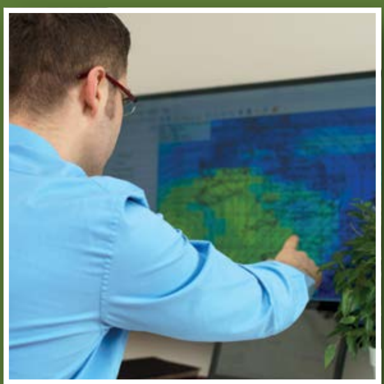
WORLD
METEOROLOGICAL
ORGANIZATION

GFCS
GLOBAL FRAMEWORK FOR
CLIMATE SERVICES

WEATHER CLIMATE WATER

Use of Climate Predictions to Manage Risks



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Contents

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Definitions of Key Terms

Climate data: Historical and real-time climate data, together with direct model outputs covering historical and future periods. Information about how these observations and model outputs were generated ("metadata") should accompany all climate data.

Climate product: A derived synthesis of climate data. A product combines climate data with climate knowledge to add value. Climate information: climate data, climate products and/or climate knowledge.

Climate service: Providing climate information in a way that assists decision-making by individuals and organizations. A service requires appropriate engagement together with an effective access mechanism and must respond to user needs.

Climate forecast (prediction). A climate forecast (prediction) is a probabilistic statement about future climate conditions on timescales ranging from seasons to decades. It is based on conditions that are known at present and assumptions about the physical processes that will determine future changes.

Deterministic forecast (prediction). Forecasts (predictions) of an event of a specific magnitude at a specific time and place.

Probabilistic forecast (prediction). Forecasts (predictions) of the probability of an event of a certain (range of) magnitude(s) may occur in a specific region in a particular time period.

Summary

Demand for climate information to inform decision- and policymaking is growing as the private and public sectors increasingly recognize the relevance and value of such information for building climate resilience and in mitigating and adapting to changing climate. Various types of users are seeking tailored and actionable climate information on a wide range of timescales, from past, current and future climate. Their needs are broad, including long-term decisions and planning, early warning of potential hazards and managing risks arising from climate variability and change. A focus for collaboration within the Global Framework for Climate Services (GFCS) is to ensure that providers of climate prediction products interact more effectively with users to meet this demand by developing climate services.

The purpose of this publication is to provide an understanding and examples of the range of currently available operational climate prediction products and services and climate products

that are still under research and development with the potential of transitioning into operations. It is intended for all audiences from policymakers to practitioners and users. In particular, it should help National Meteorological and Hydrological Services (NMHSs) which are not currently providing climate services to visualize the possibilities and, perhaps, start creating services in their own environments and countries. Much of the content is based on WMO publications and contributions from the WMO Global Producing Centres of Long-Range Forecasts (GPCLRFs). The figures shown should not be used as actual predictions; they are intended to illustrate products and services.

1. Introduction

During the past few decades, national and international investment in climate observations, research and modelling have resulted in significant progress in experimental and practical climate prediction, as well as significant improvement in scientific understanding of climate variability and change. These efforts provide a robust scientific foundation for producing climate prediction products, i.e. products based on forecasts for the coming months and years. Timely, actionable and reliable climate prediction plays a crucial role in decision-making for individual users, users in a variety of sectors and national development planning to help manage development opportunities and risks, and for adaptation and mitigation.

The effective application of climate prediction also relies on climate information becoming appropriately integrated into different users' policies and practices. Through effective climate services, climate information can be disseminated to enable this integration into robust decision-making. This process involves strong partnerships among providers, such as NMHSs and their stakeholders, including government agencies, private interests and academia, for the purpose of interpreting and applying climate prediction information for decision-making, sustainable development and improving climate prediction products. Climate services also rely heavily on strong relationships between providers and users of information, requiring a two-way flow of information regarding science capability, information requirements and feedback on the use of information.

This publication outlines the current landscape for climate prediction products and services among the WMO Global Producing Centres (GPCs). Section 2 introduces the scope of climate prediction products and gives examples of such products from a range of centres. Section 3 details the necessary processes involved in turning these products into sustainable and effective climate services, again using case studies to illustrate the steps taken. Section 4 then provides a library of case studies of climate prediction products and services across a range of sectors. Section 5 describes the ultimate goal to enhance climate products and services.

2. Climate prediction

A climate prediction is a probabilistic statement about future climate conditions on different time (months to years) and spatial (global, regional or local) scales. It is based on conditions that are known at present and scientific understanding about the physical and dynamical processes that will determine future changes. Climate prediction is used for long-term decision-making, planning, early warning of potential hazards and adaptation to climate variability and change.

The following describes predictions on different timescales (Hewitt, Silva, Golding et al., 2015). It is perhaps ambiguous as to where the forecast period changes from weather forecasts to climate predictions, particularly on the 10–30-day time window. Users often do not want, or need, to know this distinction between weather and climate services, with many users requiring information across these different timescales. In this publication, the following terms are used to span users' interests from weeks to a decade:

Extended-range forecast. A forecast beyond 10 days and up to 30 days describing weather parameters, usually averaged and expressed as a departure from climate values for that period. Examples include 10-day and two-week forecasts, extreme climate event probability predictions, three-category (above normal, normal, below normal) probabilistic forecasts of rainfall and temperature, etc.

Long-range forecast. A forecast from 30 days up to one year that generally includes monthly outlooks providing a description of averaged weather parameters expressed as a departure (deviation, variation, anomaly) from climate values for that month (not necessarily the coming month); three-month or 90-day outlooks that provide a description of averaged weather parameters expressed as a departure from climate values for that period (which is not necessarily the coming three-month or 90-day period); and seasonal outlooks that provide a description of averaged weather parameters expressed as a departure from climate values for that season. Examples include climate forecasts for variables such as precipitation, surface air temperature, mean sea-level pressure, 500 hPa geopotential height; forecasts of tropical storm activity; and large-scale climate variability phenomena such as El Niño/Southern Oscillation (ENSO) and the Madden-Julian Oscillation (MJO).

Interannual prediction. A prediction from one to several years in advance that describes the large-scale climatic state. This prediction is initialized with indicators of the current climate to capture the evolution of modes of internal climate variability, such as ENSO. Examples include prediction of the climatic trend of variables such as precipitation, temperature, mean sea-level pressure and 500 hPa geopotential height.

Decadal prediction. A prediction of fluctuations in the climate system over the next 10 years, taking into account natural variability, as well as human influences. This is achieved by initializing climate models with observations of the current climate state, in addition to specifying changes in radiative forcing due to greenhouse gases, aerosols and solar variability.

The WMO GPCLRFs (Figure 1) combined provide an extensive amount of information on these timescales, which are indicated in Table 3. Predictions are provided at the global, regional and national levels for a large variety of users, including individual decision- and policymakers, as well as federal, state and local organizations and humanitarian agencies. These centres set the context for predicting climate and weather and their forecasts are used by regional and local forecasting centres. Regional predictions are generally conducted by WMO Regional Climate Centres (RCCs). These centres of excellence assist WMO Members in a given region to deliver better climate products and services, including regional long-range forecasts, and to strengthen their capacity to meet national climate information needs. In addition, national climate predictions are usually the responsibility of the NMHS. Using global, regional and local forecasts, GPCLRFs, RCCs, NMHSs and other agencies provide climate services tailored to the needs of government, the public, and private industry.

Figure 1. WMO Global Producing Centres of Long-Range Forecasts

Table 1. Current climate predictions of WMO Global Producing Centres of Long-Range Forecasts

Global Producing Centres of Long-Range Forecasts	*ERF*	*LRF*	*IP*	*DP*
Australian Bureau of Meteorology (BOM) http://www.bom.gov.au/	X	X		
China Meteorological Administration (CMA)/Beijing Climate Centre (BCC) http://bcc.cma.gov.cn/	X	X	X	X*
Brazilian National Institute for Space Research (INPE)/Centre for Weather Forecasts and Climate Studies (CPTEC) http://www.cptec.inpe.br/		X		
European Centre for Medium-Range Weather Forecasts (ECMWF) http://www.ecmwf.int	X	X	X	
Météo-France http://www.meteofrance.com	X*	X		
United Kingdom Met Office http://www.metoffice.gov.uk	X	X	X	X
Hydrometeorological Centre of the Russian Federation http://neacc.meteoinfo.ru	X	X		
Meteorological Service of Canada (MSC) http://www.ec.gc.ca/meteo-weather	X	X	X*	X*
South African Weather Service (SAWS) http://www.weathersa.co.za	X	X		
Korea Meteorological Administration (KMA) http://web.kma.go.kr/eng	X	X	X	
Japan Meteorological Agency (JMA)/Tokyo Climate Centre (TCC) http://ds.data.jma.go.jp/tcc/tcc	X	X		
NOAA Climate Prediction Center (CPC) http://www.cpc.noaa.gov	X	X	X	

* Produced in research mode

In addition, KMA and NOAA National Centers for Environmental Prediction (NCEPs) have organized a joint activity to sustain and develop the Lead Centre for Long-Range Forecasting Multi-Model Ensemble (LC-LRFMME). The goal of the Lead Centre is to provide a conduit for sharing model data for long-term climate predictions and to develop a well-calibrated MME system for mitigating adverse impacts and maximizing benefits of climate conditions. At present, the global seasonal forecasts from 12 WMO GPCs for 2 m air temperature, precipitation, mean sea-level pressure, 850 hPa air temperature, 500 hPa geopotential height and sea-surface temperature (SST) (if available) are collected at LC-LRFMME between the first and 20th day of each month, and the forecast data are used in various seasonal forecast products. Table 2 shows the digital data and graphical products in standard format available from LC-LRFMME. The product display on the LC-LRFMME website (www.wmolc.org) includes monthly and seasonal mean anomalies from individual GPCs and a synthesis of information in terms of consistency in the sign of anomalies from all GPCs. In addition, the website contains four types of deterministic multi-model ensemble (MME) (simple composite mean, regular multiple regression, singular value decomposition and genetic algorithm) and probabilistic MME prediction are shown. Access to the website is password-protected and information on how to gain access to the forecast products is provided.

Table 2. Lead Centre for Long-Range Forecasting Multi-Model Ensemble products: digital data and graphical products from Global Producing Centres

Digital products	*Graphical products*
Both forecast and hindcast data of monthly mean anomalies of the GPC ensemble mean for lead 1~3), following the month of submissions · 2 m surface temperature · Precipitation · Mean sea-level pressure · 850 hPa temperature · 500 hPa geopotential height · SST	Individual forecast · Plots for each GPC forecast anomalies in common graphical format (rectangular, time series, stereographic type, etc.) · Consistency map · SST Plume (Nino3.4 SST anomalies) Deterministic multi-model ensemble · Simple composite mean (SCM) · Regular multiple regression · Singular value decomposition (SVD) · Genetic algorithm (GA) Probabilistic multi-model ensemble · Tercile-based categorical probabilities

2.1 Climate predictions from WMO Global Producing Centres of Long-Range Forecasts at the global level

Presented below are examples of global climate prediction products that are currently available through the GPCLRFs. Examples of regional- and national-level prediction products will not be described in this section. We encourage users of this publication to visit each centre’s website to learn more about its products and to explore products that may be beneficial if adapted/developed for their regions in partnership with the GPCLRF. Each centre will also have its individual data-access policy and descriptions of precise information available for different purposes. The product descriptions below are taken from WMO publications and from climate centres’ websites.

2.1.1 Global precipitation

The MME approach has proved extremely effective at quantifying prediction uncertainty due to uncertainty in model formulation and initialization and generally produces more robust predictions than any single model. The multi-model approach is the basis for several international collaborative research efforts, including operational European and North American systems. The North American Multi-Model Ensemble (NMME) is an operational multi-model seasonal forecasting system consisting of coupled models from United States (US) modelling centres, including National Oceanic and Atmospheric Administration (NOAA)/ NCEPs), the NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), the International Research Institute for Climate and Society (IRI), the National Center for Atmospheric Research (NCAR), the National Aeronautics and Space Administration (NASA) and MSC. This system is currently delivering real-time seasonal-to-interannual predictions on the NOAA Climate Prediction Center (CPC) operational schedule. The hindcast and real-time prediction data are readily available and in graphical format from CPC. Moreover, NMME forecasts are currently being used as guidance for operational forecasters (http://www.cpc.ncep.noaa.gov/products/NMME/).

