WORLD METEOROLOGICAL ORGANIZATION

GFCS
GLOBAL FRAMEWORK FOR CLIMATE SERVICES

WEATHER CLIMATE WATER

Climate Services for Supporting Climate Change Adaptation

Supplement to the Technical Guidelines for The National Adaptation Plan Process





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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at http://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html. Acronyms may also be found at http://www.wmo.int/pages/themes/acronyms/index_en.html.

WMO-No. 1170

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ISBN 978-92-63-11170-8

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EXECUTIVE SUMMARY

Because of the current and projected impacts on climate due to the high levels of greenhouse-gas (GHG) emissions, adaptation is a necessary strategy at all scales in a changing climate. At its 17th session, the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) established the National Adaptation Plan (NAP) process as a way to facilitate effective adaptation planning in Least Developed Countries (LDCs) and other developing countries. The four key elements that need to be undertaken in the development of NAPs are: Laying the groundwork and addressing gaps; Preparatory elements; Implementation strategies; and Reporting, monitoring and review. Implementation strategies in the NAP process involve decisions related to climate risk management, which have to be based on reliable, relevant, usable and timely climate information. A number of activities in the different elements of the NAP process require effective and timely climate services consisting of the collection of climate data; generation and provision of a wide range of information on past, present and future climate; development of products that help improve the understanding of climate and its impacts on natural and human systems; and the application of these data, information and products for decision-making in all walks of life and at all levels of society.

World Climate Conference-3 (Geneva, 2009) decided to establish a Global Framework for Climate Services (GFCS), a UN-led initiative spearheaded by WMO. The vision of GFCS is to enable society to better manage the risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to such risks. This will be done through the development and incorporation of science-based climate information and prediction into planning, policy and practice. The scope and thrusts of GFCS encompass five initial priority areas, namely Agriculture and food security, Disaster risk reduction, Energy, Health, and Water. National Meteorological and Hydrological Services (NMHSs) play an important role in the provision of climate services at the national level that are needed in support of the NAP process. The work of NMHSs can contribute to enhancing the safety and well-being of society, ending poverty, sustaining development and economic growth, improving access to clean drinking water, enhancing food production, achieving good health outcomes, mitigating and adapting to climate change, exploiting renewable energy sources and increasing the prosperity of populations as follows:

(a) NMHSs can provide effective and timely climate services such as the analysis of current climate and future climate change scenarios, assessment of climate vulnerabilities and identification of adaptation options, enhancement of capacity for planning and implementation of adaptation, etc.

(b) Partnerships between NMHSs and academia, government departments, international and non-governmental organizations (NGOs) and, where appropriate and possible, the private sector and civil society, provide better data coverage and information processing, higher-resolution models and more precise and useful specialized products for societal benefits, including opportunities to better support government and other decision-makers regarding safety, the economy and security.

(c) NMHSs can provide weather and climate information to the farming community that can be particularly helpful in anticipating, preparing for, and responding to, agriculture or food security risks on short timescales to address problems triggered by climate extremes (droughts, thermal extremes), as well as longer-term risks associated with climate change (increased frequency of cyclones, desertification).

(d) NMHSs can assist disaster risk reduction through the provision of historical and real-time data on loss and damage, provision of multisectoral plans, climate information to guide decisions regarding appropriate levels of investment, and risk financing and transfer.

(e) NMHSs, working together with the public and private sectors, can implement multihazard early warning systems to significantly reduce the number of fatalities caused by weather-, water- and climate-related disasters, enhance resilience of societies, sustain productivity and economic growth and reduce damage to property.

(f) NMHSs can provide weather and climate information to help health decision-makers improve, inter alia, understanding of the mechanisms of climate impacts on disease transmission and occurrence and identifying populations at risk (e.g. risk mapping). NMHSs can also provide decadal climate projection maps for human vulnerability assessment and adaptation planning. Such tools and methodologies can help officials in the health sector incorporate the information generated in routine health decisions.

(g) NMHSs can provide long time series of climate data to the water sector in support of hydrological modelling to enable greater understanding of the impacts of climate variability on water resources availability and through the provision of improved climate prediction services on timescales from seasons to decades and spatial scales from local to regional to support improved water resources management and prioritized allocation of resources to the wide variety of water-demand sectors, including urban water supply, irrigation systems, flood storage capacity, etc.

(h) NMHSs can provide a range of services to support decisions by water managers that include identification of extreme weather and climate hazards that pose water-related risks; identification of populations vulnerable to weather and climate hazards, including those in the coastal zone; implementation of risk management and emergency preparedness practices and procedures; development and implementation of water and environmental policy; and development and implementation of water- and flood-management policies and strategies.

(i) NMHSs can provide detailed and tailored weather and climate information (historical and projected) for: initial assessment of energy resources; the development of codes, standards and site-specific designs and policies to assist with the construction and maintenance of energy system infrastructure; site selection and financing; operations and maintenance; and energy supply in a balanced/integrated manner to meet the energy demand.

NMHSs are encouraged to continue their active role in the UNFCCC Least Developed Countries Expert Group (LEG) process and to provide technical advice to LDCs for preparing and implementing NAPs and other contributions to the LDC work programme.

CLIMATE SERVICES FOR SUPPORTING CLIMATE CHANGE ADAPTATION

1. INTRODUCTION

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (IPCC, 2014). Impacts from recent climate-related extremes, such as heatwaves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality and consequences for mental health and human well-being. Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty. Climate-related hazards affect poor people's lives directly through impacts on livelihoods, reductions in crop yields, destruction of homes and indirectly through, for example, increased food prices and food insecurity.

Because of the current and projected climate disruption precipitated by high levels of GHG emissions, adaptation is a necessary strategy at all scales in a changing climate. The United Nations Development Programme (UNDP) emphasizes the use of strategies to respond to climate change impacts: "Adaptation is a process by which strategies to moderate, cope with, and take advantage of, the consequences of climate events are enhanced, developed and implemented." (Lim and Spanger-Siegfred, 2005). The capacity and potential for humans to adapt are unevenly distributed across different regions and populations and developing countries generally have less capacity to adapt (Schneider et al., 2007).

Climate services develop and provide science-based and user-specific information relating to past, present and potential future climate and address all sectors affected by climate at global, regional and local scales. They connect natural and socioeconomic research with practice. They help society cope with climate variability and change through the transformation of climate-related data – together with other relevant information – into customized products such as projections, trends, economic analysis and services to user communities in different sectors. For example, the provision of more and better climate services will allow farmers to fine-tune their planting and marketing strategies, based on seasonal climate forecasts; empower disaster-risk managers to prepare more effectively for droughts and heavy precipitation; assist public health services to target vaccine and other prevention campaigns to limit climate-related disease outbreaks, such as malaria and meningitis; and help improve the management of water resources. These activities all contribute to appropriate adaptation planning in a changing climate.

2. PROCESS TO FORMULATE AND IMPLEMENT NATIONAL ADAPTATION PLANS TO COPE WITH CLIMATE CHANGE

At its 17th session, UNFCCC COP acknowledged that, climate change risks magnify development challenges for LDCs because of their lower level of development (UNFCCC, 2012) and that national adaptation planning can enable all developing and LDC Parties to assess their vulnerabilities, mainstream climate change risks and address adaptation. With this in mind, COP established the NAP process as a means to facilitate effective adaptation planning in LDCs and other developing countries (UNFCCC, 2012).

The agreed objectives of the NAP process are to:

(a) Reduce vulnerability to the impacts of climate change by building adaptive capacity and resilience;

(b) Facilitate the integration of climate change adaptation, in a coherent manner, into relevant new and existing policies, programmes and activities, in particular development-planning processes and strategies, within all relevant sectors and at different levels, as appropriate.

NMHSs can help meet the demand for climate services to address climate change and adaptation, particularly at the local level, by combining climate change projections with local climate data and knowledge. These products can then be used to devise adaptation strategies, including preparing for, and adjusting to, changing patterns of extreme events. Climate services, such as those developed under GFCS, provide essential information for adaptation at the national and local levels and should receive commensurate support.

Elements of National Adaptation Plans

Initial guidelines for the formulation of NAPs by LDC Parties are given in the annex to UNFCCC Decision 5/CP.17. They are divided into four main elements: Laying the groundwork and addressing gaps; Preparatory elements; Implementation strategies; and Reporting, monitoring and review. An example of how the NAP process can progress is shown in Figure 1.

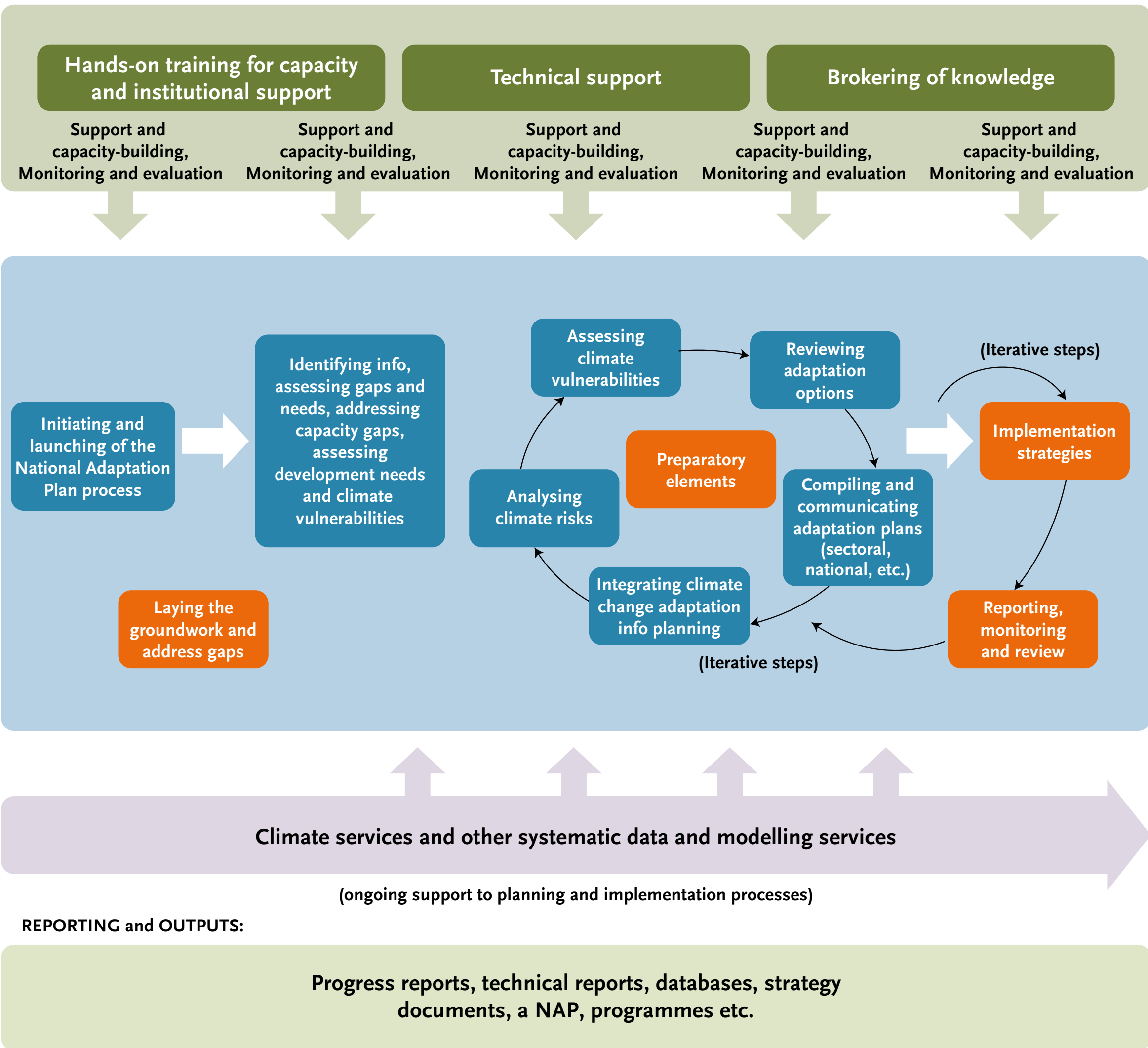


Figure 1. An example of how the National Adaptation Plan process can progress

Source: Least Developed Countries Expert Group, 2012

Box 1. Elements of the National Adaptation Plan process

1. Laying the groundwork and addressing gaps

This element aims to create a national mandate and strategy for the NAP process that establishes clear responsibilities for government ministries and departments and specifies key milestones and expected outputs of the NAP process and the frequency of such outputs over time. Activities undertaken under this element should be planned with a view to identifying weaknesses and gaps in enabling environments and addressing them, as necessary, to support the formulation of comprehensive adaptation plans, programmes and policies, through, inter alia:

- Initiating and launching the NAP process;
- Stocktaking: identifying available information on climate change impacts, vulnerability and adaptation and assessing gaps and needs of the enabling environment for the NAP process;
- Addressing capacity gaps and weaknesses in undertaking the NAP process;
- Comprehensively and iteratively assessing development needs and climate vulnerabilities.

2. Preparatory elements

In developing NAPs, consideration should be given to identifying specific needs, options and priorities on a country-driven basis, utilizing the services of national and, where appropriate, regional institutions, and the effective and continued promotion of participatory and gender-sensitive approaches coordinated with sustainable development objectives, policies, plans and programmes. Activities may include the following:

- Analysing current climate and future climate-change scenarios;
- Assessing climate vulnerabilities and identifying adaptation options at the sectoral, subnational, national and other appropriate levels;
- Reviewing and appraising adaptation options;
- Compiling and communicating NAPs;
- Integrating climate change adaptation into national and subnational development and sectoral planning.

3. Implementation strategies

Activities carried out as part of the implementation strategies should take into consideration the following:

- Prioritizing climate change adaptation in national planning;
- Developing a (long-term) national adaptation implementation strategy;
- Enhancing capacity for planning and implementation of adaptation:
- Promoting coordination and synergy at the regional level and with other multilateral environmental agreements.

4. Reporting, monitoring and review

These activities, including NAP documents, could be included in national strategies and plans, as appropriate. Under this element, Parties should undertake a regular review, at intervals that they determine:

- Monitoring the NAP process;
- Reviewing the NAP process to assess progress, effectiveness and gaps;
- Iteratively updating NAPs;
- Outreach on the NAP process and reporting on progress and effectiveness.

