WORLD
METEOROLOGICAL
ORGANIZATION

BULLETIN

Vol. 67 (2) - 2018

WEATHER CLIMATE WATER

Climate Change:
Science and solutions

Ólafur Eliasson, Climate and Art

WMO BULLETIN

The journal of the World Meteorological Organization

Volume 67 (2) - 2018

The WMO Bulletin is published twice per year in English, French, Russian and Spanish editions.

Subscription rates

	Surface mail	Air mail
1 year	CHF 30	CHF 43
2 years	CHF 55	CHF 75

E-mail: pubsales@wmo.int

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Hong Kong Victoria Harbour sunrise
Photographer: Hon Ming Tse

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Nature and the City, Hong Kong, China
Photographer: Chi Kin Carlo Yuen

The World Meteorological Organization has been awarded the 2018 LUI Che Woo Prize for Welfare Betterment. The citation recognizes that the persistent effort of WMO has been "pivotal in the tenfold reduction in global loss of life from extreme weather, climate and water-related events observed over the past half-century."

This award for the Reduction of the Impact of Natural Disasters is a tribute to the great advances that have been made in weather and climate services and to the 24/7 efforts by National Meteorological and Hydrological Services (NMHSs) in providing authoritative weather forecasts and disaster warnings that protect public safety.

The LUI Che Woo Foundation is based in Hong Kong, China. As Secretary-General of WMO, I collected this prestigious prize at a ceremony on 3 October and delivered a public lecture entitled Towards a Weather and Climate Resilient World. The prize of nearly US$2.5 million will allow WMO to strengthen initiatives on disaster risk reduction – in particular global multi-hazard early warning systems – to support both Members and United Nations humanitarian operations.

In this context, we have made a joint commitment with the World Bank toward the creation of an Alliance for Hydromet Development to boost climate and weather science and information for a resilient world. We have also signed a new framework agreement with the World Bank to simplify and streamline the process for providing WMO technical expertise.

Now, more than ever before, WMO and NMHSs play a vital role in building weather and climate resilience in support of the 2030 Agenda for Sustainable Development, disaster risk reduction and climate change. UN Secretary-General António Guterres has declared climate change to be one of his overriding priorities and is relying on WMO's scientific information services for a major Climate Summit in September 2019.

Continuing the trend of previous years, 2018 has been marked by high-impact extreme weather events, including heatwaves and drought, intense tropical cyclones and devastating flooding. Once again, 2018 will be one of the warmest years on record, despite the cooling La Niña at the start of the year.

Climate change is a reality and its impacts are increasing. This was underlined, with great scientific authority, the Intergovernmental Panel on Climate Change (IPCC) in the Special Report on Global Warming of 1.5 °C (SR15). The report assesses the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Governments invited the IPCC to prepare the report in 2015 when they adopted the Paris Agreement to combat climate change. The Paris Agreement sets a long-term goal of holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C. At that time, relatively little was known about the risks avoided in a 1.5 °C world compared with a 2 °C warmer world, or about the pathway of greenhouse gas emissions compatible with limiting global warming to 1.5 °C.

At the current rate of emissions, the world will reach 1.5 °C warming by 2040. The new IPCC report makes it clear that limiting warming to 1.5 °C would require unprecedented changes, as detailed in this issue of the Bulletin.

This Bulletin also showcases some of latest initiatives to roll out user-driven climate services; to improve forecasting and warning services for greater resilience, and to strengthen education and training which are key in preparing us for the future.

Climate change adaptation is no longer an option, it is a must. The longer we delay, the more difficult and costly this will be. This is why WMO is seeking to boost its scientific support to inform climate change mitigation and adaptation and to help Members become more resilient through a fully integrated, "seamless" Earth-system approach to weather, climate and water domains.

Petteri Taalas
Secretary-General
World Meteorological Organization

IPCC issues Special Report on Global Warming of 1.5 °C

Every bit of warming matters.

By **Clare Nullis**, Communications and Public Affairs, WMO

It has been described as the most important report ever published in the 30-year history of the Intergovernmental Panel on Climate Change (IPCC) and an "ear-splitting wake-up call to the world."

The new report on ***Global Warming of 1.5 °C*** made headline news around the world with its stark message that limiting warming to 1.5 °C would require unprecedented transitions in all aspects of society. The report stresses the huge benefits to human welfare, ecosystems and sustainable economic development in keeping warming to 1.5 °C compared to 2 °C, or higher.

The 33-page Summary for Policymakers and the underlying report was approved by IPCC member governments in Incheon, Republic of Korea, on 6 October. Ninety-one authors and review editors from 40 countries collaborated on the report, which cited more than 6 000 scientific references. It was produced jointly by all three IPCC Working Groups, on the physical science basis of climate change; on impacts, adaptation and vulnerability; and on mitigation of climate change.

WMO is one of the co-sponsors of the Nobel-prize winning IPCC, which was asked to prepare the report when governments adopted the Paris Agreement to combat climate change. The Paris Agreement sets a long-term goal of holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C.

The report underlines that we are already seeing the consequences of 1 °C of global warming through more extreme weather, rising sea levels and diminishing Arctic sea ice, among other changes.

Limiting warming to 1.5 °C is technically possible within the laws of physics, according to the report. But this would entail global emissions of carbon dioxide declining by about 45% from 2010 levels by 2030 to zero by 2050. At the current rate of emissions, the world will reach 1.5 °C warming by between 2030 and 2052 and is on track for more than 3 °C to 4 °C warming by 2100.

"This report by the world's leading climate scientists is an ear-splitting wake-up call to the world. It confirms that climate change is running faster than we are – and we are running out of time," declared UN Secretary-General António Guterres.

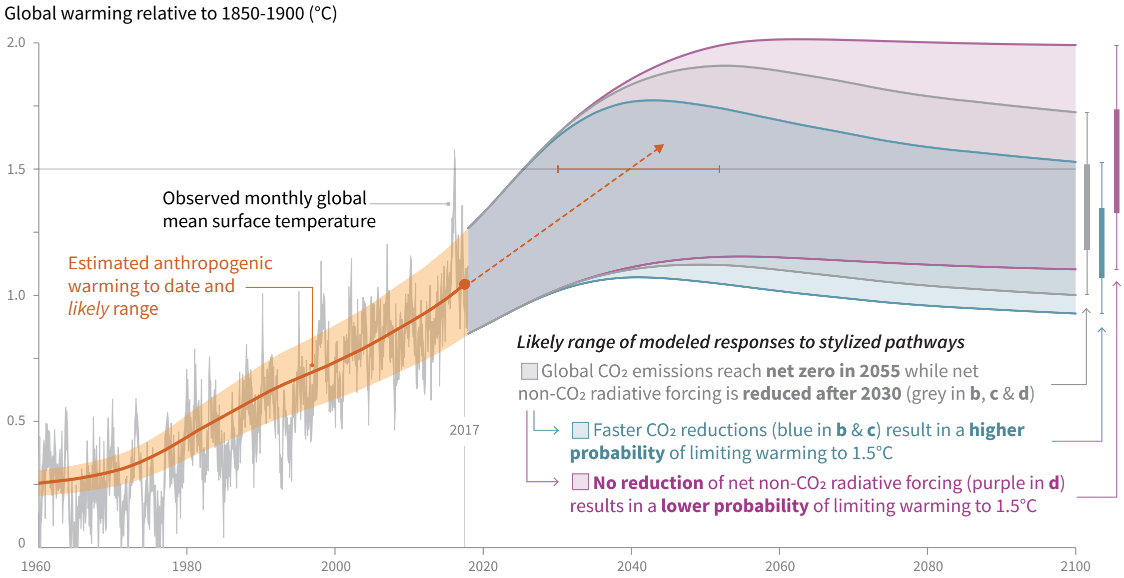
The report highlights a number of impacts which could be limited by lower temperature increases.

- Sea level rise: Sea level will continue to rise well beyond 2100, when it is projected to be 26 to 77 cm higher than the 1986–2005 baseline under a 1.5 °C temperature increase, about 10 cm lower than for a global warming of 2 °C. This would mean that up to 10 million fewer people would be exposed to related impacts such as saltwater intrusion, flooding and damage to infrastructure in low-lying coastal areas and small islands. Exceeding 1.5 °C risks triggering instabilities in the Greenland and Antarctic ice sheets, which could result in multi-metre rise in sea level over hundreds to thousands of years.

- Sea ice: The likelihood of an Arctic Ocean free of sea ice in summer would be once per century with global warming of 1.5 °C, compared with at least once per decade with 2 °C.

Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways



- Ocean health: Limiting global warming would slow the increases in ocean temperature and acidity and decreases in ocean oxygen levels and so would reduce risks to marine biodiversity, fisheries, and ecosystems. But with 1.5 °C, coral reefs are expected to decline by 70–90%, whereas more than 99% would be lost with 2 °C.

- Biodiversity: Impacts on biodiversity and ecosystems, including species loss and extinction, will be lower at 1.5 °C but will still hit thousands of species. Six percent of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5 °C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2 °C. High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss.

- Extreme events: Climate models predict increases in mean temperature in most land and ocean regions, hot extremes (increased number of days with temperature up to 3 °C higher) in most inhabited regions, increased frequency, intensity and/or amount of heavy precipitation in several regions, and increased intensity and frequency of droughts and precipitation deficits in some regions. There are big regional differences, with a particularly high risk for the Mediterranean, sub-Saharan Africa and Small Island States.

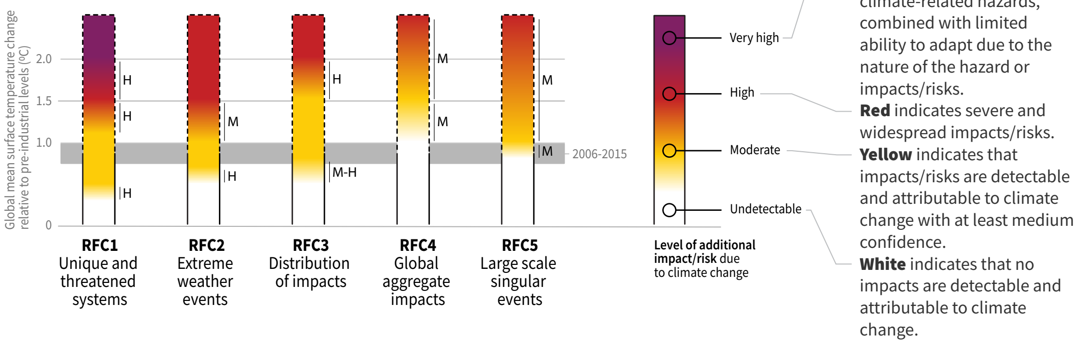
- Human welfare: Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5 °C and increase further with 2 °C. Limiting warming to 1.5 °C rather than 2 °C could result in 420 million fewer people being exposed to severe heatwaves.

- Water: Depending on future socioeconomic conditions, limiting global warming to 1.5 °C, compared to 2 °C, might reduce the proportion of the world population exposed to a climate change induced increase in water scarcity by up to 50%.

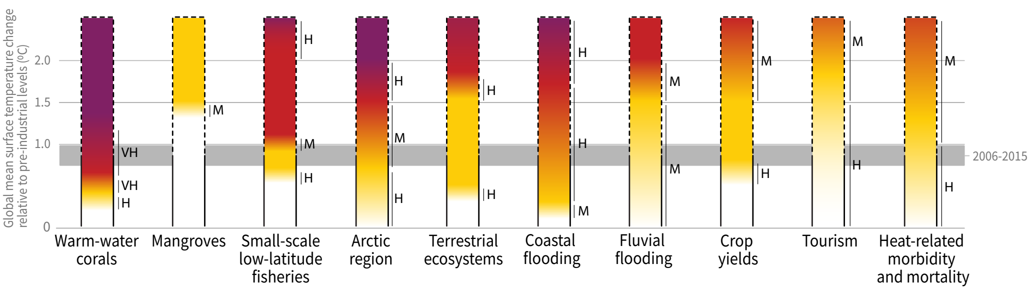
How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Source: IPCC Special Report on Global Warming of 1.5°C

Emission Pathways

Pathways limiting global warming to 1.5 °C with no or limited overshoot in temperature above that level would require rapid and far-reaching transitions in every sector of society and the economy. These systems transitions are unprecedented in terms of scale, according to the report.

By 2050, renewable energy would have to supply half to two-thirds of primary energy, with coal dropping to 1–7%. The shift to cleaner energy would need to be matched by progress in other sectors including better land management and sustainable agriculture, transport and diets.

CO_2 emissions from industry would need to be about 75–90% lower in 2050 relative to 2010, as compared to 50–80% for global warming of 2 °C. Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage.

All pathways that limit global warming to 1.5 °C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 Gigatonnes (GtCO2) of CO_2 over the 21st century. Avoiding reliance on future largescale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030.

Existing and potential CO_2 removal measures include afforestation and reforestation, land restoration and soil carbon sequestration, direct air carbon capture and storage. Most of these could have significant impacts on land, energy, water, or nutrients if deployed at large scale. Afforestation and bioenergy may compete with other land uses and may have significant impacts on agricultural and food systems, biodiversity and other ecosystem functions and services. Effective governance is needed to limit such trade-offs and ensure permanence of carbon removal in terrestrial, geological and ocean reservoirs.

The effectiveness of new techniques such as solar radiation modification is unproven at large scale and some may carry significant risks for sustainable development, the report notes.

Sustainable Development

The full title of the report is *"Global Warming of 1.5 °C: an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty."*

The title reflects the importance of a coordinated, holistic support for the 2030 agenda on sustainable development, disaster risk reduction and climate change.

A mix of adaptation and mitigation options implemented in a integrated manner can enable rapid, systemic transitions in urban and rural areas. There are multiple synergies and benefits for sustainable development (particularly for SDG 3 - health, 7- clean energy, 11- cities, 12- responsible consumption and production, 14- oceans), although trade-offs are possible.

The report will be a key scientific input into the Katowice Climate Change Conference in Poland in December, when governments review the Paris Agreement to tackle climate change, in a process known as the Talanoa Dialogue.

One of the underlying conclusions is that limiting global warming to 1.5 °C compared with 2 °C would reduce challenging impacts on ecosystems, human health and well-being, making it easier to achieve the UN Sustainable Development Goals and reduce poverty.

"Climate change adaptation is no longer an option, it is a necessity. This report makes it clear that the longer we delay, the more difficult and costly it will be," said WMO Secretary-General Petteri Taalas.

WMO is intensifying efforts to further strengthen early warning systems to protect lives in the face of more extreme events. Improved climate services are helping to increase resilience in our food and health systems, urban and coastal planning, energy and infrastructure and water management, he said.

WMO support for IPCC

Global Warming of 1.5 °C is the first in a series of Special Reports to be produced in the IPCC's Sixth Assessment Cycle. Next year the IPCC will release the Special Report on the Ocean and Cryosphere in a Changing Climate, and Climate Change and Land.

WMO will continue to provide support to the IPCC throughout the Sixth Assessment Cycle and is intensifying its scientific support for climate change mitigation and adaptation through a new strategy entailing fully integrated, "seamless" Earth-system approach to weather, climate and water domains.

Over the last two decades, climate science has made unprecedented progress in better understanding of the functioning of the climate system and in assessing consequences of human interference. Now, more than ever before, we need science to support adaptation to climate extremes and climate change, and to help to guide transformations needed for sustainable development of the planet.

Developing Human Resources for Providing Climate Services

By **Enric Aguilar**, Commission for Climatology, Member of the EC-Panel of Experts on Education and Training, Center for Climate Change, University Rovira i Virgili, Tarragona, Spain

In the ten years since the World Climate Conference-3 (WCC-3) and the development of the Global Framework for Climate Services (GFCS), climate services have been recognized as critical to society for making decisions on how to cope with climate variability and change. Implementation of the GFCS uncovered large gaps in climate service competency across all WMO Regions, particularly in less developed countries. The Report of the High-level Taskforce for the GFCS in 2011 (WMO publication no. 1065) indicated that over one third of national services had only Category I: Basic Capacity or below infrastructure for delivery of climate services. This fact has led to intensive capacity development efforts by WMO and its partner agencies and institutions.

Basic Climate Service Capacity is defined as securing, archiving and opening access to a country's climate record as a climatological dataset. It is the foundation for delivering climate services, however, that includes only a limited interaction with users. Higher capacity levels include producing information products, predictions (probabilistic forecasts), and projections (estimated impacts under various scenarios, such as reduced or increased greenhouse gas emissions) and higher levels of user interaction. This is necessary in order to develop customized products and services needed by governments and industries. From 2014–2018, the Expert Team on Education and Training of the WMO Commission for Climatology (CCl) Open Panel of Experts on Capacity Development developed a Competency Framework for Provision of Climate Services. The new Competency Framework, published in WMO Technical Regulations, Volume I (WMO publication No. 49), identifies five competency units:

1. Create and manage climate datasets
2. Derive products from climate data
3. Create and/or interpret climate forecasts, climate projections and model output
4. Ensure the quality of climate information and services
5. Communicate climatological information with users

These high-level competency units describe the core functions of a full-capacity national climate service. Each unit includes more detailed descriptions of what comprises performance of these tasks as well as learning outcomes to guide assessment and training.

But the definition of a competency framework is only a first step in ensuring capacity development of human resources. It must be followed by implementation, including adaptation and adoption of the framework, competency assessment procedures and provision of adequate training to close competency gaps. In this regard, in the 2019–2023 period, a CCl Expert Team on Human Resources Development will:

- Publish the drafted Guidelines for the Assessment of Competencies for the Provision of Climate Services

- Develop a Basic Instructional Package for Climate Services (BIP-CS) based on the competency framework and associated learning outcomes. The BIP-CS will be a general qualification for climate services personnel, and will be appropriate for a university curriculum as well as professional development

- Liaise with other national meteorological and hydrological service focus areas to enhance training materials in the context of other existing

- Advise on implementation of the competencies, collecting and sharing information about verification and acknowledgment of competencies (such as a Seal of Approval or Chartered meteorologists/ climatologists)

- Increase accessibility and facilitate the choice of existing training materials in cooperation with national training centres, the COMET Programme, EUMETCAL, Copernicus Training, etc., and through the Climate Services Toolkit and WMO Global Campus mechanisms

- Investigate existing mentoring options for climatologists and advise on the potential development of a WMO mentoring programme

For nearly 20 years, CCl capacity development workshops have developed competency in creating and managing climate datasets and deriving climate products from them in all WMO Regions. Such activities will benefit from the implementation of the competency framework as well as from the WMO Global Campus initiative (see *The WMO Global Campus: An update and proposal for the future*, on page 65). The WMO Global Campus, which aims to help education and training institutions to work together more collaboratively, would benefit climate services training by building a community of practice that continually shares expertise and experience, and by enhancing access to existing training opportunities while also stimulating new ones, multiplying the effectiveness of institutions through their increased connectedness.

As a vision for the next decade, capacity development of human resources for the provision of climate services should include:

1. **Encouraging new institutions to engage in the WMO Global Campus initiative.** There are many institutions which offer specific training in climate services. Further collaboration and increased visibility will help both providers and users.

2. **Supporting and further developing successful ideas by adapting them or replicating them in different languages,** such as the Climate Services Tool Kit, the Météo-France Course on Climate Services or the CCl workshops.

3. **Using the WMO Global Campus to promote and disseminate training approaches that can increase the reach of training.** In addition to blended-learning and distance learning, use of the WMOLearn Resource Catalogue to make course materials available would be of enormous help. It can especially aid in the compilation of training resources in WMO and local languages.

4. **Implementation of competency management for the recognition of education and training achievements in climate service areas.** This can take the form of a badging system or designated learning paths resulting in transcripts with equivalences to a credits system (e.g. European Credit Transfer and Accumulation System (ECTS)), and could be standardized through WMO Global Campus involvement.

5. As education and training needs in the field of climate services are maturing, **the WMO community should network to foster and monitor the creation of higher education programmes** adapted to WMO Competencies for the Provision of Climate Services and following the BIP-CS, when it becomes available.

6. **Seeking further human and economic resources** specifically dedicated to training and the WMO Global Campus initiative.

Impact-based Forecasting and Warning: Weather Ready Nations

By **Rochelle Campbell**, Hydrologic Research Center, **Daniel Beardsley**, U.S. National Weather Service, International Affairs Office, and **Sezin Tokar**, USAID Office of U.S. Foreign Disaster Assistance

High impact hydrometeorological events do not recognize national boundaries. Flash floods, floods, landslides and drought, in particular, give rise to multiple casualties and significant damage to livelihoods and property. In order to significantly reduce losses, communities and individuals need to become more resilient through actions that integrate weather and climate information in decision-making processes.

To provide communities with such integrated weather and climate information, National Hydrological and Meteorological Services (NMHSs) need to develop capacity along the entire service delivery chain. By doing so, they will improve targeted impact-based forecasting, timely dissemination of accurate and easily understandable information, and delivery to the public and other sectors. The adoption of such a robust approach is identified as a high priority in the *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services*[1] (2015, WMO-No 1150) as well as in the *Multi-hazard Early Warning Systems: A Checklist*[2] (2018), which supports the *Sendai Framework for Disaster Risk Reduction 2015-2030*[3] (United Nations, 2015).

Many NMHSs are moving towards a Multi-hazard Impact-based Forecast and Warning Services approach that translates meteorological and hydrological hazards into sector and location-specific impacts and the development of responses to mitigate those impacts. The United States National Weather Service's Weather-Ready Nation (WRN) programme and the European and United Kingdom's Impact Based Decision Support Services (IDSS) are examples. Both, as well as the *WMO Guidelines*, place an increased emphasis on preparation to respond to weather-related events.

It is becoming urgent for more countries to make the transition from focusing only on the accuracy of hazard-based forecasting to also outlining the potential impacts of a forecast – an evolution from "what the weather will be" to "what the weather will do." To assist countries to do so, the U.S. National Weather Service-International Affairs Office, the U.S. Agency for International Development (USAID)/Office of U.S. Foreign Disaster Assistance (USFDA), University Corporation for Atmospheric Research (UCAR) and the Hydrologic Research Center are partnering with various NMHSs and National Disaster Management Agencies (NDMAs) to transfer the Weather-Ready Nations approach. Barbados, Costa Rica, El Salvador, Guatemala, Indonesia and South Africa are currently in the implementation phase.

The programme strengthens capacity at NMHS and NDMAs towards better and augmented use of weather, water and climate information to save lives, reduce human suffering and lessen the economic impacts of hydrometeorological hazards. As a result, participating NMHSs are going beyond producing accurate forecasts and timely warnings to better understanding and anticipating the likely human and economic impacts due to severe weather. There have been notable improvements in communicating their impacts to various stakeholders.

1 library.wmo.int/index.php?lvl=notice_display&id=17257#.W64-9hMzZhF

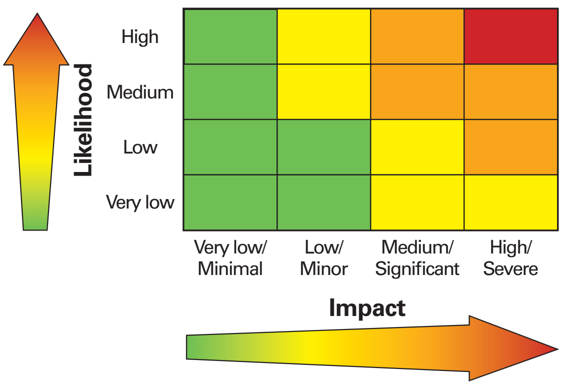
2 library.wmo.int/index.php?lvl=notice_display&id=20228#.W64_OxMzZhE

3 www.unisdr.org/we/coordinate/sendai-framework

Village house destroyed after flash flood.
Photo: Rochelle Campbell

The targeted information produced by the NHMSs – combined with NDMAs relevant country-specific information such as topography, flood and landslide hazard maps, population demographics and geo-located critical infrastructure and other vulnerability and exposures – aid to rapidly identify populations at risk, exposed assets, physical and social vulnerabilities and to support the quantification of impacts for early action.

Warning Risk Level (green, yellow, amber, red)



Specifically, the goals of the Weather-Ready Nations programme include production of local scale, relevant, impact-based forecasts that can be made into accurate, timely and easily understandable weather, water and climate information services which can, in turn, be easily integrated into decision-making processes. This is achieved through a four-phase approach that defines the What, Where, When and Early Actions that relates to the specific hazard and includes the information in the forecast and messaging.

Close operational cooperation among the NMHSs, NDMAs and other-sector stakeholder agencies, for example agriculture, energy, transportation, health and water resources, is essential for the Weather-Ready Nations to be successful. This requires a high-level commitment from the agencies to work closely together to share data, information, expertise and responsibility. It also requires the development of operational-implementation plans by each of the collaborating agencies with some planned overlap to guide and enable fruitful collaboration. The four phases of the Weather-Ready Nations programme are as outlined below.

Phase One: Developing matrices for impact-based forecasting

NMHSs and NDMAs work together to understand what information they need to improve decisions that protect lives, livelihoods and property and how they will disseminate reliable and specific forecasts that integrate human, economic, and cultural criteria as the first step. The NMHSs and NDMAs then jointly develop a risk matrix that illustrates the level of impact and the likelihood of occurrence for a specific hazard. Using the matrix, the NMHSs will be able to communicate the probability or likelihood of a potential hazard or multiple hazards and severity of its impacts. NDMAs are then better informed to make effective and timely decisions that factor in potential risk, impacts, costs and benefits.

From paper maps to GIS layers - Identifying vulnerable areas for different hazards.