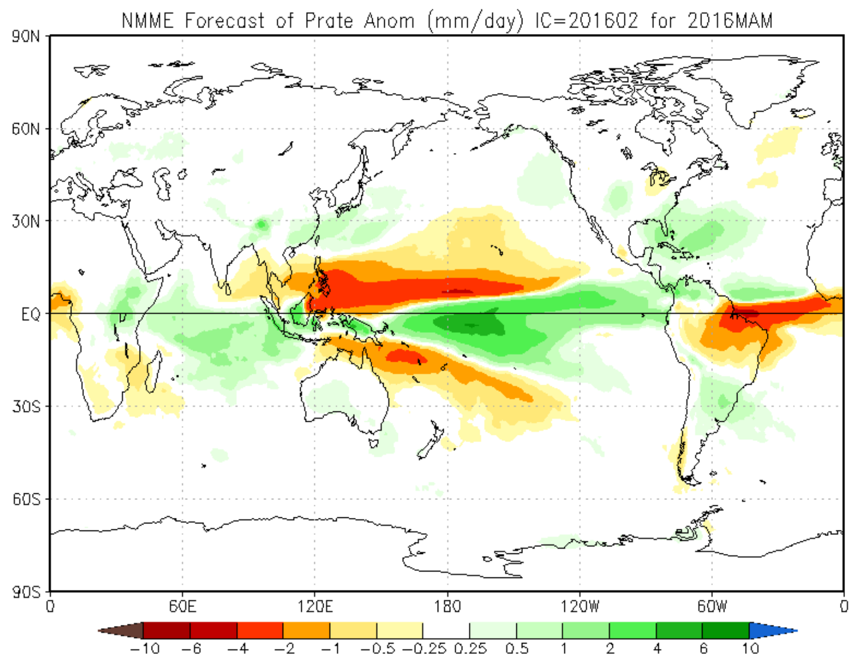

Figure 2. Example of North American Multi-Model Ensemble forecast of global precipitation rate anomalies

Source: NOAA Climate Prediction Center

2.1.2 Global temperature

The KMA MME is another operational multi-model seasonal forecasting system consisting of coupled models from 12 GPCs. The hindcast and real-time prediction data are readily available on the LC-LRFMME website (http://www.wmolc.org). An example of KMA's probabilistic forecasts of surface air temperature is given in Figure 3.

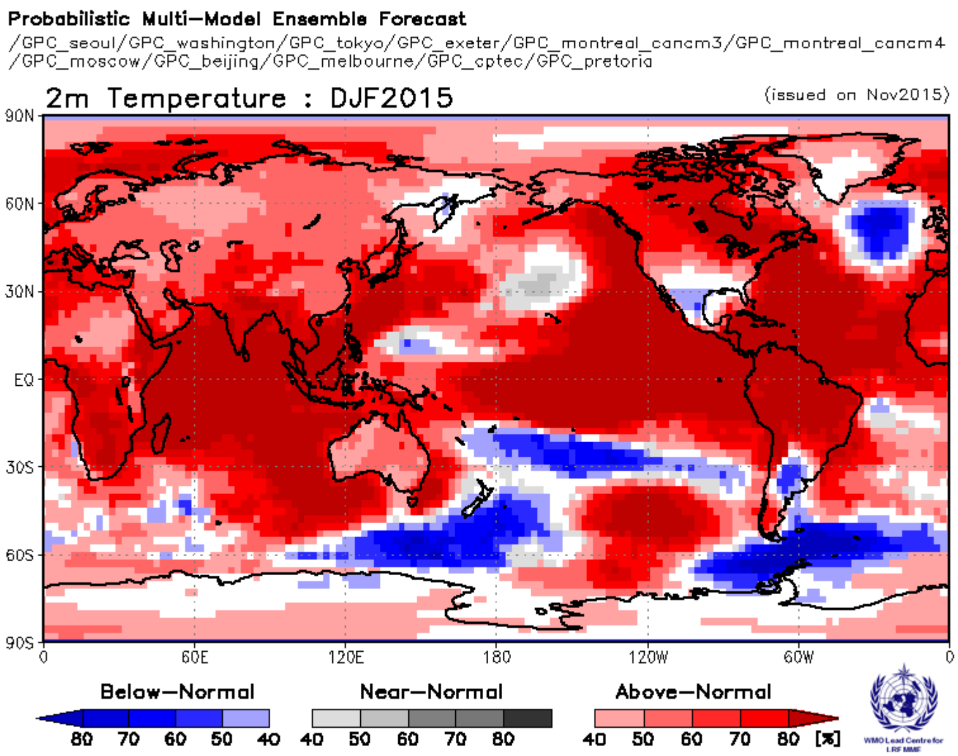

Figure 3. Example of probabilistic forecasts of surface-air temperature for the season December 2015–January/February 2016. The tercile category with the highest forecast probability is indicated by shaded areas. The most likely category for below normal, above normal and near normal is depicted in blue, red and grey shadings respectively. White areas indicate equal chances for all categories in both cases.

Source: Korea Meteorological Administration

An emerging area of scientific understanding and modelling capability is that of decadal forecasting, predicting fluctuations in the climate system over the next few years through knowledge of the current state of the climate and multi-year variability of the oceans, and specifying changes in radiative forcing due to greenhouse gases, aerosols (both volcanic and man-made) and solar variability. Decadal forecasting potentially has a broad range of applications for policymaking and investment decisions. It is also scientifically valuable for testing how well climate models simulate natural variability and capture longer-term trends by running uninitialized simulations over a longer period. As decadal forecasts are still predominantly carried out in research mode, expert advice is therefore needed at this early stage of development to assess the reliability of regional predictions and advise on their application.

Figure 4 shows, as an illustration, a five-year annual global mean temperature forecast produced from an ensemble prediction system using the latest version of the UK Met Office Hadley Centre's climate model, HadGEM3, initialized with the current state of the climate system (atmosphere and ocean).

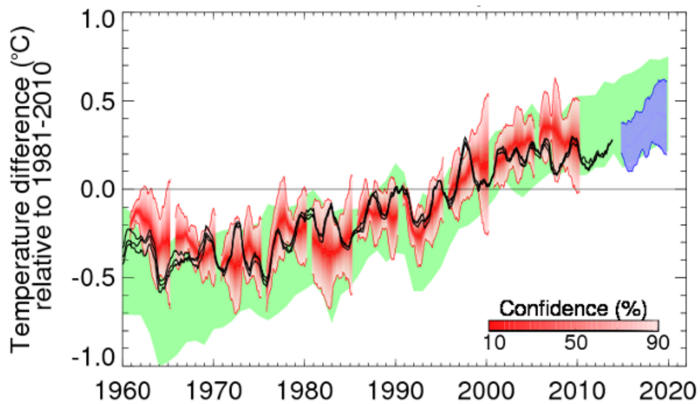

Figure 4. Annual global mean temperature forecast. Observed (black) and predicted (blue) global average annual surface air temperature difference relative to 1981–2010. Previous predictions starting from November 1960, 1965 … 2005 are shown in red, and 22 model simulations from the Coupled Model Intercomparison Project phase 5 (CMIP5), that have not been initialized with observations, are shown in green. In all cases, the shading represents the probable range, such that the observations are expected to lie within the shading 90% of the time.

Source: UK Met Office

The maps in Figure 5 show the predicted change in global temperature from November 2014–October 2019, November 2013–October 2018 and 1981–2010 averages, respectively. Map A is the most likely forecast outcome. Maps B and C indicate the range of forecast temperatures, such that we expect only a 10% chance of temperatures at particular locations being less than those in B, and only a 10% chance of temperatures higher than in C. It is to be noted that these ranges are for each individual location. The chances of these limits being met everywhere are very small, so the complete patterns shown in maps B and C are very unlikely to be realized.

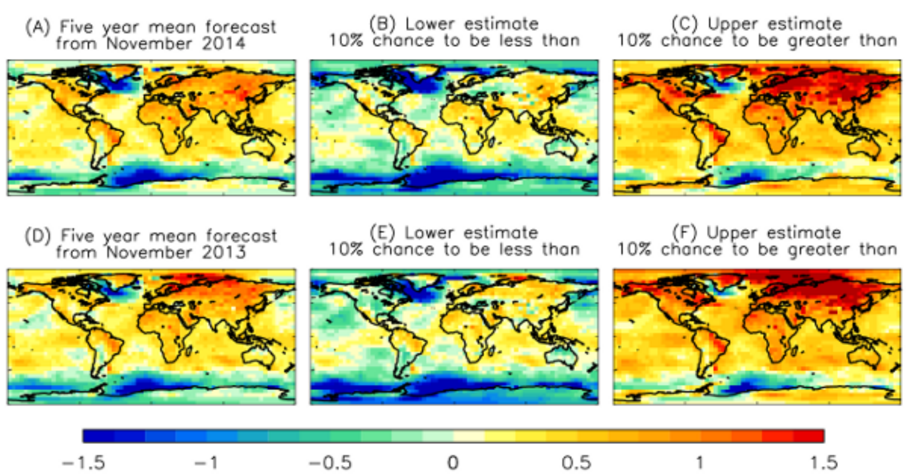

Figure 5. Surface temperature differences relative to 1981–2010 for the future 5- to 10-year period

Source: UK Met Office

2.1.3 El Niño/Southern Oscillation

The El Niño/Southern Oscillation is a naturally occurring phenomenon involving fluctuating ocean temperatures in the central and eastern equatorial Pacific, coupled with changes in the atmosphere. This phenomenon has a major influence on climate patterns across large parts of the world. It is the most predictable season-to-season and year-to-year fluctuation of the climate system. Successful predictions of ENSO have been made since the 1980s and, over time, our understanding of key processes and climate variability has improved, as have observations to initialize the models, and the forecast models have become sufficiently more skilful for many sectors of society to prepare for the hazards associated with ENSO, such as heavy rains, floods and drought. The value of these predictions can translate into savings of numerous lives and billions of dollars.

The National Climate Centre (NCC) of the Australian Bureau of Meteorology (BoM) provides a product which combines international model outlooks (Figure 6) for the so-called Niño3.4 region in the central equatorial Pacific Ocean. The main variable that is considered from the coupled climate model's ENSO forecasts is the Niño3.4 index which is defined as the average of SST anomalies over the region 5°N–5°S and 170°–120°W. NCC classifies the Niño3.4 temperature anomaly as "warm" if it exceeds 0.8°C, which is about one standard deviation above average. Similarly, anomaly predictions below –0.8°C are classified as "cool", with those in between classified as "neutral". Both the ensemble mean (the average of these forecasts) and the individual forecasts are useful to decision-makers (http://www.bom.gov.au/climate/ahead/about-ENSO-outlooks.shtml).

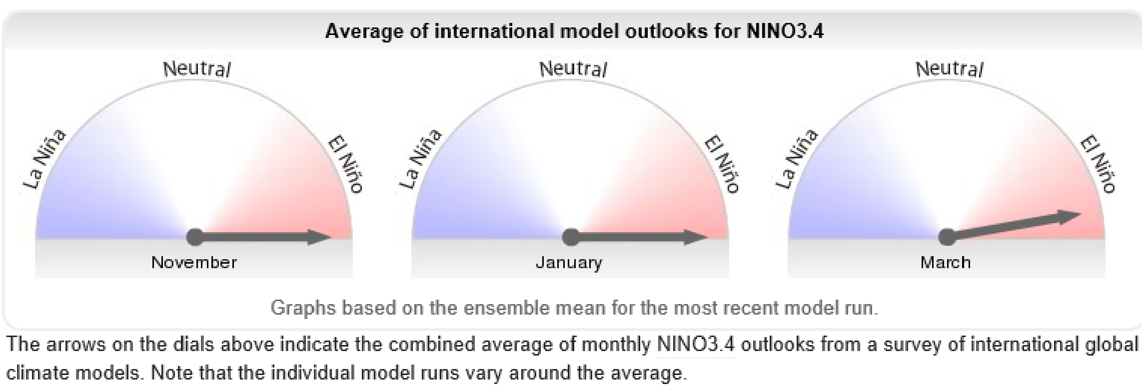

Figure 6. Average of international model outlooks for Niño3.4: red indicates warm anomalies, blue cool and white neutral.

Source: Australian Bureau of Meteorology

NOAA's CPP also produces tropical Pacific mean SST consolidated outlooks for the Niño3.4 region (Figure 7). The Climate Prediction Center defines El Niño conditions as existing when a one-month positive SST anomaly of 0.5°C or greater is observed in the Niño 3.4 region of the equatorial Pacific Ocean (5°N–5°S, 120°W–170°W) and an expectation that the three-month Oceanic Niño Index (ONI) threshold will be met and an atmospheric response typically associated with El Niño is observed over the equatorial Pacific Ocean. La Niña conditions are defined as existing when a one-month negative SST anomaly of –0.5°C or less is observed in the Niño3.4 region and an expectation that the three-month ONI threshold will be met and an atmospheric response typically associated with La Niña is observed over the equatorial Pacific Ocean.