3. NEED FOR CLIMATE SERVICES TO SUPPORT THE NATIONAL ADAPTATION PLAN PROCESS

A number of activities in the different elements of the NAP process described above, such as analysis of current climate and future climate change scenarios, assessment of climate vulnerabilities and identification of adaptation options, enhancement of capacity for planning and implementation of adaptation, etc., require effective and timely climate services. A recent World Bank report entitled Shock Waves: Managing the Impacts of Climate Change on Poverty (Hallegatte et al., 2015) shows that, between now and 2030, good, climate-informed development gives the best chance for warding off increases in poverty due to climate change. Short-term, contemporary problems, such as identification and early warning of an impending climate-related hazard that could result in a disaster, will assist decision-makers in undertaking proactive actions to cope with disasters.

All countries are having difficulties in coping adequately with the increasing effects of hydrometeorological hazards, whether through a growth in the number of severe events, increased exposure, heightened vulnerability or all three. Efforts have to be directed towards strengthening capacities at national and local levels, with international support where necessary. It has been estimated that upgrading all hydrometeorological information and early warning capacity in developing countries would save an average of 23 000 lives annually and would provide between US$ 3 billion and US$ 30 billion per year in additional economic benefits related to disaster risk reduction (Rogers and Tsirkunov, 2013). Hence, there is a strong need for adequate resourcing of hydrometeorological service delivery and contributing to guaranteeing the sustainability of such services as part of longer-term development (WMO, 2015(a)).

The socioeconomic consequences of hydrometeorological hazards are often most keenly felt at the local level; consequently, climate-risk management requires that decision-making be based on climate information that can be “downscaled” to a local context. The WMO Strategy for Service Delivery (WMO, 2014(a)) lays out seven steps which are intended to help NMHSs review their current service-delivery practices and start implementing the Strategy.

Climate services consist of the collection of climate data; generation and provision of a wide range of information on past, present and future climate; development of products that help improve the understanding of climate and its impacts on natural and human systems; and the application of these data, information and products for decision-making in all walks of life and at all levels of society. Depending on users’ needs, these data and information products may be combined with non-meteorological data, such as agricultural production, health trends, population distributions in high-risk areas, road and infrastructure maps for the delivery of goods, and other socioeconomic variables. International cooperation in seamless research on hydrometeorological and climate services has led to advances in predictive accuracy and increased lead time, facilitating applications in a wide range of user sectors (Figure 2).

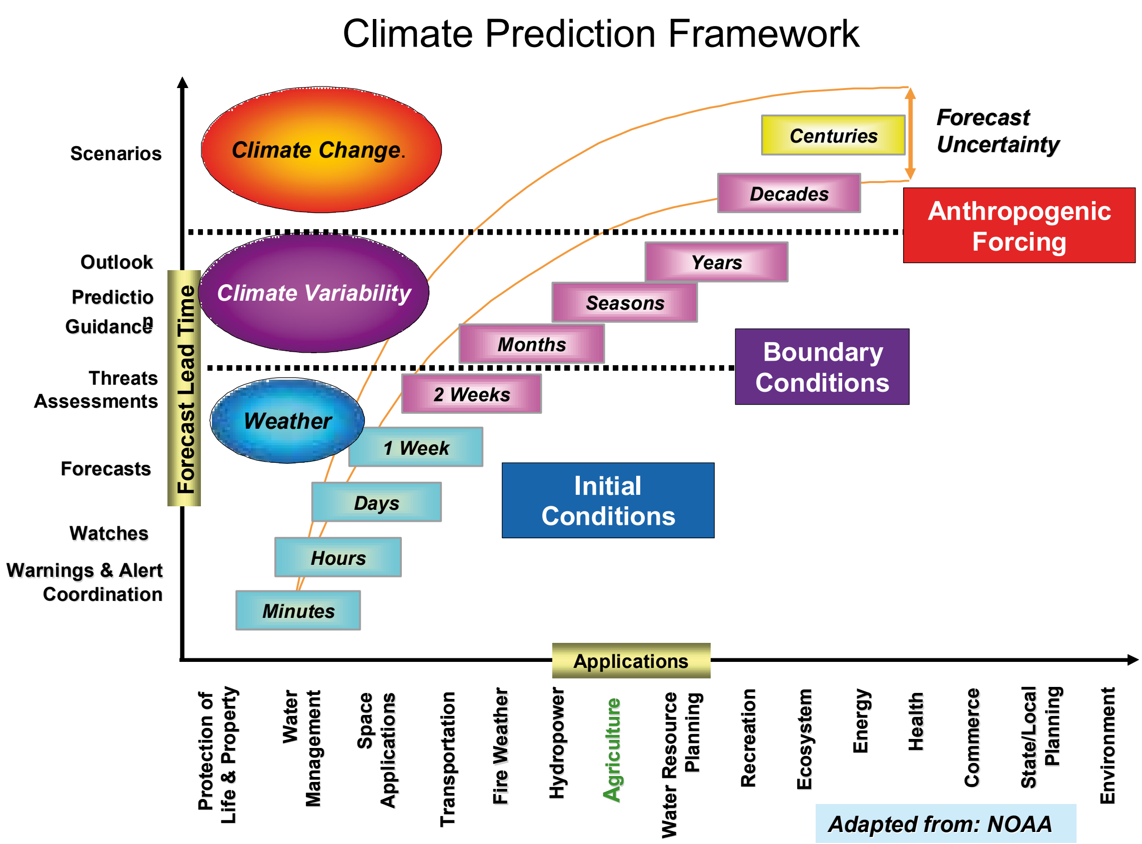


Figure 2. Seamless hydrometeorological and climate services

Implementation strategies in the NAP process involve decisions related to climate-risk management which have to be based on reliable, relevant, usable and timely information about the climate. Some examples of climate products and the nature of climate services they provide are given below:

(a) Eight- to 14-day probabilistic outlooks provide information to decision-makers in weather- and climate-sensitive sectors and for businesses sensitive to intra-monthly climate variation;

(b) Weekly regional hazard outlooks for food security provide advance notice of food-security issues in the regions of interest. The outlooks are preliminary input to the Famine Early Warning System Network (FEWS NET) monthly food-security outlooks;

(c) One-month temperature and precipitation outlooks provide information to decision-makers in weather and climate activities and for businesses sensitive to seasonal and interannual climate variations;

(d) Monthly and seasonal drought outlooks provide advance notice of potential drought improvement, persistence or development for the upcoming one-month and three-month periods to aid various sectors of the economy (agriculture, water resources management, forestry, energy, recreation, finance);

(e) Monthly climate outlooks: monthly forecasts of temperature, precipitation and sunshine duration across a country (presented in various formats, including text, maps and tables). This information is used by the energy and water sectors, for example, to anticipate resource needs;

(f) Annual climate outlooks comprising probabilistic forecast maps, plumes, histograms and heat-stress index maps for government (contingency planning) and industry (particularly energy and water sectors).

A coherent national plan for climate services could enhance community understanding of climate variability and change, together with the associated risks and opportunities. Hence, all countries around the world are now being encouraged to develop and implement national plans for climate services to enhance social, economic and environmental benefits through better-informed climate-risk management and improved capability for adaptation to climate variability and change.

4. GLOBAL FRAMEWORK FOR CLIMATE SERVICES

World Climate Conference-3, held in Geneva in 2009 decided to establish the GFCS, a UN-led initiative spearheaded by WMO to guide the development and application of science-based climate information and services in support of decision-making in climate-sensitive sectors. Thirteen Heads of State or Government, 81 ministers and 2 500 scientists unanimously agreed to develop GFCS. A High-Level Task Force (HLT) was appointed through an intergovernmental process to prepare a report that would include recommendations on the proposed elements of GFCS and the next steps for its implementation. The Task Force produced the report Climate Knowledge for Action: A Global Framework for Climate Services as the basis for GFCS (WMO, 2011(a)).

To ensure that GFCS provides the greatest benefit to those who are most in need of climate services, HLT recommended that the following eight principles be adhered to in its implementation:

Principle 1: All countries will benefit, but priority shall go to building the capacity of climate-vulnerable developing countries.

Principle 2: The primary goal of the Framework will be to ensure greater availability of, access to, and use of, climate services for all countries.

Principle 3: Framework activities will address three geographic domains: global, regional and national climate services will be the core element of the Framework.

Principle 5: Climate information is primarily an international public good provided by governments, which will have a central role in its management through the Framework.

Principle 6: The Framework will promote the free and open exchange of climate-relevant

observational data, while respecting national and international data policies.

Principle 7: The role of the Framework will be to facilitate and strengthen, not to duplicate.

Principle 8: The Framework will be built through user–provider partnerships that include all stakeholders.

The vision of the Global Framework for Climate Services is to enable society to better manage the risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to such risks.
This will be done through the development and incorporation of science-based climate information and prediction into planning, policy and practice.

The vision of GFCS supports the Sendai Framework for Disaster Risk Reduction (SFDRR), which succeeded the Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters and was adopted at the Third World United Nations Conference on Disaster Risk Reduction (WCDRR-III) held in Sendai, Japan, in March 2015. The vision supports both SFDRR's overarching goal to "Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience" and it's four priorities for action:

(a) Understanding disaster risk;

(b) Strengthening disaster risk governance to manage disaster risk;

(c) Investing in disaster risk reduction (DRR) for resilience; and

(d) Enhancing disaster preparedness for effective response and to "build back better" in recovery, rehabilitation and reconstruction.

As shown in Figure 3, GFCS places emphasis on hazard analysis through the use of historical and real-time hazard data and meteorological, hydrological and climatological forecasts and trend analysis. This analysis, in combination with the analysis of exposure and vulnerability, helps in effective risk assessment, which facilitates effective decision-making to promote societal resilience in the priority areas of the GFCS.

The vision of GFCS also supports the Sustainable Development Goals (SDGs) adopted by world leaders at the UN General Assembly in New York in September 2015.

The GFCS Implementation Plan (WMO, 2014(b)) highlights the priorities for early focus under different Priority Areas and the deliverables and targets over two-, six- and 10-year horizons. It is

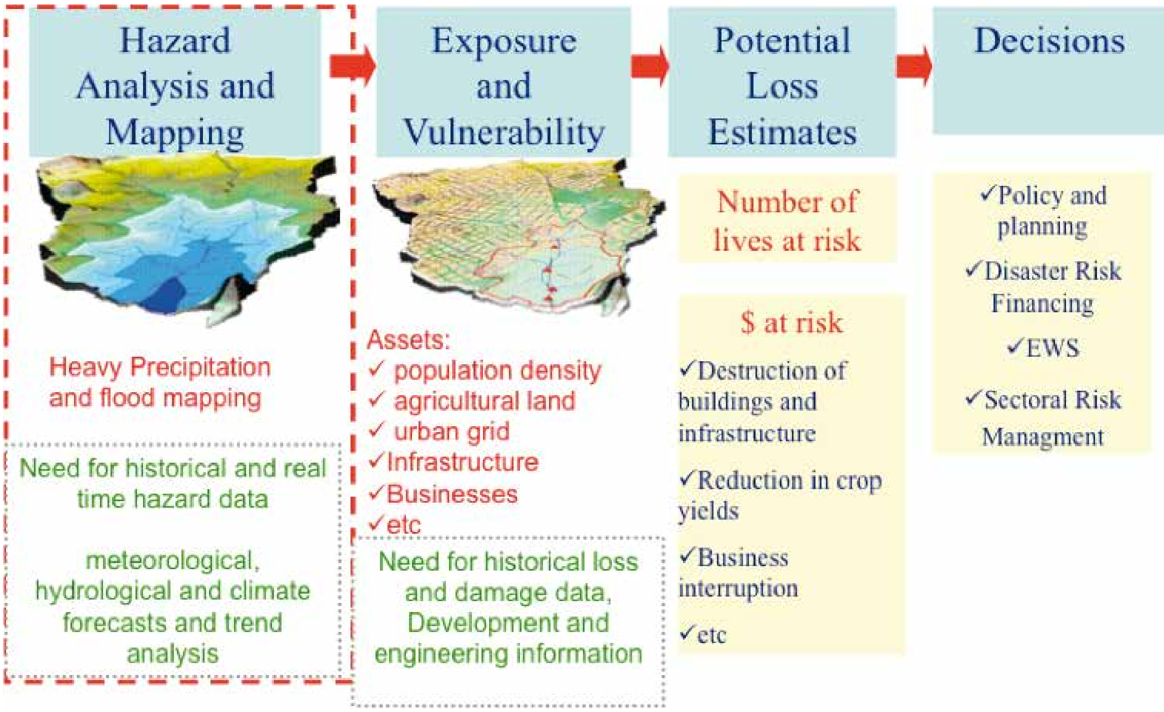


Figure 3. GFCS facilitates hazard analysis and risk assessment to promote sectoral risk management and societal resilience.

expected that significant improvements in national climate service provider capabilities will be realized during the second phase of implementation (development phase).

Pillars of the Global Framework for Climate Services

The Framework is an end-to-end system that uses observations, technology and scientific understanding as inputs to the development of climate services to meet user requirements.

It is designed around five major components or "pillars", as shown in Figure 4.

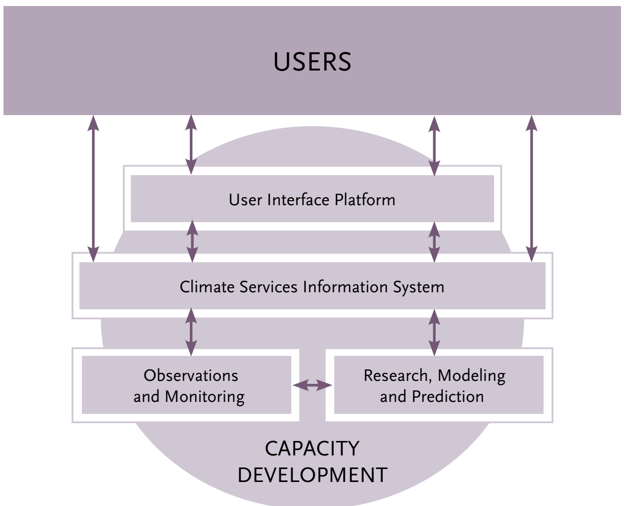


Figure 4. Schematic illustration of the GFCS pillars with the indication that the Capacity development component encompasses the other components. Arrows depict flows of information and feedback. The concepts underlying this diagram are especially applicable at national and subnational or local levels.