Both agencies collaborate to identify how the likelihood of forecasted hazards (primary, secondary and tertiary) is associated with the key impacts. The experience of NDMAs in responding to disaster situations provide NMHSs with an understanding of the interdependencies of the infrastructure systems and essential services and by providing geo-spatial data overlays of exposure and vulnerability. A final component of this phase is the inclusion of advisory or response tables. These tables will provide guidance on what actions will be taken by the NMHSs and NDMAs when a severe weather event is likely to occur. Combining information on the evolving hazard likelihood, possible exposure and vulnerability data through appropriate decision support tools will contribute to the rapid identification of social and environmental risks.

This process is repeated for various sectors such as transportation, health, agricultural communities and community emergency volunteer teams. The matrices and tables are then tailored to the specific needs of each user. By speaking directly to the users and understanding the information they require as well as the information that does not help, NMHSs and the NDMAs improve delivery of tailored forecasts.

Phase Two: Technology and communication tools

The implementation of a multi-hazard impact-based forecasting and early warning approach involves new types of meteorological and hydrological product and warning information as well as new visual and practical presentation of information, including maps, user-specific graphics and weather symbols. This will require either the development of a new web-based display system or the use of existing software that is available to both NMHSs and NDMAs. A web-based tool that incorporates high resolution regional numerical modelling, observations, exposure and vulnerability layers; a tailored impact-based forecast and warning product – together with associated training of users – assists in improving service delivery by developing tailor-made forecasts that specifically address the weather-information needs of various users.

Impact-based forecasting requires that the NMHSs communicate their information so that it supports improved decision-making and planning. There is a growing body of knowledge about how people at risk interpret, understand, and use information in making decisions which NMHSs can use in this process. Incorporating a dissemination platform that links to a geographic information system (GIS)-based impact-based forecasting tool can broaden dissemination of the warning, taking advantage of a wide variety of media sources such as cellular telephony, SMS, radio, television, web page, Facebook, Twitter and WhatsApp. Equally important is both the consistency of the message sent to stakeholders and service delivery before, during, and after a severe weather event. This requires NHMSs to communicate forecasts and NDMAs to disseminate warnings quickly and effectively to as far-reaching an audience as soon as possible.

Phase Three: Development of standard operating procedures

Standard Operating Procedures are intended to help increase and guide early action in case of severe weather events, including drought, flooding, hurricanes and extreme heat/cold, and their impacts such as disease outbreaks. Standard Operating Procedures outline what actions need to be taken by whom and when, once there is the likelihood of a potential or impending severe weather event. This includes the mitigation or prevention of the impacts through disaster preparedness and response.

Standard Operating Procedures provide a structured framework for the initiation of early actions to mitigate the impacts of severe weather with a focus on four key areas:

- Strengthened, on-time information and analysis of the foreseen impacts of weather events
- Strengthened coordination that enables partners to implement early action in a timely way
- Improved early action and preparedness planning at country level.

The target audience for Standard Operating Procedures are NMHSs, NDMAs and other relevant partners at local, regional and national levels.

Phase Four: Training and outreach

A key component in the sustainability of the Weather Ready Nations programme is the capacity-building of the NMHSs, NDMAs and other relevant entities who may be called upon to support core partners before, during or after emergencies. The capacity-building programmes aims to employ a blended learning approach that incorporates the advantages of online courses such as simulation-based training, individual assisted learning and residence training. The training plans will take into consideration the following components:

- User training for emerging science and technology
- Communication and collaboration
- Management through decision support

The training is a critical element in preparing personnel to respond to emergency situations in a team-focused and collaborative environment.

NMHSs and NDMAs play a critical role in providing outreach and education material to establish weather-ready communities that are aware, involved and prepared for the potential impacts of severe weather. Communities and individuals that are educated in understanding the types of severe weather events, their potential impacts, and the importance of community planning for these hazards are in a much stronger position to respond appropriately and help themselves.

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World Meteorological Organization, 2015: *WMO Guidelines on Multi-hazard Impact-based Forecast and Warning services* (WMO-No. 1150); 2018: *Multi-hazard Early Warning Systems: A Checklist*

Disclaimer

The programme was made possible through support provided by the Office of U.S. Foreign Disaster Assistance, U.S. Agency for International Development, under the terms of Award No. AID-OFDA-T-11-00002. The opinions expressed in this publication are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development.

Strengthening Climate Services for the Health Sector in the Caribbean

By **Adrian Trotman**[1], **Roché Mahon**[1], **Joy Shumake-Guillemot**[2], **Rachel Lowe**[3,4] and **Anna M. Stewart-Ibarra**[5]

The climate science community can play an important role in addressing public health challenges. Many human diseases and health conditions are sensitive to changes in temperature, precipitation, humidity, wind and other environmental conditions such as air and water quality. Climate information can thus be used as a sign of risk and to inform disease monitoring and health research. In some cases, it can be used to predict when and where disease outbreaks may occur, in relation to expected climate conditions.

Tailored climate services can assist the health sector to make better decisions on how to allocate scarce resources (for example, finance, personnel, equipment and pharmaceuticals). They can help identify high-risk communities by monitoring environmental factors, alerting local communities and health providers to harmful conditions, and increasing awareness and preventive actions through education and training campaigns. The value gained by incorporating climate information into health decision-making processes can create more effective and efficient health services, thus reducing morbidity and mortality attributed to climate-sensitive health issues.

Climate services for health are an emerging field of applied science, defined as "the entire iterative process of joint collaboration between relevant multidisciplinary partners to identify, generate and build capacity to access, develop, deliver, and use relevant and reliable climate knowledge to enhance health decisions" (WMO/WHO, 2016).

Providing climate services for the health sector requires intensive collaboration. However, synergy between the health and climate communities does not necessarily occur naturally and may need to be catalysed and cultivated. Traditionally, there has been little investment in global issues related to climate and health, particularly in the Caribbean (WMO, 2014). This is not the case for other sectors, such as water, agriculture and disaster risk management, where the application of weather and climate services has been better documented and illustrated. However, many climate information products related to flood and drought, tropical cyclones, and extreme temperatures and heat, at a range of timescales (for example, hourly to decadal), have potential applications in the Caribbean health sector.

Demand for climate services for health in the Caribbean

The demand for a coherent and integrated approach to management of climate risks to human health underpins the objectives of the Global Framework for Climate Services (GFCS) Health Exemplar (WMO, 2014), which calls for:

1. Strengthened communication and partnerships among climate and health actors at all levels

2. Increased capacity of the health sector to effectively access, understand and use climate and weather information for health decisions

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3. Improved health and climate research and evidence of the linkage of climate and health

4. Climate and weather data effectively mainstreamed into health operations

The need for investment in systematic collaboration between the climate and health communities is arguably greatest in highly vulnerable, cash-strapped small island developing States (SIDS). Such States are exposed to extreme weather and climate events, rising temperatures and changes in ocean and ecosystem conditions. These factors influence disease transmission and the determinants of good health, such as clean water, safe and sufficient food, local economy and safe housing.

In recent years, the Caribbean has experienced a high human and socioeconomic cost burden from extreme wind and rain events that directly threaten life, result in damage and loss to housing and health facilities, and contribute to psychosocial illnesses. Exposure to strong ultraviolet rays, which can result in skin damage, is also a concern in a region where tourism is a significant socioeconomic sector. In addition, multiple climate-sensitive diseases, such as those borne by the Aedes aegypti mosquito (dengue, chikungunya and Zika viruses), as well as rodent-borne and waterborne diseases associated with flood waters (including leptospirosis, cholera and other gastro-intestinal diseases) have become more prominent in the region. Health experts have also identified emerging health risks from extreme heat and elevated levels of Saharan dust, which can be monitored and forecast with the help of the meteorological community.

Vector-borne diseases

The recent unprecedented public health crisis of co-occurring epidemics due to viruses borne by the Aedes aegypti mosquito is a top health priority in the Caribbean. Illnesses due to the dengue, chikungunya and Zika viruses have increased rapidly over the last three decades, exacerbating the physical and economic strain on already stretched health systems. For example, since 2013, Barbados has experienced three outbreaks of dengue, one of chikungunya and one of Zika (Lowe et al., 2018). In 2016, when a global public health emergency was declared for Zika, Barbados reported 926 suspected cases of which 147 were positive, while Dominica reported 1 263 suspected cases of which 79 were confirmed (Ryan et al., 2017). In the same year, Barbados also reported 314 dengue-positive cases (including 15 dengue/Zika co-infections) and 3 chikungunya-positive cases (Ryan et al., 2018).

Extreme heat

Extreme heat exposure, particularly during acute heatwaves, has been shown to increase morbidity and mortality of vulnerable populations and to reduce workforce productivity. Long-term exposure to elevated day and night temperatures poses other types of physiological stress on the body. People with chronic non-communicable diseases, such as heart disease, stroke and diabetes, and those with mental health concerns face special challenges with thermoregulation compared to healthy adults. As the Caribbean continues along a trend of increasing temperatures (Stephenson et al., 2014), it has become of critical public health importance to better understand the impact of excess heat, heat spells and heat stress in populations with non-communicable diseases.

Saharan dust

Significant amounts of desert dust travel thousands of miles from the Sahara region to the Caribbean annually on prevailing upper level winds. This often results in many countries exceeding the World Health Organization and United States Environmental Protection Agency air quality standards for fine (PM2.5) and coarse (PM10) particulate matter. Episodes of acute sand and dust exposure are affected by global wind and precipitation patterns, and environmental and climate conditions in the Sahara, and have serious implications for respiratory and ocular health in the Caribbean. Persons who already suffer from asthma and allergic rhinitis may become increasingly symptomatic during periods of elevated dust and PM10 concentrations.

The Caribbean region can no longer sustain the high human and economic burden of treatment, and the lives and quality of life lost to these climate-sensitive diseases. Anticipating disease transmission with climate intelligence is thus a priority, to support implementation of preventive measures.

Increasing regional capacity to develop climate services for health

There has been widespread recognition of the climate–health linkages and the importance of public health. However, Caribbean SIDS have been slow to take advantage of the opportunity presented by the development and integration of climate services into national and health sector planning and practice. Many countries in the region have absent or weak institutional arrangements that stunt meaningful collaboration between the health and climate sectors. They also have few intersectoral platforms or meeting spaces for mutual sharing, lack localized integrated empirical studies linking climate and health outcomes, and have a paucity of health-specific climate information tools and resources to mainstream into health operations.

In recognition of the challenges faced by SIDS, WMO has designated them a primary beneficiary target group for the GFCS. From 2013 to 2017, WMO carried out the Programme for Building Regional Climate Capacity in the Caribbean (the BRCCC Programme), which was funded by the United States Agency for International Development (USAID). The technical arm of the Caribbean Meteorological Organisation – the Caribbean Institute for Meteorology and Hydrology (CIMH) – implemented the programme.

CIMH, a WMO Regional Climate Centre (RCC) since 2017, was then in the demonstration phase of becoming an RCC. As such, it was routinely producing regional climate products and services in collaboration with its regional network of National Meteorological and Hydrological Services (NMHSs). These included climate data management services, historical and reference climatologies, climate monitoring, long-range (seasonal) forecast products and climate watches.

The BRCCC Programme was intended to increase the relevance and reach of CIMH by developing, testing and disseminating a new generation of climate tools and information products to support Early Warning Information Systems across Climate Timescales (herein referred to as EWISACTs). There was to be special focus on decision-making information for health and other GFCS priority sectors, as well as for the Caribbean's mainstay tourism industry.

The Caribbean's sectoral EWISACTs focus is on full "end-to-end" integration between climate information and early sectoral decision-making related to climate risk management. It channels the GFCS vision of enabling societies to better manage the risks and opportunities arising from climate variability and change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice (WMO, 2011).

In the climate information chain, this integration begins with analysis of climate-related vulnerabilities in the operational processes of end users. It continues with the co-development of products and services to address underlying vulnerabilities and then the co-delivery of user-defined climate impact prediction products and services at spatial and temporal resolutions required by end users. The idea is that focusing on meeting end-user needs for climate information and collaboratively developing products can enhance the quality of information available to sectors such as health, and also the uptake and use of tailored climate information.

Since 2015, CIMH has worked on an emerging, multipronged health–climate portfolio in collaboration with national and regional partners such as ministries of health, NMHSs, the Caribbean Public Health Agency (CARPHA), the Pan American Health Organization (PAHO) and other international, interdisciplinary research partners. The Caribbean experience in applying GFCS Health Exemplar principles to establish and strengthen these interscalar relationships at national, regional and international levels to advance health–climate services design, development and delivery in the Caribbean is described below.

Strengthening communication and partnerships

CIMH began the process of integrating social science approaches with its traditional physical science approaches to improve the development and delivery of climate services under the BRCCC Programme. Researchers at CIMH conducted a comprehensive end-user baseline assessment, which allowed health practitioners to communicate their need for and capacity to use available climate monitoring and forecast information produced operationally by CIMH.

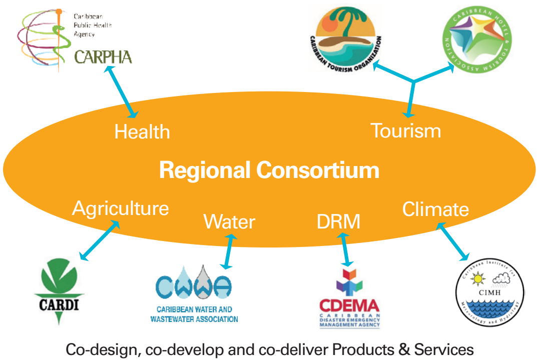


Figure 1. Consortium of Sectoral EWISACTs Coordination Partners – a group of six regional sector agencies and a regional climate service provider (CIMH) – committed to the co-design, co-development and co-delivery of user-specific and actionable climate information products

This revealed that health practitioners consider the dry and wet seasons when developing their annual public health plans, but do not formally incorporate climate information into their planning process.

Given the embryonic status of the application of climate science in the Caribbean health sector, it was clear that the sector should be a target beneficiary of the next generation of climate services.

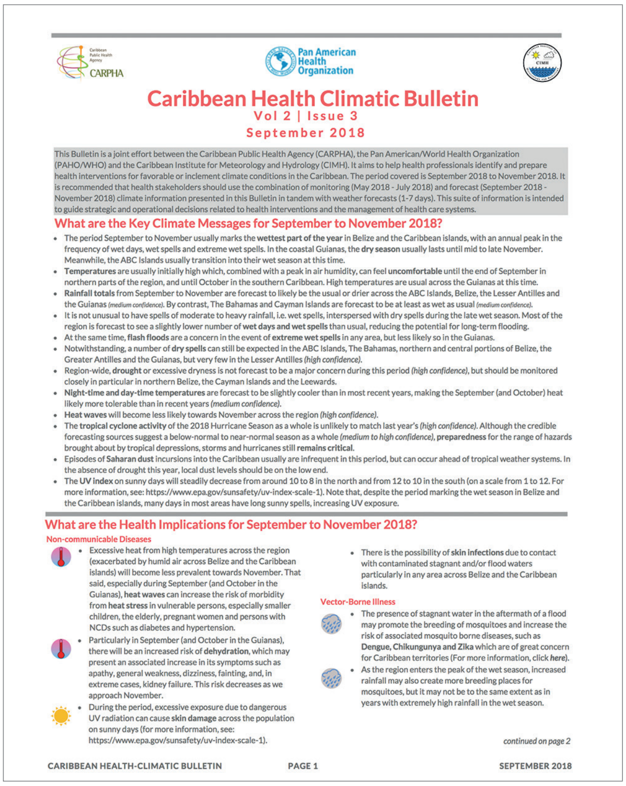
A key strategy pursued by CIMH has been the signing of formal agreements across institutions for collaboration in the development and integration of climate services in decision-making. This was underpinned by a desire to break away from the traditional mode of working in siloes towards a new model of inter-institutional collaboration for cumulative, integrated impact for sectoral climate services.

A Consortium of Sectoral EWISACTs Coordination Partners – a group of six regional sector agencies and a regional climate service provider (CIMH) – committed to the co-design, co-development and co-delivery of user-specific and actionable climate information products (**Figure 1**). CARPHA joined the Consortium in 2017 as the regional health partner, and is supported by PAHO in its activities.

Increasing the capacity of the health sector

The development and operational dissemination of sector-specific climate bulletins increases the capacity of sectors to access, understand and use climate information. These bulletins routinely translate the potential risks and opportunities associated with seasonal climate monitoring and forecast information for specific sectors. The Consortium partners have been instrumental in developing the first generation of achievable sector-specific and actionable climate information products that synthesize and provide messaging on the implications of climate for sectors, using information from the existing suite of CIMH technical climate products.

The Caribbean Health Climatic Bulletin, launched in June 2017, is a product of the collaboration between CIMH, CARPHA and PAHO (**Figure 2**). The Bulletin provides an overview of the climate over the forecast period and information on recent climate conditions and events. Through health partners, it also provides insights on what health risks may be exacerbated due to observed and anticipated climate conditions. Thus, the Bulletin offers guidance on numerous climate-sensitive health issues, including respiratory illnesses, non-communicable diseases, vector-borne illnesses, gastro-intestinal illnesses, well-being and mental health. This information is intended to inform strategic and operational decisions related to health interventions and the management of health-care systems.


CARPHA — Pan American Health Organization — CIMH

Caribbean Health Climatic Bulletin

Vol 2 | Issue 3

September 2018

This Bulletin is a joint effort between the Caribbean Public Health Agency (CARPHA), the Pan American/World Health Organization (PAHO/WHO) and the Caribbean Institute for Meteorology and Hydrology (CIMH). It aims to help health professionals identify and prepare health interventions for favorable or inclement climate conditions in the Caribbean. The period covered is September 2018 to November 2018. It is recommended that health stakeholders should use the combination of monitoring (May 2018 - July 2018) and forecast (September 2018 - November 2018) climate information presented in this Bulletin in tandem with weather forecasts (1-7 days). This suite of information is intended to guide strategic and operational decisions related to health interventions and the management of health care systems.

What are the Key Climate Messages for September to November 2018?

- The period September to November usually marks the **wettest part of the year** in Belize and the Caribbean islands, with an annual peak in the frequency of wet days, wet spells and extreme wet spells. In the coastal Guianas, the **dry season** usually lasts until mid to late November. Meanwhile, the ABC Islands usually transition into their wet season at this time.
- **Temperatures** are usually initially high which, combined with a peak in air humidity, can feel **uncomfortable** until the end of September in northern parts of the region, and until October in the southern Caribbean. High temperatures are usual across the Guianas at this time.
- **Rainfall totals** from September to November are forecast to likely be the usual or drier across the ABC Islands, Belize, the Lesser Antilles and the Guianas *(medium confidence)*. By contrast, The Bahamas and Cayman Islands are forecast to be at least as wet as usual *(medium confidence)*.
- It is not unusual to have spells of moderate to heavy rainfall, i.e. wet spells, interspersed with dry spells during the late wet season. Most of the region is forecast to see a slightly lower number of **wet days and wet spells** than usual, reducing the potential for long-term flooding.
- At the same time, **flash floods** are a concern in the event of **extreme wet spells** in any area, but less likely so in the Guianas.
- Notwithstanding, a number of **dry spells** can still be expected in the ABC Islands, The Bahamas, northern and central portions of Belize, the Greater Antilles and the Guianas, but very few in the Lesser Antilles *(high confidence)*.
- Region-wide, **drought** or excessive dryness is not forecast to be a major concern during this period *(high confidence)*, but should be monitored closely in particular in northern Belize, the Cayman Islands and the Leewards.
- **Night-time and day-time temperatures** are forecast to be slightly cooler than in most recent years, making the September (and October) heat likely more tolerable than in recent years *(medium confidence)*.
- **Heat waves** will become less likely towards November across the region *(high confidence)*.
- The **tropical cyclone activity** of the 2018 Hurricane Season as a whole is unlikely to match last year's *(high confidence)*. Although the credible forecasting sources suggest a below-normal to near-normal season as a whole *(medium to high confidence)*, **preparedness** for the range of hazards brought about by tropical depressions, storms and hurricanes still **remains critical.**
- Episodes of **Saharan dust** incursions into the Caribbean usually are infrequent in this period, but can occur ahead of tropical weather systems. In the absence of drought this year, local dust levels should be on the low end.
- The **UV index** on sunny days will steadily decrease from around 10 to 8 in the north and from 12 to 10 in the south (on a scale from 1 to 12. For more information, see: https://www.epa.gov/sunsafety/uv-index-scale-1). Note that, despite the period marking the wet season in Belize and the Caribbean islands, many days in most areas have long sunny spells, increasing UV exposure.

What are the Health Implications for September to November 2018?

Non-communicable Diseases

- Excessive heat from high temperatures across the region (exacerbated by humid air across Belize and the Caribbean islands) will become less prevalent towards November. That said, especially during September (and October in the Guianas), **heat waves** can increase the risk of morbidity from **heat stress** in vulnerable persons, especially smaller children, the elderly, pregnant women and persons with NCDs such as diabetes and hypertension.
- Particularly in September (and October in the Guianas), there will be an increased risk of **dehydration**, which may present an associated increase in its symptoms such as apathy, general weakness, dizziness, fainting, and, in extreme cases, kidney failure. This risk decreases as we approach November.
- During the period, excessive exposure due to dangerous UV radiation can cause **skin damage** across the population on sunny days (for more information, see: https://www.epa.gov/sunsafety/uv-index-scale-1).
- There is the possibility of **skin infections** due to contact with contaminated stagnant and/or flood waters particularly in any area across Belize and the Caribbean islands.

Vector-Borne Illness

- The presence of stagnant water in the aftermath of a flood may promote the breeding of mosquitoes and increase the risk of associated mosquito borne diseases, such as **Dengue, Chikungunya and Zika** which are of great concern for Caribbean territories (For more information, click *here*).
- As the region enters the peak of the wet season, increased rainfall may also create more breeding places for mosquitoes, but it may not be to the same extent as in years with extremely high rainfall in the wet season.

continued on page 2

CARIBBEAN HEALTH-CLIMATIC BULLETIN — PAGE 1 — SEPTEMBER 2018

Figure 2. Page 1 of the September 2018 issue of the quarterly Caribbean Health Climatic Bulletin

The Health Climatic Bulletin is available on the websites of the Caribbean RCC (rcc.cimh.edu.bb), CARPHA (carpha.org/What-We-Do/Environmental-Health-and-Sustainable-Development) and PAHO (www.paho.org/ocpc/).

Improving health and climate research

Initial evaluations indicate that health sector end users find the Health Climatic Bulletin useful. However, its health warnings are based on qualitative expert statements on probable health risks, which could be strengthened by integrating quantitative probabilistic forecasts of disease risk (Lowe et al., 2018). Thus, research is needed to develop more precise disease forecast products using climate information.

Climate services for vector-borne diseases

Work on heat health and sand/dust health has focused on enhancing understanding of the physical processes associated with extreme heat thresholds, as well as the dust cycle, to predict future events in the Caribbean. In contrast, work on vector-borne diseases has moved towards an integrated approach that is generating breakthroughs on the linkages between climate and diseases transmitted by the *Aedes aegypti* mosquito. Advances require interdisciplinary skills to integrate and analyse climate, entomological and epidemiological data – a skill set combination that was not readily available in the Caribbean. CIMH, in association with CARPHA, PAHO, ministries of health and NMHSs, engaged an interdisciplinary, international research team to address this gap.

The team conducted a pilot study in Barbados and Dominica from February to July 2017 to develop a modelling framework. Outputs of this study provide evidence for the role of climate in seasonal and interannual variability in *Aedes aegypti* dynamics and dengue transmission. This lays the groundwork for developing a climate-driven early warning system for viruses transmitted by this mosquito in the Caribbean. To date, three research publications have emerged from the pilot study, sharing the results on arbovirus epidemiology and climate in the Caribbean with the wider international community. Novel early warning tools, which could be used by the public health sector to prevent and respond to concurrent vector-borne disease outbreaks (**Figure 3**), have also been developed.

Face-to-face workshops and technical webinars were convened with the Caribbean health and climate communities to build capacity, as part of the pilot study. Efforts are already under way to extend the scope of the research to additional Caribbean countries.

This work on vector-borne diseases demonstrates the feasibility of developing climate services for health and the importance of strong long-term partnerships across the climate and health sectors. The collaborative interdisciplinary model is likely to be replicated in the other health–climate priority areas being pursued by CIMH and its partners. When fully developed, the wide-ranging research outputs on diseases borne by Aedes aegypti, on extreme heat and non-communicable diseases, as well as on Saharan dust and respiratory illnesses, will eventually be included in the quarterly Caribbean HCB to provide climate-smart decision-making guidance for Caribbean health practitioners.