In addition, CPC provides the monthly ENSO Diagnostic Discussion, which indicates the expected occurrence (or lack of occurrence) of El Niño or La Niña for the next three to six months. It also addresses current oceanic and atmospheric conditions in the Pacific and provides climate outlooks for the following one to three seasons. It includes analysis of current and recent patterns in surface and subsurface water temperature anomalies in the tropical Pacific; related analyses such as rainfall, outgoing long-wave radiation; influencing factors such as MJO and Kelvin waves; and statistical and coupled model predictions. Also, CPC provides an ENSO Alert System: an El Niño or La Niña Watch is issued when conditions are favourable for the development of El Niño or La Niña conditions within the next six months; an El Niño or La Niña Advisory is issued when El Niño or La Niña conditions are observed and expected to continue; and a final El Niño or La Niña Advisory is issued once El Niño or La Niña conditions have ended.
(http://www.cpc.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.html).

NOAA's ENSO blog (https://www.climate.gov/news-features/department/enso-blog) is an outreach effort to communicate with the public about the science and impacts of El Niño, La Niña and other climate–weather connections. Targeting the weather- and climate-interested public, the blog publishes original content on topics that range from the physical science underlying ENSO to its societal, economic and environmental impacts. The project is a collaboration between ENSO experts from NOAA and IRI and the writers and data visualizers of Climate.gov.

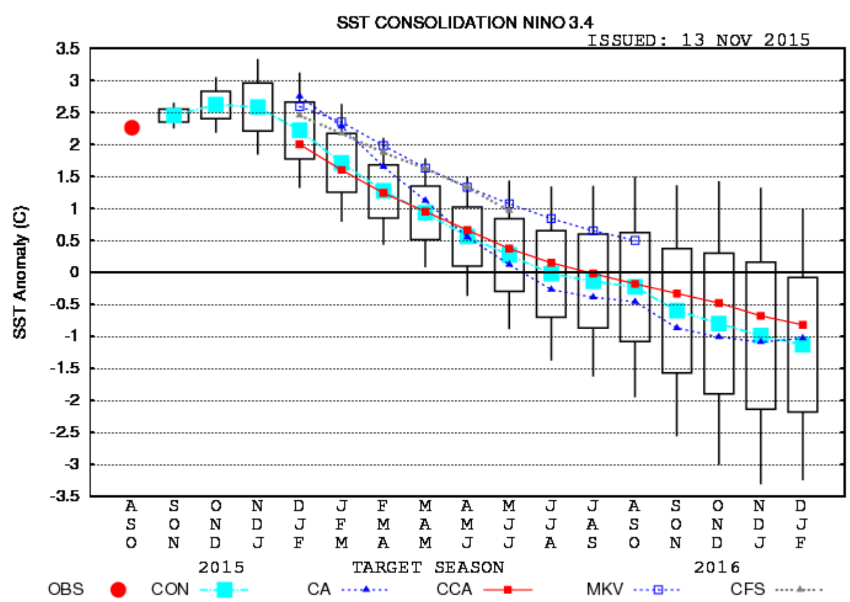

Figure 7. Sea-surface temperature consolidated Niño3.4 outlook

Source: NOAA/Climate Prediction Center

The UK Met Office provides tropical Pacific SST forecasts (Figure 8) which are used for monitoring the state of the equatorial Pacific Ocean, especially the anomalous warming and cooling associated with El Niño and La Niña. Forecasts are provided for each of four regions that help to describe the state of the tropical Pacific, particularly in relation to ENSO.

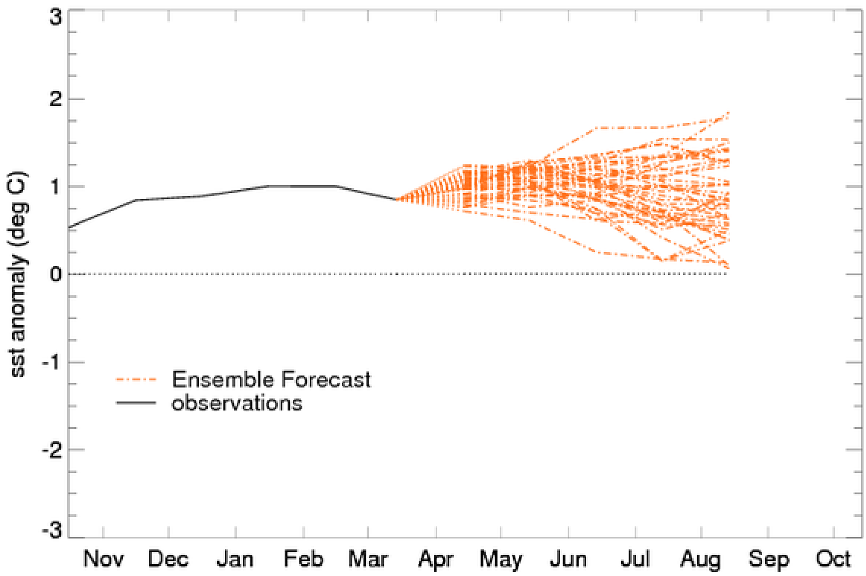

Figure 8. Example of a tropical Pacific sea-surface temperature forecast

Source: UK Met Office

2.1.4 Global tropical hazards

Further climate prediction products focus on distinct climate regions, for instance the tropics, the North Atlantic, or regions prone to tropical cyclones. The NOAA/CPC Global Tropics Hazards and Benefits Outlook (Figure 9) provides an outlook for the upcoming Week 2 time periods for areas expecting enhanced or suppressed rainfall integrated over a week and regions where conditions are especially favourable or unfavourable for tropical cyclogenesis (the Week 2 outlook starts from Day 7, which is slightly different from the definition of a long-range forecast, as described above). This outlook provides advance notice of potential hazards related to climate, weather and hydrological events across the tropics and aids various sectors of the US economy (finance, energy, agriculture, water resource management) with foreign interests.

The anomalous rainfall outlooks target broad-scale conditions and local conditions will vary. The product synthesizes information and expert analysis from a number of CPC outlooks, as well as other operational monitoring products. The physical basis for the outlooks include ENSO, MJO, other coherent subseasonal tropical variability, interactions with the extra-tropical circulation, statistical and dynamical tropical cyclone tools and numerical weather forecast guidance.

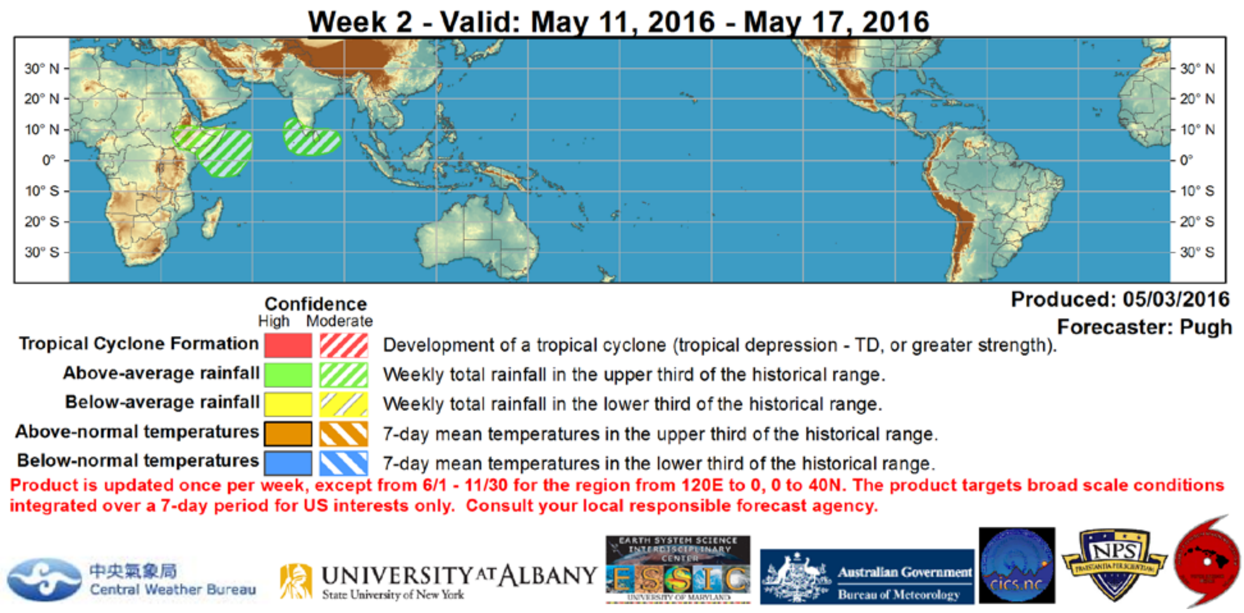

Figure 9. Global tropics hazards and benefits outlook for Week 2

Source: NOAA/Climate Prediction Center

2.2 Remarks

The examples given here are GCP products that are currently available through GPCLRFs. Again, we encourage users of this publication to visit each Centre's web page to learn more about its products and to explore the possibility that those products would be beneficial if adapted/developed for their regions in partnership with GCP. As will be seen in the following section, the majority of climate services require regional or local climate information. Strong collaboration between GPCLRFs and NMHSs will allow for information to be robustly transferred from the global scale to smaller scales.

3. From climate predictions to services

Any business or individual undertaking activities that are affected by the weather is likely to be affected by future changes in climate or, at least, should consider how future changes might affect them. Many GPCs listed above, NMHSs and other organizations are beginning to transform the types of climate prediction products, explored in the previous section, into end-to-end climate services to support decision-makers.

These agencies often work closely with users to provide insight into how climate may affect their activities and to help them plan appropriate actions. Users' needs are typically related to their economic or social activities, which translate into specific, non-meteorological variables. Work involves tailoring prediction products to match the needs of users. Climate services are available for a wide range of users, including government, industry and the general public, both locally, nationally, regionally and, sometimes, globally. The services are often tailored specifically to the needs of individual users, however, and are not, therefore, made openly available to all users.

Applications include the mitigation of weather-related natural disasters and uses for social and economic good in agriculture, energy, transportation, water resources and health. Types of climate prediction service products are listed in Table 3, and some case studies are explored in greater detail in the next section. This section will now include a brief overview of the ways in which climate prediction products are translated into climate services and the recognized benefits of such services. We also introduce some key access points for current research and development of climate services, as well as further sources of information.

Table 3. Types of climate prediction services

Timescale	*Description*
Extended-range services (10–30 days)	Services on this timescale are most frequently sought by users of weather services who require additional lead-time for decision-making: for instance, those in the transport sector, making daily decisions to grit roads in the winter, but also requiring additional notice a few weeks in advance in order to organize grit stocks and personnel.
Long-range services (30 days to one year)	The majority of existing climate prediction services fall into this category, due in part to the advanced nature of prediction science and understanding of skill on these timescales, but also due to the relevance of this timescale for a range of decision-makers. Examples of services on this timescale include prototyping seasonal information for the utilities sector, famine early warning services and hydrological outlooks (see case studies, section 4) for resource and response planners.
Annual and decadal services (one year to next 10 years ahead)	The science and prediction capabilities on these timescales are less advanced than the other timescales and the predictive skill is lower. Climate services using this science are, therefore, still in their infancy.
Multi-timescale services	Many centres are beginning to explore the value of providing services to a single user group over multiple timescales. This can provide a seamless service influencing decisions from out to a year ahead, to more detailed information for the coming month. One example of a multi-timescale climate service is the Yangtze Basin Services provided by CMA for the Three Gorges operations (see case study, section 4).

3.1 Developing climate predictions into services

Climate services differ from the products explored in the previous section as they go far beyond the provision of forecast information. Services are developed through thorough and ongoing engagement between providers and users. The different stages of this process are expanded below.

Figure 10. Process of developing climate services

3.1.1 User engagement

This stage refers to the understanding of user needs, decision-making cycles, dependencies, etc. This stage in the process is essential to establish trust in climate information by users to enhance uptake and usefulness of the climate information. For example, the importance of this engagement is demonstrated in the case study Development of Prototype Services for the Utilities Sector (see section 4). Over a period of the United Kingdom winter season 2014/2015, scientists working closely with the utilities sector prototyped potential seasonal forecast products and evaluated their benefit and value to the trial customers. Development of this climate service involved a lengthy period of meetings, workshops and interviews between the energy sector and the Met Office. From this, a more thorough understanding of the sector was gained and three distinct user groups were identified for further engagement (Table 4). Users were fully involved in the design of products, determining the spatial resolution and extent of forecasts, the lead times and frequency of forecasts, the levels of interpretation required for each user group and many details of the presentation of information.