User needs are met by each of the pillars as follows:

(a) User Interface Platform (users can make their voices heard through the Platform and make sure climate services are relevant to their needs);

(b) Climate Services Information System (the production and distribution system for climate data and information products that address user needs);

(c) Observations and monitoring (the essential infrastructure for generating the necessary climate data);

(d) Research, modelling and prediction (to advance the science needed for improved climate services that meet user needs);

(e) Capacity development (to support the systematic development of the institutions, infrastructure and human resources needed for effective climate services).

These five pillars do not function as stand-alone entities and, as Figure 4 demonstrates, they need to interact with each other in order to make the production, delivery and application of climate services fully effective.

Priority Areas of the Global Framework for Climate Services

The scope and thrusts of GFCS include five initial Priority Areas, namely Agriculture and food security, Disaster risk reduction, Energy, Health, and Water. GFCS therefore focuses considerable early attention on these areas. There are some specific guidelines, which are described in the sections that follow, on how these sectors might be supplied with climate services at the national level, including how providers, intermediaries and end users might interact.

5. ROLE OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES IN THE PROVISION OF CLIMATE SERVICES AND SUPPORT TO THE NATIONAL ADAPTATION PLAN PROCESS

The Convention of WMO reaffirms the vital importance of the mission of NMHSs in observing and understanding weather and climate and in providing meteorological, hydrological and related services in support of relevant national needs, which should include:

(a) Protection of life and property;

(b) Safeguarding the environment;

(c) Contributing to sustainable development;

(d) Promoting long-term observation and collection of meteorological, hydrological and climatological data, including related environmental data;

(e) Promotion of endogenous capacity-building;

(f) Meeting international commitments; and

(g) Contributing to international cooperation.

The *Guide to Climatological Practices* (WMO, 2011(b)) provides guidance to NMHSs in developing national activities linked to climate information and services. NMHSs adhere to the basic principles and modern practices important for the development and implementation of all climate services and the methods of best practice in climatology.

It has taken many years of research, investment, coordination, collaboration and effort to develop the present capability of providing weather and climate services through the active involvement of 191 NMHSs worldwide. Over time, knowledge about the weather has improved and the use of weather forecasts has evolved into a daily life routine, where an increasing number of decisions are dependent on them. As climate is the accumulation over time of weather conditions and climate information is generated, based on similar models that require similar inputs, climate services are naturally – and strongly – rooted in the existing capabilities for the provision of weather services.

As has been the case since the beginning of the modern era of societal and environmental management, knowledge of weather and hydrological and climate processes is key to all aspects of human endeavour as observed from their influence on cultures, traditions and development paths of societies. It is within this framework that various NMHSs have been well positioned to monitor, forecast and issue warnings on a wide range of weather-, climate- and water-related events that affect human life and socioeconomic development (WMO, 2015(b)). For example, with regard to natural hazards, NMHSs have been tasked with monitoring and providing warnings of individual events and sensitizing the population on their impacts to save lives, enhance resilience of societies, sustain productivity and economic growth and reduce damage to property.

Beyond the year 2015, SFDRR, the SDGs adopted by world leaders at the UN General Assembly in New York in September 2015 and the new agreement under UNFCCC adopted in Paris in December 2015 will have a significant influence on the demands from NMHSs for user-oriented weather, hydrological, climate and related environmental services to meet the evolving needs of governments, partners and other decision-makers to achieve sustainable development. The myriad advances in science and technology provided by NMHSs and their partners, that include the provision of multi-hazard early warnings and related services, 24 hours a day, 365 days a year, and climate services through GFCS, can provide societies with the underpinning information to reduce and mitigate the impacts of natural hazards and maximize the benefits from weather- and climate-related opportunities. The efforts of NMHSs contribute to enhancing the safety and well-being of society, ending poverty, sustaining development and economic growth, improving access to clean drinking water, enhancing food production, achieving good health outcomes, mitigating and adapting to climate change, exploiting renewable energy sources and increasing the prosperity of their populations.

Support provided by National Meteorological and Hydrological Services to adaptation in the Priority Areas of the Global Framework for Climate Services

Climate services are inextricably linked with traditional weather services in observing elements of climate and weather, in keeping and preserving records and developing and delivering the

Box 2. Guide to Climatological Practices

The first edition of the WMO *Guide to Climatological Practices* was published in 1960, with the second edition appearing in 1983. While many basic fundamentals of climate science and climatological practices have remained consistent over time, scientific advances in climatological knowledge and data-analysis techniques, as well as changes in technology, computer capabilities and instrumentation, required the revision of the Guide and the third edition was published in 2011 (WMO, 2011(b)).

The third edition comprises six chapters: Information on climatology and its scope;the Organization and functions of a National Climate Service and international climate programmes; Climate observations, stations and networks; Climate data management; Characterizing climate from datasets; Statistical methods for analysing datasets; and Services and products. Procedures in the Guide have been taken, where possible, from decisions on standards and recommended practices and procedures. The main decisions concerning climate practices are contained in the WMO Technical Regulations, manuals and reports of World Meteorological Congress and the Executive Council, and originate mainly from recommendations of the WMO Commission for Climatology.

http://www.wmo.int/pages/prog/wcp/ccl/guide/guide_climat_practices.php weather and climate services and being the main source of climate information. NMHSs are the official authoritative source and – in most countries – the single source for weather and climate data and the single voice on weather warnings in their respective countries. In many, they are also responsible for climate, hydrology, air quality, seismic and tsunami warnings and space weather.

All around the world, NMHSs design, operate and maintain the national observing systems; handle data management, including quality analysis and quality control (QA/QC); develop and maintain data archives; undertake climate monitoring; provide the oversight on climate standards; carry out climate diagnostics, climate analysis and climate assessment; disseminate climate products based on the data via a variety of media; and participate in regional climate outlook forums and some interaction with users, to meet requests and gather feedback.

Partnerships between NMHSs and academia, government departments, international and non-governmental organizations and, where appropriate and possible, the private sector and civil society, help society make better decisions based on more complete and accurate weather, water and climate information. These partnerships provide better data coverage and information processing, higher-resolution models and more precise and useful specialized products for societal benefits, including opportunities to better support government and other decision-makers regarding safety, the economy and security. NMHSs work with these partnerships to develop appropriate national frameworks that facilitate the gathering and sharing of data and expertise to make the information easy to access in real time, in useful forms and at low cost. Climate services provided by NMHSs within the framework of WMO in the different GFCS Priority Areas are described below with appropriate reference to the elements of the NAP process.

Box 3. Climate products, climate models and climate outlooks

Climate products

According to the WMO *Guide to Climatological Practices* (WMO, 2011(b)), climate products include the following:

Climatological data periodicals. Most NMHSs issue monthly bulletins containing data from a selection of stations within particular areas or states or the country as a whole. Some also publish periodicals for different intervals such as a week or a season. These periodicals contain timely climate data that can be of great importance to various economic, social and environmental sectors.

Occasional publications. Occasional publications are designed for users who need information in planning for capital investments or in designing equipment and buildings to last for decades and centuries; for members of the general public whose interests are academic or casual; and for researchers in the atmospheric and oceanic sciences. They are also designed to summarize or explain unusual events, such as extreme weather, and to describe or update an important predicted event such as a strong El Niño.

Standard products. It is usually beneficial to develop a standard product that can be used by a wide range of users. For example, both energy-management entities and fruit-growers can make use of a degree-day product. Such standard products fill the gap between the climate data periodicals and those tailored for individual users. Increasingly, products are being requested and delivered using the Internet.

- *The Role of Climatological Normals in a Changing Climate* (WMO/TD-No. 1377)

Specialized products. It is often necessary to develop products that are specific to an individual user or sector. Developing these products involves analysing the data and presenting the information with a focus on the specifications that will enable the user to gain optimum benefit from the application of the information. Flood analysis is one example of such a product, as flood-frequency estimates are required for the planning and assessment of flood defences, the design of structures and the preparation of flood-risk maps.

- *Technical Material for Water Resources Assessment* (WMO-No. 1095) http://www.wmo.int/pages/prog/hwrp/publications/Technical_report_series/1095_en_4_Web.pdf

- *Integrated Water Resource Management as a Tool for Adaptation to Climate Change*
  http://www.apfm.info/publications/manuals/Cap-Net%20IWRM%20Adaptation%20to%20Climate%20Change%20Tool.pdf
- *Urban Flood Management* (WMO-No. 1372)
  http://www.apfm.info/publications/manuals/Cap-Net%20WMO%20Urban%20Flood%20Management.pdf
- *Guide to Hydrological Practices* (WMO-No. 168)
  http://www.whycos.org/chy/guide/168_Vol_II_en.pdf
- *Heatwaves and Health: Guidance on Warning-System Development* (WMO-No. 1142)
  https://drive.google.com/a/wmo.int/file/d/0BwdvoC9AeWjUb2NHYVNyQU5QaW8/view?pli=1

Climate monitoring products. For monitoring and diagnosing the climate of a country, it is necessary to understand its current climate conditions as part of the global climate system. In addition to monitoring local climates for national interests and relating current episodes to historical patterns, the Climate Service should aim to place the local variations within a larger regional and even global context and provide summarized information. Good monitoring products are essential for climate predictions and updates.

Indices. Climate indices are widely used to characterize features of the climate for climate prediction and to detect climate change. They may apply to individual climatological stations or describe some aspect of the climate of an area. Indices usually combine several elements into characteristics of, for example, droughts, continentality, phenological plant phases, heating degree-days, large-scale circulation patterns and teleconnections. Examples of indices are the El Niño–Southern Oscillation Index; the North Atlantic Oscillation Index, etc.

Climate models and climate outlooks include the following:

Climate predictions and projections. A climate prediction is a probabilistic statement about the future climate on timescales ranging from years to decades. It is based on conditions that are known at present and assumptions about the physical processes that will determine future changes. A climate projection is usually a statement about the likelihood that something will happen several decades to centuries in the future if certain influential conditions develop. In contrast to a prediction, a projection specifically allows for significant changes in the set of boundary conditions, such as an increase in greenhouse gases, which might influence the future climate.

- Regional Climate Outlook Forums
  https://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

Climate scenarios. A major use of global climate models is the generation of climate scenarios. A climate scenario refers to a plausible future climate constructed for investigating the potential consequences of human-induced climate change, but should also represent future conditions that account for natural climate variability. The IPCC reports and publications (for example, IPCC, 2013) provide a good source of information about climate scenarios.

- IPCC publications portal
  http://ipcc.ch/publications_and_data/publications_and_data_reports.shtml

Global climate models. Global climate models (GCMs) are designed mainly for representing climate processes on a global scale. They provide the essential means to study climate variability for the past, present and future. Initially, GCMs were directed at coupling the atmosphere and ocean: most state-of-the-art GCMs now include representations of the cryosphere, biosphere, land surface and land chemistry in increasingly complex integrated models that are sometimes called climate system models.

Downscaling: regional climate models. The downscaling relates the properties of a large-scale model to smaller-scale regions. The approach can be either dynamical or statistical or a combination of the two. The dynamical approach involves nesting limited-area high-resolution models within a coarser global model. Tools used in this process are known as regional climate models. They typically use the synoptic and larger-scale information from a GCM to drive a regional or mesoscale dynamical model.

Local climate models. Unlike global and regional climate models, which seek to model the climate of the entire globe or a large part of the globe over an extended period of time, local climate models attempt to simulate microscale climate over a limited area of a few square metres to a square kilometre for a short time.

Reanalysis products. The time-critical nature of weather prediction means that the initializing analysis must usually begin before all observations are available. Reanalysis uses the same process (and often the same systems), but as it is done weeks or even years later, it is able to use a more complete set of observations. These reanalysis systems generally incorporate a prediction model that provides information on how the environment is changing with time, while maintaining internal consistency.

Climate outlooks. Climate outlooks are forecasts of the values of climate elements averaged over timescales of about one month to one year. The climate elements typically forecast are average surface air temperature and total precipitation for a given period. Since the ENSO phenomenon has a significant impact on the climate in many parts of the world, forecasts of the beginning, end and intensity of ENSO events and forecasts of tropical Pacific Ocean sea-surface temperatures are also included in climate outlooks.

The examples of different climate products and data displays are available in the WMO *Guide to Climatological Practices* (WMO, 2011(b)).

Agriculture and food security

Agriculture is inherently sensitive to climate conditions and is among the sectors most vulnerable to weather and climate risks. Despite impressive advances in agricultural technology over the last half a century, climate variability has a significant influence on agriculture, which is heavily dependent on rainfall, sunshine and temperature. Progress continues in the fight against hunger, yet an unacceptably large number of people still lack the food they need for an active and healthy life. The latest available estimates indicate that about 795 million people in the world – just over one in nine – were undernourished (FAO, IFAD and WFP, 2015). Of the total annual crop losses in world agriculture, many are due to direct weather and climatic effects, such as droughts, flash floods, untimely rains, frost, hail and severe storms (Hay, 2007). The number of hydrometeorological hazards in particular (such as droughts, floods, tropical storms and wildfires), which were measured on an average of 195 per year in 1987 and 1998 increased to 365 per year from 2000 to 2008 (WMO, 2014(b)). Human-induced climate change has introduced a new, complicating factor into the food security equation: modifying natural climate variability.

Agriculture and food security in the 21st century face multiple challenges. Extreme weather, climate variability and long-term climate change pose important challenges to future agriculture and food security. Climate-related disasters, such as droughts and floods, can lead to crop failure, food insecurity, destruction of key livelihood assets, mass migration of people and negative national economic growth (WMO, 2014(c)). Adverse weather and climate conditions directly affect agricultural productivity, livelihoods, water security, land use, agricultural marketing systems, market instability, food prices, trade, and economic policies. Small-holder farmers, fishers, livestock herders and forest-dependent communities are often highly vulnerable to these impacts. A recent FAO study (FAO, 2015(a)) highlighted that between 2003 and 2013, economic impacts of climate-related disasters on agricultural sectors in developing countries accounted for about 25 % of the total recorded damage and loss. Climate change is expected to affect all the components that influence food security: availability, access, stability and utilization.

Climate change will act as a hunger-risk multiplier, exacerbating the risk factors that impact food security. The Intergovernmental Panel on Climate Change (IPCC) has highlighted multiple climate risks to agriculture and food security and described the potential for meteorological information to improve early warning systems for meteorological risks. Climate change will exacerbate existing threats to food security and livelihoods from a combination of increasing frequency of climate hazards, diminishing agricultural production in vulnerable regions, expanding health risks, increasing water scarcity and intensifying conflicts over scarce resources, which will likely lead to new humanitarian crises, as well as increasing displacement. Fisheries are threatened by changes to the environment associated with increased GHG emissions, including higher water temperatures and increases in ocean acidification, which change marine fish distribution. Climate change can affect the production and health of animals, and the suitability and range of pasture lands.