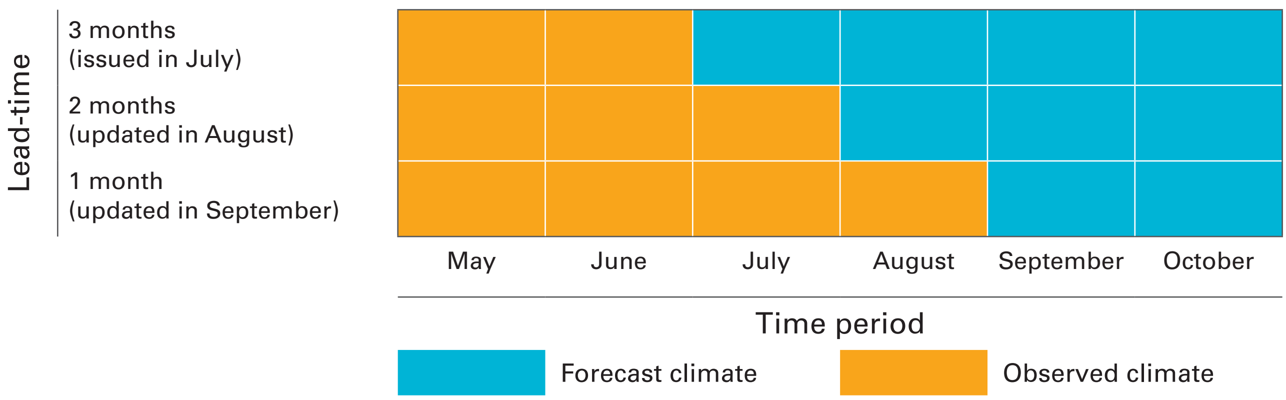


Figure 3. Schematic showing type (for example, observed or forecast) of climate information needed to produce a dengue forecast in Barbados for the target month of October. Source: Lowe et al. (2018)

Mainstreaming climate and weather data effectively in health operations

Recent innovative research-to-operations advances, in tandem with the integration of social science oriented participatory approaches, are catalysing co-production of the next generation of climate services for health in the Caribbean. The region now has access to several early warning products related to human health. This includes a novel modelling framework to forecast the risk of dengue outbreaks using climate information, developed for Barbados (**Figure 3**). There is significant potential to operationalize the model and to extend it to other countries in the Caribbean as it uses climate indicators and forecasts routinely produced by CIMH. Thus, this research has put the Caribbean firmly on track to develop a climate-based early warning system for dengue and other mosquito-borne diseases in the region.

The next phase will focus on putting initial investments in health–climate research into practice. This will improve national and regional health outcomes by building further components required for an operational climate-driven health early warning information system. One will be the development of a modelling platform, based on a geographic information system, that integrates and analyses currently disparate streams of atmospheric, environmental, epidemiological, entomological and other socioecological data in a common database. These data will feed into a spatiotemporal prediction model that generates seasonal disease risk maps and/or outlooks that are linked to an epidemic alert and response system that serves as an evidence-based decision support tool for the public health sector.

The integration of these various research and development streams into health operations has great potential to reduce risks for climate-sensitive diseases that currently undermine the productivity and sustainable development of Caribbean SIDS.

Acknowledgements

Activities and progress on the Caribbean's health–climate portfolio were supported by the USAID (Grant ID: AID-538-10-14-00001) BRCCC Programme (rcc.cimh.edu.bb/brccc) with funding made possible by the generous support of the American people. R.L. was supported by a Royal Society Dorothy Hodgkin Fellowship. Many thanks to the other contributors of the *Aedes aegypti* climate research team: Sadie Ryan, Mercy Borbor, Moory Romero, Cédric van Meerbeeck and Shelly-Ann Cox. The authors are also grateful to Shermaine Clauzel, Lyndon Forbes Robertson and Avery Hinds (CARPHA) and Adrianus Vlugman and Karen Polson-Edwards (PAHO) for their continued support in co-delivering the Caribbean HCB. Thanks also to Andrea Sealy and Ashford Reyes (CIMH) for their leadership on the Saharan dust modelling portfolio.

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Strengthening Climate Services for the Food Security Sector

By **James Hansen**[1], **Katiuscia Fara**[2], **Kathryn Milliken**[2], **Clement Boyce**[3], **Ladislaus Chang'a**[4], **Erica Allis**[5]

The Global Framework for Climate Services (GFCS) enables vulnerable sectors and populations to better manage climate variability and adapt to climate change. How? By developing and incorporating science-based climate information into planning, policy and practice. The GFCS places the decision context and information needs of "users" at the centre of the design process. The development of such climate services alters the dynamic between the "user" and the "provider," valuing each actor's knowledge and engaging them both in a co-production process. This approach challenges the conventional linear supply chain for weather and climate information, in which data are generated, information produced, a product designed, and handed over to the user for consumption, without a real understanding of whether this information is useful for decision-making.

In late 2013, with support from the Norwegian Ministry of Foreign Affairs, the GFCS embarked on a multi-agency[6] proof of concept. The GFCS Adaptation Programme for Africa aimed to increase the resilience of those most vulnerable to the impacts of weather and climate-related hazards, through the development of more effective climate services in Tanzania and Malawi. It focused in particular on the sectors that address food security, health and disaster risk reduction.

This article outlines the learning generated through the food security component of the project. The component was jointly led by the World Food Programme (WFP) and CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS), with activities implemented with the Tanzania Meteorological Agency (TMA), Malawian Department of Climate Change and Meteorological Services (DCCMS), and a range of national and local partners.

Developing climate services for agriculture and food security

Rural populations in Tanzania and Malawi are particularly vulnerable to the impacts of climate variability and change. Intense droughts and floods in the past decades, coupled with increased rainfall variability and changes in precipitation patterns, have diminished the ability of vulnerable communities to recover after each event and contributed to higher levels of food insecurity. The initiative targeted food insecure, vulnerable communities in Longido, Kiteto and Kondoa districts in Tanzania, and Balaka and Zomba districts in Malawi. Whenever possible, programme activities were integrated with the WFP's Rural Resilience Initiative (R4), which provides an integrated risk management package of microinsurance, credit, savings, and disaster risk reduction activities.

Understanding user needs

At the outset of the programme in 2014, WFP coordinated national stakeholder consultations in both countries to learn what climate information was available and how it was disseminated to end users. A separate set of consultations were also held with community members through a community-based participatory planning exercise organised by WFP. The consultations allowed partners to understand different community member climate information needs, including their

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4 Tanzania Meteorological Agency (TMA), Dar es Salaam, Tanzania

5 Global Framework for Climate Services, WMO

6 WMO (lead implementing partner), World Food Programme (WFP), World Health Organization (WHO), International Federation of Red Cross and Red Crescent Societies (IFRC), CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS), Centre for International Climate and Environmental Research (CICERO) and Chr. Michelsen Institute (CMI).

preferred communication channels, their current ability to access and trust in weather forecasts, and the types of information products that communities would find most useful. CCAFS (through the World Agroforestry Centre) also conducted a study to assess farmers' information needs, and establish a baseline. This study surveyed 660 farmers and interviewed 85 key informants (Coulibaly et al.2015a,b). The outcomes of the stakeholder consultations and survey assessment were validated through a national Information and Communication Technologies (ICT) and Radio Stakeholder Consultation workshop (Hampson et al., 2015; Kaur et al., 2015).

The baseline assessments and validation workshop guided the development of climate services and the integrated delivery approach needed to reach community members. The baseline survey helped to define an integrated, participatory approach to the production and delivery of information. It identified the priority needs of community members, such as farmers and pastoralists, for climate information products. The findings indicated that community members consider a range of issues in order to take decisions on their livelihoods: seasonal forecasts; timing of rainfall onset; probability of extreme events; timing of rainfall cessation; and intra-season distribution of rainfall. They emphasized that information should be timelier and relevant to local scale. They also want information that would guide their understanding on the best available decisions and options depending on the content of forecasts. In both countries, agricultural extension officers, radio and mobile phones (particularly for women) were identified as the preferred communication channels for climate services. The interviews revealed that community members continue to take crop and livelihood management decisions on indigenous climate knowledge even though they recognized that these were not always reliable. In the majority of cases, community members would trust traditional knowledge more than official weather forecasts.

Climate Service Delivery

Agricultural extension workers, meteorological service staff, Red Cross volunteers and other intermediaries were trained to access, understand, and communicate climate information through the Participatory Climate Services for Agriculture (PICSA) methodology. PICSA, developed by the University of Reading, combines

Cecilia Schubert (CCAFS)

local climate information with participatory planning tools to support farmer decision-making around relevant management options and risks. In an initial workshop, farmers evaluate their farming and livelihood strategies in light of climate risk with the aid of participatory resource mapping and seasonal calendars. Climate time-series information is used to understand local climate variability and trends, and to calculate probabilities of meeting requirements for different management options in the seasonal calendar. The farmers identify options for changing agricultural and other livelihood practices as well as the associated risks, costs, benefits, and sensitivity to seasonal rainfall conditions. Just before a new growing season, facilitators introduce the seasonal forecast, review its interpretation, and use it to update the seasonal calendar developed earlier with the crop/cultivar-specific risks. Participants then review their earlier plans and decide on adjustments for the upcoming season. The PICSA approach was used to train 325 intermediaries in both countries, through five training workshops.

In addition to training intermediaries, climate services were also delivered through radio and SMS. Farm Radio Trust (FRT) and Farm Radio International (FRI) were chosen as partners for the development and delivery of interactive climate services radio programming (Perkins et al., 2015). Zodiak Broadcasting Station was engaged in Malawi, where agro-climatic information was delivered to 3 595 farmers through SMS, and an estimated 5 000 farmers through nation-wide radio programming in 2016. FRT implemented a system to collect feedback on climate services through the national radio programme and an interactive SMS platform. In Tanzania, Farm SMS, developed in 2012 through a partnership between TMA, CCAFS and


Cecilia Schubert (CCAFS)

Sokione University of Agriculture, was leveraged and further expanded under this programme to 6 000 registered users – a tenfold increase from its original user base pre-programme.

Because scoping studies found that men have much greater access to radio, particular attention was given to increasing women's access to climate information delivered by radio. For example, in Malawi, dedicated radio listening groups were created and solar power radios purchased to ensure that women would also be able to access information. The listening groups proved extremely popular and members were deemed "local climate experts" as they were able to further convey the key messages from the programmes.

Co-production of climate information

One of the novel components of this programme, which supported co-production of climate information, was the use of district-level Planning and Review (P&R) Days. These were held with a range of actors when a seasonal forecast was released. Together district government, NMHS staff, agricultural extension staff and other relevant local and district-level stakeholders discussed and co-produced the messages to be delivered to food insecure communities, together with a portfolio of options (advisories) prior to the start of each agricultural season. P&R Days also enabled regular assessment of progress, and feedback to NMHSs to improve the services provided to communities. They were conducted in Malawi in October and November 2015 and in Tanzania in December 2016.

Historical climate data are a key input to PICSA. Where data were not available or adequate, the NMHS undertook data rescue, quality control, and digitization. The NMHS analysed the historical data in order to characterize the climate of the district, and presented the analyses to intermediaries, and later the farmers, to help them to understand their local climate. This was achieved with the support from the University of Reading. In Tanzania, TMA trained staff on the best available seasonal forecast downscaling tools, including the IRI's Climate Predictability Tool (CPT). Since 2014, the seasonal forecasts in Tanzania are downscaled for the seasonal rain periods in five districts. In Malawi, DCCMS downscaled the national seasonal forecast to 27 of the country's 28 districts, and updated the district seasonal forecasts midway through the season. In doing so, DCCMS tried to develop a locally-derived, tailored seasonal forecast for Balaka district, thus responding to a direct request from beneficiaries for better and more accurate seasonal forecasts.

Results

CCAFS and WFP commissioned Statistics for Sustainable Development to conduct an independent assessment of how effective the various climate service activities were at serving the needs of farming and pastoralist communities. This was complimented by the overarching monitoring and evaluation of the programme led by CICERO and CMI.

Climate services influence decisions

Although access to climate information, and the communication channels used, varied by location, the majority of farmers who accessed climate information reported changing one or more management decisions (**see Table 1 on page 24**). In Malawi, 97% of respondents of the sample population reported making changes to their crops, livestock or livelihoods from one season to the next, while 52% of respondents in Tanzania reported changes. There were, however, substantial differences between the three districts in Tanzania: 70% of respondents in Kiteto and 68% in Kondoa changed management decisions in response to climate services, but only 8% of respondents in Longido reported any changes.

Most of the reported cases of climate information use involve crop management. For example, in Balaka, Malawi, seven out of eight farmers interviewed reported switching to an earlier-maturing variety of maize based on their local climatology. Pastoralists did not act on climate information, as indicated by the small percentage of respondents who used climate information in Longido, Tanzania. The overarching monitoring and evaluation efforts of the programme, led by CICERO in Tanzania, provide a possible explanation. During the interviews in Longido, extension officers reported they had not provided seasonal forecasts during the PICSA training as planned because they felt they were consistently inaccurate (West et al., 2018). Another possible explanation is that the project launched in the district before P&R Days were introduced to translate/tailor seasonal forecasts. A lesson learnt here is the need to develop more specific guidance/advisories for pastoralists.

The CICERO report highlighted the importance of recognizing social constraints on adaptation strategies and that inputs of climate information alone do not always result in behavioural change (West et al., 2018). For example, some interviewees found it undesirable to switch crop varieties when the proposed alternate varieties could not be substituted for household consumption (West et al. 2018).

The results differed in Malawi where farmers, for example, reported adopting hybrid seed, mulching and conservation agriculture practices in response to PICSA training, resulting in increased crop yields. Livestock herders reportedly began vaccinating their livestock and consulting more with veterinary officers after receiving climate information through radio and SMS.

"Above all, [the interventions] opened my mind such that I now know what is happening in terms of weather and I am able to plan accordingly."
Malawi case study interviewee

"I know I sustained [through the hunger months] because of the combination of different crops that I made." Malawi case study interviewee

Climate services improved agricultural livelihoods

Most farmers who received climate information and PICSA training perceived that their families were better off as a result. A large portion of respondents reported


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approaching agriculture as more of a business, and increased confidence in farming and livelihood decision-making (**Table 1**). Resulting benefits included increased farm production and income, improved ability to provide for family healthcare and school fees, reduced need to work as day laborers on other farmers, and improved standing within communities and households. In Balaka, interviewees reported being admired by neighbours for achieving even a small yield during a year when many people had completely failed harvests.

"I can say [the initiative] has influenced my yield because if I still planted local maize last season, I would not have been speaking of one bag that I harvested." Malawi case study interviewee

"After selling some of my cattle that were of the local breed, I used the money to buy a new breed (Boran), which has started producing more milk. I also used some of the money to build a house and toilet." Longido case study interviewee

Although women reported using the climate information training activities more frequently for decision-making than men, a higher proportion of men than women reported that their households benefited. A possible cause is access to resources and decision-making within the households – men are most likely to be able to invest greater resources and have more effective access to markets and resources (i.e. better seeds) than women.

Effectiveness of communication channels

Local communities found the tailored radio programmes particularly useful, especially the presence of guest experts who offered advice and to whom questions could be addressed. The co-production of the content delivered by the radio programmes, brought together NMHS staff, experts from Ministry of Agriculture and extension officers, WFP and Farm Radio. Field reviews, conducted by WFP with radio listening groups to ensure women had an opportunity to listen, found that this was a very useful way of communicating information.

Lessons Learnt

Both the successes and the challenges encountered in the first phase of the Adaptation Programme in Africa offer useful lessons.

A one-time community consultation and needs assessment are not adequate for tailoring services to the needs of vulnerable user communities. Responses focused on existing generalized climate products, and were not adequate for prioritizing new or improved products or communication channels. It is important to implement periodic co-design processes that capture users' evolving understanding of climate services.

Effective and sustainable mechanisms for co-production of climate services at scale remained elusive during the initial implementation of the programme. The P&R Days and the development of messages for radio programmes proved successful examples of working together. However, the programme saw only incremental changes to the way the two participating NMHSs provided services.


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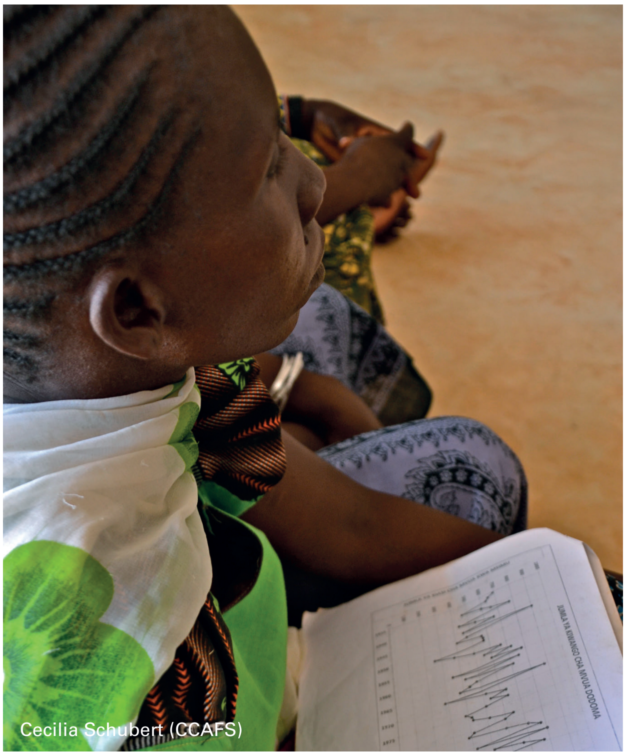
Smallholder farmers are now able to act on and benefit from climate services. Co-design processes remain relevant for enhancing understanding of the forecasts. However, NMHSs could consider applying recalibration procedures to model outputs and making skill assessments publicly available to address concerns related to accuracy. It is also recommended

Table 1. Proportion of farmers/pastoralists interviewed who reported that PICSA participation influenced management and well-being. Source Stats4SD (2017).

Reported change in response to PICSA	Malawi (n=193)	Tanzania (n=611)
Changed crop, livestock or livelihood management as a result	97%	52%
Changed crop management as a result	96%	33%
Changed livestock management as a result	47%	25%
Changed livelihood enterprises as a result	22%	8%
Improved ability to cope with bad seasons caused by the weather	80%	88%
Improved household food security	77%	83%
Increased household income	80%	85%
Increased confidence in farm and livelihood decision-making	98%	94%
Farming seen as more of a business than before	92%	80%
Improved standing within community	84%	83%
Improved standing within household	84%	85%
Shared the information and learning with peers	85%	88%



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to incorporate indigenous knowledge into the climate services in order to support confidence in the products (West et al., 2018 and Kakota et al., 2016).

Routinely providing location-specific historical and climate forecast information, tailored to farmers' needs and participatory communication processes, places heavy demands on NMHSs. Both NMHSs faced challenges in processing and analysing historical station records to provide the information that PICSA requires.Gaps in digitized, quality-controlled, long-term station observation data were an obstacle to scaling up climate services tailored to farmer needs, at the local spatial scale of decision-making. Capacity and resources are required to scale climate services.

Well-structured participatory processes, such as PICSA, enable communities to understand and act on historical and seasonal forecast information, but require substantial effort and investment to scale up. While PICSA is a promising tool, it needs to be calibrated to the local context and the seasonal calendar, then refined throughout the growing season based on user feedback. Furthermore, it is crucial for countries lacking a strong agricultural extension agency to leverage other intermediaries such as Red Cross volunteers, as was done in Malawi and Tanzania.

Training sessions are more effective when the training plan is developed together with the community.

The experience in Malawi and Tanzania highlighted that radio programmes can achieve a relatively high coverage of people without too much investment, and should receive more attention in climate service delivery. Interactive radio programming is a cost-effective channel for building awareness and providing regular access to information at weather time scales.

The integration of climate services into other risk management and resilience-building efforts can generate greater success in overall adaptation outcomes. For example, farmers targeted by the R4 initiative in Malawi received an integrated set of risk management services that included climate information. Extending farmers' access to climatic information as well as to training and knowledge on new agricultural practices and tools better equips them to make livelihood decisions in face of a forecasted climate risk.

Finally, the experience further highlighted some of the underpinning principles of climate services – it is an interdisciplinary undertaking and partnerships are key. Not all partners may understand what climate services are at the outset, thus implementers should invest time early on to explain the concepts and the co-dependencies of different climate service activities.This joint planning can help ensure that the co-production feedback loop is well understood by the producers of climate information, the intermediaries channelling that information, and the organisations helping the target audiences access climate information. Genuine co-production means that these different interdependencies are continuously being improved and prioritized. It also helps to facilitate institutional cultural shifts towards service delivery at the timescale needed for ensuring communities can adapt to climate change.

Next Steps

In September 2018, the second phase of the GFCS Adaptation Programme launched in Tanzania and Malawi. Phase II will build on the achievements and lessons learnt from Phase I. It aims to operationalize the National Frameworks for Climate Services and


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increase the resilience of vulnerable populations to the impacts of weather and climate related risks. It will accomplish this by strengthening the capacities of actors involved in the co-production of climate services (including producers, intermediaries and end-users) so that they can work together to deliver climate information that will help vulnerable populations make better-informed and actionable decisions when faced with the prognosis of a climate risk.

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The Climandes Project: Sharing experiences in designing user-driven climate services[1]

By **Andrea van der Elst** and **MeteoSwiss Climandes Team**, MeteoSwiss

In 2016, El Niño-driven weather patterns significantly contributed to causing an intensification of global food insecurity. An analysis of the 2016 El Niño event, which affected more than 60 million people worldwide, revealed that a major part of the exposed population was uninformed and unprepared for the pronounced climate anomalies. According to the World Economic Forum (WEF) *Global Risks Report 2018*, extreme weather events and temperatures are among the most pressing global challenges in terms of impact and likelihood. As a result, a single event can push vulnerable people further into poverty and destroy hard-won development gains.

Enhanced understanding and access to weather and climate information is a critical component for reducing climate risks and increasing societal resilience and preparedness for climate variability and change. However, even where relevant weather and climate forecasts are available, often this information is not meaningful, accessible or understood by most user groups, especially smallholder farmers in remote rural areas (Carr and Onzere, 2017). There is a need for user-tailored information about the past, current and future climate to enable smarter decision-making. To coordinate and guide these initiatives, heads of state, governments and scientists worked together on the *Global Framework for Climate Services* (GFCS) at the Third World Climate Conference (WCC-3) in 2009. When the GFCS launched in 2012, it introduced the User Interface Platform (UIP) as one of the basic components for developing climate services. The UIP promotes interaction between users and providers of climate services to improve the messaging and delivery of climate services to fit users' needs.

Climate services support the achievement of the recently established landmark global agendas, including the *Sendai Framework for Disaster Risk Reduction 2015-2030* (UNISDR, 2015), the *Paris Agreement* of the United Nations Framework Convention on Climate Change (UNFCCC, 2015) and *Transforming our world: the 2030 Agenda for Sustainable Development* (UN, 2015). Weather and climate information on a broad range of spatial and temporal scales are vital for the promoted National Adaption Plans (NAPs), climate risk assessments and achieving the climate-sensitive sustainable development goals. Such information provides for multi-hazard early-warning systems that enable proper disaster preparedness and help safeguard lives and livelihoods. The Climandes project in Peru offers an example of successful implementation of such vital climate services.

The Climandes Project: Climate services for the Andes

The Swiss Agency for Development and Cooperation (SDC) launched Climandes (Servicios climáticos para el desarrollo) in 2012 under the Global Programme Climate Change and Environment. It is one of the eight prioritized projects of WMO for the implementation of the GFCS. This partnership between the Peruvian National Meteorological and Hydrological Service (SENAMHI) and the Swiss Federal Office of Meteorology

1 This article provides an overview of the MeteoSwiss and SENAMHI Peru report on the main findings in developing user-driven services and establishing a prototype User Interface Platform (UIP). The report, "What we can learn from the Climandes project: A checklist for practitioners, scientists and policy makers," is available at bit.ly/2OY5Kc5

and Climatology (MeteoSwiss) aimed to develop and provide climate services for the agricultural sector of the Andean highlands with an emphasis on food security in subsistence farming. After two three-year project phases, Climandes has successfully translated the GFCS into practical solutions at the local level, increasing the resilience of agricultural communities in the Peruvian Andes.

Puno, located about 4 000 metres above sea level in the southern Andes highlands, is one of four Peruvian regions with a very high food insecurity (INEI, 2013), and one of the two focus regions for the Climandes pilot. Puno's 1.4 million inhabitants account for 5% of Peru's total population. Some 43% of the population work in the agricultural sector – a majority in small-scale subsistence farms (INEI/MINAM, 2013). These smallholder farmers are especially exposed to the impacts of adverse weather and climate events due to high inter-annual climate variability and weak adaptive and rebuilding capacities.

A prototype for user engagement

The specific activities for setting up a UIP have not yet been well-defined or specified in an implementation-ready manner. In fact, a recent review of the GFCS concluded that "the purpose and functioning of a UIP is not well understood by many climate service producers and users" (*Mid-term Review of the Global Framework for Climate Services*, WMO, 2017, www.wmo.int/gfcs//ibcs-5). To address this issue, the Climandes project developed a prototype UIP designed for strong engagement with key stakeholders. These include information providers, intermediary users, such as sectoral experts and representatives as well as local communities and small-scale farmers.

Two-stage approach for evidence-based action[2]

SENAMHI and MeteoSwiss implemented the pilot UIP in a structured two-stage approach in order to co-develop climate services and tailor them to specific users and user groups.

The first stage provided the evidence necessary to plan subsequent action in the second stage. It mapped out all the relevant stakeholders, integrating sectoral expertise and building strategic alliances. SENAMHI and MeteoSwiss also conducted a representative household survey assessing climate vulnerability of 726 small-scale farmers in fifteen districts of Puno.

2 A checklist for the proposed two-stage approach for designing user-driven climate services can be found in the report.

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The investigation identified their major climate-related agricultural problems, evaluated their decision-making processes and helped to determine their weather and climate information needs. It revealed that the farmers frequently suffer from significant crop failures due to climate-induced hazards, especially frost and drought events. These harvest losses directly translate into food security problems as they have limited ability to recover. There was considerable potential for increased use of weather and climate information, but their integration into decision-making appeared to be hindered by four key constraints: accessibility to, comprehension and accuracy of the weather and climate information, and, not least, the lack of acceptance (or trust) of the provider and their products.