Table 4. Different user groups identified for the trials

User group	*Expertise*	*Requirements*
Expert meteorologists for traders	Similar levels of expertise in long-range forecasting to Met Office scientists	Whatever information is available to summarize and communicate to their trading colleagues; expert interpretation of drivers behind the forecast and communication of relative uncertainty.
Traders	Lower expertise	Summary information from long-range forecasting systems, often provided by the group above; some are keen to see the information translated into impacts variables.
Operational planners	Cannot, in general, make use of information already provided.	More information needed to make decisions; some can see the value of highly tailored products, relating much more directly to the decisions they need to make.

This engagement then continued throughout a first season of prototypes, with some users providing detailed feedback and allowing the product to be updated and improved to suit user needs. Figure 11 shows one result of this engagement: clear presentation of complex information using appropriate language. Evaluation following the initial prototyping phase also demonstrated that most users had a high level of ownership and trust of the service, and an expectation of an ongoing relationship with the provider.

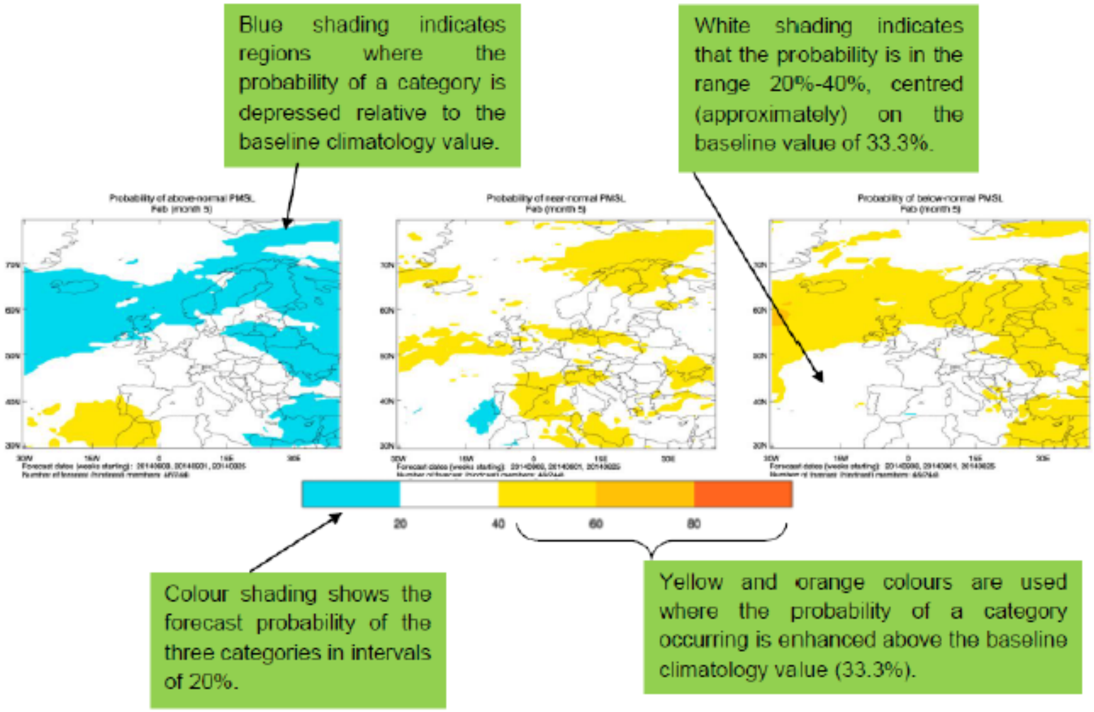

Figure 11. Explanation of an example tercile probability plot provided in the utilities prototype product guidance

Source: UK Met Office

3.1.2 Delivery of products

For a successful climate service, this component involves both a mechanism for delivery of information (for example: via web portal, e-mail, phone call, mobile app, television) but also opportunities for interaction, assistance with interpretation, troubleshooting or a collaborative decision-making process.

This approach is exemplified in the climate service provided by CMA for the Yangtze Basin – and in particular for the Three Gorges Dam decision-makers – by using the Forecast System on Dynamic and Analogue Skills (FODAS), which has functions of monthly and seasonal climate forecasting. Based on the dynamical model BCC-CGCM output and merging analogue forecast error information selected from a historical dataset, FODAS is able to produce corrected monthly and seasonal precipitation and temperature forecast data and images. The Three Gorges Project was completed in 2009. In the same year, the project entered a stage of fully fledged operation and management. Meanwhile, the upper Yangtze River escalated into a cascade development. As a result, service needs have been shifting from supporting local construction activities to allowing water resources to produce more benefits. Over the past 20 years, the Yangtze River Basin has reported increased disastrous incidences of floods and droughts. These disastrous events constituted a great challenge not only to the safe operation and scientific control of water reservoirs, but also to the combined benefits generated by the water conservancy project, including flood control, drought resistance, power generation, water storage and shipping.

In this context, prediction products are provided for the Yangtze River upstream of the dam and precipitation and surface rainfall in the key periods, including the precipitation process, storage period, supply period, receding period and flood season. Products are delivered to the Three Gorges Cascade Dispatching and Communication Centre through operational systems, a dedicated webpage and e-mail on a regular basis. in addition, consultation meetings are held on a regular or occasional basis to discuss the predictions. Table 5 gives a calendar for delivery of products and meetings to support these activities.

Table 5. Hubei Provincial Climate Centre/CMA climate services activities: calendar for delivery of products for the Yangtze Basin

Type	*Products*	*Time*	*Delivery*
Monthly forecast	Monthly precipitation trends and surface rainfall prediction for Yangtze River Basin	Day 9 each month	All provided to Three Gorges Cascade Dispatching and Communication Centre, via website, operational systems and e-mail
	The previous month Yangtze River Basin precipitation prediction quality assessment	Day 10 each month	
	Monthly precipitation trends, surface rainfall and extension period predictions for Yangtze River Basin	The last three days of each month	
Key periods forecast	Receding period surface rainfall forecasts (May–June)	10 March	Video conferences are staged periodically when an extensive heavy rainfall event is predicted to occur over the upper Yangtze River or when the Three Gorges Reservoir enters an unusual scheduling mode.
	Forecasts for flood season precipitation, Yangtze River Basin (the start time of Jinsha River rainy season and the first heavy rainfall event)	10 April	
	Forecasts for storage period surface rainfall (September–November) (the end of the Jinsha River rainy season and the last heavy rainfall event)	10 August	
	Forecasts for water supply period precipitation trends, Yangtze River Basin	10 November	
	Annual surface rainfall prediction, Yangtze River Basin		
Communication	Understanding of users' needs and defining the focus of service	Start of the year, mid-April–May, 10 August	Joint forum or video conference

	Final service requirements meeting to summarize services rendered in the year and gather new service requirements	End of the year	Video conference

An important part of the delivery of climate prediction into services is understanding fully and helping the user to understand how uncertainties in prediction are transferred into services and the decision-making process. Climate service providers will approach this challenge in different ways, for instance, directly providing climate prediction in terms of probabilities and uncertainty (Figure 12), capacity-building and training for users, discussions around the predictions as part of the climate service, or in decision-support systems which help users to manage risk according to the uncertainties inherent in both climate predictions and external factors.

One important consideration in this context is the provision of "seamless" forecasts, whereby a range of products are offered through the climate service, meeting the users' needs from the long term to the short term. For instance, from the seasonal timescale downwards, farmers may use forecasts to make an informed choice of crops prior to the season. During the season they will then require information on irrigation use and the application of fertilizer and/or pesticides. On a sub-monthly basis, they may also have key points for action in their decision cycle: whether, for instance, to leave crops a further week or two before harvesting. In instances where decision-makers already make use of seasonal forecasts, both longer and shorter timescale information could be of additional benefit. This is particularly true where predictions on one timescale alone may lack sufficient certainty or skill. A "ready-set-go" concept has been proposed by the Red Cross Climate Centre/IRI for use in disaster risk reduction, in which seasonal forecasts are used to begin monitoring subseasonal predictions – for instance, to gather resources, train staff and enable early warning systems ("ready"); sub-monthly forecasts can then be used to alert personnel to a potential need for action ("set'); and weather forecasts are then used to direct action, distribute instructions to communities and, if needed, evacuate ("go"). This concept could be transferred to other sectors and used as a structure for delivering cross-timescale climate services.

3.1.3 Feedback, monitoring and evaluation

Feedback, monitoring and evaluation are essential for capturing the user's experience and hence improving the service and its utility. This should be a continuous process and allow both providers and users to evaluate the benefits of the service. The Australian Bureau of Meteorology has ensured continuous engagement and feedback from the agricultural community through the Climate Champion programme (see section 4.4.2) with the aim of talking to researchers and farmers about what agriculture needs most from climate research.

In 2015, 20 "climate champions" from across the agriculture sector in Australia were able to trial BoM's climate prediction products and give feedback on the information they need and how useful the predictions are in managing risk. This interaction is designed both to improve farmers' access to information and their understanding of how to make use of the information given input from the scientists, and to improve the accuracy and value of the forecast tools and potentially to influence future climate research building on the feedback from users. (See case studies, section 4.)

3.2 Understanding the benefits of climate services

There is an emerging activity in the field of climate services aiming to quantify the benefits of these services. This is due in part to pressure for NMHSs to justify infrastructure and research funding, but also to enable and support a growing market for climate services. Many methodologies exist to demonstrate and quantify the value of weather services and many of these can be extended for use with climate services. WMO, jointly with the World Bank Group and Climate Services Partnership, recently published a book entitled *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services*, which outlines many of these approaches and provides some case studies.

Major projects in some regions aim globally to understand better the potential for climate services on prediction timescales. The EUPORIAS project funded by the European Commission is improving the ability of both providers and users to maximize the societal benefit of climate science on timescales of monthly to decadal prediction. Working in close relation with a number of European stakeholders, this project is developing climate service prototypes addressing the needs of specific users. Over four years, the 24 project partners – representing a diverse community ranging from United Nations organizations to small enterprises – is increasing the resilience of Europe to climate variability and change by demonstrating how climate information can become directly usable by decision-makers in different sectors (information on the outputs of this project can be found at http://www.euporias.eu). The Climate Services Partnership provides a library of case studies in addition to those detailed here, which show different approaches taken by a variety of providers working with users from many sectors (http://www.climate-services.org/case_studies/). WMO provides a further selection at http://library.wmo.int/pmb_ged/tudor-rose.

4. Examples of climate services

The case studies in this section have been chosen to demonstrate the process of climate service development as described in section 3. They have also been selected to cover climate prediction services from each of the five priority areas of GFCS: Agriculture and food security, Water resources, Health, Disaster risk reduction, and Energy. Further details on each of the case studies can be sought from the relevant institutions.

4.1 Agriculture and food security

Agriculture and food security are closely linked to climate conditions through extreme events such as droughts and heatwaves, floods and storms. 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. Agricultural systems that wisely use climate information can help to make better informed decisions at policy, institutional and community levels that improve the efficient use of limited resources and increase crop, livestock and fisheries' production by reducing impacts of climate risks and enhancing opportunities. Decision-makers are increasingly aware of the value of climate information – and getting timely information to farmers is key. For example, drought early warning systems can inform governments and international aid agencies of upcoming food-security crises months before the situation develops into a famine to ensure timely action.

Similarly, advance climate information can help to optimize farm-level activities, improve efficient use of resources, and make decisions to reduce vulnerability (http://gfcs.wmo.int/food_and_security).

4.1.1 Hazard outlooks for areas at risk of reduced crop production or livestock vulnerability

Drought is one of the greatest challenges in the developing world due to its impact on drinking water and food production. In response to this challenge, the international community has mobilized to develop famine early warning systems (FEWS) to bring safe food and water to populations in need. The NOAA CPC provides graphical monthly climate outlooks (http://www.fews.net/) for Africa, Central America, the Caribbean, and Central Asia. They are valid for one week and highlight areas that might be exposed to reduced crop production or livestock vulnerability due to flooding or drought.