Climate services in agriculture can help develop sustainable and economically viable agricultural systems, improve production and quality, reduce losses and risks, decrease costs, increase efficiency in the use of water, labour and energy, conserve natural resources and decrease pollution by agricultural chemicals or other agents that contribute to the degradation of the environment (WMO, 2014(c)). Climate services are critical for strengthening the information and early warning systems on food and agriculture.

Weather and climate data

Under activity in stocktaking in the first element of the NAP process – Laying the groundwork and addressing gaps – one important question relates to the type of data and knowledge available to assess current and future climate risks, vulnerability and adaptation. Another question relates to identifying gaps regarding the capacity, adequacy of data and information, and resources required to engage in the NAP process. This activity establishes the knowledge base for developing an NAP, drawing on available data and information. A gap analysis will identify areas that require strengthening in order for the country to successfully undertake the NAP process. Potential barriers to the design and implementation of adaptation will be identified and a plan to address them developed. Another activity under the second element of the NAP process (Preparatory elements) is related to the analysis of current climate and future climate change scenarios. One question that needs to be addressed here is: "Which climatic patterns in the country, according to observed data, are most important in terms of adjustment, adaptation or acclimatization of social systems?". In the Priority Area Agriculture, the aspect of weather- and climate-data collection and sharing provides useful information to these activities in the NAP process.

Data collection and sharing is an important task in determining weather and climate impacts on agriculture and food security outlooks. The agriculture and food-security community relies on appropriate and timely phenological, environmental and climate information at relevant space- and timescale data points to make informed decisions. Priority activities include upgrading the monitoring and data-collection network in rural areas, increasing the sharing of data from existing networks, and improving systematic data archival and management. Available, accessible, comprehensive and useful weather and climate data can help agriculture and food-security decision-makers improve their understanding of climate's impact on agricultural development and food systems and their estimates of populations at risk (e.g. risk mapping). Weather and climate data can be particularly helpful to anticipate, prepare for, and respond to, agriculture or food-security risks, on both short timescales to address problems triggered by climate extremes (droughts, thermal extremes) and longer-term risks associated with climate change (increased frequency of cyclones, desertification).

An excellent example of an existing activity that is improving the use of meteorological and climate data is the Livelihoods, Early Assessment and Protection food-security early warning tool in use in Ethiopia. Such early warning systems for drought, famine and climate extremes have great potential for improving food security.

One priority action area is improved data collection and use (meteorological, agrometeorological, climatic, agronomic, pest and disease), which includes the following activities (WMO, 2014(c)):

- Sharing data from existing networks;

- Upgrading the monitoring and data-collection network in rural areas, as well as systematic data archival and management;

- Improving the reporting of national yield, area and production statistics, as well as of other data (pest and diseases).

NMHSs can provide weather and climate information to the agricultural sectors (agriculture, livestock, fishery and forestry) that can be particularly helpful to anticipate, prepare for, and respond to, agriculture or food-security risks, on both short timescales to address problems triggered by climate extremes (droughts, floods, thermal extremes) and longer-term risks associated with climate change (increasing temperature, loss of biodiversity, land and forest degradation, salinization and desertification). NMHS databases which are currently available increase climate knowledge and improve prediction capabilities, facilitating agricultural and food-security decision-making from international policy level to local operational farm-management strategies. Through the analysis of long-term climatic data and use of current weather observations, NMHSs provide agrometeorological advisories and services to the agricultural sectors on a regular basis during the cropping season. These enable farmers, herders and fishers to make appropriate operational decisions on their livelihoods for efficient management of natural resources and to improve agricultural productivity.

Information products and services

Under the first element of the NAP process (Laying the groundwork and addressing gaps), the third activity focuses on addressing capacity gaps and weaknesses. The fourth activity focuses on comprehensively and iteratively assessing development needs and climate vulnerabilities. Under the second element of the NAP process (Preparatory elements), one important question that needs to be answered regards the appropriate indices of climate trends which could support planning and decision-making. Two other activities in this element cover the aspects of assessing climate vulnerabilities and identifying adaptation options at sector, subnational, national and other appropriate levels and reviewing adaptation options. In the Priority Area Agriculture, emphasis is placed on assessing the needs of the agriculture sector and the provision of appropriate data, information products and services to the agricultural community (Table 1) and how the capacity gaps and weaknesses in this process can be addressed.

Table 1. Weather and climate data, information products and services to the agricultural community

Area	Variable(s)	Information products and services
Weather	Air temperature	• Temperature probabilities • Chilling hours • Degree-days • Hours or days above or below selected temperatures • Interdiurnal variability • Maximum and minimum temperature statistics • Growing season statistics (dates when threshold temperature values for the growth of various kinds of crops begin and end).
	Precipitation	Probability of a specified amount during a period • Number of days with specified amounts of precipitation • Probabilities of thundershowers • Duration and amount of snow cover • Dates on which snow cover begins and ends. • Probability of extreme precipitation amounts
	Wind	• Windrose • Maximum wind, average wind speed • Diurnal variation • Hours of wind less than selected speed

Area	Variable(s)	Information products and services
	Sky cover, sunshine and radiation	• Per cent possible sunshine • Number of clear, partly cloudy, cloudy days • Amounts of global and net radiation
	Humidity	• Probability of a specified relative humidity • Duration of a specified threshold of humidity
	Free water evaporation	• Total amount • Diurnal variation of evaporation • Relative dryness of air • Evapotranspiration
	Dew	• Duration and amount of dew • Diurnal variation of dew • Association of dew with vegetative wetting • Probability of dew formation based on the season
	Hazards and extreme events	• Frost • Cold wave • Hail • Heatwave • Cyclones • Floods • Rare sunshine • Waterlogging • Gales
	Weather forecasts	• Nowcasting • Very short-range forecasts • Short-range forecasts • Medium-range forecasts • Long-range forecasts
Climate	Recent and historical climate data	• Statistics of data • Probabilities • Extreme-value analysis • Long-term means and trends • Diagnostics of climate-variability characteristics • Diagnostics, assessment and attribution of current seasonal/subseasonal rainfall and temperature patterns and their anomalies, including the associated circulation features
	Climate extremes	• Drought frequencies • Drought indices • Indices of climate extremes or other, more complex indices that combine several parameters with different thresholds (e.g. temperature with precipitation and humidity) • Information on the distribution, frequency and intensity of climate extremes, such as forest and grassland fires, droughts, floods and heatwaves, including special reports on contemporary and past events
	Climate forecasts	• Monthly, seasonal and decadal forecasts on rainfall and temperature, adequately incorporating aspects of uncertainty • Global climate models • Regional climate models • Information on the relevance of major drivers of climate variability (El Niño/La Niña, North Atlantic Oscillation, Indian Ocean Dipole, Madden-Julian Oscillation)
	Climate products	• Products (datasets, text, maps, charts, statistics, etc.) that describe the past, present and future climate of different locations and regions in a country • Climate monitoring products such as national state-of-the-climate reports • Climate change projection products, including downscaled national projections based on appropriate IPCC scenarios

Area	Variable(s)	Information products and services
Land	Soil temperature	• Mean and standard deviation at standard depth • Depth of frost penetration • Probability of occurrence of specified temperatures at standard depths • Dates when threshold values of temperature (germination, vegetation) are reached.
	Soil water	• Soil–water balance: moisture assessment and forecasts • Actual evapotranspiration • Irrigation scheduling

Preparedness is urgently needed to improve the effectiveness of response and recovery, such as establishing early warning systems to shift from crisis management to risk management for long-term planning strategies to cope with climate extremes and climate change in the agriculture sector. Through effective delivery of climate services, NMHSs can help inform decision-making in disaster risk reduction and adaptation planning in agricultural sectors. Linking climate service development to adaptation planning will, therefore, be critical.

Agriculture and food security users also have experience with, and need for, functioning and applied weather and climate services that are particularly critical for risk and preparedness management and short-range planning (WMO, 2014(c)). Common, albeit not exclusive, decisions that benefit from the use of information about the weather and climate include:

- Identification of extreme weather and climate hazards that pose risks to agriculture and food security;
- Identification of populations vulnerable to weather and climate hazards;
- Plant and animal pest- and disease-control strategies;
- Regulation and laws;
- Pesticide and herbicide applications, fertilizer management, farm and irrigation management;
- Weather- and climate-sensitive decisions in the agriculture and food-security value chains;
- Decisions on export and import of agricultural inputs and products;
- Decisions related to marketing agriculture and food-security products.

Recent publications in this regard include the following:

- *Guidelines for Preparation of the Drought Management Plans* (ISBN: 978-80-972060-1-7)

http://www.droughtmanagement.info/literature/GWPCEE_Guidelines_Preparation_Drought_Management_Plans_2015.pdf

- *Drought Monitoring and Early Warning* (WMO-No. 1006)

http://www.wamis.org/agm/pubs/brochures/WMO1006e.pdf

Intra- and interseasonal variability has a major impact on agriculture and food security. Seasonal climate outlooks can influence decisions on which varieties to plant and when or the best timing for spraying where plant disease outbreaks are likely to occur or perhaps estimating the quantity of water needed for irrigation or whether to reduce livestock numbers if a drought is forecast. Farmers may be unprepared for expected weather conditions and make decisions based on an

Box 4. Tools and products to provide climate services for the agricultural sector

Detailed observations and real-time dissemination of meteorological information, quantification by remote-sensing (radar and satellites) and derived indices and operational services are important for facilitating tactical on-farm operational decisions at different crop-growth stages by farmers. The economic value of weather information products is steadily increasing as a result of rising public awareness. Facilities for data quantity and quality control, quick processing and analysis have made this possible. To make information available to assist farmers all the time at the field level, to prepare advisories and to facilitate long-term planning, it is necessary to combine the agricultural and the meteorological data. The tools and products include the following:

- Primary tools, including data, quantification, statistics, indices and modelling;
- Monitoring and early warning tools for preparedness strategies;
- Forecasting and prediction tools to guide preparedness with probabilities;
- Direct preparedness strategies for crop, forest and livestock protection;
- Determination of crop weather/climate requirements; classification of land into crop suitability zones, integrating both climate and soil factors; and more detailed determination of differences in the impacts of climatic events, particularly recurring events (whether or not related to ENSO phenomena), such as droughts, floods and cyclones, under different preparedness strategies.

The data for agrometeorological applications and their distribution; database management; statistical methods of agrometeorological data analysis; weather and climate forecasts for agriculture; climate and weather risk assessment for agricultural planning and agrometeorological services for selected crop production, forestry, livestock, aquaculture and fisheries and for arresting land degradation are described in detail in the WMO *Guide to Agricultural Meteorological Practices* (WMO, 2010). Two examples of the tools and products for farmers are given below.

Standardized Precipitation Index

Drought is an insidious natural hazard that results from lower levels of precipitation than what is considered normal. Drought means different things to different users, such as water managers, agricultural producers, hydroelectric power-plant operators and wildlife biologists. Even within sectors, there are many different perspectives of drought because impacts may differ markedly. Over the years, many drought indices have been developed and used by meteorologists and climatologists around the world. Experts who participated in the Interregional Workshop on Indices and Early Warning Systems for Drought (University of Nebraska-Lincoln, USA, December 2009) elaborated and approved the Lincoln Declaration on Drought Indices, which recommended that the Standardized Precipitation Index (SPI) be used by all NMHSs worldwide to characterize meteorological droughts, in addition to other drought indices that were in use in their Service (WMO, 2012).

- *Standardized Precipitation Index User Guide* (WMO-No. 1090)
  http://www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdf

SPI (McKee et al., 1993; 1995) is a powerful, flexible index that is simple to calculate. It can be computed for different timescales, provide early warning of drought and help assess drought severity. The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater-than-median precipitation and negative values indicate less-than-median precipitation. Because SPI is normalized, wetter and drier climates can be represented in the same way, thus, it can also be used to monitor wet periods. McKee et al. (1993) used the classification system shown in the SPI value table below to define drought intensities resulting from SPI. They also defined the criteria for a drought event for any of the timescales.

A drought event occurs any time SPI is continuously negative and reaches an intensity of 1.0 or less. The event ends when SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end and an intensity for each month that the event continues. The positive sum of SPI for all the months within a drought event can be termed the drought's "magnitude".

SPI value	Category
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
–.99 to .99	Near-normal
–1.0 to -1.49	Moderately dry
–1.5 to -1.99	Severely dry
–2 and less	Extremely dry

The latest SPI program (SPI_SL_6.exe) and instructions for Windows/PC use can be found at http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx.

Agricultural Stress Index

The Agricultural Stress Index (ASI) is an index based on the integration of the Vegetation Health Index (VHI) in two dimensions that are critical in the assessment of a drought event in agriculture. The first step of the ASI calculation is a temporal averaging of VHI, assessing the intensity and duration of dry periods occurring during the crop cycle at pixel level. The second step determines the spatial extent of drought events by calculating the percentage of pixels in arable areas with a VHI value below 35 % (this value was identified as a critical threshold in assessing the extent of drought. Finally, each administrative area is classified according to its percentage of affected area to facilitate the quick interpretation of results by analysts (FAO, 2015(b)).

http://www.fao.org/giews/earthobservation/asis/index_1.jsp?lang=en

Agricultural weather forecasts

An agricultural weather forecast refers to all weather elements that immediately affect farm planning or operations. The elements will vary from place to place and from season to season. Normally, a weather forecast includes the following parameters:

- Amount and type of cloud cover;
- Rainfall and snow;
- Maximum, minimum and dewpoint temperatures;
- Relative humidity;
- Wind speed and direction;
- Extreme events, such as heatwaves and cold waves, fog, frost, hail, thunderstorms, wind squalls and gales, low-pressure areas, different intensities of depressions, cyclones and tornadoes.

Formats of forecasts for agriculture vary widely in different agricultural contexts due to the high degree of variability among users, crops, agrotechniques, etc. Specialized forecasts can be tailored for crops, animal husbandry, forestry, fisheries and horticulture.