From the survey data, an economic model was able to estimate the potential value of improved access to frost warnings: a 10% increase of quinoa harvests, valued at US$ 2.7 million per year for the Puno region. Communication of such potential socio-economic benefits to policymakers could raise awareness and, hopefully, increase public investment in climate services.

The second stage, building on the data gathered in the first stage, put climate services into practice. Particular attention was paid to the development of user-tailored climate services through the involvement of end-users in two rural communities SENAMHI and MeteoSwiss held monthly climate field workshops to establish regular input and feedback. These workshops aimed to raise farmers' awareness, help them overcome the factors affecting their use of this information and evaluate the impact and benefit of those services. It was found that co-developed climate services in Climandes had significantly increased the user communities' trust in SENAMHI and improved the use of scientific information in agricultural decision-making ('acceptance') in order to fulfil their potential socio-economic benefits. Farmers also reported that the information provided coincided with reality – thus was accurate.

In response to the farmers' preferred ways of receiving communications, SENAMHI established two distribution channels to better reach the target population – thus addressing accessibility. The regional SENAMHI office in Puno now delivers weekly text messages via SMS with forecasts and early warnings of frost and drought events. Two radio stations also provide daily weather predictions in the local languages Quechua and Aymara as well as in Spanish. However, the understanding of weather and climate information still remains a critical point in the user community and improved only slightly over the period of intervention – that is comprehension.

Empowering climate provider and user communities

The GFCS found that co-developed climate services are not well-resourced at the institutional level of many meteorological services, especially in developing countries and countries with emerging economies. Climandes chose the twinning approach as it enables capacity development in all GFCS areas through peer-to-peer training, provision of continuous support and coaching to both providers and end-users.

Capacity development through innovative education and training activities was another focus of the project. Through Climandes, e-learning has been implemented at SENAMHI, which now manages its own e-learning Moodle platform. SENAMHI hosted blended learning courses that combined online and classroom courses. This was a very effective means for providing information on specific climate service-related topics, spanning from data quality and seasonal forecasts to methodologies estimating the socio-economic benefits of climate services. The courses attracted international participation and encouraged information exchange between meteorological professionals in the region: for example, through monthly online briefings on seasonal forecasts. Student exchanges within the region as well as between Switzerland and Peru supported the development of the necessary capacities. Climandes also contributed to the WMO Regional Training Centre (RTC) in Peru and to the efforts of the WMO Regional Education and Training Programme. As a result of the training activities, WMO appointed SENAMHI in June 2018 as the second component of the RTC-Peru, in tandem with the National Agrarian University UNALM.

Filling gaps on the provider side

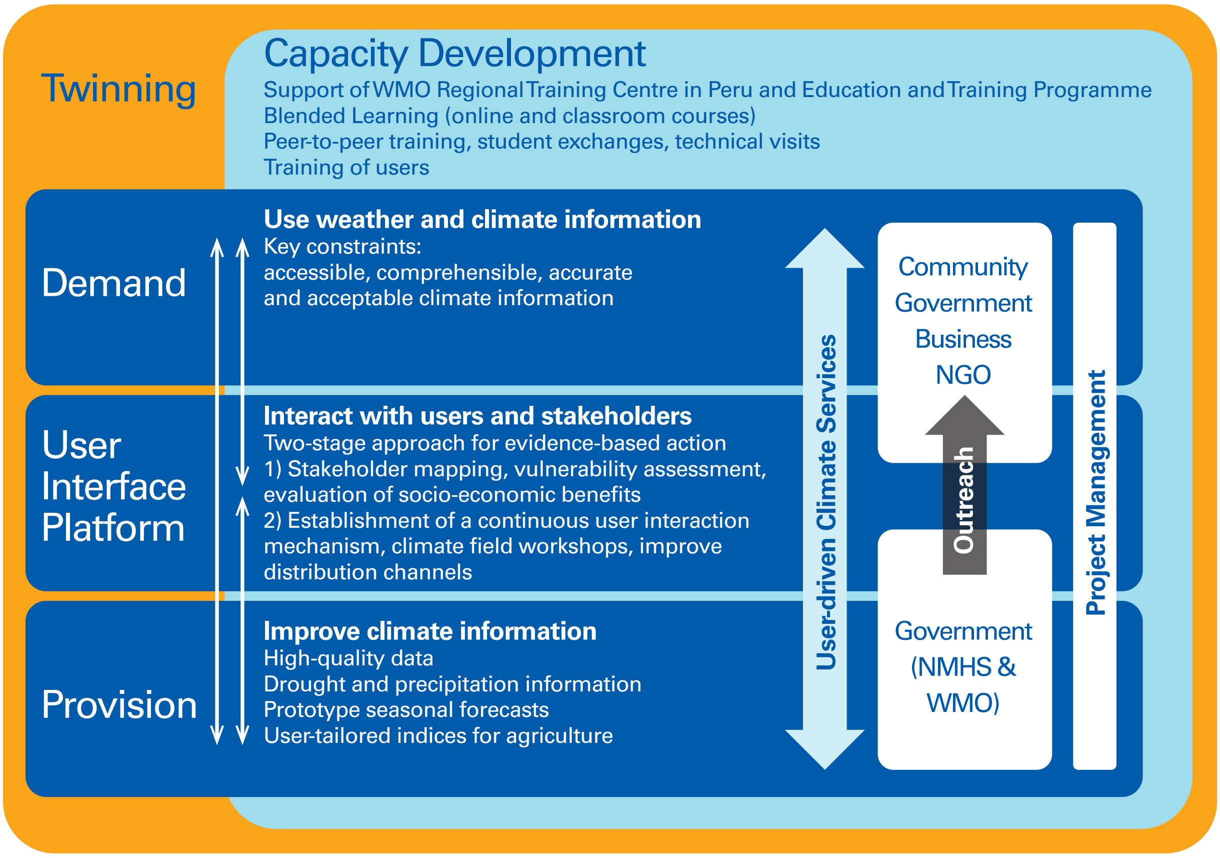
The early engagement of users revealed their requirements for climate services. These helped SENAMHI to develop their products and highlight the necessary scientific, technical and operational capacities needed to produce them. The limited availability of high-quality observations, a prerequisite for climate services, posed a major challenge in the study region. To tackle this issue, SENAMHI introduced homogenization (removal of non-climatic influences) of observational time series, quality control procedures and developed gridded daily datasets (merging station data and satellite datasets). Based on this improved data on temperature and precipitation, user-relevant indices were then monitored. These indices were derived from the user surveys and further refined with a combination of expert analyses of the meteorological and agronomic data. A climatological analysis was also conducted of indices such as consecutive days below certain plant-specific temperature thresholds during the growing season, and drought indices which capture the water requirements of crops. This enhanced information was of direct interest for various user groups in the agricultural sector and now strengthens SENAMHI's advisory role, particularly for drought, frost monitoring and warning.

Another significant achievement is the continuous verification of SENAMHI's seasonal forecasts. This has led to prototype forecast products that include information on the forecast quality ("skill") in addition to their uncertainty. These prototypes are currently being tested on selected users in order to avoid any risk to their credibility. In Climandes, the SENAMHI statistical seasonal forecasts for seasonal mean values of temperature and precipitation have been complemented with dynamical European Centre for Medium-Range Weather Forecasts (ECMWF) seasonal forecasts, which now include agro-specific indices.

SENAMHI's increased scientific, technical and operational capacities permitted the Service to organize the first Data Management Workshop in the South American region, which attracted 150 participants from 15 countries. The event, an effective step towards spreading Climandes, permitted an exchange of information between meteorological service providers and professionals of the region.

Conclusions

Proof-of-concept – The two-stage approach was an important factor in the success of the project. Climandes demonstrates that evidence-based climate services need to be developed by a team that includes a variety of stakeholders – individual smallholder farmers, private and public partner institutions and national governmental institutions. Moreover, expertise from natural, economic and social sciences as well as traditional knowledge plays an important role in understanding the relevant decision-making processes. As a result, the two-stage approach for the pilot UIP involved a number of generic elements that can be applied to other sectors with quite different user



profiles. Climandes provides a proof-of-concept that the GFCS User Interface Platform (UIP) is a suitable tool that can be scaled up geographically and into other contexts and sectors.

Early user engagement – The involvement of the user community from an early stage was crucial for implementing climate services and seeing the benefits. Through the user-participatory approach, Climandes managed to overcome to a great extent the four key constraints (lack of accessibility, comprehension, accuracy and acceptance) to the use of weather and climate information. The SENAMHI regional office played an important role in the effective provision of climate services as they have hands-on knowledge of the hazards to which local communities are exposed and the ability to reach out and engage with the local population. As such, decentralized resources of meteorological services in the implementation countries remains essential to establishing and maintaining the UIP.

The twinning approach – SENAMHI and MeteoSwiss found the twinning approach successful. Emphasis was put on a wide spectrum of capacity-development elements and less on infrastructure investments. All activities were developed in collaboration with the regional and national offices of SENAMHI and MeteoSwiss, which included peer-to-peer interaction, on-the-job training and building professional networks. As a result, SENAMHI has grown stronger technically and institutionally and now brings valuable expertise in user-driven climate services to the region.

Inclusive climate services – The Climandes project demonstrated that improved access to weather and climate information for the most vulnerable significantly enhances their disaster preparedness and contributes to protecting their livelihoods. Climandes strived for unrestricted and unlimited access to climate services for vulnerable groups, especially the poor, the under-educated and women. Climandes contributes to the GFCS and the global agendas by improving the climate adaptation capacities of agricultural communities in the Peruvian Andes. The estimated potential socio-economic benefit of enhanced use of climate and weather information is likely to exceed the costs of developing and maintaining the provision of that service.

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The new MeteoSwiss and SENAMHI Report is available on: www.meteoswiss.admin.ch/content/dam/meteoswiss/de/Forschung-und-Zusammenarbeit/Internationale-Zusammenarbeit/doc/UIP_Publication.pdf

To learn more about Climandes, visit the public Climandes websites of MeteoSwiss (www.meteoswiss.ch/climandes), SENAMHI (www.senamhi.gob.pe) and WMO (public.wmo.int/en/projects/climandes).

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Integrated Urban Services for European cities: the Stockholm case

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Accelerating urban population growth, especially in developing countries, has become a driving force of human development. Hydrometeorological events, climate change and air pollution have an increasingly significant impact on crowded, densely populated cities. In addition, the complexity and interdependence of urban systems augment the vulnerability of cities. A single extreme event can lead to a widespread breakdown of infrastructure, often through domino effects.

Many organizations, including WMO, recognize that rapid urbanization necessitates new types of services that make best use of science and technology. Such Integrated Urban Weather, Environment and Climate Services should assist cities with planning and in facing hazards like storm surges, floods, heatwaves and air pollution episodes, especially in changing climates. The aim is to develop urban services that meet the special needs of cities through a combination of dense observation networks, high-resolution forecasts, multi-hazard early warning systems and long-term urban climate projections at sub-urban scales for the design and planning of sustainable and resilient cities. Several recent international studies have been initiated to explore these issues.

In June, the WMO Executive Council adopted a conceptual and methodological approach in the *Guide for Urban Integrated Hydro-meteorological, Climate and Environmental Services*. However, many cities – for example, Hong Kong, Paris, Shanghai, Singapore and Toronto – have already started the implementation of Integrated Urban Services. Urban service requirements are city specific, and their configuration follows local stakeholder needs. Stockholm provides one of the best examples of such a service in Europe, with a focus on urban planning for the creation of an attractive and healthy city environment for future citizens.

Background and concept

Stockholm's ambition is to be one of Europe's leading green cities. It was selected as Europe's first green capital in 2010 and is now working to be free of fossil fuels by 2040. Stockholm is a growing city with an official target to build 140 000 new homes by 2030. This will require significant changes in the urban infrastructure. A first cooperation on urban services between Stockholm City and the Swedish Meteorological and Hydrological Institute (SMHI) was achieved from 2010–2012 within the FP7 (the European Commission (EC) 7^{th} *Framework Programme for Research and Technological Development*) project SUDPLAN (www.hindawi.com/journals/amete/2012/240894/).

SMHI later devised a Sectoral Information System named UrbanSIS, targeting infrastructure and health sectors operating in cities, as part of a Copernicus proof-of-concept project from 2015–2018. The objective was to develop, demonstrate and put into production a method to downscale to the urban level (1 × 1 km^2) a set of atmospheric essential climate variables (ECVs). This was to enable calculation of impact indicators related to flooding events, heatwaves and air pollution episodes, which are of prime importance for end users in Stockholm (**Table 1**). The cities of Bologna (Italy) and Rotterdam (Netherlands) were also participants.

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Table 1. UrbanSIS output in the form of 26 ECVs and 65 sectoral impact indicators. A full description of the data produced is given at urbansis.climate.copernicus.eu/urban-sis-climate-indicators/.

ECV	Unit	ECV	Unit
Air temperature at 2 m above ground (T2m)	°C	Global radiation	W m^{-2}
Air temp. over urbanized tile (T2m_URBAN)	°C	Direct shortwave radiation	W m^{-2}
Air temp. over vegetated tile (T2m_NATURE)	°C	Diffuse shortwave radiation	W m^{-2}
Air temperature at approx. 12 m (layer 1)	°C	Local runoff	mm h^{-1}
Air temperature at approx. 38 m (layer 2)	°C	Surface runoff	mm h^{-1}
Air temperature at approx. 50 m (layer 3)	°C	Evapotranspiration	mm
Precipitation (15 min and 1 h)	mm	River discharge	m^3 h^{-1}
Snowfall	mm	Soil moisture	mm
Relative humidity	%	Snow cover	mm
Wind speed (at 10 m above ground)	m s^{-1}	O_3 concentration	µg m^{-3}
Wind direction (at 10 m above ground)	degrees	NO_2 concentration	µg m^{-3}
Gustiness	m s^{-1}	PM_{10} concentration	µg m^{-3}
Boundary layer height	m	$PM_{2.5}$ concentration	µg m^{-3}

Sector	Indicator area	Indicator type
health indicators	***Air quality***	EU limit values: concentrations EU limit/WHO guidelines values: exposure Mortality long-term exposure Mortality short-term exposure
	Heat stress	Number of hot days Heat wave duration Heat induced mortality
	Discomfort	Thom Discomfort index Universal Thermal Climate Index Frequency of tropical nights
Energy indicators	***Energy consumption***	Heating degree days Cooling degrees days
	Solar energy	Monthly shortwave solar insolation
Infrastructure indicators	***Flooding***	Extreme precipitation Extreme precipitation intensity/duration
	Green infrastructure	Growing season length
	Transport infrastructure	Frost days Ice days Zero-crossings
Non-sector specific indicators		Daily max/min/mean air temperature

The information was provided in three datasets, each one based on five years of hourly gridded 1 × 1 km^2 data, representing:

- A historical period of specific years: 2006, 2007, 2012, 2013, 2014
- Five years of data taken from a climate scenario representing present conditions (1980–2010)
- Five years of data taken from a climate scenario representing future conditions (2030–2065)

The quality of the downscaling was evaluated against observations. The two datasets representing present and future conditions were created assuming strong forcing (IPCC´s scenario RCP8.5). Note that present and future datasets should be interpreted as “representative” and not “true historical” years. A novelty of producing the gridded 1 × 1 km^2 data was the use of a spatially high-resolution numerical weather prediction (NWP) model (1 km grid resolution) integrated for long periods of time (years).

Stakeholders in Stockholm and their requirements

Workshops and interviews with stakeholders and future users of the UrbanSIS data were held in the early phases of the project, which were followed up in other projects (Swedish projects: HazardSupport and MUMS, and the EC's Horizon 2020 project Clarity). Governmental agencies (Swedish Contingencies Agency, Swedish Transport Administration, National Board of Housing, Building and Planning, Stockholm County Administrative Board and Public Health Agency of Sweden), associations (Swedish Water and Wastewater Association), a private insurance company (Länsförsäkringar), local stakeholders (Stockholm City and Stockholm Vatten och Avfall) and consultancies (WSP, Tyréns and SWECO) were among the end users and stakeholders.

The definition of which ECVs and impact indicators to deliver on the urban scale was discussed and concluded through further workshops and interviews. The participants were urban climate and health experts from the University of Reading (United Kingdom), the University of Umeå (Sweden) and SMHI, as well as traditional urban end users representing consultants and city authorities from Stockholm and Bologna , another demonstration city. It was clear that there was a need for information representing the conditions of today, as well as information of what is likely to happen in the future, from the end-user viewpoint. Another finding of the dialogue was that some of the impact indicators should have city-specific characteristics.

The stakeholder input resulted in a portal with the large number of ECVs and indicators (**Table 1**). These data are delivered in a detailed way to technically advanced end users, such as consultants, urban engineers/scientists and health experts, to be used as input to specific local impact models. They are also in a format that can be directly used by urban planners for dimensional planning. Special effort was made to generate information that can be used for assessing and planning adaptation to urban hazards such as intense rainfall, heatwaves and extreme air pollution episodes.

Dynamic downscaling approach

The downscaling modelling chain consists of three numerical models as depicted in **Figure 1**. The meteorological/climate state was generated by the HARMONIE model (in two settings, as described below, depending on the period) and provided to the air quality model MATCH and the hydrological model HYPE.

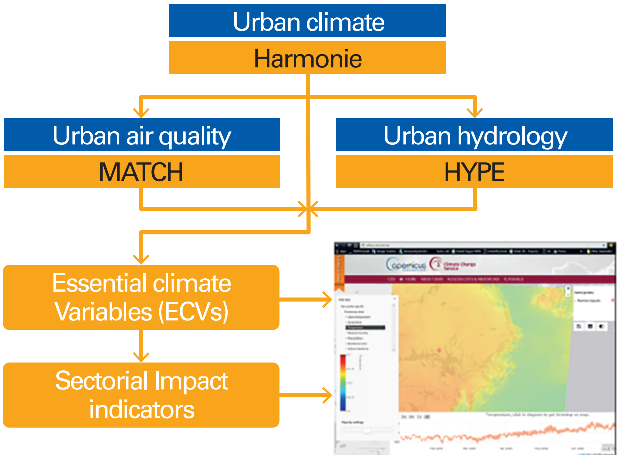


Figure 1. General flow chart representing the dynamical downscaling approach applied in UrbanSIS

For the historical period, lateral boundary data were provided to the NWP system HARMONIE-AROME (cycle 40h1.1) using UERRA-ALADIN reanalysis and surface observations. For present and future conditions, lateral and surface boundary data for the climate setting HCLIM-AROME were derived from the GLOBAQUA project.

High-resolution physiography data were generated by processing different open-access databases and products: (i) spatial coverage of land-cover types from Urban Atlas 2012 (Copernicus Land Monitoring Services), (ii) building polygons from OpenStreetMap, (iii) building heights from Lidar measurements (Swedish Forest Agency) and (iv) time series of leaf area indices from the Copernicus Global Land Service. The resulting 300 × 300 m^2 grids were then interpolated by the surface/atmosphere scheme SURFEX to the final model grid at 1 × 1 km^2 and combined with the default European ecosystem classification and surface parameters dataset ECOCLIMAP-II. Details of the model set-up and validation are given at urbansis.climate.copernicus.eu/project-deliverables/.

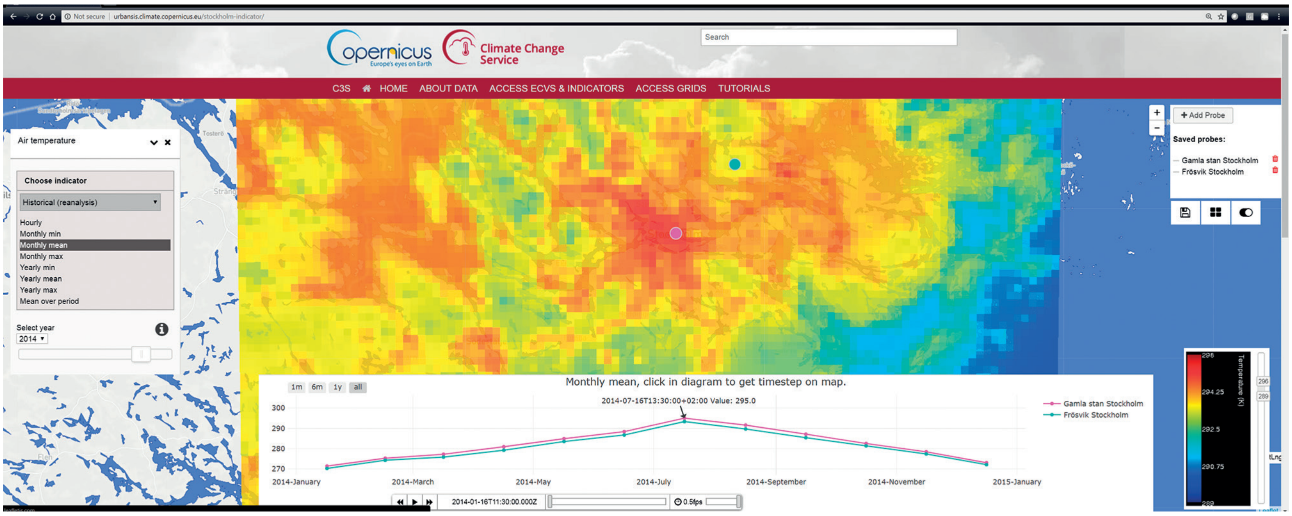


Figure 2. Image of the UrbanSIS portal mapping the UHI over Stockholm in July 2014 and the time series of monthly mean T2m (in K) over two locations

Climate scenarios

The computational costs for high-resolution dynamical downscaling are considerable; therefore climate scenario data delivered was only for selected five-year periods. Moreover, urban downscaling was affordable for only one climate scenario realization, raising important challenges on how to communicate its representativeness and uncertainties.

There were user requirements to have extreme scenarios for the future climate data, so it was decided to use the RCP8.5 scenario. Output from a regional model was taken from the FP7 GLOBAQUA project, which offered three-dimensional data at a spatial resolution of 20 × 20 km² for the periods 1980–2010 and 2030–2065. Within each 30–35-year window and for each city, five representative years were selected that encompassed combinations of cold/wet, cold/dry, warm/wet, warm/dry and "normal" summer seasons. The chosen seasons were selected to have episodes of extreme events.

Examples of outputs

Spatiotemporal air temperature gradients in Stockholm

In UrbanSIS, the aim was to understand how climate is affected by a city's morphology, and how this affects human comfort and health, especially during hot periods. The high-resolution urban climate data provided for Stockholm revealed a characteristic thermal fingerprint. This was expressed in the form of the urban heat island (UHI) or inner-city gradients associated with, for example, park cool islands. **Figure 2** provides an example of the spatial coverage of the city's UHI, its intensity and how it evolves with time.

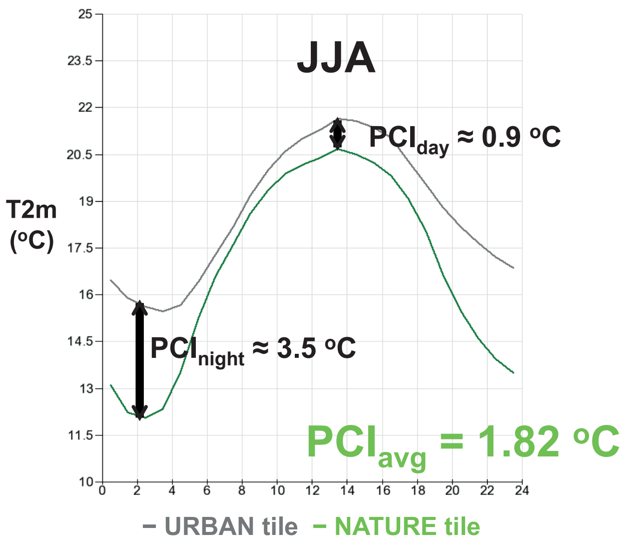


Figure 3. Mean daily profile of T2m in the summer of the five-year historical period over nature and urban tiles representing, respectively, the Observatorielunden park in Stockholm and the built-up area surrounding it (PCIavg is the average cooling promoted by this 4-hectare green area in summer conditions)

Analysis of the interaction of Stockholm's heterogeneous surface with the atmosphere revealed cooling induced by urban parks, as shown in **Figure 3**, with distinct diurnal and seasonal cycles.