Outlooks are based on the long-term monitoring of the climate, monthly to seasonal climate forecasts, crop and pasture conditions and field reports. The bulletin features both long-term (past conditions throughout the season) monitoring of the climate system and outlooks into the near future for about one week to a season. The objective is to provide targeted forecasts for areas that are vulnerable to droughts or flooding that might result in adverse impacts on crops or pastures. Hence, the hazard outlooks are based on a wide range of information, including raingauge data and satellite rainfall estimates, rainfall and surface temperature forecasts up to 16 days, and subseasonal and seasonal climate forecasts. Other inputs to the hazard outlooks include the United States Geological Survey riverflow forecasts and water requirement satisfaction index for crops and rangelands, NASA's normalized difference vegetation index (NDVI) and field observations.

The preliminary hazards outlook bulletin is prepared every week and distributed to partners in the Famine Early Warning Systems Network (FEWSNET), including the field representatives who have expert knowledge of conditions on the ground. A teleconference then takes place for a live discussion of current weather and climate conditions and the preliminary hazards outlooks. The feedback received during the teleconference allows for the finalization of the hazards outlooks. The hazards outlooks are disseminated through the website and an e-mail distribution list. This information is provided to the United States Agency for International Development for informed decisions in humanitarian response planning based on the level of food-security threats. Food-security outlooks are used to develop contingency plans so that food and safe water can be delivered in a timely manner to populations afflicted by natural disasters such as droughts or floods.

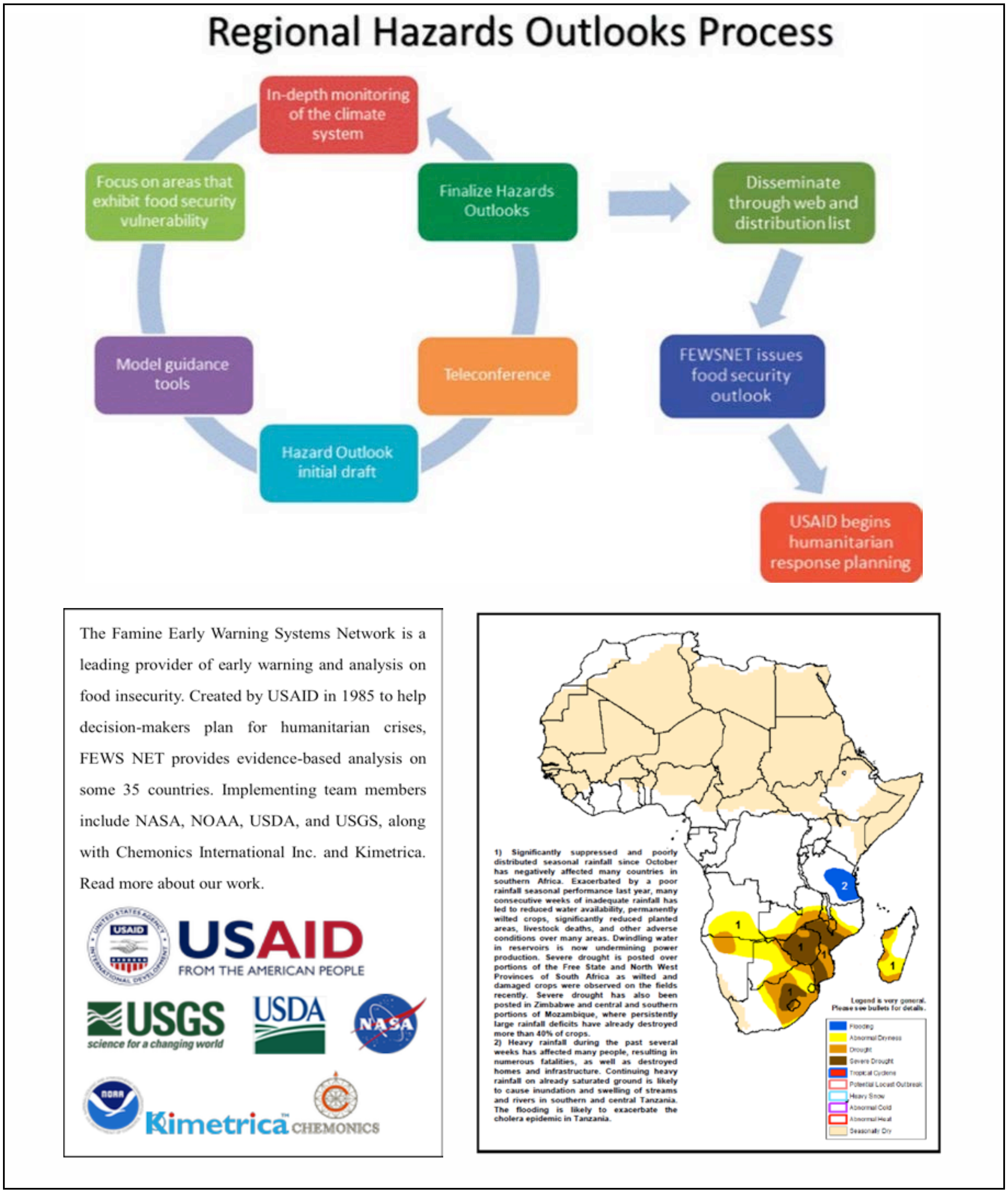

Figure 12. Above: schematic for the process of the regional hazards outlooks for food security. Below right: example of a regional hazards outlook for food security. Areas in brown, yellow and blue are areas that exhibit drought, abnormal dryness, and flooding, respectively. Highlighted areas are numbered based on the evolution of weather and climate conditions that led to the events.

Source: NOAA/Climate Prediction Center

4.1.2 Climate forecast for farming activities in north-east China

Liaoning is a major agricultural province and one of the key commodity grain-producing bases in China. Climate forecasts are important for guiding farming activities in the province. The Shenyang Regional Climate Centre (SRCC) provides an array of climate prediction products for farming activities. For example, SRCC forecasts the date of the first significant spring rainfall (greater than 10 mm in April) in Liaoning; the date of having a stable 5°C, a temperature desirable for rice seeding; and the date of having a stable 8°C for corn, in addition to the predictions of spring droughts, summer low-temperature stress, summer droughts and floods, and early autumn frosts and droughts. The season- or event-oriented forecasts serve as valuable consultation for government decision-makers. SRCC has been successfully producing monthly and seasonal climate forecast products for a couple of years by using its regular climate forecast system and FODAS. For example, the forecast of the date of the first significant rainfall in spring may help define the timing and growth of crops in the fields, which would in turn have a direct impact on agricultural production for the year.

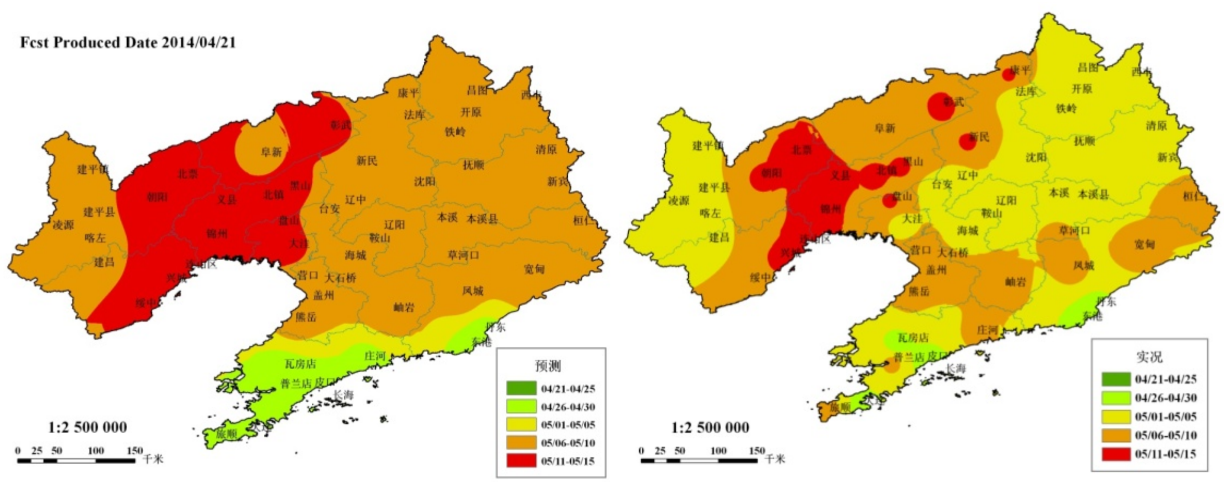

Figure 13. The observation (left) and forecast (right) of the date of the first significant precipitation in Liaoning Province

Source: Liaoning Provincial Climate Centre/CMA

The Shenyang Regional Climate Centre provides predictions of the first significant rainfall event for spring sowing in the Liaoning Province Spring Climate Trend Predictions released at the end of each February. A correction is made for the Liaoning Province April Climate Trend Predictions routinely released at the end of March. A rolling prediction of first significant spring rainfall is made every five days, starting on 11 April. A special report is also released describing the precipitation prediction for the next 30 days and for the first significant spring rainfall.

A series of consultation meetings and conferences sponsored by the Liaoning provincial government, the Liaoning Provincial Agriculture Commission and Meteorological Bureau are held throughout the year to discuss climate predictions and trends for the next month and season. For example, the first significant spring rainfall prediction product is made available to the Provincial Agriculture Commission for reference on a regular basis. In April 2014, Liaoning climatologists made an accurate prediction of the date of first significant spring rainfall 20 days in advance of the actual rainfall, which provided a strong basis for government decision-makers to plan agricultural production activities, allowing sufficient time for field preparations.

4.1.3 Early warning for food security and operational interventions

The World Food Programme (WFP) is well positioned to offer an integrated portfolio of tools to enable governments and communities to prepare and respond to shocks while building long-term resilience. A successful example of this are WFP's Rural Resilience Initiative (R4), the Food Security Climate Resilience Facility (FoodSECuRE) and the Weather Risk Management Facility.

The Food Security Climate Resilience Facility (FoodSECuRE) is a corporate mechanism that triggers community-level action before climatic shocks occur and provides predictable multi-year funding for post-disaster resilience building activities. The R4 Rural Resilience Initiative is a comprehensive risk-management approach to help communities become more resilient to climate variability and shocks. The Weather Risk Management Facility jointly developed with the International Fund for Agricultural Development (IFAD), aims at reducing smallholders' vulnerability to weather-related risks that limit agricultural production and food security.

Furthermore WFP's Vulnerability Analysis and Mapping Unit (VAM) scaled up the effort to develop the Seasonal Monitor System (https://www.wfp.org/content/seasonal-monitor and http://vam.wfp.org/sites/seasonal_monitor). This is a near-global system to monitor growing-season conditions for all its areas of operations (Central and South America, West Africa, East Africa, southern Africa, Middle East and Central Asia, Asia and Pacific). It was set up in mid-2014 in response to increasing requests for growing-season conditions analysis and crop and pasture production assessments for a particular region or country.

The system is based purely on freely available satellite rainfall and vegetation datasets: the near-global satellite rainfall estimate dataset CHIRPS from the Climate Hazards Group at the University of California Santa Barbara and NASA's global MODIS NDVI product. A range of outputs is produced, mainly aggregations of rainfall amounts at varying timescales, indicators of onset of the growing season and vegetation indicators, as well as anomalies of most parameters relative to a 20-year average (12 in the case of NDVI). The main output of the system is a region-specific monthly report, which describes current growing-season conditions and provides an outlook for the months ahead based on available seasonal forecast information (from Regional Climate Outlook Forums, for instance).

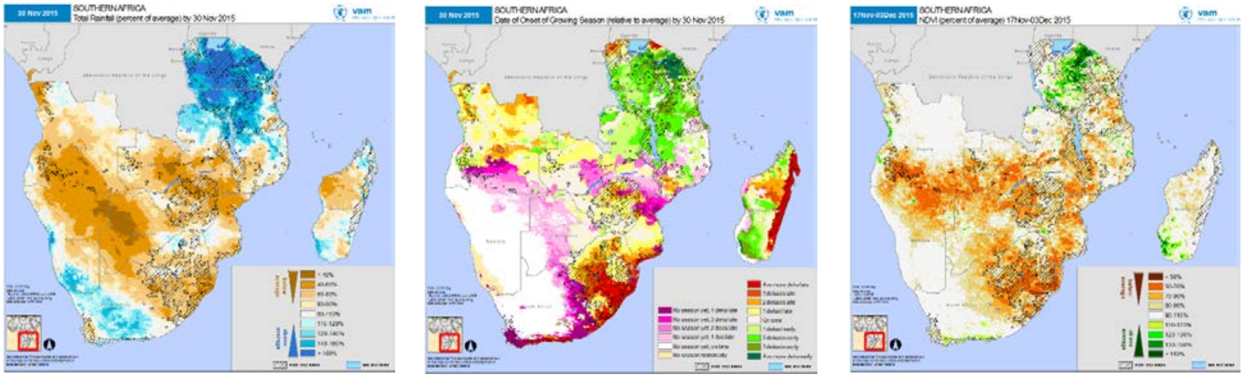

Figure 14. Examples of three products for the southern Africa region, on which the seasonal monitor reports are based: 30-day rainfall against average (left); comparison of the current date of start of the growing season with a long-term average (centre); and vegetation index compared with average (right). The products display remarkable consistency (rainfall deficits match delays in the onset of season which match sparser/less green vegetation than usual). This internal consistency underpins the strength of the diagnostics provided to users.