Detailed information on the considerations related to agricultural weather forecasts, including the different elements and format thereof, specific description of the processing of weather forecasts of single weather variables for agricultural purposes, etc., can be found in the WMO *Guide to Agricultural Meteorological Practices* (WMO, 2010).

understanding of general climate patterns in their regions. Better climate predictions three to six months in advance can help shape appropriate decisions, reduce impact and take advantage of favourable forecast conditions. Seasonal forecasts provide probability distribution for monthly to seasonal means of climate parameters (in terms of their departures from long-term averages), such as rainfall and temperature, several months in advance that can be used for crop-yield estimates. Yet, information about growing-season weather beyond the seasonal average is also needed, such as growing degree-days, chill days and changes in the growing season (WMO, 2014(c)). This approach addresses the activity, comprehensively and iteratively, of assessing development needs and climate vulnerabilities in the first element of the NAP process: Laying the groundwork and addressing gaps. The activity on enhancing capacity for planning and implementation of adaptation under the third element (Implementation strategies) of the NAP process is also addressed by this approach.

Seasonal climate forecasts tend to be more useful during ENSO events. Although the ENSO phenomenon occurs within the tropical Pacific, it affects interannual weather variability in many other regions of the world. Good teleconnections with ENSO do exist, for example, with the regional climate during cropping seasons in West Africa, southern Africa and the October–December "short rains" in East Africa. Seasonal climate outlooks issued by NMHSs in these regions can influence decisions on which varieties to plant and when, or the best timing for spraying where plant disease outbreaks are likely to occur, or perhaps estimate the quantity of water needed for irrigation or whether to reduce livestock numbers if a drought is forecast. Countries in these regions jointly access forecasts based on such teleconnections through the Regional Climate Outlook Forum (RCOF) process and develop a consensus-based seasonal climate outlook. In East Africa, the Food Security Outlook (FSO) process links output from the Greater Horn of Africa COF to deliver early warning of risks that could affect food security in the coming six months. This process uses meteorological and seasonal climate projections based on ENSO, sea-surface temperatures of the Indian and Atlantic Oceans and other influences of rainfall in the Greater Horn of Africa. The input data come from a variety of sources, including the Intergovernmental Authority on Development Climate Prediction and Applications Centre, NMHSs and the FEWS NET partners, including NOAA and the UK Met Office. The data are fed into dynamic and statistical models to produce rainfall forecasts that are analysed and interpreted by experts. The rainfall forecasts are then related to food-security and vulnerability data provided by the World Food Programme, the United Nations Food and Agriculture Organization and NGOs to produce the FSO reports which provide decision-makers with crucial early insights for food-security risk reduction. The FSO and RCOF processes include development of user capacity to understand and use the information.

Numerous projects around the world aim to deliver reliable, timely, locally understandable climate information with response options to farmers, considering inputs, credit, market and financial aspects. They include interdisciplinary training, knowledge-building and awareness-raising. Examples of existing activities in this category include the World AgroMeteorological Information Service (WAMIS) of WMO which hosts agrometeorological bulletins and advisories issued by NMHSs, aiding user evaluation of various bulletins and sharing insight into improving their own bulletins. More than 50 countries and institutions participate in this service (http://www.wamis.org). WAMIS also hosts a tools and resources section, which contains data, information, dissemination and feedback. Other examples include software, Web portals, training resources and tutorials, climate and agriculture working groups in Africa and Indonesia, such as the Farmer Field Schools of Indonesia and resilience-building initiatives focused on weather-indexed insurance, micro-credit and risk reduction activities (WMO, 2014(c)). WAMIS provides a good example of what can be learned from international experiences and international cooperation in adaptation planning under the third element (Implementation strategies) of the NAP process.

Disaster risk reduction

Natural hazards involving weather, climate and water are a major source of death, injury and physical destruction. Natural hazards become natural disasters when people's lives and livelihoods are destroyed. Natural hazards cause significant loss of life every year. They cause human and material losses that erode gains in economic development and are a major obstacle to sustainable development. Nine in 10 of the most commonly reported disasters are directly or indirectly related to weather or climate. During the past five decades, disasters of hydrometeorological origin, such as droughts, floods, storms, tropical cyclones and wildfires, have caused major losses of human lives and livelihoods and the destruction of economic and social infrastructure, as well as environmental damage. According to the Centre for Research on the Epidemiology of Disasters (CRED, 2015), 11 938 disasters occurred from 1970 to 2014, leading to a total loss of 3.48 million lives and economic losses amounting to US$ 2.69 trillion.

Among the 10 costliest storm events between 1980 and 2014, ordered by overall losses (Munich RE, 2015), Hurricane Katrina in the USA in August 2005 ranked first with overall losses of US$ 125 billion and 1 322 fatalities, followed by Hurricane Sandy, which struck the Bahamas, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, Canada and the USA in October 2012 with overall losses of US$ 68.5 billion and 210 fatalities. Among the 10 costliest floods from 1980 to 2014, the floods and landslides in Thailand in November 2011 were ranked first, with overall losses of US$ 43 billion and 813 fatalities.

A higher number of disasters that are linked to environmental hazards occur in developing countries, where their impacts are greater. According to Munich RE (2013), the average percentage of direct losses per year with respect to Gross Domestic Product is highest in emerging economies at 2.9 %, compared with developing economies (1.3 %) and industrialized countries (0.8 %).

Natural hazards occur across different space- and time scales and each is unique in some way. Tornadoes and flash floods are short-lived violent events that affect relatively small areas. Other hazards, such as droughts, develop slowly but can affect large areas of a continent and entire populations of smaller countries for months or even years. In temperate latitudes, protracted periods of hot weather (heatwaves) in summer can lead to severe heat stress in vulnerable populations. An extreme weather event can involve multiple hazards at the same time or in quick succession. In addition to high winds and heavy rain, a tropical storm can result in flooding and mudslides.

Figure 5 shows how the frequency of disasters increased steadily from 1970, peaking fin 2000. Such changes in weather and climate extremes and their related impacts pose challenges for national and local disaster risk reduction systems. Better climate services can help meet these challenges, in both the short and the long term, by providing decision-makers with enhanced tools and systems to analyse and manage risk under current hydrometeorological conditions and in the face of climatic variability and change (WMO, 2014(d)). The value of climate services in reducing disaster risk is broadly recognized, given the preponderance of hydrometeorological hazards in shaping disaster risk, and the fundamental role that climate information plays in disaster risk reduction efforts (WMO, 2014(d)). Disaster risk reduction decisions are taken by a broad group that encompasses disaster risk managers, as well as government sectors, humanitarian and development agencies and banks, the private sector, NGOs, communities and individuals. Multiple consultations, meetings and publications conclude that these actors need climate information that is tailored to their specific decision-making needs and is provided in appropriate language and formats that facilitate action (Helmuth et al., 2011).

To reduce and mitigate disasters, NMHSs provide quick, timely, accurate, broadly disseminated and understandable information, as well as high-quality services to inform governments and the public to take appropriate actions in response to warnings. Under climate services for disaster risk reduction, there are six priority categories of activities (Figure 6) that would catalyse the provision of related products and services by NMHSs and promote widespread implementation of programmes and initiatives that incorporate climate information and services (WMO, 2014(d)). These categories are aligned with existing disaster risk reduction structures and are compatible with other relevant international initiatives, including SFDRR.

These categories include:

(a) **Risk assessment.** Information on weather and climate hazards needs to be complemented with exposure and vulnerability information to develop a complete picture of risk. Climate information is critical for the analysis of hazard patterns and trends.

(b) **Loss data.** Historical and real-time data on loss and damage provide a crucial input for assessing risks of future disasters. Over time, climate services provide information on historical and ongoing extreme climate events and help to identify and build processes for integrating this information into loss- and damage-accounting systems.

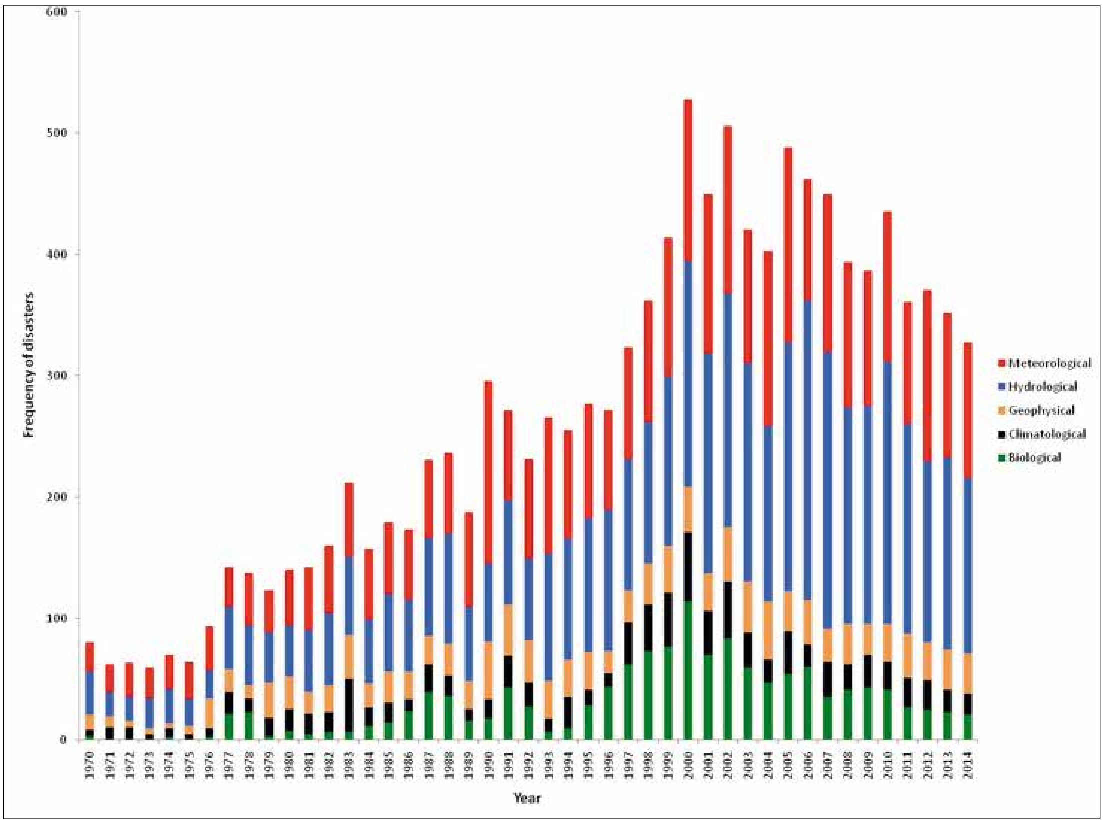


Figure 5. Frequency of natural disasters from 1970 to 2014

Source: CRED, 2015

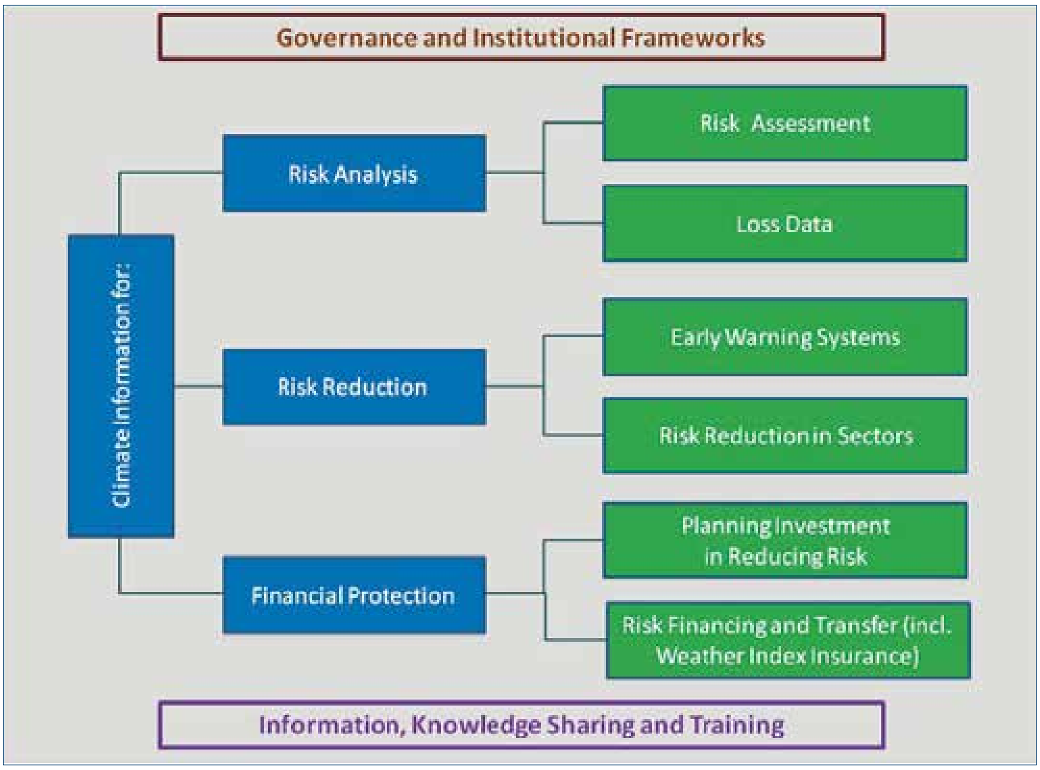


Figure 6. Priority categories of activity under climate services for disaster risk reduction (in green)

(c) **Early warning systems.** Lessons learned from a number of good national practices in multi-hazard early warning systems indicate that these systems enable decisions to protect lives and livelihoods in short- and longer-term timeframes by extending the lead time for contingency planning and preparation. Both short-term weather forecasts and seasonal forecasts can be used to build reliable deterministic or probabilistic risk scenarios and, in turn, to strengthen disaster preparedness.

(d) **Risk reduction in climate-sensitive sectors.** Climate-sensitive sectors include agriculture, health, water, energy, housing, infrastructure, tourism, industry and trade. Multisectoral plans to reduce disaster risk and to adapt to climate change consider historical, current and long-term risk in order to avoid investment that locks in future risk or results in maladaptation, such as infrastructure that cannot withstand shorter return times for heavy rain.

(e) **Planning investment in reducing risk.** Sound financial planning and investment play a crucial role in reducing the risk of disaster. Climate information is an important component of the evidence base required to guide decisions regarding appropriate levels of investment to minimize potential impacts on the economy, ensuring uninterrupted delivery of critical services and infrastructure, investing in the development of early warning systems and contingency planning, reserving contingency funds for emergency use and potentially subsidizing vulnerable or affected sectors to help protect socioeconomic welfare.