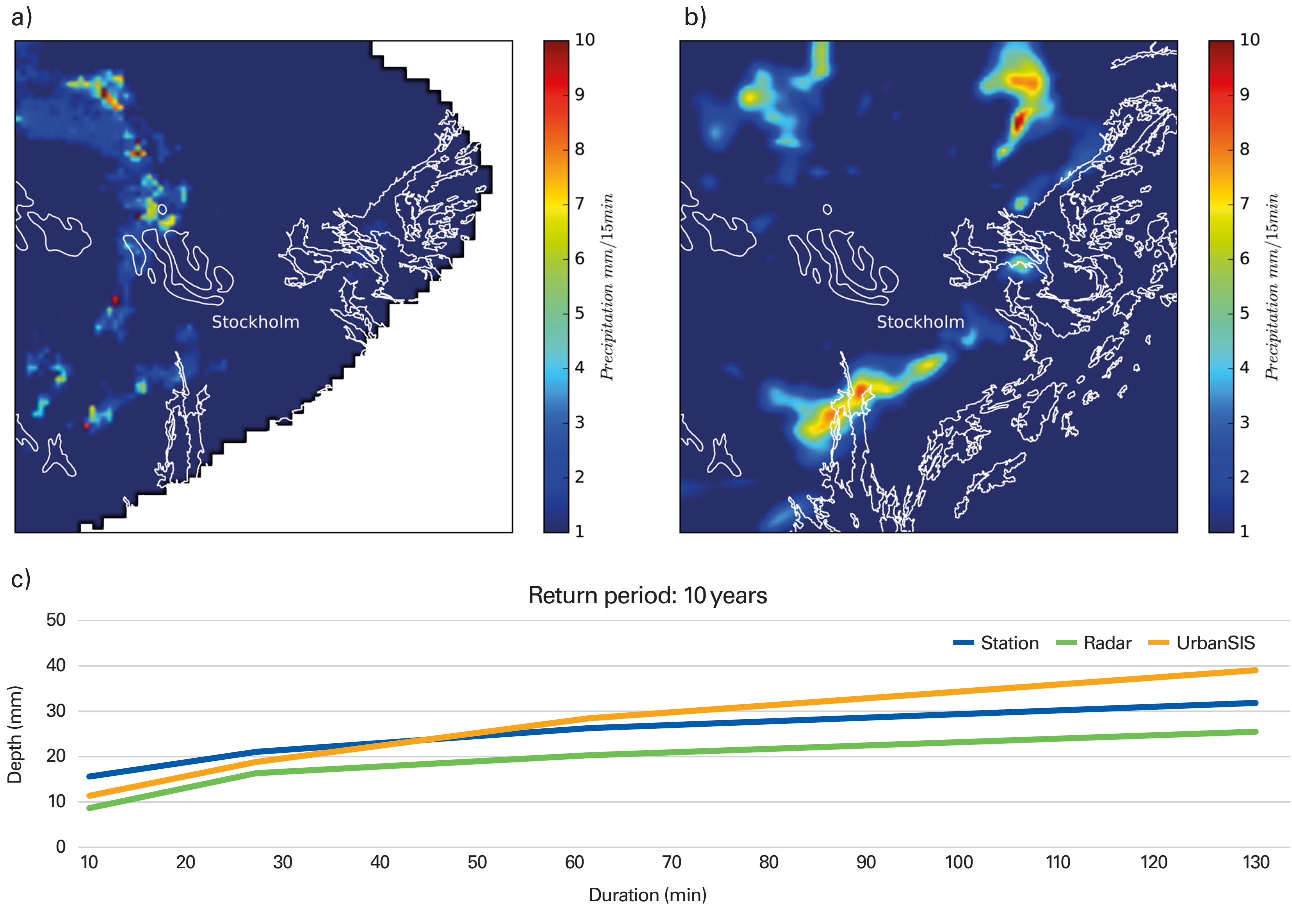


Figure 4. Images of rainfall: (a) as observed by radar and (b) as simulated by UrbanSIS in the Stockholm domain around noon on 2013-06-09. (c) Observed and simulated 10-year DDF statistics for Stockholm.

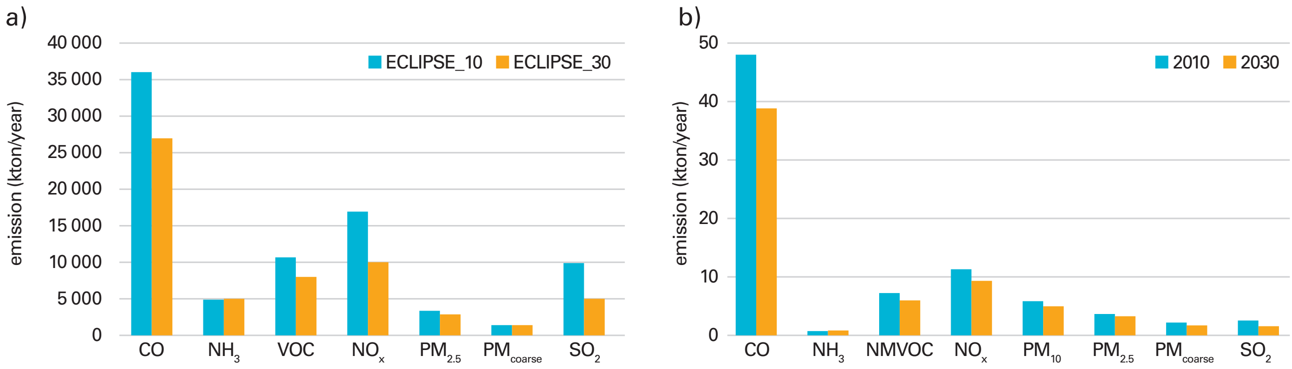
High-resolution dynamical downscaling of intense rainfall

One key motivation for dynamical downscaling, that is of very high resolution, is the extreme small-scale variability of rainfall. UrbanSIS was able to simulate intense small-scale rainfall events in a realistic way. **Figure 4a** shows a radar image taken during one of the most intense small-scale rainfalls observed in the evaluation period. **Figure 4b** shows the simulated rainfall at almost the same time. A perfect match is not attainable because of the chaotic nature of rainfall generation and uncertainties in the radar data. However, the simulated rainfall generally has a similar spatial extent and structure, as well as similar peak intensities, to the actual rainfall. The UrbanSIS simulations are realistic in statistical terms. **Figure 4c** shows the type of depth–duration–frequency (DDF) statistics that are widely used in urban hydrological engineering. The simulated statistics match well with the observed statistics from station and radar data, especially for the shortest durations (<1 h).

The type of agreement shown in **Figure 4** is not attainable in lower-resolution climate models. This suggests that future changes in local rainfall extremes are potentially more realistically estimated by UrbanSIS. Future projections in Stockholm indicate a stronger increase in local rainfall extremes than that estimated by lower-resolution climate models. This has strong implications for adapting cities and their water-related infrastructure to climate change.

Health risks of air pollution in the future

MATCH is a chemical transport model developed at SMHI. It has been used offline with the climate model in UrbanSIS to deliver gridded 1 × 1 km^2 urban background concentrations of pollutants – nitrogen dioxide (NO_2), ozone (O_3), inhalable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) – over Stockholm. The air quality simulations were performed in two steps, first on the European scale to obtain long-range contributions from outside the city and then as a nested high-resolution simulation over Stockholm.



CO: carbon monoxide
NH_3: ammonia
VOC: volatile organic compounds
NMVOC: non-methane volatile organic compounds
NO_x: nitrogen oxides
$PM_{2.5}$ and PM_{10}: particles with aerodynamic diameter smaller than respectively 2.5 and 10 μm
PM_{coarse}: particles with aerodynamic diameter between 2.5 and 10 μm
SO_2: sulfur dioxide

Figure 5. (a) Total emissions inside the pan-European domain, referring to 2010 (blue) and 2030 (orange) projected within the ECLIPSE project and (b) total emissions inside the Stockholm urban domain, referring to 2010 (blue) and 2030 (orange), as projected by the Stockholm municipality

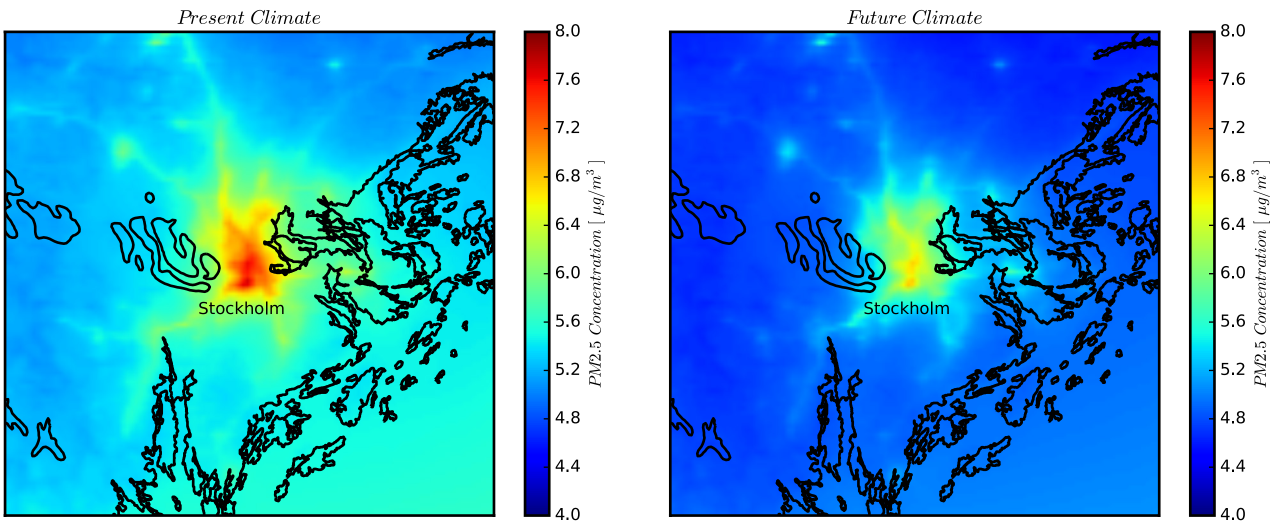


Figure 6. Annual mean PM2.5 concentrations over Stockholm for (a) present (~2010) and (b) future (~2030).

The assumed emission changes from the present (1980–2010) to the future (2030–2065) for the pan-European simulations were taken from the ECLIPSE project (**Figure 5a**). Local emission development in Stockholm was provided by the municipality and represented the years of 2010 and 2030 (**Figure 5b**).

Figure 6 shows the expected development of $PM_{2.5}$ mean urban background concentrations from the present to the future. A general decrease of about 0.5 micrograms per cubic meter (μg m^{-3}) from a present level of about 5 μg m^{-3} can be expected around the city, while the central parts will, due to local emission reductions, decrease by up to 1 μg m^{-3} from present levels of 7–8 μg m^{-3}.

One air quality indicator is the estimated number of deaths in the age group 30+ due to long-term exposure to $PM_{2.5}$. A relative risk factor of 1.062 per 10 μg m^{-3} was taken from the WHO HRAPIE project. UrbanSIS shows, for $PM_{2.5}$ exposure over the Stockholm domain, 568 deaths per year during present conditions and 507 deaths for the future scenario.

This type of health indicator must be presented together with the assumptions made. In this case, the

Figure 7. Aerial view of Stockholm (Copyright: Stockholm Stad).

population size and the city design with residential areas remained constant from the present to the future. These assumptions are obviously not realistic. Reaction from stakeholders involved in urban planning indicated that more scenarios should be included, to isolate the impact of climate change or urban design on air quality. Such scenario assessments are being assessed for Stockholm within follow-up projects.

Guidance on uncertainties

As a guide for end users to judge the quality and uncertainties of UrbanSIS output, SMHI suggested a three-level quality colour scale:

- Green = good quality: results can be used without considering certain limitations or restrictions (Go ahead!);
- Yellow = medium quality: results are useful, but the user should be aware of certain limitations/restrictions (Caution!)
- Red = poor quality: results can partly be useful, but the user must understand the limitations/restrictions (Warning!).

The quality scale is applied to three aspects:

a) Downscaling model performance (Model)

b) Determination of impact indicators (Indicator)

c) Climate scenario uncertainties (Scenario).

The Model and Indicator aspects are classified individually for each city. For the Scenario" aspect, the ECVs are given the same classification for all European cities. (Further details are available at urbansis.climate.copernicus.eu/wp-content/uploads/2018/01/C3S_D441.5.4.2_UrbanSIS_201711_Uncertainties_scalability_rev.pdf.)

Lessons learned and future research and development

The approach of combining dynamical downscaling for meteorology, air quality and hydrology can provide useful and consistent climatological impact indicators on the urban scale. Access to high-resolution physiography, local emission inventory and local water channelling data is vital. These can partly be retrieved from European services, such as Urban Atlas. However, consistency among different data sources, for the urban and regional scales, has to be taken into account. Daily, monthly and seasonal profiles of local emission of chemical species can be fine-tuned using sector-related proxies (for example, traffic). In-depth sensitivity studies are needed to transform regional-scale emission inventories to the local scale. Additionally, local observations for different indicators during the historical simulation period are beneficial to validate and increase confidence in the results.

The considerable computational costs somewhat limit the domain size and number of simulated years. The small domain size resulted in a strong precipitation bias due to spin-up problems, especially during strongly forced winter conditions. The known resolution dependency of the coarser forcing data on the spin-up was not confirmed in this modelling set-up. Further research is needed to better understand and reduce this issue.

For urban simulation, precipitation bias meant that regional-scale simulated precipitation needed to be included, especially for river flow and accumulated snow. The limitation in number of years and future scenarios required careful selection and assessment of how the selected years and scenarios represented the climatological distribution for different indicators for present-day climate and future projections, including the assessment of their uncertainties. Downscaling specific historical extreme events, as worst-case scenarios, was considered and how these events could be affected in a future climate scenario examined.

So far, the aim of this approach has been to support long-term urban planning. However, the approach can also be adapted for short-term forecasts of weather and air pollution and early warning. For example, it could be used to carry out urban downscaling with a standard NWP and for running air quality model with Copernicus Atmospheric Monitoring Service (CAMS) results on the boundaries.

As a continuation of UrbanSIS, SMHI is now working with the city of Stockholm on the simulation of urban climate and effects on human comfort for distinct urban development scenarios: (i) the development plan for 2030; (ii) a strong increase of green infrastructure ("green scenario"); and (iii) sprawling and densification ("grey scenario"). This effort has demonstrated that downscaling the larger-scale climate information over a city provides new insights for urban planning and development, including landscape architecture and the use of nature-based solutions. It also delivers innovative and efficient solutions for the adaptation of cities to climate change.

Moving towards Integrated Urban Services

The WMO concept of the Urban Integrated Hydro-meteorological, Climate and Environmental Services and demonstrated European experience, such as that of Stockholm, provide the following recommendations for WMO Members (National Meteorological and Hydrological Services (NMHSs), first of all) and interested cities:

- Do not wait for a disaster to occur- Integrated Urban Services are already assisting decision-makers and end users (existing well-functioning urban services can be used as templates for development)

- NMHSs should contribute to the promotion, development and coordination of Integrated Urban Services, including knowledge transfer

- Ensure that legal and institutional frameworks are in place that clearly define government agency interactions and responsibilities to enable creation and maintenance of integrated services

- Engage with relevant stakeholders (agencies, the public, NMHSs, city government, private sector and businesses) from the beginning, including raising awareness and getting feedback

- Conduct further research, including multidisciplinary cross-cutting studies, to develop urban service capabilities

- Encourage NMHSs to facilitate wider accessibility of data via influencing ownership issues and technical support

- Showcase demonstration projects on urban services

Summary

The concept of an Integrated Urban Hydro-meteorological Climate and Environmental Service was proffered by WMO to meet the future needs of its Members, especially in meeting the United Nations Sustainable Development Goals. UrbanSIS in Stockholm is an excellent demonstration of an initiative integrating the various scientific disciplines in an innovative holistic way. Weather, air quality and hydrological models are used to produce spatial (1 km) and temporal (15 minutes to 1 hour) high resolution data for state-of-the-art eco-centric city planning and design.

The WMO initiative was undertaken cooperatively and collaboratively with other cities – Bologna and Rotterdam – to efficiently develop and generalize its capability. WMO is following up on the *Guide for Urban Integrated Hydro-meteorological, Climate and Environmental Services, Part 1: Concept and Methodology* with additional demonstration city examples with greater hazardous, geographic and economic diversity.

Climate and Art

By **Erica Allis**[1], **Coleen Vogel**[2], **Hannelie Coetzee**[3], **Michelle Rogers**[4]

A Love Poem in the Time of Climate Change

Sonnet XVII
by Craig Santos Perez

I don't love you as if you were rare earth metals, diamonds,
or reserves of crude oil that propagate war:
I love you as one loves most vulnerable things,
urgently, between the habitat and its loss.
I love you as the seed that doesn't sprout but carries
the heritage of our roots, secured, within a vault,
and thanks to your love the organic taste that ripens
from the fruit lives sweetly on my tongue.
I love you without knowing how, or when, the world will end—
I love you naturally without pesticides or pills—
I love you like this because we won't survive any other way,
except in this form in which humans and nature are kin,
so close that your emissions of carbon are mine,
so close that your sea rises with my heat.

(Source: March 3,2017 newrepublic.com)

Craig Santos Perez is a native Chamoru (Chamorro) from the Pacific Island of Guåhan and currently works at the University of Hawaii, Mānoa. He is a poet, scholar, reviewer, artist, environmentalist, and activist. For over a decade… "I have written about indigenous connections to nature, as well as environmental justice issues in the Pacific, and this has led me to writing more deeply about climate change." "I am inspired by the ecologies of the Pacific islands, the resilience of Pacific Islanders, the wisdom of Pacific cultures, the brilliance of Pacific scholarship and the beauty of Pacific arts." "My goal in my eco-poetry is to educate readers about environmental issues, inspire them to live more sustainably, and to empower them to act in the climate movement."

Our world is facing great challenges, climate change being one of the most pressing of our time. The increased occurrence of extreme events such as droughts, floods and heat waves are already impacting on everyday life around the globe as well as harming fragile ecosystems (see various IPCC reports). As societies struggle to reign in emissions and develop adaptation strategies, a radical departure from traditional forms of discourse on the topic is becoming more apparent. However, the scale and long-term consequences of climate change can leave us feeling incapacitated, fearful and like a victim of change.

Proposed solutions to such challenges – including those linked to the Sustainable Development Goals, the Paris Climate Accord, the Global Framework for Climate Services (GFCS) and Disaster Risk Reduction (e.g the Sendai Framework) – often call for more science to improve our understanding and the technology to navigate such change. The problems of sustainability and climate change are thus often portrayed within notions of "boundaries", "guard rails" beyond which we cannot transgress and "limits" to growth and development. Institutions are spending a considerable amount of effort and time on contemplating how to best measure our progress using a range of indicators and measures. These efforts are useful but are they the only options we have?

Do we have to feel powerless in the face of such change? How can we harness our imaginations, powerful as they are, to contemplate positive actions that could help us navigate such a complex changing world?

One way in which we can all begin to think more creatively about these challenging contexts is through the arts. We might, through art, begin to think of creative futures and shared pathways towards a more just and

1 Global Framework for Climate Services (GFCS) Office, WMO
2 University of the Witwatersrand, Johannesburg, South Africa
3 Independent artist
4 Artist and co-founder of Arts for Environment

"thrivable" future. By creating "safe spaces" that incite conversation, by drawing upon different visual and/or acoustic mediums and by contextualizing knowledge in evocative ways, we can explore the various pathways of change that can help us see and understand our own world views better, as well as those of others:

"…Sustainability can no longer rely exclusively on scientific knowledge production to determine the right path to a single sustainable future. Rather it relies on how well society explores, imaginatively inhabits, and evaluates multiple possible futures; on the kind of stories societies tell about who they are and what is important to them; and on the avenues for collective action that open up as consequence. This view also implies a significant, ontological shift: instead of a world made of objects whose reality can be established in absolute terms, we must contend with dynamic and contingent cultural forms that shape the ways such facts are constituted, expressed, and interpreted."[5]

The goal of this article is to stimulate thought on how the arts, in all their rich forms, can help nudge us toward thinking more holistically about climate change. We interviewed eight artists, at least one from each of the six WMO regions, who are working at the intersection of climate and arts. We draw on various artists' impressions and art forms, including scenes from the 10 to 21 September 2018 Watershed event at the University of the Witwatersrand in Johannesburg, South Africa, organized in partnership with Professor Lenore Manderson, Earth, Itself, through the Institute at Brown for Environment and Society (IBES).

In this article, we are not limiting the role of art to that of a form of "media" that can assist in communicating science and the challenges of climate change, as useful as this may be. We offer an additional and more fundamental view. We share how some are exploring, together with artists and scientists, ways to better understand the world in which we live.

Each of the artists has a passion to re-imagine a world that is sustainable and loving. Science alone will not enable such a place. We can all help in shifting perceptions, most critically our own, and enabling actions for a sustainable planet and for personal and wider transformation:

"Our perceptions of who we are and what we are capable of need to be expanded, not contracted into demeaning or fanciful explanations. We need to know far more about our species and this Universe we inhabit. We cannot afford the luxury of arrogance that denies other ways of knowing."[6]

These themes could find interesting connecting points and synergies in the research and advocacy work undertaken by WMO through the WWRP (World Weather Research Programme) and WCRP (World Climate Research Programme) and its climate services efforts (GFCS), and many other initiatives. Awareness of the importance of global policy agendas (Sendai, Paris Agreement, GFCS, and SDGs) does not necessarily prompt individual or collective action, a range of partnerships is required to effectively advance progress. Engagement across cultural, value, and geo-political boundaries, amongst others, offers promise in this regard[7].

What if the challenge of sustainability is not to prove the world more real but to prove it more imaginary?

- Maggs and Robinson 2016; Bendor et al., 2017, 1

While only a few artists are profiled in this piece, we would like to recognize and thank all the artists that contribute to a higher understanding of the world in which we live and touch our very hearts – evoking discourse on the critical issues of our time, contemplation of our desired future conditions, and motivating action towards our collective goals. We would also like to thank the Member States and Territories, development partners, and entities like the European Commission that create opportunities for scientists and artists to collaborate.

5 Resilience Alliance- Bendor, R., D. Maggs, R. Peake, J. Robinson, and S. Williams. 2017. "The imaginary worlds of sustainability: observations from an interactive art installation". Ecology and Society 22(2):17. doi.org/10.5751/ES-09240-220217

6 Margaret Wheatley, Who do we Choose to be? Facing reality claiming leadership restoring sanity, Berrett-Koehler Publishers, Oaklands, California, 2017, 184).

7 24 July 2018, USAID Strengthening Learning on CIS Newsletter

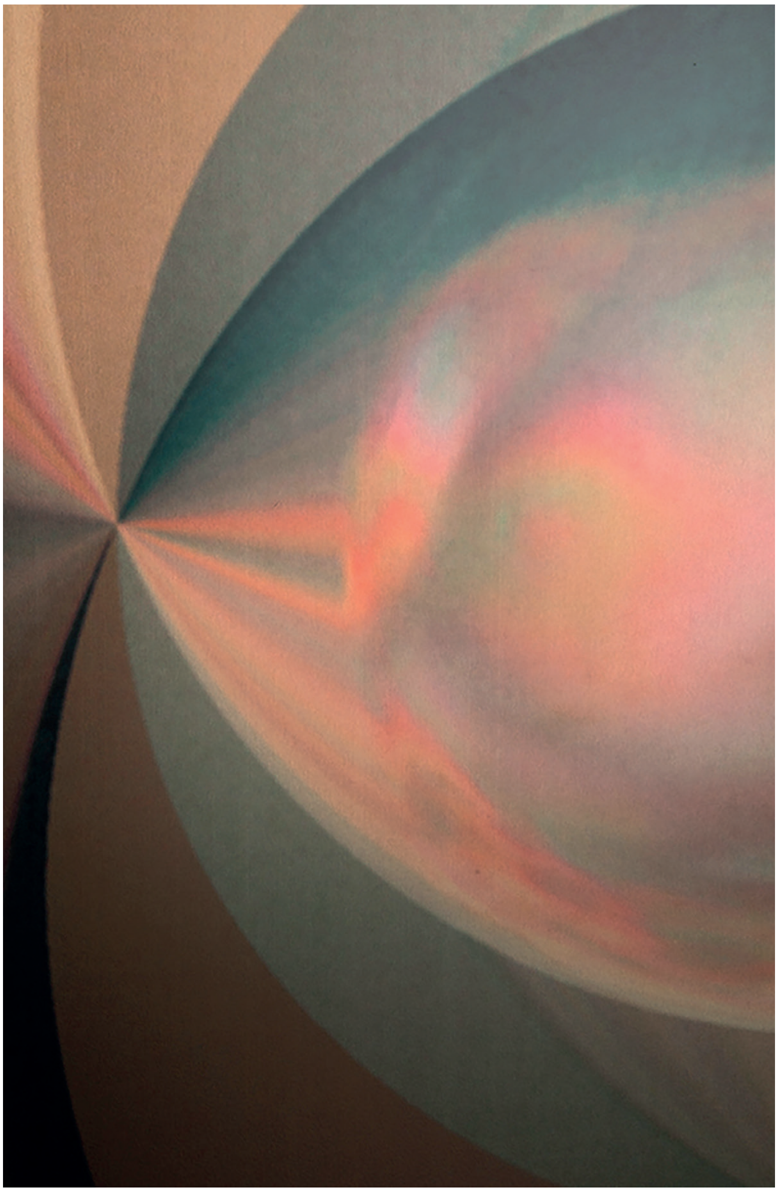
As Above, So Below by Jasmine Targett

For Jasmine Targett, art contributes to a conversation. Ever since learning about the ozone hole in the 6th grade, her art has focused on the "invisible aspects that impact our existence and unite us and the themes we struggle with in our humanity." She aims to celebrate the things her local community is doing while engaging them on the broader, complex issues and wields her craft to empower. "If you scare someone you disempower them, we need to communicate information in a way that is practical and usable. When you experience something that is pleasurable you invite that back into the mind, whereas if you experience something that is terrifying, you push it away."

In As Above, So Below, a Nacreous cloud formation, has been filtered through a prism lens. "I had been looking for different ways that the environment was speaking to us visually, of making it known that our presence was shifting its natural trajectory." Her research brought her to the nacreous mother of pearl clouds, whose illusive, iridescent beauty belies the darker and more sinister reality of stratospheric ozone destruction. "Often we cannot physically see how the environment is changing around us because it is happening at a rate and in a realm that we cannot fully see or understand, but there in the sky is an early warning signal, and it 'nacreous cloud' is incredibly beautiful and evocative, but there is a slight unease when you look at it, I don't know why you are in the atmosphere, you do not quite make sense, you reference something that I know and understand which are clouds, but on a primal level I have a slight feeling of trepidation".