Source: https://www.wfp.org/content/seasonal-monitor

A new tool has recently been added: a data visualization platform that allows users to monitor rainfall and vegetation conditions for any arbitrary administrative unit (three levels, country, province and district) within the near global data coverage (all countries within 50°S to 50°N).

For the chosen administrative unit and selected year, the platform displays temporal plots of the current and long-term average rainfall and NDVI, as well as anomalies of each parameter, allowing users to assess the performance of the selected growing season. Plots can be downloaded as graphic files for user's reports; the raw and derived data can also be downloaded as spreadsheet files, so that users can create their own plots and make their own downstream processing of the data. Data are available as of 1981 (for rainfall) and from 2002 (NDVI). The platform can be reached at: http://dataviz.vam.wfp.org/Agroclimatic_Charts.

In parallel, there is growing interest and need for country-specific climate analyses. These have been done in-depth for three countries – Niger, Sudan and Uganda – in the context of a joint WFP–IFAD agreement on the applications and joint mainstreaming of climate and Earth observational data analysis. The analysis consists in the mapping of averages, inter-annual variability and medium-term trends of a range of indicators including seasonal rainfall, average vegetation cover, dates and length of growing period, within-season rainfall distribution, etc. A similar but smaller-scale effort has been carried out for a number of Asian countries in the scope of the initiatives of the Consolidated Livelihood Exercise for Analysing Resilience (CLEAR).

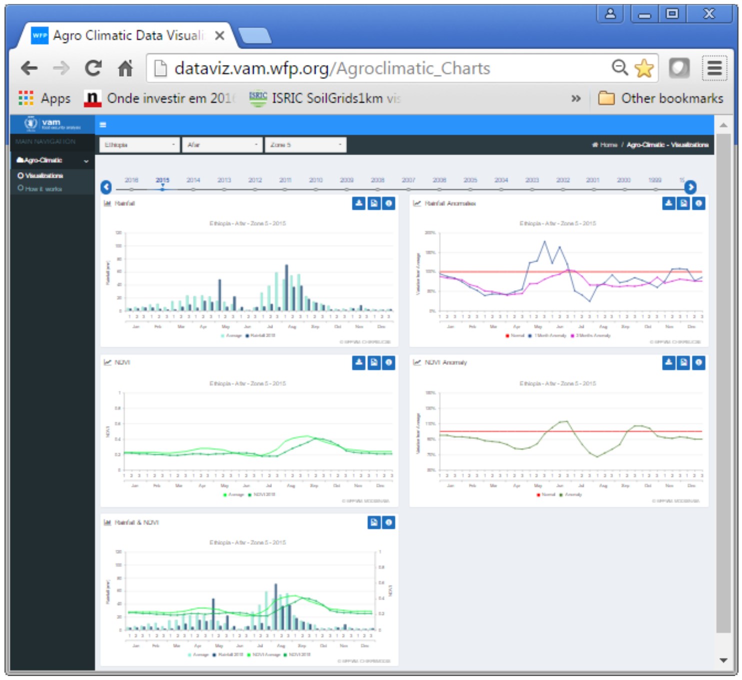

Figure 15. Data visualization platform, showing results for an administrative division in Ethiopia for 2015. All plots and data can be downloaded by users. Plot elements can be toggled off and on for clarity or enhancement.

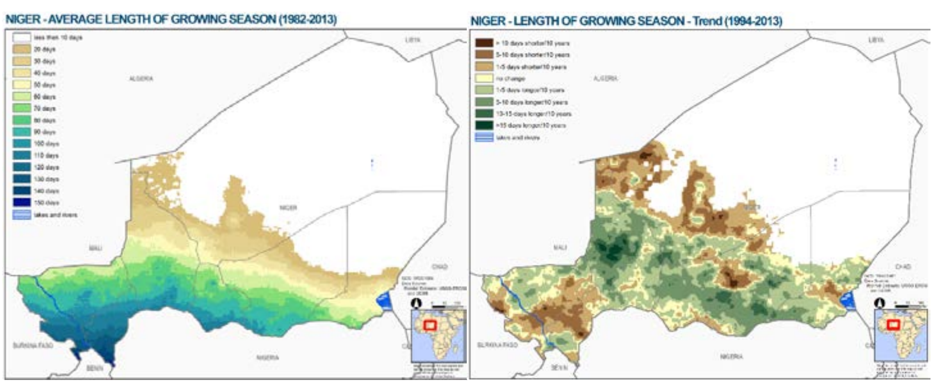

Figure 16. Example of outputs from a Niger Climate Analysis: average length of the growing season (left); and 20-year trend in length of the growing season (right). Typical Sahelian growing season latitudinal gradient is evident as is an indicative trend of decreasing growing-season length in the south-west of the country, its most productive area.

Source: http://vam.wfp.org/sites/seasonal_monitor

Given the volumes of food procurement in which WFP engages, specific analysis mapping the impact of El Niño/La Niña on proxy indicators of crop production and on actual crop statistics are carried out in order to help WFP fine-tune its procurement strategies. These analyses also allow WFP to carry out a priori identification of El Niño-/La Niña-affected regions and the nature of the impact.

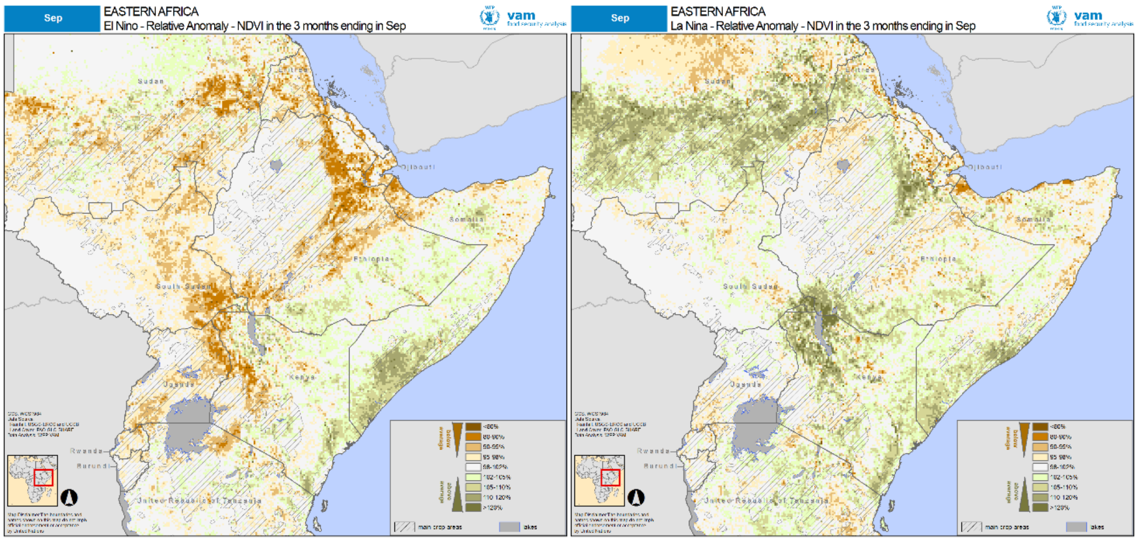

Figure 17. Example of outputs of an ENSO impact analysis for East Africa based on 1981–2011 satellite vegetation data. Maps compare average July–September vegetation index between El Niño seasons and neutral seasons (left) and between La Niña seasons and neutral seasons (right). Detrimental impacts on vegetation during El Niño seasons contrast with the improvements brought about by La Niña seasons.

Source: http://vam.wfp.org/sites/seasonal_monitor

4.2 Water

Water is a key driver of economic and social development, while it also has a basic function in maintaining the natural environment. Managers, whether in governmental or private sectors, have to make difficult decisions on water allocation, often apportioning diminishing supplies between ever-increasing demands. Drivers such as demographic changes and industrial pressure further increase the stress on water resources. To improve water management through the use of climate services, it is important to identify the tasks and the products of the service. These will include climate-prediction products, seasonal climate outlooks, downscaling products at various levels and different downscaling methodologies describing the underlying assumptions and uncertainties. Improving water management also requires the establishment of professional interactions between climate service developers and water managers at scientific and operational levels and across the full spectrum of water resources, including surface water, regulated and non-regulated systems, groundwater and the freshwater–ocean interface (http://gfcs.wmo.int/water).

4.2.1 Climate outlooks help water-supply planning

In the early 2000s, Tampa, Florida (USA) experienced prolonged drought conditions. As surface water became scarce, the regional water utility – Tampa Bay Water – made the decision to use groundwater to meet consumers' needs. Pumping groundwater lowered water levels in the region's wetlands and lakes, eventually damaging ecosystems and reducing wildlife habitat. When the extent of damage to natural systems became clear, Tampa Bay Water recognized that it needed to provide water for the environment, as well as for its customers. To supply both needs, water operations managers needed forecasting tools to help anticipate potential reductions in surface-water supply so that they could take steps to reserve sufficient water for ecosystems.

Figure 18. **Overuse of groundwater in the Tampa Bay metro area drained wetlands and caused severe degradation of natural resources (left). A new strategy using multiple water sources has allowed many areas to recover (right).**

Source: http://www.climate.gov

Outlooks from NOAA/CPC are used to anticipate temperature and precipitation patterns weeks and months into the future. A particularly important factor in Florida's climate is the months-to-years-long pattern of warming and cooling waters in the central Pacific associated with ENSO. The state of ENSO has proved to be a reliable indicator of wet or dry conditions in Florida. By tracking this pattern, water operations managers gain crucial insights into what they can expect from the climate system. Given experience using climate outlooks, this allows them to anticipate when surface water is likely to become scarce, enabling them to make timely decisions to save groundwater and, ultimately, the ecosystems that depend upon it.

4.2.2 Hydrological Outlook UK

Hydrological Outlook UK provides information on a monthly basis about likely future hydrological conditions across the United Kingdom. Well-established observational networks assess the current status of riverflows and groundwater levels and a number of techniques are then used to predict for the next few months ahead. The outputs include a highlights map, as well as a detailed text interpretation of the forecasts. Further supporting outputs of the raw precipitation, temperature, groundwater and riverflow forecasts are also available. The outlooks are intended to provide guidance on the likely water situation over the coming months and could be used alongside other sources of information such as flood warnings and meteorological forecasts.

Hydrological Outlook UK is produced by a collaboration led by the UK Centre for Ecology & Hydrology, and involves the British Geological Survey, the Environment Agency, the Met Office, the Scottish Environment Protection Agency, Natural Resources Wales, and the Rivers Agency, Northern Ireland. Users can receive monthly outlooks via e-mail by registering on the Hydrological Outlook UK website (http://www.hydoutuk.net/latest-outlook).