(f) **Risk financing and transfer.** Disaster-risk financing and transfer can be broadly defined as structured sharing of the potential financial impacts of disasters caused by natural hazards, often, but not systematically, through insurance mechanisms. Risk financing and transfer require climate services to inform risk assessments and catastrophe risk analysis, ideally based on at least 30 years of hydrometeorological and other asset and vulnerability information. In the case of innovative risk-transfer tools, such as weather derivatives or index-based insurance, climate information is also needed to determine payout structures, as these are not based on actual losses but are triggered by meteorological parameters, such as wind, rainfall and temperature. Forecasts of these types of parameters have been used for both portfolio risk management and diversification purposes.

As shown in Figure 6, the six categories of activities are drawn from more general areas of disaster risk reduction practice, which may benefit over time in other ways from enhanced climate services. Risk assessment and loss data are both forms of risk analysis. Early warning systems and sectoral risk reduction fall within the broader heading of risk reduction actions. Finally, both planning investment in reducing risk and risk financing and transfer comprise a part of a larger category of financial protection activity aimed at lessening the economic impact of disasters. Clearly, there is a great deal of interaction between the areas, as, for instance, risk analysis is the basis for effective risk reduction and financial planning and planning investment is required to finance both risk analysis and risk reduction.

The boxes at the top and bottom of Figure 6 represent the essential role of governance and institutional frameworks and information and knowledge-sharing in integrating climate services into all these disaster risk reduction activities. These elements are part of all six of the priority categories, and should also be considered priority elements of GFCS for disaster risk reduction.

The above activities and the ones described below under weather and climate data and information products and services for the Priority Area Disaster risk reduction are linked to the following activities under the various elements of the NAP process:

(a) **Laying the groundwork and addressing the gaps.** Stocktaking: identifying available information on climate change impacts, vulnerability and adaptation and assessing gaps and needs of the enabling environment for the NAP process; addressing capacity gaps and weaknesses in undertaking the NAP process; and comprehensively and iteratively assessing development needs and climate vulnerabilities;

(b) **Preparatory elements.** Analysing current climate and future climate change scenarios (What risks does climate change hold for the country? What are the major current climate hazards?); assessing climate vulnerabilities and identifying adaptation options at sectoral, subnational, national and other appropriate levels; reviewing adaptation options;

(c) **Implementation strategies.** Prioritizing climate change adaptation in national planning; developing a (long-term) national adaptation implementation strategy (What is the most appropriate strategy for the implementation of adaptation activities, including timing, target areas/beneficiaries, responsible authorities and sequencing of activities? How can the implementation build on and complement existing adaptation activities?); enhancing capacity for planning and implementation of adaptation; promoting coordination and synergy at the regional level and with other multilateral environmental agreements (How can the cross-sectoral and regional coordination of adaptation planning be promoted and enhanced?; How can synergy with other multilateral environmental agreements in the planning and implementation process be identified and promoted?).

Table 2 shows the different weather and climate service data and products that support the different elements of the NAP process.

Table 2. Different weather and climate service data and information products and services for the Priority Area Disaster risk reduction that support the different elements of the NAP process

Element	Step	Weather and climate data and information products and services
Laying the groundwork and addressing the gaps	Stocktaking: identifying available information on climate change impacts, vulnerability and adaptation and assessing gaps and needs of the enabling environment for the NAP process	Historical extreme climate events • Archive of past losses • In situ and space-based Earth system observing networks for the monitoring and detection of hazards, designed with consideration for decision-making spatial and temporal requirements • Archives and real-time data records and metadata flagging when events can be expected for dynamic risk assessment • Real-time monitoring of hazards and development of historical databases and metadata per standards
	Addressing capacity gaps and weaknesses in undertaking the NAP process	• Identify responsible bodies for developing and implementing appropriate measures, warning communication and awareness and education activities
	Comprehensively and iteratively assessing development needs and climate vulnerabilities	• Provide understanding of risk-assessment demand and requirements • Incorporate relevant climate observations, statistical analysis, forecasts and projections of the weather, hydrological and climate-related extremes in risk-assessment processes
Preparatory elements	Analysing current climate and future climate change scenarios	• Forward-looking forecasts and trend analysis of hazard characteristics at different temporal and spatial resolutions • Risk analysis (multi-hazard, multi-level and multi-sector) • Identification of information requirements and channels

Element	Step	Weather and climate data and information products and services
	Assessing climate vulnerabilities and identifying adaptation options at sector, subnational, national and other appropriate levels	• Define requirements for climate services and other non-climate inputs for planning investment in reducing climate vulnerabilities • Engage stakeholders for implementation – finance and planning ministries, disaster risk management authorities, local authorities and government, private sector, etc. • Establish coordination and information channels for relevant inputs
	Reviewing and appraising adaptation options	• Identify stakeholders and existing processes for hazard loss-accounting system implementation • Identify information channels • Coordinate development of relevant climate products and services in relation to specific application to decision-making in different sectors
Implementation strategies	Prioritizing climate change adaptation in national planning	• Identify priority regions based on analysis of vulnerability to weather and climate extremes and other important factors and future projections
	Developing a (long-term) national adaptation implementation strategy	• Identify the areas where current information on weather and climate is inadequate • Strengthen the meteorological observation networks, data analysis and applications
	Enhancing capacity for planning and implementation of adaptation	• Strengthen operational climate services, including analysis, forecasts and projection of climatic regimes and probabilities and scenarios related to extreme patterns • Promote interoperability of health, socioeconomic and biological data with weather, hydrological and climate extremes and changes in their characteristics
	Promoting coordination and synergy at the regional level and with other multilateral environmental agreements	• Strengthen cooperation with WMO Regional Climate Centres

Weather and climate data

NMHSs can provide past climate data which are essential for quantifying hazard characteristics of a region, in particular the frequency, severity and location of climatic extremes by retrieving and computerizing all available data at the highest temporal and spatial resolution possible in order to capture the characteristic features of particular hazards. While historical climate data remain the prime resource for analysing hydrometeorological hazard patterns, emerging trends in rainfall and temperature over the past several decades suggest that hazard characteristics may be changing. For instance, what had been a one in a 100-year flood or drought in a location may now have become a one in a 30-year flood or drought. Essentially, the statistics of the past 10–20 years may be more representative of the current climate than the longer-term statistics. While there are statistical techniques for generating pseudo-records from relatively short records, the best hope of obtaining data for estimating future risk is through modelling of the climate system.

As there is a significant difference between a hazard and disaster – with not every hazardous event becoming a disaster – NMHSs can pay special attention to gathering and documenting the meteorological and related conditions associated with the latter, since the information can often be used later in strengthening resilience during the post-disaster reconstruction phase. The disaster databases compiled by the insurance group Munich RE and CRED, for example, are useful resources for identifying events for which complementary weather and climate datasets could be compiled at national level.

Information products and services

An essential starting point for reducing risks from disasters is a quantitative assessment that combines information about the hazards with exposures and vulnerabilities of the population or assets, such as agricultural production, infrastructure and homes. NMHSs can provide information on weather and climate hazards which can be complemented with exposure and vulnerability information to develop a complete picture of risk. Armed with evidence concerning risk, individuals, communities, organizations, businesses and governments can make decisions to protect themselves from loss and adapt to the changing climate. Climate information is critical for the analysis of hazard patterns and trends. NMHSs can also provide information on historical and ongoing extreme climate events, which can help to identify and build processes for integrating this information into loss- and damage-accounting systems.

In the past five decades, mortality rates from disasters have decreased in some regions as a consequence of the development of multi-hazard early warning systems by NMHSs working together with the public and private sectors, which aim to further reduce significantly the number of fatalities caused by weather-, water- and climate-related natural disasters. These systems enable decisions to protect lives and livelihoods in short- and longer-term time frames by extending the lead time for contingency planning and preparation. By helping governments and populations to avert potential disasters and maximize opportunities for sustainable development, NMHSs are one of the main components of countries' risk-information management, crisis management and development infrastructure.

NMHSs can also provide climate services for risk financing and transfer to inform risk assessments and catastrophe risk analyses, which are ideally based on at least 30 years of hydrometeorological data and other asset and vulnerability information. Moreover, NMHSs provide climate information for innovative risk-transfer tools, such as weather derivatives or index-based insurance in order to determine payout structures, as payouts are not based on actual losses but are triggered by meteorological parameters such as wind, rainfall and temperature. For example, weather-index-based crop insurance provides financial coverage to protect smallholder farmers against the potential impacts of deficient/erratic rainfall, extreme temperatures and other environmental variables. An index-based insurance contract pays out on the value of an index; in this case, the index is based on measured hydrometeorological variables, such as rainfall, temperature or river levels. Forecasts of these types of parameters have been used for both portfolio risk management and diversification purposes.

Health

Evidence-based decision-making is a fundamental principle for the health sector. The development of health-sector NAPs calls for the health community to access and use appropriate and timely epidemiological, environmental, and weather/climate information at relevant spatial and temporal resolutions to understand risks and make informed decisions.

Climate adaptation planning should aim to make the health system more climate-resilient, with the capacity to anticipate, respond to, cope with, recover from and adapt to, climate-related shocks and stresses, now and in the future. To achieve this goal, a range of health-policy and programme decisions must be climate-informed, including those identified and proposed within a NAP. Therefore, to ensure decision-makers are using the best available information related to climate change and variability, partnerships between health authorities and NHMSs should be part of a health-sector approach to developing and implementing NAPs. Collaboration with NMHSs can also help raise awareness of climate risks to health, support research which builds evidence for health policymaking and operations; and provide both information and climate service products tailored to respond to specific health-decision needs.

The World Health Organization (WHO) has developed guidance for the development of Health-National Adaptation Plans[1], which suggests ways to engage in the overall NAP process at the national level; identify national strategic goals for building health resilience to climate change; and how to develop a national plan with prioritized activities to achieve these goals, within a specific time period and given available resources. This process begins with a thorough Health Vulnerability and Adaptation Assessment[2]. The Operational Framework for Climate Resilient Health Systems, outlines key activities and components which are frequently included in these national plans[3]. Climate services can help to generate evidence and respond to knowledge gaps, identify adaptation needs, and contribute to risk-management tools, such as risk assessments, integrated surveillance, early warning/early action systems, and climate-informed programming.

The main components included in the WHO Operational framework for building climate-resilient health systems are reflected in Figure 7.

Building on this framework, actions which are commonly included within an NAP for health and require climate services may include:

(a) Research

(b Risk and vulnerability identification

(c) Planning disease-control strategies at different timeframes

(d) Adjustment of short- and long-term health policy and regulations

(e) Creation of integrated disease monitoring and surveillance systems

(f) Financial and human resource allocation

(g) Pharmaceutical, health supply, pesticide and vaccine supply flow

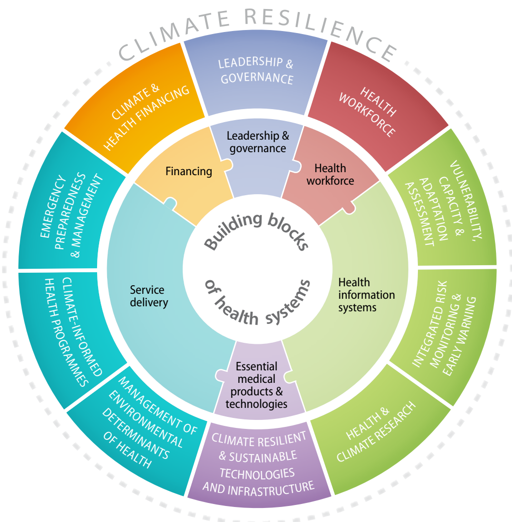


Figure 7. Ten components to build climate-resilient health systems

1 http://www.who.int/globalchange/publications/guidance-health-adaptation-planning/en/

2 http://www.who.int/globalchange/publications/vulnerability-adaptation/en/

3 http://www.who.int/globalchange/publications/building-climate-resilient-health-systems/en/

(h) Health infrastructure sitting and maintenance

(i) Emergency preparedness

(j) Community education and public health information dissemination, for example through public-service announcements and alerts to raise awareness of risks

(k) Targeted public advisories, medicines or supplies for vulnerable populations

(l) Capacity-building and training of the health workforce for potential outbreaks or signs of illness (including side-effects of medicines in extreme temperatures)

(m) Monitoring and evaluation, and impact assessment of climate sensitive interventions.

(n) Impact assessment of policies and programmes proposed under any health-determining sector (e. g. energy, water, food and agriculture, transport)

Among the above-mentioned activities, collaboration with NMHSs can be particularly helpful to:

(a) Provide capacity-building and operational guidance to health partners on how to use climate services and information products, particularly for health-risk assessment, health surveillance and health-service delivery processes, including disaster and outbreak risk management;

(b) Conduct applied and operational research on the need for, and optimal ways of, developing and delivering climate services for health, including identifying the relevant temporal and spatial aspects of meteorological and health data needed for public health analyses and identifying user requirements for product development and application, such as health early warning systems.

Weather and climate data

Health professionals need observational data from NMHSs in order to establish national and subnational level causal linkages between climate conditions and health outcomes. This first order assessment will then inform the further utility of using climate information and services to manage health risks. When strong associations are observed or known, NMHSs provide near-real-time monitoring data of local conditions: for example, air quality can directly inform population advisories or combined data of precipitation, soil moisture and surface air temperature conditions can be used to monitor daily-to-weekly suitability of vector-borne disease transmission.

Depending on the capacity of the NMHS, the availability and quality of data will vary. NMHSs can support health actions through the provision of weather and climate data (WMO, 2014(d)), such as:

(a) Data collection and access: specific measures may be needed as part of the adaptation strategy to improve (i) the availability of historical and future hazard data, metadata, tools and methodologies in hazard identification, monitoring, and mapping; but also (ii) availability of health exposure, impact, and vulnerability information, and user-capacity to incorporate climate information in routine health decisions;

(b) Integrated data management: health surveillance is analogous to systems for meteorological observations. Integrated data-management systems to analyse and monitor social indicators from health surveillance alongside climate and environmental observations. Examples, standards, and tools for integrated data management should be sought;

(c) Research and risk assessments: these require integrated data to link historical climate data and observations, with qualitative and quantitative health vulnerability and exposure information.

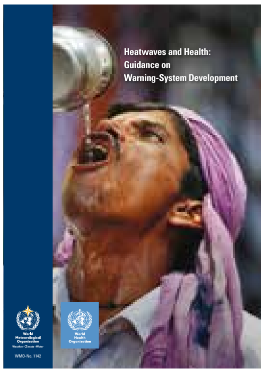
Regional and global data and information products can sometimes be used to supplement locally available data. Applied and operational research is needed to ascertain the relevant temporal and spatial scale of both meteorological and health variables to be used to answer public health questions, as well as careful attention to data quality.

