols for emergencies, backup of data and minimum offsite facilities • Staff: observers and meteorologists trained to BIP standards • 24/7 operation. • Well established quality management system • Able to access most numerical weather prediction data/products from other centres • Small research and development unit • Some partnerships as junior members
Category 3 Full	• Specialized weather products for a wide range of sectors • Well integrated into DRR communities and mature links with media	• Specialized climate products • Decadal climate prediction • Long-term climate projections	• Seasonal stream flow outlooks • Specialized hydrology products	• Advanced observation equipment • Ability to run its own numerical prediction suite • Research and development unit • Well educated/trained staff • Own training group • Developed library and information services • Active partnerships with NMHSs taking a leading role
Category 4 Advanced	• Customized weather products • Weather application tools	• Customized climate products • Climate application tools	• Customized hydrology products • Hydrology application tools	• Advanced observations • Leading Research and development team • Well-developed Education and training Unit

Table 2: Training Objectives and Specifications

NMHS Staff	Knowledge	Ability	Attitude	Tasks	Cont'd Ed.
Leadership and Managing Staff	• Challenges of NMHSs	• Management Skills	• Vision Inclusiveness • Work Ethics • Motivating • Provide pleasant work environment	• Operating Plans • Job Descriptions • Work Plans • Performance Appraisal	As deemed necessary: • Leadership and Management Training • Work Ethics Training
Meteorologists and Hydrologists	• Data Management • Climate Monitoring • Climate Forecasting • Climate Projections • Climate Applications (sector specific products; water, Agriculture, health etc.)	Proficiency: • Statistical Software Packages Run Climate Monitoring Forecasting Tools • Analyze and Interpret Results • Write Climate Diagnostics and Forecasting Bulletins • Post Information on Website, and social media Create Shapefiles • Provide Training to New Staff • Communicate and Engage the users	Work Ethics Strive To Learn and To Share Knowledge: • Dependable • Leadership and Engagement	• Perform Data Archiving and Management • Prepare Climate Monitoring and Forecast Bulletins • Prepare user tailored products (agrometeorological, hydrometeorological, climate and health, etc.) • Develop Tools For Improving Forecasts • Engage in public climate services • Carry Out R&D on Climate and Climate Applications	As deemed necessary: • Professional Development Training • Academic Training • Work Ethics Training • Management for staff aspiring to leadership positions
Engineers	• Computer and Information communication Systems Administration • Maintenance of Computer information communication systems • Data Base Management Scientific Programming Languages	Proficiency: • Computer and Information communication Systems Administration • Maintenance of Computer Systems • Data Base Management • Scientific Programming Languages	• Same As Above	• Manage Computer and communication Systems and Data Base • Provide Programming Support to Meteorologists	• Same As Above
Meteorological Technicians (Observers and Assistants)	• Understanding of synoptic and other data • Understanding the value of meteorological observations Basic Understanding of Climate Data Processing • Basic knowledge of Instruments • Understanding importance of metadata	Proficiency: • Observations and measurement • Data Processing and Archiving Use of communication platforms • Simple statistical software packages	• Appreciate the importance of taking accurate measurements • Dependable Leadership and Engagement	• Take measurements • Transmit Data • Data Quality Control • Data Archiving • Basic Data Processing • Collecting and recording metadata	• Work Ethics Training • Professional Development Training • Academic Training