As Above, So Below invites discourse on how manmade and natural elements combine to create a new environment, one in which it is difficult to understand what the outcome will be. "There are so many factors, so many things combining in different ways that we would never have expected or predicted."

Through her work Targett hopes to create more awareness on how we can work with nature and co-create as a species to reverse the negative aspects of things we have created and find positive, natural ways to work with our environment.



As Above, So Below by Jasmine Targett, 2016, aluminum picture.

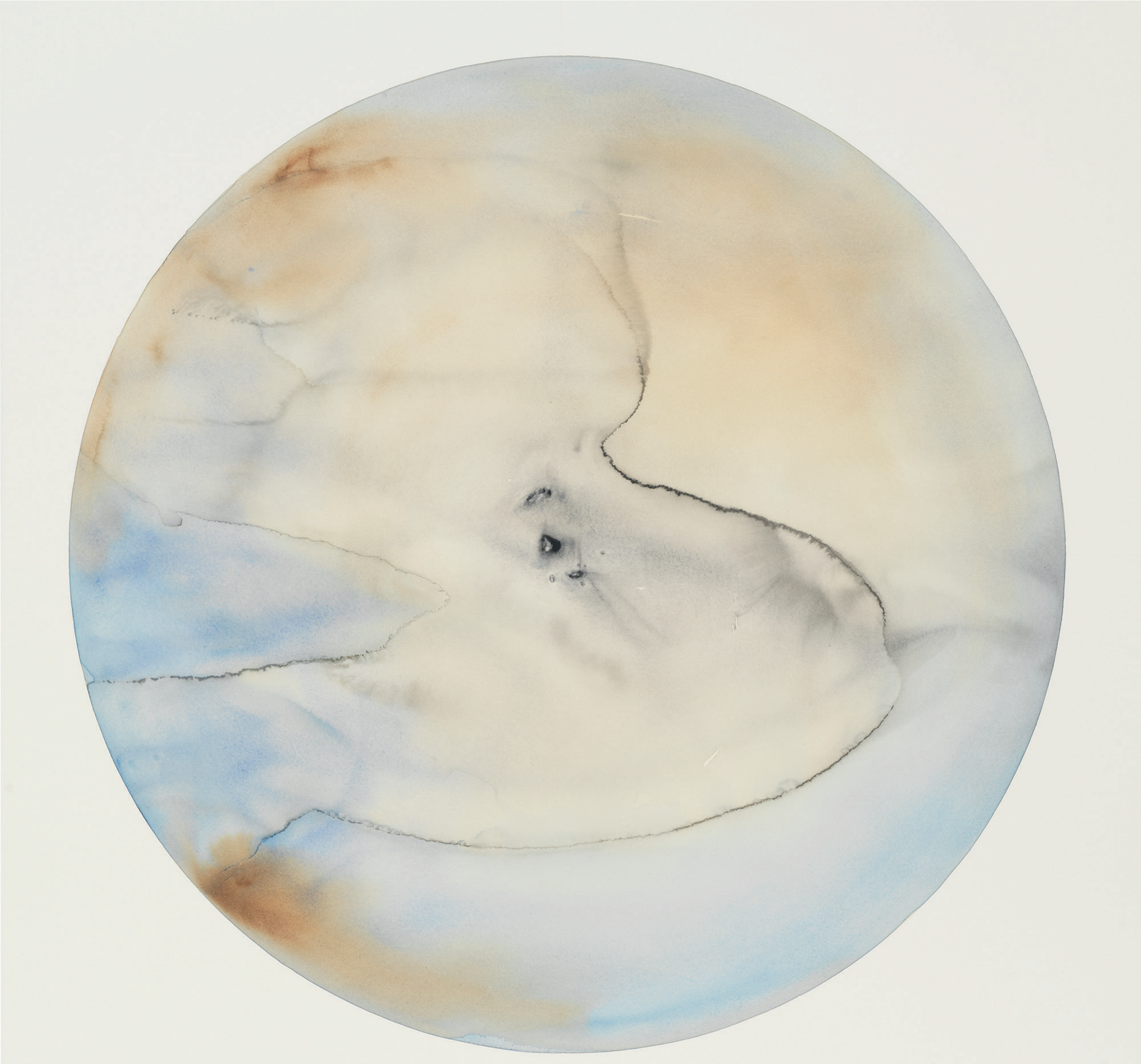
Ice Watch and Glacial Landscape no. 8 by Olafur Eliasson

Olafur Eliasson was born in Denmark to Icelandic parents and grew up exploring and drawing the raw beauty of the Icelandic landscape. Eliasson's reflections on his awakening to the climate and art space strikes a common cord in artists and scientists alike:

"It was only around the time that I was working on The weather project, at the Tate Modern in 2003, that I really began thinking as an artist about our relationship to the climate… It occurred to me at the time that the weather – and, by extension, the climate – is always acting on us and affecting us and that this is also true of our experience of an artwork as well. You might say that the climate is an agent in the experience of art, and it became important to me to make this explicit."

Shared experiences are a crucial element of Eliasson's art. In 2014, he transplanted 12 large blocks of Greenland's ice sheet to a square in Copenhagen, coinciding with the UN IPCC's Fifth Assessment Report on Climate Change. At the United Nations Framework Convention on Climate Change (UNFCCC) Conference in Paris the following year he reprised the work, placing 12 blocks of ice in the Place du Panthéon. On both occasions citizens from all walks of life were able to see, touch, and embrace the glacial ice that is disappearing around the globe.

Ice Watch by Olafur Eliasson, 2014, 12 ice blocks, City Hall Square, Copenhagen. Photographer: Anders Suhe Berg



Glacial Landscape no. 8 by Olafur Eliasson, 2018, watercolour and pencil on paper, 151cm x 151cm x 8 cm. Photographer: Jens Ziehe

"I used to think of nature being larger than me, it seemed independent of me, but also caring. But today nature has become fragile. The glaciers that I knew as a child are disappearing. We are now living in the Anthropocene, a geological era characterized by the effects of human activity on earth."[8]

When asked about the goal he is striving to achieve: "I hope to bring art into as many contexts as possible, to reach as many audiences, as many fields, as many worlds, as possible. One of the great problems in society today is that we often feel numb, untouched by the problems of others. There is a crisis in empathy wherever you look. Art, I believe, is capable of working against this, since art is constantly involved in touching people, in moving them. We may disagree on many things, but we all know the feeling of being moved by a film, a melody, a good book. Art can provide us a meeting ground, where we can discuss, disagree, and negotiate our shared reality."

Eliasson's work has been exhibited globally in institutions such as the MoMA, the Tate Modern, and the Venice Biennale. In recent works, he has melted shards of glacial ice on top of paper and added ink to create a series of abstract watercolours (see Glacial Landscape no. 8).

8 uk.phaidon.com/store/art/olafur-eliasson-experience-9780714877587/

On Earth as it is in Heaven by Michelle Rogers

On Earth as it is in Heaven by Michelle Rogers, 2008, oil on canvas, 2300 x 300 cm.

Michelle Rogers has worked in the climate, art and the environment space for the past decade. "Artists are trained to observe, I started to notice changes in the climate in every city that I knew well. I made my first environmental painting "On Earth as it is in Heaven" based on a 2008 photograph of a flooded city in China."

Rogers attributes Hurricane Sandy in NewYork (2012) as having a profound role in her career trajectory "A photographer friend shared his images of Manhattan in complete darkness after the storm and that really haunted me, the fragility of our civilization. Up to that point, I was very much on a regular career path, but I thought what's the point of having a great art career in an art bubble if the planet and everything I love is under threat."

In 2017, Rogers partnered with the International Research Institute for Climate and Society at Columbia University to re-envision Boticelli's Birth of Venus (www.sciartmagazine.com/residency-lamont-doherty-earth-observatory.html). She set-up a makeshift art studio where she engaged with scientists to inspire her environmentally focused update of the Renaissance classic and in turn inspire those scientists around her to form alliances with those outside their traditional communities to incite cultural change. "The reality of what is happening on the planet and where culture is focused is jarring. I see that we live inThe Entertainment era and people's attention is very much in the world of Internet entertainment, music, fashion and culture and so far that space is bereft of climate references and that is a real problem. There is power in culture … it is the bloodstream of every civilization and we need its attention on our survival."

One Home: An Environmental Symphony by Charlie Mauleverer

In 2015, Charlie Mauleverer, composer and environmental activist, set out to write a symphony that would serve as a call to action on climate change. Mauleverer's goal was to craft a piece that was as approachable as possible, offering compelling melodies of hope and optimism. He launched a social outreach campaign requesting people from around the world to write down, in their own language, something that they care for deeply that would be totally lost or compromised by climate change. He asked that this sentiment of love be tagged in a photograph and sent to him via email.

And so started the arrival of image after image in his inbox "Munakunanchys Raykum Kausayninchis" = "for the love of our way of life", from the ECOAN project in Peru; "لمحبة نهر النيل = for the love of the River Nile" from Fathel in Sudan.

Mauleverer received an image and message from every country in the world and then set about interweaving these messages into the choral composition that would accompanying the symphony. The piece itself is structured in seven movements, one for each continent, with instruments characteristic to the continent profiled, all leading to a final global movement which brings them all together. They culminate in a full symphonic orchestra accompanied by a choir, offering a voice to every single country in the world, with the corresponding photos from those countries serving as roving cultural backdrop. The Symphony premièred in Switzerland and was also played by the South Czech Philharmonic. Mauleverer is currently fundraising for a studio recording of the "One Home: An Environmental Symphony" while working on his first commissioned piece.

Photograph from South Czech Philharmonic performance

Summit by Teresa Borasino

Every year, HAWAPI, a small registered cultural Association in Peru, gathers a group of artists to explore a social or environmental challenge with each artist expressing their response through works of art. In 2014, HAWAPI took place at the foot of Pariacaca – a large tropical glacier located in Peru's central Andes. The city of Lima – which now has a population of over 10 million – relies entirely on glacial run off from the Pariacaca mountain range for its fresh water needs. Tropical glaciers show rapid response to changing climate patterns and so are severely threatened by the current rise in global temperatures.

Teresa Borasino, a visual artist native to Lima, took part in the 2014 expedition. The group of artists trekked to the remote Pariacaca glacier mountain range to contemplate the climate change crisis in the lead up to the UNFCCC Conference of Parties (COP 20). It was here, at the foot of Pariacaca glacier, that Borasino convened "Summit," in which the vacant red plastic chairs stand in stark contrast to the retreating glacier, representing the absence of policymakers in the areas most affected by climate change.

Today, Borasino lives and works in Amsterdam. She remains true to activism through art. In a recent interview she noted "I am deeply motivated by the beauty and wonders in the world, I am motivated by the possibility to restoring the ecological world and implementing systemic alternatives that will replace the current capitalist growth at all cost system." She leads the Fossil Free Culture Netherlands project, which successfully protested Shell as a partner to the Van Gogh Museum.

Summit by Teresa Borasino, 2014. Photograph exhibited at the Museum of Contemporary Art, Lima.

Synanthrope Series II by Hannelie Coetzee

Hyenas from the Synanthrope Series II by Hannelie Coetzee, 2018, found wood, 900mm high x 1600mm long x 300mm wide. Exhibited at the Origins Museum, Johannesburg. Available at: youtu.be/4oF6VebbPVk

Hannelie Coetzee combines her love of African life with her art. Her work is designed to facilitate conversations and build partnerships across creative arts practice and theory, the humanities, and the social, natural and physical sciences. Coetzee's work also tries to connect people to the original ecologies underneath cities. She comments that by using artists only to "illustrate" and "communicate" science, the full potential of artists and the role of art in helping us solve complex wicked challenges is not considered. Artists contribute to addressing societal ills. She stresses the role of partnership and co-design, "If you get them in early, it does not only stay theoretical. It can actually help the world. It is peoples' relations with each other, to address problems, that will improve how we live in this world. Let the ego go. We can't solve the issues we caused in our own silos anymore".

Coetzee displayed Synanthrope Series II at the September 2018 University of the Witwatersrand, South Africa Watershed event. A synanthrope refers to an animal or plant that lives near and benefits from an association with humans and the artificial habitats that humans create around them – like an urban environment. In this piece she explores the fragile relationship between humans and nature as her Hyena sculptures are taken on a stop frame animation walk through the University of the Witwatersrand Campus[9]. As part of the piece, she conducts immersive walkabouts on the mapped intercontinental watershed where participants learn

9 *Coetzee, H. (2018). Hyenas walking the Intercontinental Watershed, Johannesburg. Available at: youtu.be/4oF6VebbPVk.*

which droplets flow into the Atlantic and which flow into the Indian oceans. The work serves as a reminder that Hyenas frequent the green corridors in urban sprawl areas – highlighting the interconnections between various parts of the complex world and system we are trying to understand.

Coetzee urges viewers and readers to consider their own impact on nature and to rethink how mankind will live with limited natural resources in the future. Made from reclaimed materials, her artworks become a vehicle inside and outside the exhibition space to expand this conversation about what is beneath the urban landscape and the incorporation of integrity back into natural resources, highlighting the ever-present link between humans, nature and land.

Wind, Water by Palani Mohan

Indian born, Australian raised, Palani Mohan now lives and works in Hong Kong. When asked about how he became active in the climate and art space, "I never thought about going out to photograph climate change, it just sort of happened. It is all around us. It came after me rather than me going after it." His latest project *Wind, Water* captures the sheer energy and power of storm events around Hong Kong.

Wind, Water by Palani Mohan, 2017, Kehrer Verlag.

How to get involved

All artists interviewed advocated for more collaboration between artists and scientists. Below is a non-exhaustive list of institutions and initiatives working in this area.

The Artic Cycle: a group of artists committed to using their talents and skills to imagine a just and sustainable future for all. They believe creativity and collaboration are essential elements in the creation of a better world. Artists and Climate Change is an initiative of the Artic Cycle and contains a list of global partners operating in this creative space (artistsandclimatechange.com/resources/).

CLIMARTE is an Australian-based independent not-for-profit organisation that harnesses the creative power of the arts to inform, engage and inspire action on climate change (climarte.org).

Earth, Itself: Art/Science Collaborations. The Institute at Brown for Environment and Society (IBES) is concerned centrally with the challenges facing us in ensuring sustainable life. Earth, Itself is an integrative programme of the humanities, natural and social sciences, and creative arts, designed to further conversation about the environment in innovative, engaging, and inclusive ways (www.brown.edu/academics/institute-environment-society/earth-itself-artscience-collaborations).

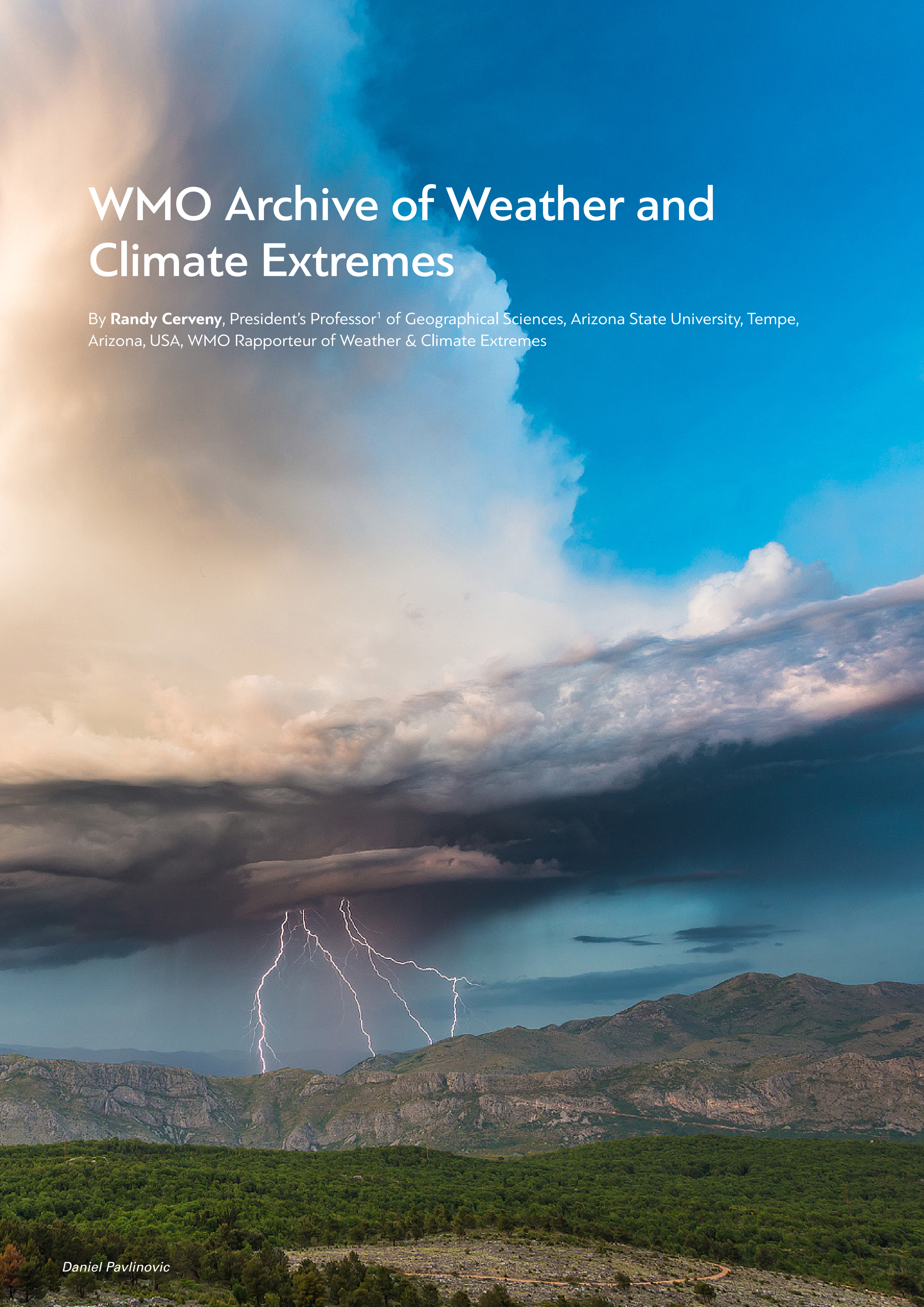
HAWAPI, a small cultural Association in Peru that each year brings together a group of artists, academics and socially engaged individuals from a diverse range of practices to create public interventions in locations affected by specific social, political or environmental issues (www.hawapi.org).

SOE.TV: Studio Olafur Eliasson, launched on 14 September 2018. The platform includes six channels, one is connected to the UN Sustainable Development Goals (SDGs) that Eliasson is working to help achieve: climate action (SDG13) and affordable and clean energy (SDG7) (www.soe.tv/).

Weather, art, and music: A Special Interest Group (SIG) of the Royal Meteorological Society since 2012. The Royal Meteorological Society is the Learned and Professional Society for weather and climate, and is based in Reading, United Kingdom. It seeks to develop innovative events that bring weather and climate scientists together with artists of all stripes in front of an enthusiastic audience, in an endeavour to find new and inspiring ways of talking about our weather and climate change (wamfest.co.uk/).

WMO Archive of Weather and Climate Extremes

By **Randy Cerveny**, President's Professor[1] of Geographical Sciences, Arizona State University, Tempe, Arizona, USA, WMO Rapporteur of Weather & Climate Extremes



Daniel Pavlinovic

In 2005, the television coverage of Hurricane Katrina, a deadly tropical cyclone that hit the North American coast near New Orleans, was both heartbreaking and enthralling to view. As I watched, I was struck by a comment that I heard several times from different reporters: "This is the worst hurricane of all time." Immediately, as an atmospheric scientist, I realized how false that statement was. For example, while Katrina was deadly with over 1 800 killed, the dreadful 1970 tropical cyclone that struck what was then called East Pakistan (now Bangladesh) had a massive death toll of 300 000 people. However, I also understood that an official death toll value or other information from an extreme weather event was something that was not easily uncovered or accessible to the general public. At that time, there was no comprehensive, and official, database of weather and climate extremes addressing the "hottest," "coldest," "windiest," "deadliest" and other extremes of our planet.

I contacted several of my colleagues (Jay Lawrimore, Roger Edwards and Chris Landsea) and we wrote an article on what was then considered the best-known and accepted weather and climate extremes for Earth for the *Bulletin of the American Meteorological Society* (Cerveny et al. 2006). In that article, we also advocated for the creation of an official global database of weather and climate extremes. Shortly after its publication, I received a call from Thomas Peterson, who later became President of the WMO Commission for Climatology (CCl). He asked me to present the CCl subgroup of which he was then chair with a proposal for an official WMO Archive of Weather and Climate Extremes . I did so and, in 2007, CCl established the WMO World Weather and Climate Extremes Archives (wmo.asu.edu/).

One important question should be addressed before going into detail on the Archive: "Why do we actually need a world archive of weather extremes?" There are six major reasons:

- Probably most importantly, knowledge of our existing weather and climate extremes is critical in determining exactly how much and how fast our world's climates are changing. Knowledge of extremes establishes our baselines so that we can access exactly how our climate is changing. For example, in 2015, a massive heat wave along the peninsula coast of Antarctic lead to the highest temperature (17.5 °C) ever recorded for the continental area of Antarctica and its nearby island (Skansi et al. 2017). Our Archive is being updated much more frequently than any of us in the early days of this Archive project thought possible.
- Knowledge of weather and climate extremes is critically important for medical and engineering concerns. For example, if a person is designing a building or bridge, knowing exactly how fast the wind speeds can actually reach is essential. Similar concerns exist with temperature and other weather variables. How hot can our temperatures reach? How cold? Our bodies operate within a specified set of conditions and the Archive helps to define those conditions.
- Our evaluation of world weather and climate extremes can sometimes advance our basic atmospheric sciences. For example, one of our recent investigations on the longest distance and duration lightning strikes has caused a long-standing fundamental meteorological definition of "lightning" to be rewritten (Lang et al. 2016).
- As mentioned above, there is a tendency for the media sometimes to "overhype" an event – particularly a weather event. We need official and accessible records of weather extremes to aid the media in putting weather events in proper perspective!
- Perhaps surprisingly to some, many locales actually commemorate and recognize the occurrence of major weather events. For example, a huge sign at Mount Washington Observatory in New Hampshire, USA, acknowledged their long-held record for the highest wind recorded (231 m/h or 372 km/h), only recently exceeded by a wind gust at a small island off Australia (see Courtney et al. 2012). Other locales have similar recognition of their extremes.
- Lastly, people in general are fascinated by weather and, in particular, they love weather extremes – the hottest, the coldest, the windiest and so on. So having a reliable list of these extremes helps foster people's interest in weather. In particular since the inception of the WMO Archive or Weather and Climate Extremes, I have found that children love to hear about weather extremes. Grabbing kids' interest in weather through these extremes promotes possible future careers in the atmospheric

1 Randy Cerveny was awarded the title of President's Professor in recognition of his contributions to undergraduate education.

sciences and ensures that we will have quality meteorologists and climatologists for the future.

However, while some individual countries have their own committees for determining national weather records, until 2007 there was nothing official for the world. The WMO Archive maintains official records of the world, hemispheric and regional extremes associated with a number of specific types of weather. Presently, the Archive lists extremes for temperature, pressure, rainfall, hail, wind, and lightning as well as two specific types of storms, tornadoes and tropical cyclones. One common weather variable, snowfall, is not listed because of potential issues in consistent official measurement around the world.

Evaluation process

At the time of the Archive's creation, we expected that we might have to evaluate a new record every few years. Since 2007, we have actually evaluated more than fifteen potential records in a process that has become codified over the past decade.

Following an initial assessment of a new potential extreme and available evidence by the leadership of the CCI and the Rapporteur of Weather and Climate Extremes, an ad-hoc evaluation committee of international top atmospheric scientists is assembled. In the years since its inception, we have had committees comprised of scientists from countries including Argentina, Armenia, Australia, Bangladesh, Canada, China, Colombia, Cuba, Egypt, France, Germany, India, Israel, Italy, Japan, Kuwait, Libya, Mauritius, Mexico, Mongolia, Morocco, New Zealand, Pakistan, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, Zimbabwe and several other Members of the WMO.

The members of these committees are selected for a range of specific expertise, including local climate knowledge, understanding of factors contributing to an extreme occurring at a particular location or specific climate phenomena for the world in general, and specialized knowledge. The Rapporteur, in conjunction with a committee member from the local area of the potential extreme and others, constructs a background report of the available information and data regarding the extreme observation. This report includes specifics on the exact geographic position of the observation, the type of equipment used to make the observation (and specifics on its calibration, maintenance and operation), the synoptics (regional weather) of the event and any notable unusual or unique information concerning the observation. The committee reviews the report and discusses all aspects of the potential extreme, addressing five key questions:

1. Is there need for more raw data or documentation on this event to determine its validity or invalidity? Are there other data or other analyses corresponding to this time/place extreme event?
2. Are there any concerns as to equipment, calibration, measurement procedures, or other processes/ procedures associated with the measurement of the event?
3. Are there any concerns associated with the nature of the event (massive continental high pressure) that would raise questions regarding the validity of the record?
4. Are there any other concerns associated with the event?
5. Fundamentally, does the documentation support or refute this current world weather record?