Weather and climate information products and services

Climate information can be transformed into customized products and services, and used as decision-support tools to help anticipate, prepare for and respond to, health risks on both short timescales to address health problems triggered by climate variability (such as an outbreak or thermal extremes), as well as longer time-frame risk changes associated with climate change (droughts, sea-level rise and health infrastructure protection).

Health-policy and programming decisions that can potentially be weather/climate informed are vast and depend upon the health risk being managed, the time frame of the decision (long-term planning or day-to-day emergency management), geographic scale of the issue, availability and quality of information to develop useful products and services. The different types of meteorological, hydrological and climate-information products used by the health sector are shown in Table 3, according to the time frame. Historical observations are fundamental to establishing relationships of health outcomes to climate conditions and identifying further climate-service needs. Weather information about hourly, daily, to one-month conditions is used for

Box 5. WMO–WHO publication Heatwaves and Health: Guidance on Warning-System Development



Over the past 50 years, hot days, hot nights and heatwaves have become more frequent. Their length, frequency and intensity will likely increase over most land areas during this century, according to the Intergovernmental Panel on Climate Change. In addition to health impacts, heatwaves place an increased strain on infrastructure, such as power, water and transport.

Growing concerns over climate change have brought to the fore three important aspects: adaptation, disaster risk reduction and the need for climate information and services to support them. Heat-health warning systems bring together these three facets and exemplify an effective demonstration of climate-risk management in practice. They provide meteorological and/or climate-prediction-based information on the likelihood of forthcoming hot weather that may have an effect on health. This information is used to alert decision-makers, health services and the general public to take timely action to reduce the effects of hot-weather extremes on health.

A number of countries around the world have successfully developed these early warning systems, which necessitates close coordination between meteorological and health services. The WMO–WHO publication *Heatwaves and Health: Guidance on Warning-System Development* (WMO-No. 1142) promotes more widespread development and implementation of these warning systems (WMO and WHO, 2015). The Guidance considers who is at risk from heat, outlines approaches to assessing heat stress, surveys heat-intervention strategies which are a necessary part of any truly integrated heat–health warning system and presents the underpinning science and methodologies.

emergency planning and response to extreme weather conditions and informing national/community/health facility response plans for climate-related hazards, including wildfires, floods, storms, landslides, infectious diseases, water shortages, cold weather, heat stress, chemical and radiological hazards and other potential sources of risk, including food security, mass gatherings, population displacement and infrastructure failure. Short-term climate information (1–12 months) has a broad range of applications, including adaptation of regional or national preparedness and response plans based on seasonal information. Mid-range (annual to multi-year) information (particularly about El Niño/La Niña conditions can be used to improve the predictive skill of seasonal forecasts. Long-range climate information, such as global climate models and climate scenarios, anticipate what the conditions of the climate will be decades into the future and is useful for informing research, long-range policy, planning, and investment decisions.

Table 3. Types of climate information relevant for health decision-making

Timescale	Examples of climate information products – which may be available and relevant in some regions, seasons	Examples of health-decision applications	Status: Research, Experimental*, Operational**
Historic record of climate observations	Historic time series data, summary statistics and other information products	Epidemiological trend and regression analysis to understand associations of climate and health; develop disease forecasting from current and recent observation data, particularly for infectious diseases with time lags between observed ambient conditions and diseases onset	Operational
Weather information (hourly, daily, weekly, 30 days)	Real-time monitoring of daily weather: temperature, precipitation, humidity, etc. 8–14 probabilistic outlooks Extended range forecasts from 10 to 40 days Tercile forecasts (above normal, normal, below normal) probabilistic prediction of rainfall and temperature Extreme weather probability prediction	Short-term operational decisions, such as public weather advisories, and thresholds that trigger action plans for staff deployment, delivery of supplies, and public protection	Operational Experimental
Short-term climate information (1–12 months)	Risk indexes of cyclones, floods, duststorms, windstorms, extreme temperature, fire Long-range forecasts of average, maximum and minimum temperature and precipitation conditions 1–9 months ahead (e.g. seasonal forecasts and trends) Tercile forecasts (above normal, normal, below normal) probabilistic prediction of rainfall and temperature	Short-term operational investment in preparedness, outbreak prevention, resource needs	Experimental and operational

Source: WHO/WMO Climate Services for Health National Implementation Guide (in press, 2016)

Timescale	Examples of climate information products – which may be available and relevant in some regions, seasons	Examples of health-decision applications	Status: Research, Experimental*, Operational**
Mid-term climate information (annual to multi-year)	Annual to interannual forecasts (several years ahead) describing large-scale state of the climate Status of El Niño Southern Oscillation (ENSO) conditions Dynamic and statistical climate models	1-–5-year policy decisions for disease control, research, health systems planning	Limited application of information beyond ENSO
Long-range climate information (decades)	10-–30-year decadal forecasts of surface temperature, precipitation, sea-surface temperatures, etc. Climate change scenarios, dynamic climate models, global circulation models	Long-term health infrastructure investments, research, demographic and population models, health system planning Increase understanding of disease trends, epidemic behaviour on a regional scale	Research Experimental

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* Experimental product defined here as general knowledge available, but products need to be assessed by climate scientists for local decision-making relevance

** Operational product defined here as routinely available and provided by climate practitioners

Climate services can support national adaptation activities in many ways, keeping in mind climate services for health applications vary at global, regional, and national scales. NMHSs can collaborate in research efforts to: understand the mechanisms through which climate and weather influence disease transmission and occurrence (studies of correlation and causality); estimate populations at risk of exposure to hydrometerological hazards (e.g. flood risk mapping); forecast health impacts associated with climate variability and climate change; and estimate seasonality of disease occurrence. With an established evidence base, the NMHSs can help to develop operational methods and tools (such as climate-health thresholds and indices for heatwave alerts). NMHSs can help health authorities to develop and deploy health-early warning systems and other diagnostic and alert tools that alert health professionals and communities to extreme weather events and extend the lead-time that health actors have for taking decisions and preventive measures. Decision tools, such as maps and bulletins, can help monitor and predict seasonal variation in disease incidence. Climate information can also improve the quality of monitoring and evaluation of interventions by removing climate as a confounder of health-intervention performance, such as vector control.

Referring to existing projects and services is a recommended approach to identify relevant expertise, lessons, and model products and tools that can be adapted and replicated according to local needs and capacity. The WHO/WMO Case-Studies of Climate Services for Health details a range of examples[4], including:

(a) Heat–health and cold–health early warning systems and action plans, including development and use of climate indices relevant to health outcomes (municipal/national in Europe, Australia, North America, India, China, etc);

(b) Multi-hazard early warning systems at national and municipal scale (e.g. Shanghai (China), India);

(c) Disease forecasting and early warning systems for malaria, rift valley fever, plague, waterborne diseases and meningitis (Africa, Indian Ocean, Asia, Pacific);

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[4] WHO/WMO Climate Services for Health: Case studies of improved public health decision-making in a new climate (to be issued in 2016)

(d) Forecasts, distribution modelling and public advisory systems of hazardous air quality, including wildfires, pollen and allergens, sand and dust, ultra-violet radiation and their impacts on human health, especially in cities (Americas, Europe, Asia);

(e) Health emergency and disaster management programmes across the world to deal with health risks and effects of climate and weather events;

(f) Integrated climate, health, and environment surveillance systems to support the generation of evidence on the impacts of climate variability and change on health, and risk monitoring, particularly for vector- and waterborne diseases (Africa, Americas, Europe, Asia);

(g) Climate and health working groups (Africa, South, Central and North America) serving to provide inter-sectoral collaboration and coordination of climate service development and use.

Other supporting and policy resources for health-sector NAPs include:

(a) WHO guidance documents and training materials, particularly for climate and health vulnerability and adaptation assessments to identify adaptation needs;

(b) Existing climate- and health-policy frameworks, such as the World Health Assembly and WHO Regional Committee work plans for climate and health adaptation policy and disaster preparedness and response capacity;

(c) International health regulations capacity assessment and tools;

(d) Interdisciplinary training and knowledge-sharing;

(e) UNFCCC National Communications and National Adaptation Plans of Action for health;

(f) Safe Hospitals Initiative (global) assesses and improves the safety and preparedness of existing health facilities and ensures that new facilities are designed in relation to local risks, including climate variability and change;

Water

Water management (both surface- and groundwater) is intrinsically linked to climate variability and change. Climate data are critical for the assessment of fluctuations and trends and the risks arising from exposure and vulnerability to natural hazards (floods and droughts) and for the sustainable management of the water resources. There is a wide cross-section of users from the water sector, including, for example, hydrological characterization, water supply, flood management and control, irrigation and drainage, power generation, fisheries and conservation, navigation and recreation. These users need a range of climate services (WMO, 2014(f)) to support decisions necessary for integrated water resource management (IWRM) planning, which include:

(a) Identification of extreme weather and climate hazards that pose water-related risks;

(b) Identification of populations vulnerable to weather and climate hazards, including those in the coastal zone;

(c) Allocation and re-allocation of water resources;

(d) Design and placement of infrastructure and personnel (water-management organizations, structures and facilities);

(e) Implementation of risk management and emergency preparedness practices and procedures;

(f) Dissemination of information to users, including the public (public service forecasts and alerts;

(g) Development and implementation of water and environmental policy;

(h) Development and implementation of water- and flood-management policies and strategies;

(i) Development and implementation of water-management regulations and laws.

Table 4 shows the weather and climate data, information products and services and their applications in the water sector.

Table 4. Weather and climate data, information products and services and their applications in the water sector

Area	Variable(s)	Application areas
Weather	Daily weather: air temperature, precipitation, wind, solar radiation, humidity, atmospheric pressure Weather statistics: historic time series, summary statistics	• Needed for a range of calculations in water budget and energy budget; estimation of stored energy in water; computation of evaporation using different approaches, etc. • Rainfall depth-duration-frequency datasets are provided as tables or sets of curves, having been obtained from a comprehensive probability analysis of rainfall records. They are required as a basis for: – Drainage design or flood estimation; – Irrigation scheduling; – Hydropower generation; – Potable water, industrial processing; – Pollution control; – Salinity and sedimentation; – Modelling hydrological systems.
	Open-pan evaporation	• Needed for information on total amount of evaporation and computations of evaporation from drainage basins and evapotranspiration
	Quantitative precipitation forecasting (QPF)	• The requirement for more definitive information in flood forecasting and warnings has led weather-service providers to move away from qualitative statements on rainfall (e.g. light-moderate-heavy, occasional-persistent and localized-widespread) to defining numerical or proportional ranges to these descriptors. QPF is now provided in well-defined rainfall ranges (e.g. 30 mm–50 mm) over geographically defined areas and with definition of likely start and finish times. • Medium-range forecasts are needed for demand scheduling.
Climate	Recent and historical climate data	• Floodplain mapping/zoning • Diagnostics, assessment, and attribution of current seasonal/subseasonal rainfall and temperature patterns, and their anomalies, including the associated circulation features • Extreme-value analysis • Long-term means and trends • Diagnostics of climate variability characteristics
	Climate extremes	Drought frequencies and drought indices Indices of climate extremes or other, more complex indices that combine several parameters with different thresholds (e.g. temperature with precipitation and humidity)

Area	Variable(s)	Application areas
	Climate forecasts	• Seasonal and long-range forecasts are required by major water-management undertakings, where knowledge of forthcoming seasonal water conditions is helpful. Forecasts of rainfall and temperature are most commonly needed and are presented as probabilities of conditions falling within different categories, expressed in relation to seasonal norms in 3- or 5-step categories, e.g. very low to very high. • Information on the relevance of major drivers of climate variability (El Niño/La Niña, North Atlantic Oscillation, Indian Ocean Dipole, Madden-Julian Oscillation) for mid-term policy decisions on water management.
	Decadal climate predictions	Hydrological impact modelling
	Climate change projections	Scenario-based impact modelling

Weather and climate data

In the activity on stocktaking under the first element of the NAP process (Laying the groundwork and addressing the gaps), some important questions are raised: What data and knowledge are available to assess current and future climate risks, vulnerability and adaptation? How can the storage and management of this data and knowledge best be coordinated? What gaps can be identified regarding the capacity and adequacy of data and information and required resources to engage in the NAP process?

These issues are addressed in this section on weather and climate data for the GFCS Priority Area Water. NMHSs can provide a wide range of data in different formats – point or distributed data, instantaneous or averaged – over different periods of time, to serve a number of purposes for water management. Many meteorological and hydrological models are now designed to produce probabilistic output for risk analysis, so the interfacing of climate data feeds with predictive water models is a complex matter. There are frequent gaps and mismatches between the nature and distribution of climate observing systems and those networks devised for water monitoring (WMO, 2014(f)). An improved climate–water interface will enhance the structure and development of compatible observation networks by extending them to meet user needs and ensure quality assurance of data. Recent decades have seen a progressive decline in the size and quality of meteorological and hydrological observing networks, especially in countries most at risk from climate- and water-related impacts. Of relevance, from the water perspective, is the World Hydrological Cycle Observing System (WHYCOS), a WMO programme aimed at improving basic observation activities, strengthening international cooperation and promoting the free exchange of data in the field of hydrology. It is implemented through various components (HYCOSs) at the regional and/or basin scale. Improved integration of climate and hydrological networks is seen as a necessary and essential initiative in improving the linkages between the climate and hydrological communities.

Water security in a variable and possibly changing climate continues to be a key concern at national, regional and global scales. In addressing this concern, the critical importance of ongoing climate data for the assessment of fluctuations and trends in risks arising from exposure and vulnerability to climate variability and related natural hazards is well recognized for assisting countries and communities in optimal adaptation efforts. NMHSs can provide long time series of climate data to the water sector in support of hydrological modelling to enable greater understanding of the impacts of climate variability on water resources availability.

NMHSs can also address the need for, and use and applications of, climate data to address the changes in the demand for water, through changes both in land use and also in behaviour of water users. Past weather and water observations have left an enormous legacy of data that now provide the basis of knowledge on climate variability and change. Water-management design depends heavily on historical data, whereas use of operational data may depend on rapid data delivery and assimilation into models.