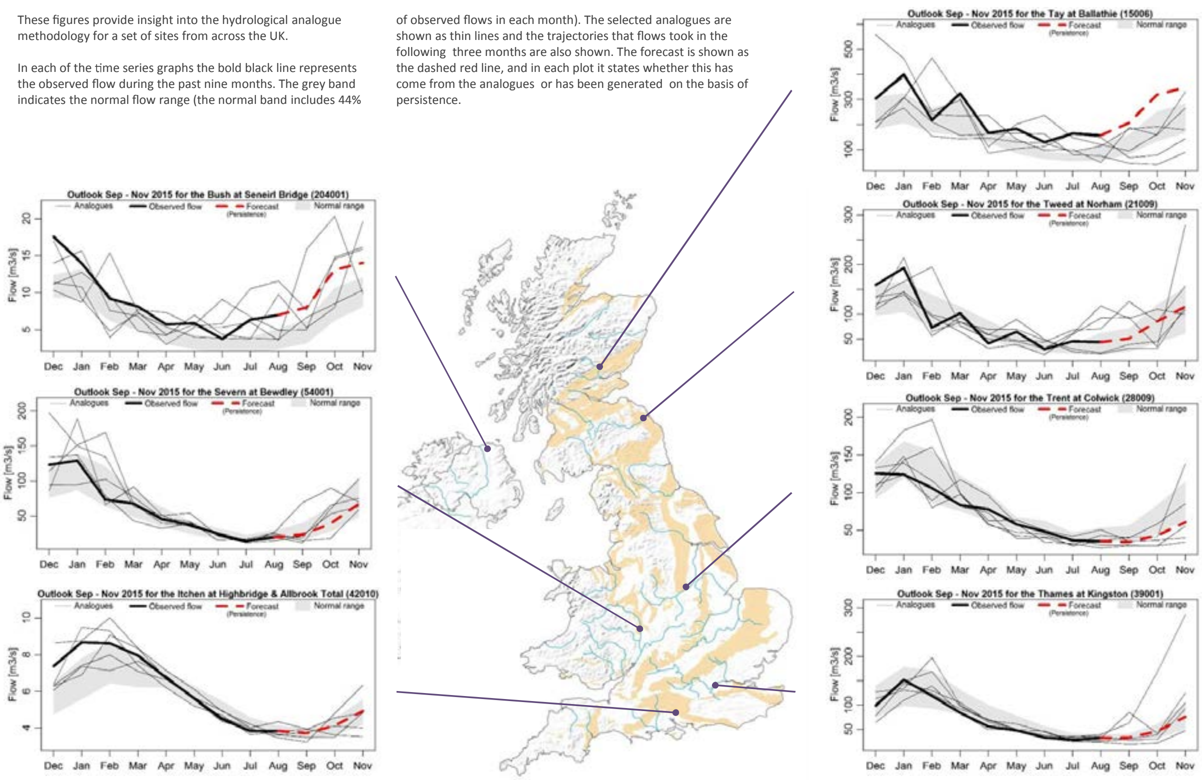

Figure 19. These figures provide insight into the hydrological analogue methodology for a set of sites across the United Kingdom.

Source: http://www.hydoutuk.net/

4.3 Health

Human health is closely linked to climate through extreme events such as heatwaves, cyclones, floods and drought. Climatic conditions also have a strong influence on the occurrence and distribution of some of the most important infectious disease burdens – particularly on poorer populations – such as diarrhea, malaria and other vector- and waterborne diseases. More fundamentally, climatic conditions affect the natural and managed ecosystem services that underpin population health, including the availability of freshwater and agricultural production, as determinants of food and potable water security, and shelter. Extreme weather, climate variability, and long-term climate change pose important challenges to the performance and management of health systems and health care services (http://gfcs.wmo.int/health).

4.3.1 Forecasting dengue fever risk for the football World Cup 2014

Brazil has reported more cases of dengue fever than anywhere else in the world this century (Teixeira, Costa, Barreto and Barreto, 2009). Many cities have tropical and subtropical climate conditions that allow the dengue mosquito to thrive during warmer, wetter and more humid months, particularly in densely populated urban areas. Dengue epidemics depend on mosquito abundance, virus circulation and human susceptibility. In order to prepare for dengue epidemics, early warning systems which take into account multiple dengue risk factors, are required to implement timely control measures. Seasonal climate forecasts provide an opportunity to anticipate dengue epidemics several months in advance.

A new predictive model framework for climate-sensitive diseases was developed as part of the Leverhulme network project EUROBRISA (led by the University of Exeter (United Kingdom) and the Brazilian Centre for Weather Forecast and Climate Studies (CPTEC)), which explored how European seasonal climate forecasts could be better exploited to improve climate resilience in South America. In collaboration with European and Brazilian climate centres, universities and the Brazilian Climate and Health Observatory, data from different sources and spatial/temporal scales (e.g. dengue, climate, cartographic, demographic, socioeconomic) were collated to formulate the model, which produces probabilistic dengue predictions for the 553 microregions of Brazil. By assessing the past performance of the model, optimum trigger alert thresholds were identified to maximize successful prediction and minimize false alarms for scenarios of medium and high risk of dengue, according to incidence alert levels defined by the Ministry of Health.

CPTEC probabilistic dengue forecasts were issued in mid-March 2014, which provided a forecast lead-time of three months. This early warning assisted the Ministry of Health and local authorities in implementing city-specific mitigation and control actions up to three months ahead of the 2014 football World Cup. The early warnings were also disseminated to the general public and visitors travelling to Brazil, raising general awareness about dengue fever and the risk of contracting the disease when travelling to endemic regions. Overall reported dengue cases for 2014 were lower than the previous year, although some outbreaks were observed in the south-east and north-east. This is a good example of climate services for public health ahead of a major global event. This type of warning can be provided before the peak dengue season each year to control or contain potentially explosive dengue epidemics. The operational use of seasonal climate forecasts in routine dengue early warnings is now a priority for the Brazilian Climate and Health Observatory, in collaboration with the National Institute for Space Research.
(http://www.preventionweb.net/files/workspace/7935_loweetaldengueews.pdf).

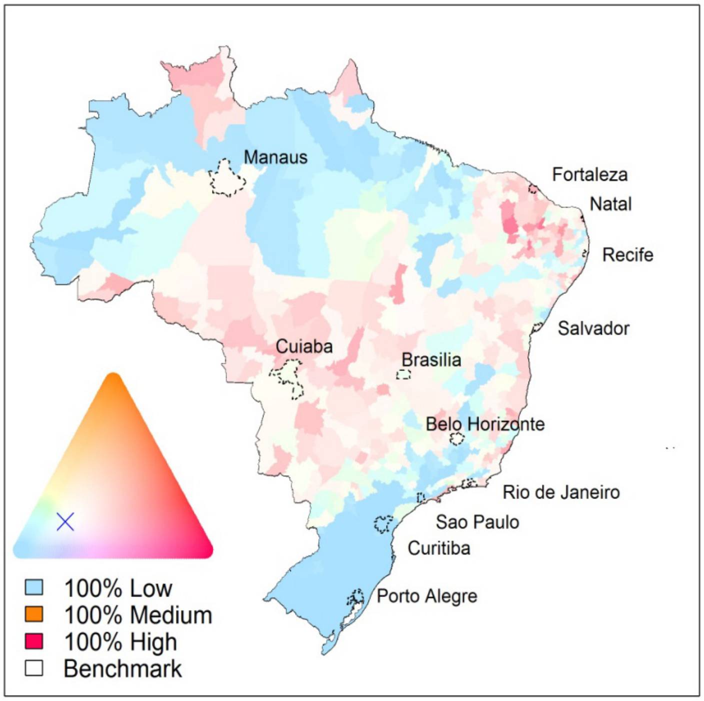

Figure 20. Dengue risk forecast for June 2014. The continuous colour palette conveys the probabilities assigned to low-, medium- and high-risk dengue categories. Darker red shows a high probability of high dengue risk. Darker blue indicates a high probability of low dengue risk. Lighter colours indicate a forecast similar to the benchmark (long-term average distribution of dengue incidence in Brazil, June, 2000–2013: p_{low} = 68%, p_{medium} = 16%, p_{high} = 16%), marked by a cross. According to the model, the most likely scenario for all 12 cities was for low risk. However, there was a greater probability of outbreaks in the north-eastern cities of Natal, Fortaleza and Recife.

Source: Centre for Weather Forecasts and Climate Studies/National Institute for Space Research, Brazil

4.4 Disaster risk reduction

Changes in weather and climate extremes and their related impacts pose challenges for global, regional, national and local disaster risk reduction systems. Climate services can help meet these challenges by giving decision-makers enhanced tools and systems to analyse and manage risk, under current hydrometeorological conditions, as well as in the face of climatic variability and change (http://gfcs.wmo.int/disaster_risk_reduction).

4.4.1 Seasonal climate forecast serves as a call to action

Lane County, Oregon, extends from the Cascade Mountains to the Pacific Ocean. Its green forests reap the benefits of ample rainfall but, each year, the region has to confront the possibility of high runoff and floods from wintertime precipitation and spring snowpack melt. In the autumn of 2010, Lane County Emergency Management learned that it might be an exceptional year: surface temperatures in the Pacific Ocean showed a clear La Niña signal, and decision-makers were aware that a strong La Niña could bring the region a higher-than-usual likelihood of seasonal flooding. As feared, when winter began, the county's rivers began to swell.

A winter outlook meeting was organized for more than 50 officials from public agencies and used to communicate potential weather conditions for the season. Based on seasonal forecasts and observations, county officials were advised to watch for heavy snowpack and a warming trend that could lead to melting snow, runoff and flood. Each of the officials then decided what actions to take based on their area of responsibility. Some officials asked their agencies to check river gauges, while others refreshed their contingency plans and monitored the weather more closely.

Figure 21. Lane County, Oregon: a winter outlook meeting/workshop (left) and a crew prepares sandbags to fight flooding (right).

Source: http://www.climate.gov

The efforts to prepare for the La Niña year did not stop with outreach to public officials. Community groups were also engaged about the winter weather, skipping over the technical explanations about climate forecasts and emphasizing the potential consequences of a wet winter and increased flooding. The group learned about possibilities for elevating their homes and purchasing flood insurance. Despite heavy rains and runoff during the winter and spring, Lane County was spared severe flood damage. Scientific information, together with local knowledge about riverflows and rainfall, was used to recognize the impending La Niña as a cause for concern, and allowed decision-makers to respond (http://toolkit.climate.gov/taking-action/seasonal-climate-forecast-serves-call-action).

4.4.2 The Climate Champion programme helps farmers manage climate risk

The Australian Bureau of Meteorology works with the Managing Climate Variability Climate Champion programme to help farmers manage climate risk by providing them with the best climate tools, products, practices and seasonal outlooks, and by helping them to gain an understanding of how they might use that information in their farm business. The Climate Champion programme aims to give climate researchers a chance to interact with farmers and obtain feedback about what they need from research. Twenty farmers, representing most of the major agricultural commodities, are taking part in the programme through which they can:

(a) Talk with researchers about the tools and information they need to help them manage climate risks;

(b) Test early research products and practices, and possibly influence the research;

(c) Influence how research findings are communicated to farmers;

(d) Help farmers in their region and commodity area to learn how to deal with climate variability and change.

For a long time, wheat has been the most popular crop in farmer Bill Yates's region of Garah (New South Wales, Australia). Yield is a challenge but the margins are superior. However, shorter winters triggered a change and now Bill grows more barley than wheat. Barley is better suited to shorter and drier seasons. The seedlings aggressively establish crown roots, which quickly explore the soil profile. Wheat often sits on a primary root system and cannot use stored moisture effectively. Part of barley's advantage is due to it being sown earlier and having more opportunity to drive roots down through moist soil without a dry band of soil stopping root growth. Barley will often reach grain fill before the heat kicks in and can also tolerate frost better. This is because it tends to flower while the head is in the leaf sheath. During droughts, barley is also hardier than wheat. If a season has been particularly dry, stock can graze on the barley and wheat to keep them going. However, if Bill gets good rain in July, barley will bounce back more quickly than wheat and allow him to harvest reasonable yields. So he can cover more bases with barley than he can with wheat, and it offers him more flexibility.

Shorter winters have also meant that he can start to think about sowing sorghum in mid-August instead of mid-September. He does this to reduce the risk of extreme temperatures when the crop is close to harvest. The decision to sow sorghum is based on temperature and rainfall. He starts by looking at the 10-day ECMWF model in the second week of August to see if the forecast daily and overnight temperatures start to increase and remain above 14°C (mean temperature). He will also look at rainfall, as this can have a cooling effect. If the next 10 days are predicted to be fine and above 14°C, then he will start sowing. There is some likelihood of frost that will damage seedling leaves or slow the plant down, but it is a smaller risk compared to losing yield because of extreme temperatures at harvest time. He would prefer to take a 5–10% hit in yield due to early season frost damage and get up to 80% more yield if the plant can flower and fill before 40°C heat. In 2013, he sowed on 25 August, two days after a big frost. The model said that it was supposed to be fine and warm for the next 10 days so he went ahead. Because many people in the area waited until mid-September to sow, they missed out on sowing sorghum.

Bill uses a combination of short-, medium- and long-term forecasts from BoM and ECMWF. When sowing, farmers are always looking at how much rain is predicted for the coming season and how much soil moisture they have. In 2014, Bill started with 100 mm of available, stored moisture and had 50 mm rainfall in-crop by mid-June. ENSO was neutral in March 2014, so he calculated a 35% probability of growing 2 tonnes per hectare using the French and Schultz formula. In summer, if there is an extreme El Niño event and little soil moisture (less than one metre), he does not sow much sorghum and, if he does, it would be with a strong perception of deriving grazing value from it. For instance, summer 2013/2014 was predicted to be ENSO-neutral – neither El Niño nor La Niña – but it turned out to be a really harsh summer. To manage this, he turned most of the crop over to feed. In the end, he had enough feed for his animals for the next three months.