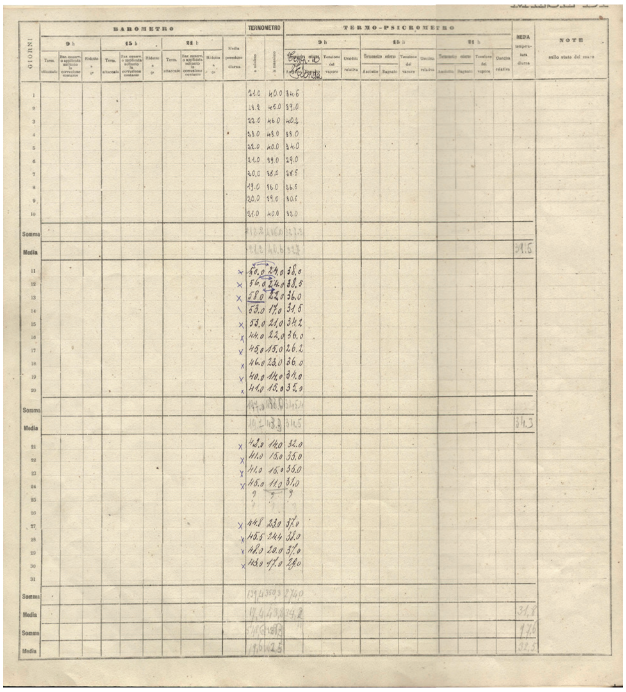
Thus far, such discussions have been via email with the Rapporteur as moderator. After their deliberations, the committee recommends a finding to the Rapporteur for final judgment and the observation is either accepted for inclusion into the Archive or dismissed.

Famous records

A two-year investigation into the long-standing temperature observation of 56 °C recorded in 1922 at El Azizia, in then Italian-controlled Libya (El Fadli et al. 2013), was one of the most famous. An international committee of 13 scientists, including scientists from Italy and Libya, concluded that the observation was invalid because of an error in recording the temperature. The announcement followed a danger-fraught investigation during the 2011 Libyan revolution. The committee had five major concerns with the record:

- problematical instrumentation
- a likely inexperienced observer
- an observation site over an asphalt-like material that was not representative of the native desert soil
- poor matching of the extreme to other nearby locations
- poor matching to subsequent temperatures recorded at the site.

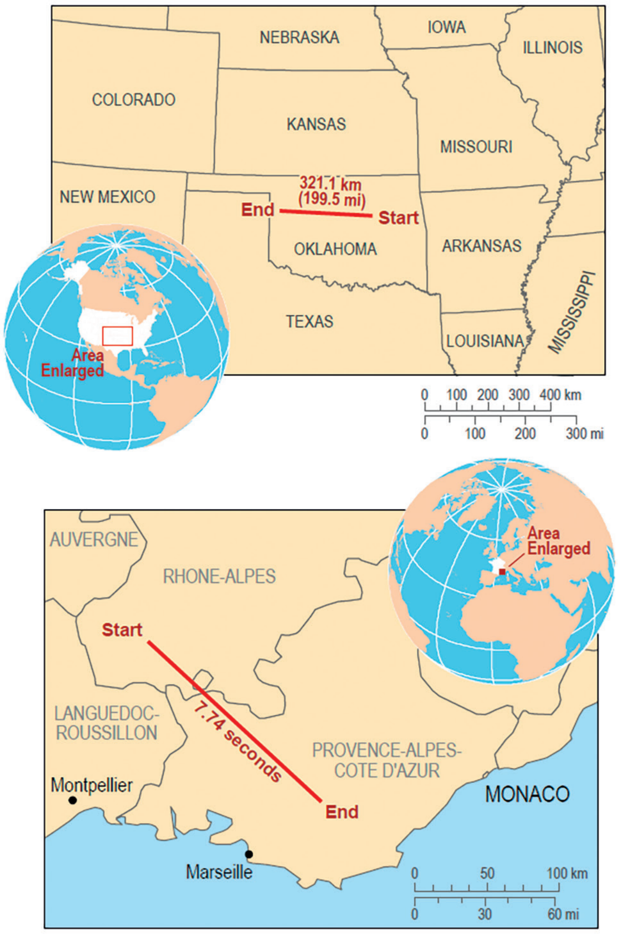
The committee concluded that the most compelling scenario for the 1922 event was that a new and inexperienced observer, not trained in the use of an unsuitable replacement instrument that could be easily misread, improperly recorded the observation and was consequently in error by about 7 °C. The announcement made world news. Following the press announcement on 13 September 2012, the WMO Extremes website traffic jumped from averaging 150 hits per day to over 24 000 hits over a three-day period. A secondary peak occurred four months later when the New York Times wrote a follow-up story on the announcement (Shimizu et al. 2014).



A photocopy of the original observer's log sheet for Azizia in September 1922 showing the misplaced temperature values for the purported record temperature recorded on 22 September 1922.

Several other investigations have garnered equal interest:

- A new record was accepted in 2011 for highest non-tornadic wind gust – A measurement of 408 km/h was made by an automatic recording station during Tropical Cyclone Olivia on 10 April 1996 at Barrow Island, Australia. The long-standing record had been 372 km/h, registered in April 1934 across the summit of Mount Washington, USA. The evaluation panel included members from Australia and from Mount Washington Observatory (Courtney et al. 2012).
- Two world rainfall records established in 2009 for La Réunion associated with the passage of the intense Tropical Cyclone Gamede in 2007 – First, an extreme rainfall rate of 3 929 mm over 72 hours recorded at Cratère Commerson became the world-record rainfall for that period. Second, a Cratère Commerson rain gauge registered a world-record rainfall total of 4 869 mm over a 4-day (96 hour) period (Quetelard et al. 2009).
- A Western Hemispheric record was established in 2012 for a hailstone of 0.879 kg or 1.9375 pounds (diameter: 203.2 mm 8.0 inches) that fell on 23 July 2010 in Vivian, South Dakota, USA. However, the world's heaviest hailstone still remains the 1.02kg (2.25lb) hailstone that fell on 14 April 1986 in Gopalganj district, Bangladesh.
- A wave height record was accepted in 2014, specifically "Highest Significant Wave Height as measured by a Buoy" – A significant height of 19 metres (62.3 feet) was recorded by an automated buoy at 0600 UTC on 4 February 2013 in the North Atlantic Ocean. The recording buoy is a part of the Met Office (UK) Marine Automatic Weather Stations (MAWS) network. This extreme wave height value was recorded following the passage of a very strong cold front that produced winds up to 43.8 knots (22.5 m/s or 50.4 mph).
- Two records were accepted in 2016 for (a) the longest reported distance and (b) the longest reported duration for a single lightning flash in, respectively, Oklahoma (United States of America) and southern France –The lightning flash over Oklahoma in 2007 covered a horizontal distance of 321 km (199.5 miles). The lightning event over southern France in 2012 lasted continuously for 7.74 seconds (Lang et al. 2016).
- Three new records for the highest temperatures recorded in the Antarctic Region were accepted



Maps indicating the geographic locations of the verified longest duration and longest distance lightning flashes for the Earth

by the WMO in 2017 –The highest temperature for the "Antarctica Region" (defined by the WMO and United Nations as all land and ice south of 60°S) of 19.8 °C (67.6 °Fahrenheit) was observed on 30 January 1982 at Signy Research Station, Borge Bay on Signy Island. The highest temperature for the "Antarctic continent" (defined as the main continental landmass and adjoining islands) is the temperature extreme of 17.5 °C (63.5 °F) recorded on 24 March 2015 at the Argentine Research Base Esperanza located near the northern tip of the Antarctic Peninsula. Thirdly, the highest temperature for the Antarctic Plateau [at or above 2500 meters (8202 feet)] was the observation of -7.0 °C (19.4 °F) made on 28 December 1980 at an Automatic Weather Station (AWS) site D-80 located inland of the Adélie Coast. The lowest temperature yet recorded by ground measurements for the Antarctic Region, and for the whole world, remained the record of –89.2 °C at Vostok station on 21 July 1983 (Skansi et al. 2017).

In 2017, an evaluation committee completed an in depth investigation of existing mortality records for five specific weather-related events in order to determine the highest documented death tolls associated with each event –The five identified and verified historical mortality extremes are the following:

- "Highest mortality (indirect strike) associated with lightning"- 469 people killed in a lightning-caused oil tank fire in Dronka, Egypt, on 2 November 1994
- "Highest mortality directly associated with a single lightning flash"- 21 people killed by a single stroke of lightning in a hut in Manica Tribal Trust Lands in Zimbabwe (at the time of incident, Rhodesia) on 23 December 1975
- "Highest mortality associated with a tropical cyclone" - an estimated 300 000 people killed directly as result of the passage of a tropical cyclone through Bangladesh (at time of incident, East Pakistan) of 12/13 November 1970
- "Highest mortality associated with a tornado"- an estimated 1 300 people killed by the 26 April 1989 tornado that destroyed the Manikganj district, Bangladesh
- "Highest mortality associated with a hailstorm" - 246 people killed as a result of a severe hailstorm occurring near Moradabad, India, on 30 April, 1888 (Cerveny et al. 2017).

Currently, a couple of investigations are ongoing regarding very high temperatures in 2016 in Kuwait and Pakistan and extremely strong winds recorded over Japan in 2004.

A living repository

A key consideration is that all extremes in the WMO Archive are accepted and listed until or unless critical evidence is presented to either refute an existing record or substantiate a new record. In other words, the Archive is a living repository. In a world undergoing climate change, new records are being made every day and it is the duty and responsibility of the Archive to ensure that the world's records of weather and climate extremes are as complete, accurate, and up-to-date as possible. Indeed, since its inception, the WMO Archive is now routinely queried by other "record-keeping" entities, such as the Guinness Book of World Records, for our expertise involving weather records.

Study and adjudication of world weather and climate records has proven to be very useful activity for both the scientific community and general public. It has increased public awareness of the activities of WMO, and provided a valuable service to a variety of people and organizations outside of the atmospheric science community.

Within the global atmospheric science organization, the work of the WMO Archive has truly helped to advance the science. Through analysis of new extremes made possible by new technologies, such as our lightning distance and duration extremes, and through analysis of traditional data sources and instrumentation (such as the investigation of temperature and wind extremes), the investigations of the many scientists contributing to Archive allows us to reanalyse new, as well as past, weather records in much more detail and with greater precision than ever before. Fundamentally, the final result is an even better set of data for analysis of important global and regional questions involving climate change. With the continued support and incredible work of the many scientists comprising the multitude of ad hoc evaluation committees, the WMO will continue to set the standard for global monitoring and adjudication of weather and climate extremes.

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Enhanced Weather Research and Forecasting in Support of the Beijing 2022 Winter Olympic and Paralympic Games

By **Mingxuan Chen**[1], **Jiannong Quan**, **Shiguang Miao**, **Ju Li** and **Min Chen**[2], **Walter Dabberdt**[3], **Zongmin Wang**[4], **Guo Deng**[5], **Chongping Ji**[6], **Jinjun Pan** and **Wei Tang**[7]

Weather is a key factor determining the success of the Winter Games. The next Winter Olympic Games will take place from 4 to 20 February 2022, in the municipality of Beijing and the neighbouring Hebei province, in China. The Paralympic Games will follow a month later, from 4 to 13 March. The scheduling of the outdoor events for the Games will rely on very short-term forecasting and nowcasting.

Accurate and reliable forecasts and warnings of temperature, humidity, visibility and wind extremes affect event scheduling, athletic performance and course conditions. They are also important for ensuring the safety of athletes, support staff, spectators and transit operations. In addition, the snow-making and snow-storage processes need accurate high-resolution short-term forecasting and nowcasting of low-level and surface temperature, humidity and wind.

The Beijing urban area will be the site of the opening and closing ceremonies, all ice competitions and the big air snowboarding events. All alpine skiing and sliding events will be held at the Haituoshan mountain area in the Yanqing district of Beijing city (~60 km north-west of central Beijing). The Nordic skiing and ski-jumping events will take place in Chongli county of Zhangjiakou city, in Hebei province (~100 km north-west of central Beijing city).

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6 Weather Forecast Office, Beijing Meteorological Service

7 Public Meteorological Service Center, CMA, Beijing

Research and development project

Forecasting for the 2022 Winter Games is a special challenge because of the continental winter monsoon conditions and the scarcity of research, operational techniques and experience in very high-resolution winter meteorological forecasting in these two complex mountain areas.

A five-part research and development project, funded by the National Key Research and Development Programme of China, has been initiated to address the forecast challenges and the specialized needs of the various outdoor events. This involves numerous organizations within the China Meteorological Administration (CMA). The project includes five programmes:

1. enhanced meteorological observations
2. very short-term forecasting and nowcasting
3. short- and medium-range prediction
4. seamless forecasting and early risk warning for key points and events
5. intelligent meteorological support services

The enhanced meteorological observation programme will continue and augment a series of high-resolution observation experiments already underway in Chongli and Haituoshan mountain areas. The in situ and remote-sensing observing systems being utilized are listed in **Table 1** and include automated weather stations (AWSs), HOBO® weather stations, X-band dual-polarization Doppler radars, cloud radars, microwave radiometers, microwave wind profilers, Doppler wind lidars, sodars, radiosoundings, satellites, twin-engine research aircraft, etc. Two new S-band Doppler weather radars are also being deployed in Haituoshan mountain area and Kangbao county of Zhangjiakou city.

The observation programme will also develop high-resolution reanalyses and conceptual models for small-scale weather attributes in the two mountain areas based on multi-sensor observations, high-resolution data assimilation/integration and special numerical simulations (for example, large-eddy simulations and computational fluid dynamics modelling under different winter synoptic conditions). These efforts are being led collaboratively by the Weather Forecast Office of Hebei Meteorological Service (HBMS) of CMA and the Institute of Urban Meteorology (IUM) of CMA's Beijing Meteorological Service (BMS).

Figure 1. Locations of the three sporting zones and the solid red line indicates the Beijing–Tianjin–Hebei (BTH) boundary (figure created with Google Earth Pro)

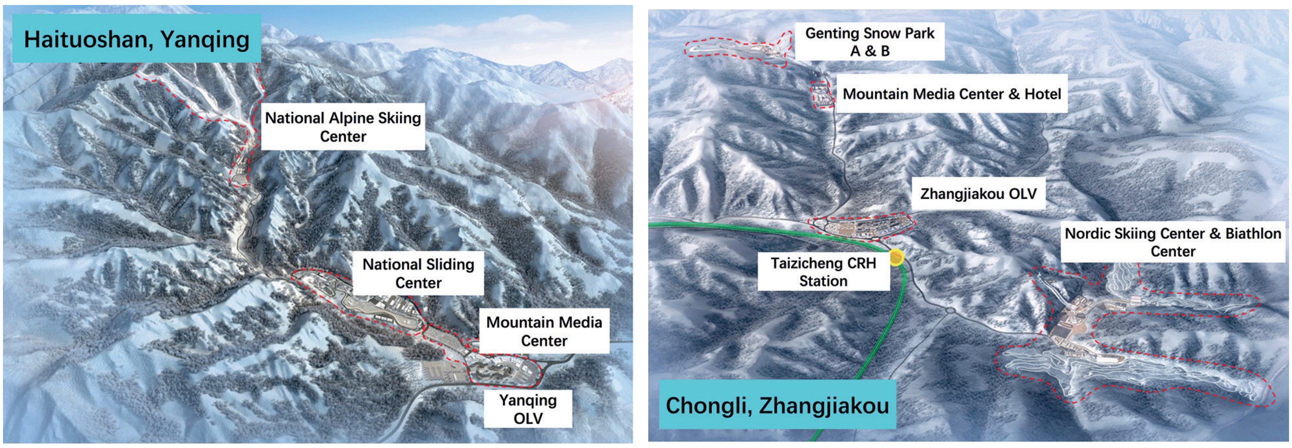

Figure 2. Locations of primary skiing and sliding centres and venues at (a) Haituoshan mountain area and (b) Chongli (OLV is the Olympic Village and CRH is the China Railway High-speed train service)

Table 1. Type and number of meteorological instruments to be deployed for the Winter Games

Type of instrument	Observation elements	Zones to be deployed (number of instruments)
AWS	Surface temperature, humidity, pressure, wind and precipitation/snow	Haituoshan (48), Chongli (91)
HOBO	Surface temperature and humidity	Haituoshan (10)
Doppler wind lidar	Three-dimensional wind	Haituoshan (3), Chongli (1)
Wind profiler	Wind profiles	Haituoshan (2), Chongli (2)
Sodar	Wind profiles	Haituoshan (1)
Microwave radiometer	Profiles of temperature and humidity	Haituoshan (1), Chongli (1)
Atmospheric emitted radiance interferometer	Profiles of temperature and humidity	Haituoshan (1)
Radiosonde	Profiles of temperature, humidity, pressure and wind	Haituoshan (1), Chongli (1)
Cloud radar	Base, height and top of cloud	Haituoshan (2), Chongli (1)
Micro pulse lidar	Aerosol profile and boundary layer height	Haituoshan (2)
Ultrasonic anemometer	Wind and turbulence	Haituoshan (5)
Aircraft	Temperature, humidity, pressure, wind and snow cover	Haituoshan (1)
S-band dual-polarization Doppler radar	Doppler wind, reflectivity and dual-polarization variables (precipitation type)	Haituoshan (1), Chongli (1)*

The goal of the very short-term forecasting and nowcasting programme is to develop high-resolution forecast techniques for the 0–24 hour period. These will be based on rapid refresh cycling, local data assimilation, improvement of key physics in high-resolution models, integration and blending of multi-source data (observations and forecasts), and downscaling and bias correction of high-resolution numerical weather prediction (NWP) over complex terrain.

Diagnostic schemes of very short-term forecasting and nowcasting of key and special weather parameters for skiing and sliding events will be based on multi-sensor observations and high-resolution forecasting. The ultimate objective is to achieve up to 500-metre resolution covering the greater Beijing–Tianjin–Hebei (BTH) region (see **Figure 1**), and 100-metre resolution in two small domains covering the key skiing and sliding areas (Chongli and Haituoshan mountain areas). There will be 10-minute update cycling for 0–12-hour forecasts based on blending and downscaling, 1 km resolution and 1-hour update cycling of deterministic NWP, and 3 km resolution of ensemble NWP covering BTH region for 0–24-hour forecasts. This effort is being led by IUM.

The CMA National Meteorological Centre is leading the short- and medium-range prediction effort. This includes development of prediction techniques for the 1–10-day period based on China's Global and Regional Analysis and Prediction System (GRAPES), satellite data assimilation, high-resolution ensemble forecasting and bias correction of NWP over complex terrain. Diagnostic schemes for 1–10-day prediction for weather-sensitive ski and sliding events based on short- and medium-range NWP are also being developed. The goal is to provide improved 3-hour update cycling for deterministic forecasts, 3 km resolution for 1–3-day ensemble forecasts and 6-hour update cycling for deterministic forecasts of 3–10 days.

The BMS Weather Forecast Office is developing techniques to provide seamless forecasting of key weather parameters – wind speed and direction, gustiness, temperature, humidity, visibility, snow, low clouds and more – out to 240 hours for different skiing events, venues and key sites. Also being developed are early warning techniques for risks of disruptive weather at individual sporting venues and other key sites based on conceptual models, bias corrections, interpretative schemes (for example, Dynamic Model

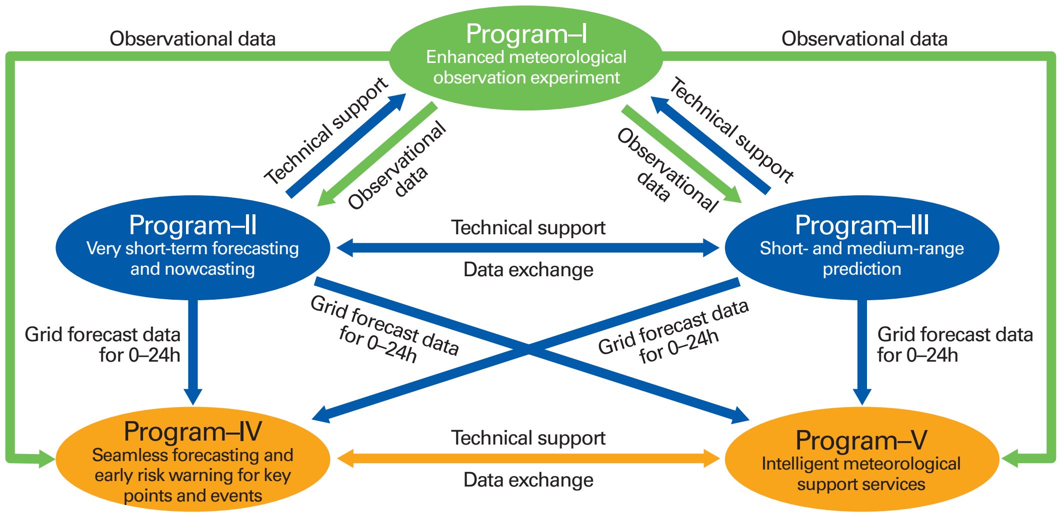

Figure 3. Relationships and roles of the five programmes comprising the research and development project

Output Statistics (DMOS), and Analog Ensembles (AnEn)), and machine learning using observations and grid forecast data from both the above-mentioned programmes and other data sources (for example, the European Centre for Medium-Range Weather Forecasts). Seamless forecasting and risk warning digital arrays, including forecasting/warning criteria designed especially to meet the specific needs of the Beijing Olympic Organizing Committee for scheduling skiing events, are also being developed.

The CMA Public Meteorological Service Centre is developing techniques to provide intelligent meteorological services for a variety of uses and end users, including skiing and ice sport events, key traffic channels, helicopter rescue operations, public viewing, broadcast media, and other applications based on data from the enhanced observing network and new and improved prediction models and forecast techniques. These services will employ a variety of innovative approaches including information technology, artificial intelligence, data mining and cloud computing. New and improved intelligent and interactive display platforms and meteorological service applications are also being prepared to meet the specific needs of end-user groups.

An international effort

Organizing and coordinating the research, development and operations efforts of the five leading CMA units is an effort perhaps on par with the organization of the Games themselves. Experts from more than 15 domestic and several international organizations will be working with the Chinese scientists and communications specialists. Other operational units from BMS, HBMS and CMA, the Institute of Atmospheric Physics (within the Chinese Academy of Sciences) and Peking University, among others, will be part of the domestic team. Cooperating international organizations include the United States National Center for Atmospheric Research (NCAR) and University Corporation for Atmospheric Research (UCAR) Community Programmes (UCP), the Austrian Zentralanstalt für Meteorologie und Geodynamik (ZAMG, the Central Institute for Meteorology and Geodynamics), Environment and Climate Change Canada, the University of Oklahoma, the University of Utah and the Korea Meteorological Administration.

Additional organizations may join the programmes in the coming months and years. Together, their objective is to provide the 2022 Winter Olympics and Paralympics with meteorological services and support that is "Wonderful, Extraordinary, Outstanding" – the overall goal of these great sporting games.

Meteorological Training in the Digital Age: Blueprint for a New Curriculum

By **Andrew Charlton-Perez**[1,2], **Sally Wolkowski**[3], **Nina Brooke**[4], **Helen Dacre**[1], **Paul Davies**[5], **R. Giles Harrison**[1], **Pete Inness**[1], **Doug Johnson**[6], **Elizabeth McCrum**[7] and **Sean Milton**[5]

The middle decades of the twenty-first century will be a critical time for the meteorology profession. The effects of climate change will be clear and progressing in most regions (Hawkins and Sutton, 2012). The likely concurrent increase in the frequency and intensity of extreme weather events (IPCC, 2012) will place meteorological forecasting in a critical societal position. There will be opportunities for meteorology to provide new and exciting benefits to society through continued improvements in the accuracy of weather forecasts (Bauer et al., 2015). The growth of an efficient renewable energy sector (Frei et al., 2013), for example, would require accurate forecasts for a range of timescales from days to seasons ahead.

Increasing computing power and new technologies – such as quantum computing (Debnath et al., 2016) and dense, real-time environmental sensor networks exploiting Internet connectivity – will offer opportunities for improving forecasting and our understanding of the atmosphere. But making the most of these opportunities, and addressing the challenges, will in part depend upon how well we train the future meteorological workforce. The meteorological community has developed a great deal of excellent, innovative practice; however, the time is right to look again at the nature of the meteorology training curriculum.

The prescribed skills and attributes for meteorologists are often defined separately for university courses and for continued professional training (usually defined by meteorological services and other providers). A fundamental opportunity to define and deliver a coherent training programme across all forms of meteorological education is being missed. To address this disconnect, we – the University of Reading and the Met Office – have worked together to develop a blueprint for the meteorological training that a complete educational programme should provide. The skills and attributes are relevant to all forms of training in meteorology, for students at university, for those undertaking continuing professional development (CPD) and for those learning via open online courses.

A shared blueprint underpinning meteorological training

Our blueprint of meteorological skills takes the form of 14 key principles, which we believe should underpin training for students entering the field over the next ten years. A curriculum that follows these principles should help to develop the skills and attributes needed by meteorologists as they begin their professional careers and grow into leadership roles. The flexibility of future careers for meteorologists and the need to provide training that is portable, generic and easily upgradable are important motivations for the blueprint. (Space constraints here mean that it is

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not possible to expand upon the team's discussions and need for training in these 14 areas. An extended version of this article with detailed discussion in each of the 14 areas is freely available online by searching for the DOI: 10.17864/1926.78851)

Meteorological training should prepare meteorologists to:

1. Move between roles that involve research and development, operational delivery, consultancy or a combination of all three
2. Be comfortable discussing and thinking about weather and climate over a range of timescales, from days to decades
3. Be responsible for their own continuing professional development and facilitate personal development of colleagues
4. Be resilient to a changing working and resource environment and confident in embracing new challenges
5. Be able to critically evaluate scientific literature
6. Be aware of the benefits and opportunities of open distribution of scientific knowledge, software and data
7. Be able to develop transparent, robust and well-documented scientific software
8. Be able to work in teams that develop scientific models and modelling systems that produce estimates of the real-world impact of meteorological variability
9. Be able to appreciate and evaluate information available through observations and measurements
10. Be competent in designing statistical tools and applying statistical thinking to the atmosphere
11. Be able to ensure that operational standards and quality are maintained within increasingly automatic systems
12. Be able to effectively understand and communicate risk and uncertainty
13. Be clear in expressing their work in the context of contradictory forecasts or interpretations
14. Be able to interpret their work in the context of a changing climate.