The technology and systems for electronic dissemination and exchange of data are generally present in most countries though, in many developing countries, the speed, reliability and capacity of systems is far from adequate. At the highest level, the WMO Information System is being developed to serve as the coordinated global infrastructure for the telecommunication and management of weather, climate, water and related data.

Information products and services

Analysing current climate and future climate change scenarios under the second element of the NAP process (Preparatory elements) highlights the importance of appropriate indices of climate trends which could support planning and decision-making. Another activity on assessing climate vulnerabilities and identifying adaptation options under this element calls for risk-management approaches, ecosystem-based approaches for adaptation, etc. The activity on developing an appropriate adaptation implementation strategy under the third element of the NAP process (Implementation strategies) calls for implementation of activities, such as timing, target areas/ beneficiaries, responsible authorities and sequencing of activities. The enhancement of the capacity for planning and implementation of adaptation under the third element of the NAP process calls for lessons to be learnt from other international experiences and international cooperation in adaptation planning. These issues are addressed in the section on information products and services for the GFCS Priority Area Water.

The improved and targeted delivery of climate information products and open communications from NMHSs can enhance the quality of information available to the water community for the assessment of fluctuations and trends in risks arising from exposure and vulnerability to climate variability and related natural hazards and can assist countries and communities in optimal adaptation efforts. Improved access to accurate and reliable climate information results in appropriate and robust design and construction of water-related structures such as culverts, bridges, dams and coastal zone infrastructure. Hence, NMHSs can provide improved climate-prediction services on timescales from seasons to decades and spatial scales from local to regional to support improved water resources management and prioritized allocation of resources to the wide variety of water-demand sectors, including urban water supply, irrigation systems, flood storage capacity, etc. In particular, advances made in the area of seasonal climate outlook forums and the establishment of regional climate centres are of interest to the water community, paying specific attention to the communication aspects of the scientific content of certain products. The establishment of professional interactions between NMHSs and water managers at scientific and operational levels can make an effective contribution to water-related risk management, such as management of extremes (floods and droughts). Increased dialogue and joint action can help maximize the usefulness of climate services and help develop new and improved applications of climate information for the water sector.

Some examples of the development of climate products through feedback from the water sector are as follows:

- **Quantitative precipitation forecasting (QPF).** The requirement for more definitive information in flood forecasting has led NMHSs to move away from qualitative statements on rainfall, (light-moderate-heavy, occasional-persistent, localized-widespread) to defining numerical or proportional ranges to these descriptors. QPF is now provided in well-defined rainfall ranges (e.g. 30 mm–50 mm) over geographically defined areas and with definition of likely start and finish times.

- **Seasonal and long-range forecasting.** NMHSs can provide these forecasts for major water-management undertakings, where knowledge of forthcoming seasonal water conditions is helpful. Forecasts of rainfall and temperature are most commonly needed and are presented as probabilities of conditions falling within different categories, expressed in relation to seasonal norms in three- or five-step categories, e.g. very low to very high.

- **Rainfall depth-duration-frequency datasets.** These are provided as tables or sets of curves, having been obtained from a comprehensive probability analysis of rainfall records. They are required as a basis for drainage design or flood estimation in a standard manner over, for example, a particular country, and so are related to a geographical distribution, either by isolines or as tables or grids.

By working collaboratively and iteratively, NMHSs and water professionals can develop tools and systems that can effectively forecast and provide information and warnings that improve water security and build resilience. In this context, NMHSs can provide a range of services to support decisions by water managers that includes identification of extreme weather and climate hazards that pose water-related risks; identification of populations vulnerable to weather and climate hazards, including those in the coastal zone; implementation of risk management and emergency preparedness practices and procedures; development and implementation of water and environmental policy; and development and implementation of water- and flood-management policies and strategies. Through improved and targeted delivery of climate information products and open communications, NMHSs can enhance the quality of information available to the water community to conduct operations, research, impact and risk assessment and planning.

Through appropriate research and modelling activities, NMHSs can improve the available products and services for the water sector in quality and reliability and thus improve the utility and confidence of water managers in climate services. Research will be necessary into methods to improve integration between climate and water science, which must include the identification of users' needs from the outset. This research approach has to ensure that climate information and services are provided in a timely manner to decision-makers and operational organizations.

NMHSs can also provide information from two existing interagency programmes in the areas of flood and drought management based in WMO: the Associated Programme on Flood Management (APFM), including the coastal zone, and the Integrated Drought Management Programme (IDMP), which provide appropriate products and services to the user communities. The Global Water Partnership and WMO have jointly developed APFM since 2001. Its mission is to assist countries in the development of integrated flood-management policies and strategies within the overall context of national development policy. The successful implementation of APFM led the agencies involved in its creation to initiate IDMP in 2012/2013. IDMP promotes an approach that moves drought-management practices from reactive – representing crisis management – to more proactive drought management, based on risk-management principles. It provides global coordination of efforts towards integrating science, policy and implementation by strengthening drought monitoring, drought risk assessment, development of drought prediction, drought early warning services and the sharing of best practices at the local, national and regional levels.

Energy

Energy is essential to almost all aspects of human welfare, including access to water, agricultural productivity, healthcare, education, job creation and environmental sustainability (UNDP, 2005). As noted by UN Secretary-General Ban Ki-Moon at the launch of the Decade of Sustainable Energy for All (SE4ALL) in September 2011, the world faces two urgent and interconnected challenges related to energy. One is related to energy access. Nearly one person in five on the planet still lacks access to electricity. More than twice that number – almost three billion people – rely on wood, coal, charcoal or animal waste for cooking and heating. This is a major barrier to eradicating poverty and building shared prosperity. As for the second challenge, where modern energy services are plentiful, the problem is different: waste and pollution. Energy-sector emissions, such as carbon dioxide, account for the largest share of global anthropogenic GHG emissions. In 2010, 35% of direct GHG emissions came from energy production. Emission reduction targets under the UNFCCC are expected to significantly increase demand for energy from renewable sources, which are highly sensitive to climate, as well as energy efficiency measures.

Energy generation and planning of operations are markedly affected by meteorological events and energy systems are increasingly exposed to the vagaries of weather and climate affecting both availability and energy demand. By taking into account weather and climate information, energy systems can therefore considerably improve their resilience to weather extremes and climate variability and change, as well as their full chain of operations during their entire life cycle. Energy is essential for the functioning of the four GFCS Priority Areas (Agriculture and food security, Water, Health and Disaster risk reduction) while, at the same time, energy efficiency and generation of renewable energy are sensitive to weather, climate and water. Through appropriate partnerships and stakeholder engagement, the application of weather and climate information can provide useful support to energy-management decisions and relevant policymaking to achieve optimal balancing of supply and demand, as well as to drive behavioural changes in energy saving.

Climate services in the energy sector are needed to support:

- Greater climate resilience and adaptation, due to its fundamental importance for development;

- The important role of efficiency and reduction of energy consumption with consequent emissions reduction in support of mitigation targets; and

- The growing renewable subsector, given the apparent climate sensitivity of renewables on the one hand and the policy priority accorded to them due to their GHG emissions reduction benefits on the other.

The main focus areas in the energy sector for climate services are:

- Identification and resource assessment;

- Impact assessments (including infrastructure and environment);

- Site selection and financing

- Operations and maintenance

- Energy integration:

  - Market trading (including supply and demand forecasts) and insurance;

  - Energy efficiency.

Weather and climate data

Detailed local assessments are necessary to provide greater confidence in understanding current climate variability and how the climate might change in the future and, therefore, which measures are warranted at the level of specific projects. There is a need to improve energy sector (and broader) decision-making by: improving local weather and climate knowledge, regardless of whether large climate changes are expected; improving access to existing meteorological and hydrological data; and developing better mechanisms so that local weather and climate data, as well as specialized analyses, are archived for the public good (Johnston et al., 2012).

Weather and climate data needs for the five focal areas in the energy sector are shown in Table 5. There are also critical data needs for the different energy subsectors: wind, solar, hydro and thermal. In the wind-power subsector, vertical gradients in mean wind speed and wind direction, as well as in turbulence intensity above the surface layer are critical to the construction, planning and operation of wind turbines. Increase in current data needs led to a boom in surface-based, remote-sensing techniques such as wind lidars (Emeis, 2014). For offshore windparks, marine boundary-layer weather and climate variables need to be assessed. Accurate measurements of incoming irradiance are essential to solar power plant project design, implementation and operations.

In the absence of surface radiation measurements, estimates of surface radiation can also be made using meteorological ground measurements such as cloud cover, temperature, visibility and water vapour in a radiative transfer model (Marion and Wilcox, 1994). Hydropower is obviously dependent on river flow, which depends on the following weather parameters: precipitation and snow amounts; air temperature, which in particular controls the snow melting process in spring in mountain areas; the altitude of the 0°C isotherm, which is of particular importance; and evaporation, which plays a strong role in controlling the water level in large-area reservoirs, in particular in tropical and subtropical regions. Floods and droughts have a strong impact on hydropower generation.

Table 5. Weather and climate data needs for the five focal areas in the energy sector

Focal area	Weather and climate data needs
Identification and resource assessment	• In situ, and satellite-derived meteorological data for assessment of resources and risks • Model-based, high-resolution historical meteorological data • Climate change projections
Impact assessments (including infrastructure and environment)	• High-grade in situ data • Detailed site-specific modelling • Historical dataset and analyses of extreme events • Projections of potential relevant meteorological and climate trends and changes • Observations and monitoring of relevant climate-related variables for identification and mitigation of environmental impacts, e.g. on human health and safety and wildlife • Air quality and gas emission database (e.g. carbon-based gases from shale gas extractions) • Database on weather/climate risks to hydro-electricity facilities, solar panel risks to buildings, energy transport risks to communities, etc.
Site selection and financing	• Very high grade in situ data, both in terms of quality of instrumentation and temporal resolution • Detailed site-specific modelling (e.g. wind-gust estimation, extreme low and high streamflows)e
Operations and maintenanc	• Site-specific ground station data • Infrastructure-specific meteorological data • Database and analyses of historical meteorologically-driven problem (forensic) events for operations and maintenance • Forecasts at various lead times • Communication methodologies for warning systems
Energy integration	• Historical datasets of meteorological/climate variables relevant for demand, insurance and energy efficiency • Historical datasets of energy demand • Model-based data to extend observation records • Ancillary datasets such as energy-system response to weather variables • Forecasts at various lead times • Climate projections • Site-specific ground station data for triggering weather index insurance policies

In the area of thermal power, data needs are diverse, as the thermal conversion efficiency depends on ambient air temperature. The efficiency of cooling systems depends on several parameters: water temperature (ocean, rivers), river flow (with special emphasis on drought periods, but also in the case of floods) and air temperature and humidity, which control the efficiency of cooling towers. Rising air and water temperature and lack of water may then lead to reduced power generation or temporary shutdowns.

Information products and services

Climate information (historical and projected) is required for an initial assessment of the energy resource and the required infrastructure and for management of weather/climate hazards and risks. The energy-sector stages or areas of focus, along with their main requirements for climate information, include the following:

(a) Identification and resource assessment requires climate information (historical and projected) and policy for an initial assessment of the energy resource and the required infrastructure and for management of weather/climate hazards and risks.

(b) Impact assessments (including infrastructure and environment) require detailed and tailored weather and climate information (historical and projected) for codes, standards, site-specific designs and policy to assist with the construction and maintenance of the energy-system infrastructure (power plants, solar collectors, coal mines), including connecting infrastructure for energy transmission, distribution and transfers. It also requires detailed site-specific and regional climate information (mainly historical) and policy for assessments and mitigation of impacts of energy systems on the surrounding environment (e.g. air-quality modifications) on human health (e.g. air particles), on ecosystems (e.g. solar plants, marine turbines) and wildlife, as well as potential contributions to GHG reduction.

(c) Site selection and financing require highly detailed, site-specific climate information (mainly historical) and policy for rigorous resource assessment, risk management and financial closure.

(d) Operations and maintenance require highly detailed, site-specific weather and climate information (predicted, historical and projected) and policy for an efficient running of the energy system, as well as site maintenance (e.g. on/off-shore wind turbines or oil rigs);

(e) Energy integration: energy supplied by individual generators needs to be dispatched in a balanced/integrated manner to suitably meet energy demand for the following purposes:

    (i) Market trading (including supply and demand forecasts) and insurance requires highly detailed weather and climate information (predicted and historical) and policy for an efficient use of generated energy via optimal balancing of supply and demand, as well as for the pricing of insurance structures used to hedge against market volatility and/or risks to assets such as wind farms, oil rigs and transmission infrastructure;

    (ii) Energy efficiency requires highly detailed climate information (predicted, historical and projected) and policy for an efficient use of generated energy via measures such as optimal infrastructure siting or use of shading on hot days to offset air-conditioning energy use.

Hydropower generation management essentially requires river-flow forecasts at the different timescales on which power systems are operated: yearly, quarterly, monthly, weekly, daily and intra-daily. Current practice is to use weather forecasts, either deterministic or probabilistic, depending on the ability and means of each company, up to one or two weeks. For longer timescales, the more advanced energy companies use intra-seasonal to seasonal forecasts but the climatological approach, which uses historical time series of precipitation and/or river flow, is more widespread. On longer timescales, for planning purposes, the general rule is to use climatological information as well, even if more and more companies have started to use climate change projections.

6. CONCLUSIONS

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Adapting to climate change is becoming a routine and necessary component of planning at all levels. UNFCCC established the NAP process as a way to facilitate adaptation planning in LDCs and other developing countries.

The timely provision of climate services to the user communities in different sectors and at different levels can support climate change adaptation. Climate data, science, information and knowledge are critical components that can facilitate the activities identified under the four key elements that need to be undertaken in the development of NAPs.

WMO and the NMHSs of its Members have a vast reservoir of expertise, service capabilities, data and tools that can be delivered through governments, programmes, technical commissions, expert teams and partner organizations. GFCS, the UN-led initiative spearheaded by WMO to guide the development and application of science-based climate information and services in support of decision-making in climate sensitive sectors, can provide effective support to the NAP process.

In the context of climate change adaptation, NMHSs are critical actors in national development planning within almost all sectors, as they serve as major custodians and providers of data and competencies required to support climate change research and climate services which underpin adaptation at national level. Key services include provision of information and scientific advice on climate variability, trends and change (including at the policy level). NMHSs are encouraged to continue their active role in the UNFCCC LEG process and to provide technical advice to LDCs for preparing and implementing NAPs and other contributions to the LDC work programme. NAPs are expected to guide the allocation of significant climate finance in the future.

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JN 152195