In his role as a Climate Champion farmer, Bill shares his skills and knowledge with other farmers in his region to help them also to manage climate risk (http://www.managingclimate.gov.au/climate-champion-program/).

4.5 Energy

Energy generation and planning of operations are markedly affected by meteorological events and energy systems are increasingly exposed to weather and climate affecting both energy supply and demand. By taking into account weather and climate information, energy systems can considerably improve their resilience to weather extremes, climate variability and change, as well as their full chain of operations during their entire life-cycle. 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 (http://gfcs.wmo.int/node/737).

4.5.1 Seasonal forecasting in West Africa: management of Manantali hydropower

The Manantali dam has a yearly energy production of 800 GWh which serves three countries of West Africa: Mali, Mauritania and Senegal. The water management challenges are not only related to power production targets, they also include socioeconomic goals such as securing and improving the income of local populations thanks to the traditional agriculture in the valley. Decisions on water releases to flood the downstream valley need to be scheduled in order to minimize the impact on energy production. Consequently, the potential amount of rain after water release is a crucial piece of information to anticipate the partial restoration of water stock into the dam.

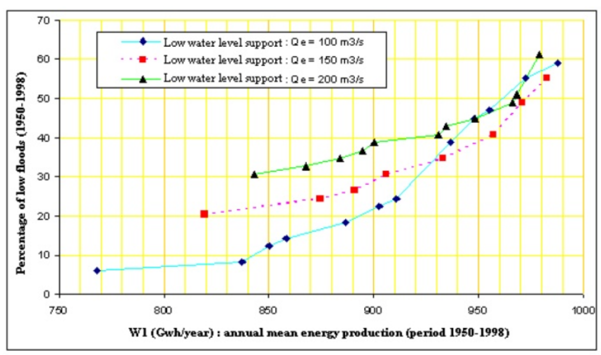

Figure 22. Relationship between energy production and the frequency of efficient flood. The graph shows the mean of the annual energy production versus the percentage of low flood (1950–1998 period) simulated for the different management scenarios.

Source: http://goo.gl/50XEpU

Accurate forecasts of riverflow are derived by coupling the estimations of the natural flow of the Senegal River at the entrance to the valley (downstream of the dam) with the seasonal forecasting model developed by Météo-France and the downscaled information (both in space and time) of the Arpege climate model rainfall forecast. The evaluation of the method by way of hindcast model runs indicates that the use of seasonal forecast information brings

80% of the maximum possible profits corresponding to a perfect forecast of the riverflow. In particular, critical dry years are generally well predicted. This information, coupled with the optimization management software of the Manantali, brings energy production optimization to some 30%–40%.

The procedure starts in Toulouse, France, where rainfall forecasts are issued at the end of July. These forecasts are specifically tailored and sent to Dakar, Senegal, at the beginning of August. The information is then transformed into a flow forecast and introduced into the decision tool used by the Permanent Water Commission.

4.5.2 Seasonal wind predictions for the energy sector

Climate has a considerable effect on energy demand and supply and influences many decisions. Energy producers, for instance, adjust their strategies based on a foreseen energy capacity and windfarm operators plan for optimal meteorological conditions to undertake maintenance work. The earlier these decisions can be planned, the sooner unforeseen operational risks can be identified.

EUPORIAS (http://www.euporias.eu/) is a collaborative project funded by the European Commission to address the use of probabilistic climate forecasts and support the development of climate services in Europe. One of the outcomes of the project is RESILIENCE (http://resilience.euporias.eu), a semi-operational, energy prototype of climate services that operates on a subseasonal to seasonal timescale. This prototype uses the 10 m wind speed forecast from ECMWF System 4 (S4) operational prediction system validated with the surface wind speed data from ERA-Interim. In order to produce usable, tailored and high-quality information ready to be included in the decision-making processes of the wind-energy sector users, the RESILIENCE prototype performs a series of measures to improve the wind forecast.

1. A post-processing stage is used to statistically resemble the observational reference and minimize forecast errors for seasonal prediction;
2. The output of seasonal forecast systems is compared to a reference, preferably observations, to assess their overall quality in a multifaceted process known as forecast quality assessment.
3. In order to estimate the multiple possible evolutions of the atmosphere-ocean system and the probabilities associated with them, the operational S4 forecasts are produced at the beginning of each month with 51 ensemble members. Each member of the ensemble uses slightly different initial conditions and different realizations of stochastic representations of subgrid physical processes in the atmosphere.
4. Probabilistic or ensemble forecasts and forecast uncertainty is taken fully into account to offer the most general and, a priori, relevant information for a user in the wind-energy sector instead of the traditional view offered by climate scientists, where only the ensemble-mean correlation is shown. The skill estimates, based on the performance of the system in the past, inform users about the expected performance of future forecasts.

The user interface designed for the energy users, in particular for windfarm managers and energy traders was developed by the Ukko Project. The Web interface (http://www.project-ukko.net) allows users to spot global patterns and trends in future wind conditions, and drill into detailed predictions on a regional level.

Figure 23. The user interface designed for windfarm managers and energy traders developed by the Ukko Project

4.6 Partnership development

Key to the development of climate services is strong partnership: between providers and users of climate information; between different disciplines bringing scientific, system and sector expertise; and between international groups with both local and global expertise. As noted earlier, this includes strong relationships between regional and global providers of climate prediction products (such as GPCLRFs) and national or local development of climate services (such as NMHSs).

4.6.1 Climate Science for Services Partnership (CSSP) between China and the United Kingdom

A major new collaborative endeavour began in 2014 between the United Kingdom and China, developing a strongly bilateral partnership between the Met Office, UK academia, CMA and the Institute of Atmospheric Physics (IAP) at the Chinese Academy of Sciences, along with other key institutes within China and the United Kingdom. The research programme is enhancing collaboration in underpinning climate science which will help both countries develop robust climate services to protect society against climate variability and prepare for a changing climate.

Through joint projects, scientist exchange programmes, workshops, training and shared PhD positions, CSSP China is maximizing the value and impact of collective capabilities and scientific expertise. This is focused on five themes:

(a) Monitoring, attribution and reanalysis;

(b) Global dynamics of climate variability and change;

(c) East Asian climate variability and extremes;

(d) Development of models and climate projection systems;

(e) Climate services.

Figure 24. The first meeting of the Climate Science for Services Partnership between China and the United Kingdom, 13–15 October 2015

Drawing on the first four themes on the underpinning science, experts from the United Kingdom and China are developing climate services through engaging closely with end users from key sectors of energy, urban environments, water resources and food security, closely aligned to the priorities and implementation plans of GFCS. Examples of the climate services work under CSSP China are given below.

One activity for this sector is to consider climate indices, which can be used to describe and predict agricultural output for users in China, and consider implications for the global food supply. There are more complex regional sensitivities that are not fully captured in the standard climatic variables assessed, and further investigation is needed to provide useful information. Further work will engage more strongly with users in China to understand their sensitivities and information requirements.

A strong programme of engagement between users and providers has taken place between the United Kingdom and Chinese researchers, leading to advances in understanding of the urban environments in China. This is being used to develop prototype climate services to increase urban resilience to rainfall and flooding and to climate-related health hazards. Figure 24 shows one result from stakeholder engagement giving the key climatological concerns for different provinces.

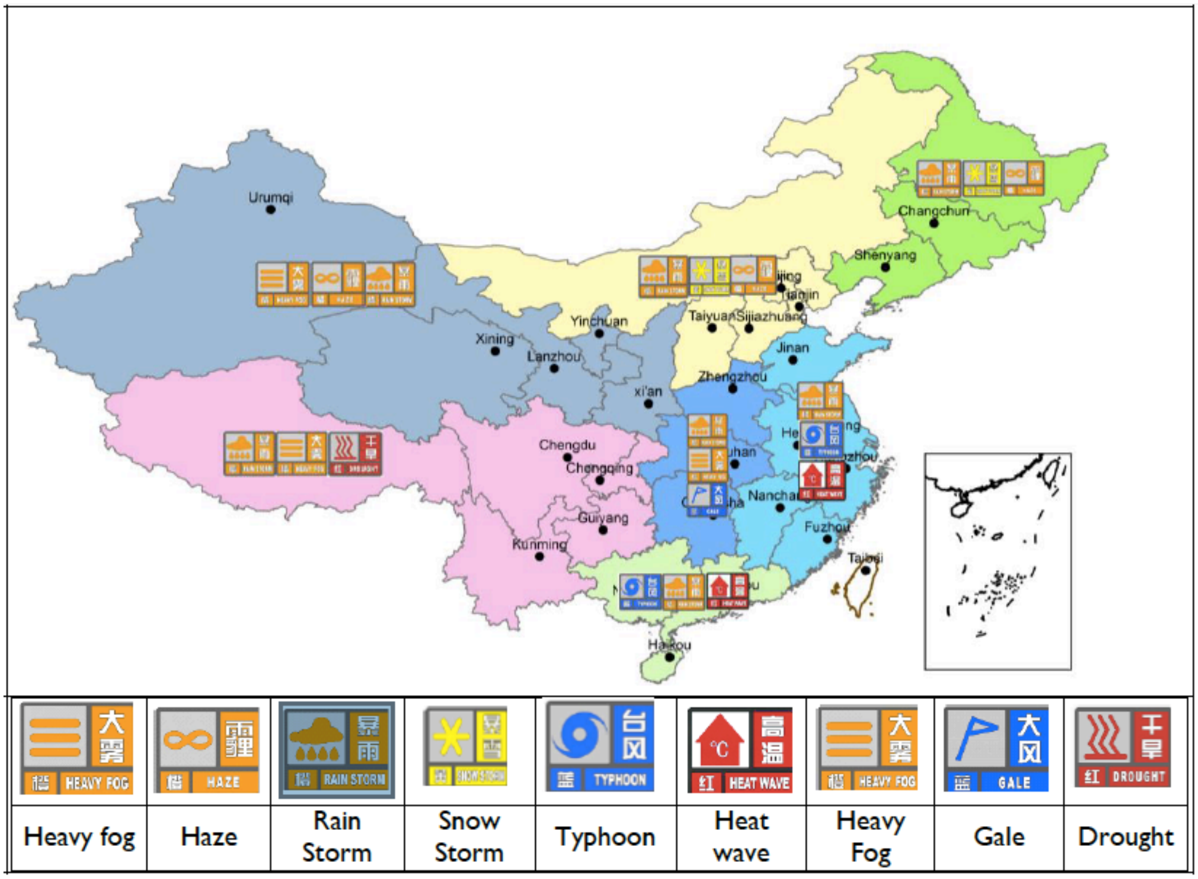

Figure 25. The climatological concerns for different provinces

Source: National Meteorological Centre/CMA

In addition to these tailored services, a number of other activities are helping to increase engagement with key sectors and share expertise:

(a) Case studies and knowledge-exchange materials are being used to translate developing science knowledge for users;

(b) A national dialogue with the energy sector is being organized in China to share knowledge, enhance engagement and improve use of climate information;

(c) A workshop on seasonal prediction for China and other countries in the East Asian region is being planned;

(d) A roadmap for a national framework for climate services is being developed to structure and prioritize activities leading to a stronger and more effective national framework for China and the United Kingdom, aligned with GFCS.

5. The ultimate goal: closer collaboration to enhance climate products and services

Climate prediction products and services are important and relevant to a wide range of users. The overview of currently available services and related benefits in this publication emphasizes the opportunities available for developing useful services for decision-makers at any scale. Key to the realization of these opportunities is close cooperation between providers, users and other stakeholders in their development. Section 3 has highlighted different examples of this cooperation and the significant benefits that this close engagement can bring to the value of a climate service.

Also essential is the collaboration across disciplines. Many of the case studies included in this publication comprise a joint effort between NMSs and experts in fields such as hydrology, agriculture, engineering and economics. This multi-disciplinary approach allows climate products to be developed into information tailored specifically to the decision-making needs of any user and hence increases the potential value and use of a service.

Finally, collaboration between climate product and service providers across scales is essential. As shown in this publication, a large range of climate products is currently available at the global scale from GPCLRFs. The opportunities exist for this information to be employed by NMHSs or national climate service providers to develop climate services with a regional or local focus. In addition to the forecast products, the websites recommended in this publication contain a wide variety of additional information on how forecasts are produced and used and on the development and delivery of climate services. By collaborating through the GFCS, both the private and public sectors are able to enhance climate products and services and to develop new projects to support the implementation of climate services, especially in least developed countries or regions.

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