It is unrealistic to expect that each of the skills could be covered to the same depth and breadth at every stage of a student's education and training. There would not be the time or expertise to do so. This increases the need for recognition of the shared and distributed nature of training for meteorologists and a common set of training principles for all education and training providers. The professional accreditation offered by learned meteorological societies can and will play an important part in this integrated training approach. The blueprint does not focus on the essential meteorological, mathematical and physical content of training in atmospheric sciences. This is already covered extensively in, for example, the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO, 2015) and similar publications by the American Meteorological Society and the Royal Meteorological Society.

Achieving the principles

We believe that developing meteorological curricula consistent with our blueprint is feasible, beneficial and enjoyable for students and staff of all institutions, albeit with some changes to teaching practice. The increased use of enquiry-based teaching approaches could be used to combine teaching of the underpinning skills in the blueprint with the teaching of meteorological fundamentals. A mixture of these approaches with lecture and vocational teaching is expected to be optimal and effective for most training providers.

Why enquiry-based learning?

Enquiry-based approaches involve students learning through their own, self-directed enquiries or investigations into a problem. The role of the teacher is crucial. The design of the learning intervention must address the required learning outcome. But it must also allow enough flexibility to tackle broader goals such as encouraging personal responsibility, interest and exploration of a problem.

Past experience of delivering enquiry-based modules has shown that providing students with authentic, meaningful problems is particularly important. A range of formal and informal assessments should be used, and students should be provided with bridging activities that allow them to move from the role of consumer to creator of information.

This enquiry-based, active learning approach is an effective way for students to learn specific-subject content and the broader skills identified in the blueprint (Hmelo-Silver et al., 2007; Deslauriers et al., 2011).

The University of Reading's enquiry-based approach to studying the Hadley cell offers an example. Students are encouraged to use the Held and Hou model (1980 to develop experiments for understanding the role of the seasonal cycle in determining the cell width. While developing their knowledge of atmospheric dynamics, students also get the chance to critically evaluate the original scientific paper (blueprint principle 5), develop robust and transparent code (blueprint principle 7) and facilitate personal development of colleagues by providing and responding to peer feedback (blueprint principle 3).

There are some challenges in implementing enquiry-based learning in meteorology (Edelson et al., 1999). These include: student motivation, the accessibility of investigation techniques, the varied background knowledge of each student cohort, student inexperience of the management of long-term activities, and practical and logistical constraints. However, experience has shown that support provided by a tutor, line manager or mentor is critical to the success of enquiry-based learning and can overcome these barriers.

Outlook

This article is intended to encourage debate on how new meteorologists can be best prepared for the digital age, and we would welcome further discussion of our ideas. Together, as a University department and professional training provider, we have discussed and developed a blueprint for the atmospheric science curriculum for new meteorologists entering the field at undergraduate, graduate and professional levels which we hope provides useful food for thought for other training providers. Measured against this blueprint, our own programmes require development to meet our own aspirations and the needs of students. By continuing our work together, we hope to further enhance and align our individual training programmes. We welcome opportunities to learn from and collaborate with other training providers across the globe through WMO initiatives like the recent Symposium on Education and Training held in Bridgetown, Barbados, in October 2017.

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The WMO Global Campus: An update and proposal for the future

By **Patrick Parrish**, Education and Training Office, WMO

"Where can I find the WMO Global Campus? How can I join?"

These and similar questions are frequently heard these days by the WMO Education and Training Office. The answers are simple, but they do require some explanation: "The WMO Global Campus is all around us, including all WMO Members that offer education and training services. You do not need to join in any official way. You will be a part of it whenever you use the resources it offers and make your own contributions to the initiative."

Confusion about the initiative may come from the name itself, a combination of almost contradictory words, "global" and "campus," which when placed together become a metaphor for the potential linkages between all education and training institutions serving WMO Members. Some may immediately think that "Global Campus" refers to a move to online learning. But while online options are considered an important component to meeting the learning needs of WMO Members, these are just one tool, one means to increasing opportunities. The WMO Global Campus is an ambitious initiative that began in the years leading up to the WMO Executive Council (EC) Session 66 in 2014, which made the decision to launch a feasibility study on the concept as a way of increasing collaboration, cooperation and sharing between education and training institutions. The 17th World Meteorological Congress extended the study one year later.

The goal of the WMO Global Campus concept is to increase capacity to educate and train professionals within WMO Member states and territories. While individual institutions are continuously working to meet expanding capacity development needs, Member surveys and requests have shown that supply is still not meeting demand. However, through collaboration and sharing, it is expected that this gap can be bridged.

But the more ambitious and innovative a concept, the more time it can take time for tangible results to appear. Thus, the initial excitement and high expectations seems to fade away while teams work diligently, but sometimes invisibly, to create viable plans and effective solutions. The WMO Global Campus efforts have followed this pattern. Nonetheless, the Global Campus Working Group of the EC Panel of Experts on Education and Training has impressive outcomes to report.

WMO Global Achievements

- The WMOLearn portal (learn.wmo.int) was established early in 2017 on the WMO public website. This portal points to all external tools and resources related to WMO Global Campus activities, as well as news and highlights on collaborative projects.

- A WMO Global Campus Roadmap has been completed and is available for review on the WMOLearn portal. This Roadmap provides information on the background, justification, priorities, activities and implementation goals for the initiative. As befits a "feasibility study," the Roadmap will be updated up to the time it is submitted as a report to 18th World Meteorological Congress in 2019, when ongoing implementation will be decided.

- The WMOLearn Events Calendar was launched in mid-2017, thanks to host and developer, the Caribbean Institute of Meteorology and Hydrology, and the Task Team advisors. The calendar is based on the EUMETSAT/WMO VLab calendar, which was provided to support the initiative. Further refinements have led to its current implementation at learningevents.wmo.int, which features information on courses and other learning opportunities in all WMO regions. This calendar, when adopted for use by Member education and training institutions, will function as a one-stop location for information on upcoming events, including a search capability to narrow in on specific needs.

- The new WMOLearn Library is a new addition to the WMO E-Library (library.wmo.int). Using this section of the E-Library, users will be able to find learning resources from both WMO Publications as well as from external providers. The WMOLearn Resource Catalogue is expected to offer hundreds of learning resources representing nearly all service areas of Members before the end of 2018. Special attention is being given to resources related to WMO competency frameworks, with initial task teams stressing Aeronautical Meteorology and Climate Services. The resources will be useful for both training providers, to aid in the creation of courses and course materials, and individual learners.

The WMOLearn Events Calendar features information on courses and other learning opportunities in all WMO regions.

- Collaborative projects between institutions are promoted and their products made accessible from WMOLearn. The project descriptions on the portal are intended to inspire new collaborative ventures and new offerings from the community. Other mechanisms for promoting collaboration and sharing best practices are in planning, including a database of experts.

- The COMET Translations Resource Centre (TRC) has been developed as a collaboration between the COMET Programme and the Meteorological Service of Canada, and with input from WMO. The TRC offers A Guide to Translation Project Management; several Glossaries related to meteorology topic areas; a guide to Writing and Editing for Adaptation, Translation, and Localization; information on Planning and Preparing a translations projects; and information on translation tools. A community forum is also provided (courses.comet.ucar.edu/course/view.php?id=181).

Quality assurance has been a consideration each step of the way, and processes are in place for both the Events Calendar and Resource Catalogue to encourage the sharing of only high-quality learning opportunities. All contributors are made aware of quality standards and must acknowledge that they are followed. The portals are monitored by expert teams.

The WMO Global Campus aims to build a wide community of practice of education and training providers in WMO disciplinary areas. A publication is planned to highlight innovations within the Education and Training Programme, and a community blog is being investigated.

Promotional materials are needed to encourage participation, and efforts are planned to ensure high visibility of all WMO Global Campus activities and tools. Social media will play a key role with WMO Global Campus Connect, including both a Facebook group (www.facebook.com/groups/1879738025638713/) and a WMO Global Campus Connect LinkedIn group (www.linkedin.com/groups/7403773).

The Global Campus is also regional, and Regional Associations are being encouraged to increase regional collaborations on education and training activities, including needs assessments and cooperative projects. Regional resources are also highlighted on WMOLearn, and meetings of training providers in many regions are being planned. Meetings of Regional Training Centres are in planning in various regions and subregions.

The WMO Global Campus Feasibility Study will continue at least through Congress 18 in 2019, and more activities will emerge or be enhanced during this time. But the only way for this initiative to be fully successful is with the involvement of all Members. You are encouraged to visit WMOLearn and use the Calendar and Catalogue to find learning opportunities. If you are a training provider, you are encouraged to share your courses and products there as well. And of course, we hope you will find inspiration to collaborate with other training providers to achieve your development goals.

Argentina's First Steps Towards a Global Campus

WMO Regional Training Centre Argentina: National Meteorological Service and University of Buenos Aires

By **Marinés Campos** and **Moira Doyle**

The WMO Global Campus initiative has sparked action for increasing collaboration to support the capacity-development needs of Members. The two components of the WMO Regional Training Centre (RTC) Argentina – the University of Buenos Aires and the National Meteorological Service (SMN) – have taken a lead. How does a university and a National Meteorological Service collaborate at local, regional and global levels to stimulate a revolution in meteorology training?

The University of Buenos Aires has a long history of meteorology education. The Department of Atmospheric and Oceanographic Science (DCAO), established in 1955, was one of the first institutions officially recognized as a WMO RTC. This recognition, together with financial support from WMO, enabled many Latin American students to obtain degrees in meteorology when there were no opportunities in their own countries. The University offers the added value of free tuition for national and international students. DCAO has world-renown professors with access to the latest advances in training and research. It has recently started to offer an introductory course in meteorology that is open to all regional, Spanish-speaking university students and graduates via distance learning.

SMN became an RTC component in 1983, offering regional on-the-job and classroom training. Over the years, rapid advances in technology have increased training demands, and made training even more critical to success. SMN has, therefore, strengthened its national and international training commitments to support the development and maintenance of skilled workforces and bases all its learning outcomes on WMO competency frameworks.

SMN has adopted new technologies and approaches to promote active engagement of students. Distance learning has significantly boosted training opportunities. The SMN Moodle learning management system allows wide reach into the region. It offers easy access to improved training resources, quick revisions, appropriate learning tools for challenging learning activities, and a means to connect people and ideas through discussion forums. SMN now offers both online and blended training with national and regional coverage (WMO Regional Association III and IV, Spanish-speaking countries). The response has been overwhelming: there were over 180 regional participants and over 200 national participants in eight online courses in 2017.

How can two such different institutions develop a lasting, healthy relationship? Each has a specific role and must perform it with excellence and for the benefit of the other. But the gap between theory and practice is well known. Collaboration is essential for understanding and benefiting from each institution's unique needs and capabilities.

Collaboration for local improvement

The University is working towards revising its curricula to be more aligned with the current basic instruction packages for meteorologists and meteorological technicians, and continuous dialogue with SMN helps to focus efforts. Collaboration has been enhanced as SMN supported development of the operational components in the new curricula.

The University and SMN work together to transfer current research into operation through training and to provide reliable operational data for research. The University also welcomes SMN operational staff to attend courses to update their knowledge and skills, allowing them to register without being regular students. WMO competency frameworks and guidelines help the two RTC components use a common language, which smooths the way for the partnership.

Strong theory plus good practice equals reliable training, which enables professionals and technicians to achieve the standards required for their jobs. However, difficulties remain in keeping pace with advances due to limited financial and human resources. Further collaboration is seen as a way to enhance efficiency.

SMN finances scholarships for University students who may eventually enter the meteorology profession. SMN professionals serve as professors and trainers at the University, with some final courses hosted by SMN. This obviously benefits the University, but also benefits SMN because it is essentially shaping future professionals. In addition, the trainers themselves improve their knowledge and skills during the process.

Collaboration for regional improvement

The RTC components are also eager to meet the learning needs of WMO Members in RA-III and IV. They have accomplished this by working with the WMO Education and Training Office – as well as other supporting partners and institutions – to help lead the WMO Online Course for Trainers for RA-III and RA-IV, and by hosting the WMO Training Development Workshop in Buenos Aires.

These courses have inspired innovative solutions, motivated improvements, and increased participation and sharing in the region. The bilingual Training Development Workshop organized in 2016 highlighted a further need to bridge language barriers to maintain up-to-date knowledge and skills.

A change in mindset occurs as courses are transformed into active, student-centred learning environments, using online capabilities to connect worldwide, or generate face-to-face bonds. Opportunities open up. It is the international community, mobilized by WMO, that has made this possible. Such collaboration produces strong, direct and positive effects, which are transformed into action plans, achievements and better services.

The training community of practice, CALMet, has been another venue for innovation for the RTC, through its online and face-to-face conferences.

Collaboration for global improvement

The RTC components recently worked on the international WMO/Coordination Group for Meteorological Satellites Virtual Lab (VLab) project Conceptual Models for Southern Hemisphere, managed by EUMETSAT. Five countries were involved. The collaboration led to the development of a workbook for the application of conceptual models for forecasters (supported by WMO) and the new GOES-16 satellite training programme.

Both RTC components took part in developing recommendations from the WMO Education and Training Symposium in 2017. This included the recommendation that RTCs and other training institutions share resources and strive to develop relationships to advance training and capacity development.

Argentina is part of the global collaboration that is already taking place, but much more can be done. Participation in regional and international projects – where the experience and knowledge of experts from northern and southern hemisphere centres are brought to bear – can lead to the development of highly valuable training resources that can be applied worldwide. For example, the southern hemisphere circulation surprises many northern hemisphere professionals when they see South American weather maps. Including southern hemisphere cases in meteorological training courses will increase the knowledge of graduates worldwide.

Argentina's RTC components have experienced the advantages of working together in a global community. They know how to join others in the region and in the world. But a strategic plan is needed, an organized structure for continuous collaboration/cooperation/coordination, so efforts and achievements can be followed through.

The WMO Global Campus is ideal for an international educational hub, a revolution in meteorology training that strengthens bonds. Argentina's RTC components support the Global Campus initiative.

Monitoring, Predicting and Managing Meteorological Disasters

By **Qing-Cun Zeng**, Institute of Atmospheric Physics, Chinese Academy of Sciences

Protecting people's lives and property against weather, climate and water-related disasters has been, and continues to be, a critical task in global sustainable development. It is especially important to meteorologists because nearly 90% of natural disasters are due to or are triggered by meteorological hazards.

China is located in a monsoon zone, where the weather and climate are highly variable, and where severe weather and climate disasters occur frequently. Chinese people have long suffered from such disasters, and have therefore gained experience in disaster mitigation and in the development of meteorological sciences. As far back as 2200–2100 B.C., records show that Emperor Yu helped the Chinese people by devising methods to combat floods and tame rivers. The mitigation of weather, climate and water-related disasters remains a high priority of the China Meteorological Administration (CMA) and associated research activities.

One cannot minimize the significant efforts of WMO in this area. WMO coordinates observations, monitoring and exchange of data worldwide and promotes research to improve predictive skill for extreme meteorological events. For example, the WMO Global Data-Processing and Forecasting System (GDPFS) facilitates data sharing as well as the sharing of numerical weather and climate prediction capabilities. Chinese meteorologists benefit from WMO activities, and, in turn, make efforts to contribute to them, thus ensuring the common welfare of humankind.

Progress and recent achievements

Scientists have made significant progress in monitoring, predicting and managing weather, climate and water-related disasters over the last century. This has been due to application of satellite remote-sensing data, numerical weather/climate prediction and data processing using high-performance computers, which started in the 1960s and matured in the 1990s.

The following now exist: a complete set of meteorological satellites capable of monitoring every weather system occurring at any time and in any place; sophisticated meteorological models capable of predicting weather from several hours to several days ahead and climate anomalies from months to years ahead; and supercomputers capable of processing "big data" quickly.

Examples of tropical cyclones (hurricanes in the Atlantic region and typhoons in the Pacific region) and long-term flooding permit us to demonstrate the progress and recent achievements. Tropical cyclones are often the cause of weather-related disasters, while long-term flooding is a typical climate-related disaster.

Tropical cyclones (hurricanes and typhoons)

In 1900, no warning was given when Hurricane *Galveston* (1900), one of the worst natural disasters in the history of the USA, made landfall in Galveston, Texas, because no monitoring and prediction were available at that time. The hurricane completely destroyed the city, and some 6 000 to 8 000 people lost their lives.

In 1992, meteorological satellites provided continuous monitoring for Hurricane *Andrew*. But the effective warning was given only 24 hours before the hurricane made landfall, because numerical weather prediction (NWP) was not sufficiently advanced at that time.

A mere 20 years later, warning that Hurricane *Sandy* (2012) would make landfall was issued 5 days before it reached the coast of the USA, despite the storm's unusual trajectory. This was the result of advancements in NWP modelling with assimilated meteorological satellite data. Interestingly, NWP models without assimilated meteorological satellite data predicted that the hurricane would move continuously eastward without turning to the coastal zone and making landfall.

In 2014, Chinese FengYun-2 and FengYun-3, as well as American and Japanese, geostationary satellites followed the development and trajectory (12–20 July, **Figure 1**) of Super Typhoon *Rammasun*. **Figure 2** shows the trajectory of the centre as predicted by various NWP models on 16 July 2014 (3 days before landfall on Hainan Province).

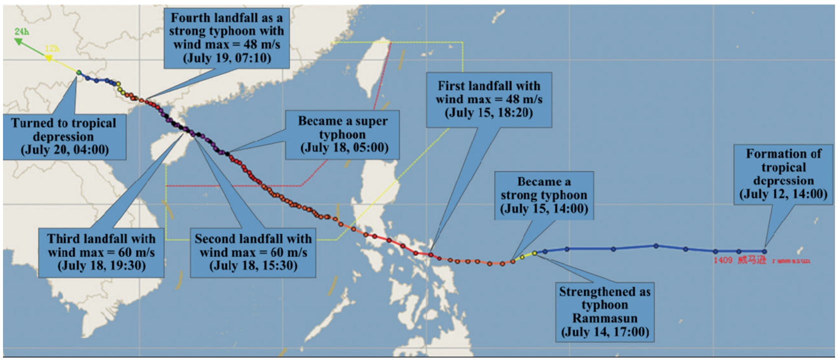


Figure 1. Development and trajectory of the centre of Typhoon Rammasun (12–20 July 2014)

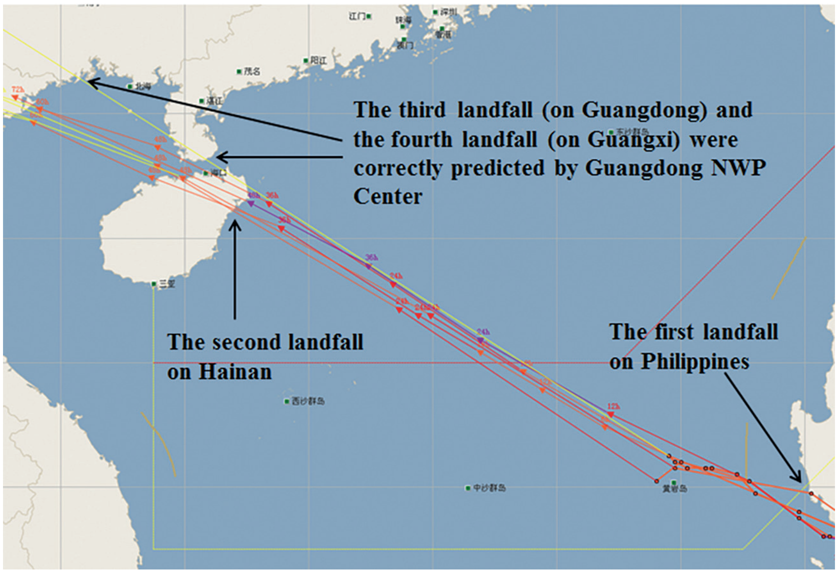


Figure 2. NWP models predictions of the trajectory of the centre of Typhoon Rammasun on 16 July (3 days before landfall on Hainan Province)

The satellite data and NWP models permitted the CMA to issue warnings to ships and fishermen before *Rammasun* entered the South China Sea, and warnings of landfall in Hainan Province 36 hours in advance. Provincial and city governments could make plans and take immediate actions to mitigate damage with such early warnings. When *Rammasun* made second and third landfalls on Hainan and Guangdong Provinces, respectively, it brought strong winds (maximum of 60–63 m s^{-1}), heavy rainfall and flooding (3 m) to the coastal zone and high ocean waves (13 m). These caused serious damage.

There was no loss of human life in Guangdong Province from *Rammasun*, because of the continuous monitoring, accurate prediction, strategic planning and appropriate responses. However, economic losses were substantial, due to the strength and complicated asymmetric structure of the typhoon. These are still difficult to predict and require further investigation.

Long-term flooding

Monsoon regions often have dense human populations and traditional agriculture practices – especially for crop production. People's safety and crop harvests are seriously affected by climate-related disasters such as floods and droughts. The prediction of climate-related disasters is therefore very important.

WMO set up the World Climate Research Programme (WCRP) in 1983, after routine NWP was established in several developed countries. It published a 10-year plan for the development of dynamical (numerical) climate predictions (DCPs).

During the implementation of WCRP in China, experiences in 1989 showed that it might be possible to extend DCPs to two seasons and even to a 1-year time frame. Extra-seasonal prediction (for two seasons) using a DCP model (IAP-DCP) became one of the operational schemes in routine climate prediction at CMA in 1994.

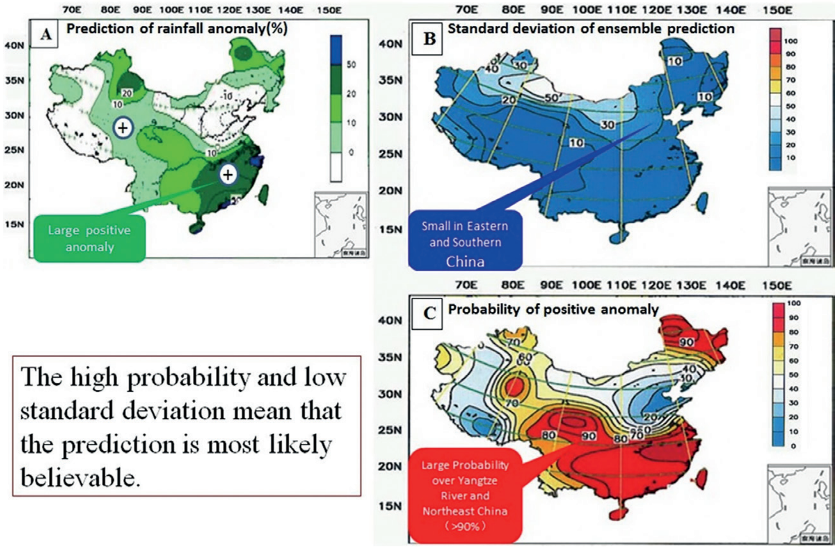


Figure 3. Real-time prediction of precipitation anomalies (%) for summer (JJA) 1998, by IAP-DCP, initiated from 1 to 28 February. The prediction consisted of: (A) ensemble prediction of rainfall anomaly for summer (JJA) 1998, (B) standard deviation of ensemble prediction samples and (C) probability of positive anomaly.

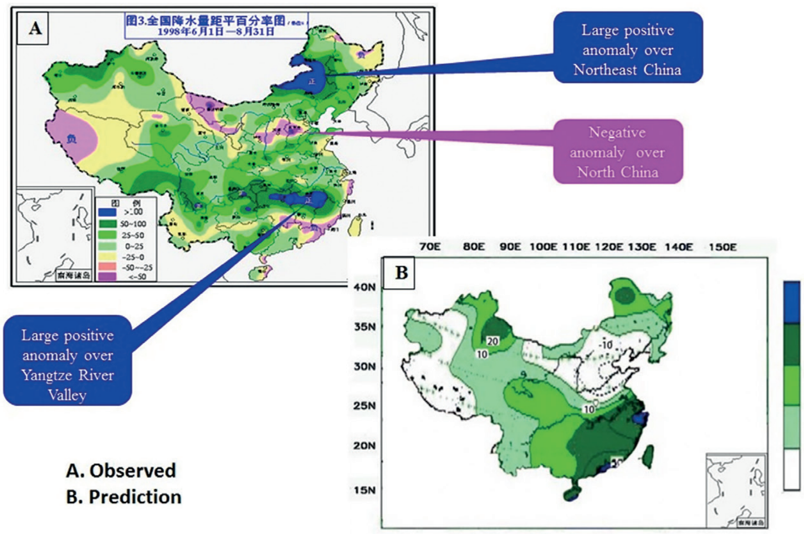


Figure 4. Percentage of summer rainfall anomaly for 1998: (A) observations and (B) predictions

Taking the summer (June, July, August (JJA)) rainfall anomaly prediction as an example, IAP-DCP consists of three parts: ensemble predictions initiated as of every February; a correction system to remove model bias by statistics based on hindcasts; and a final (formal) prediction, which consists of three components as shown in **Figure 3** (A–C). The figure shows real-time prediction of precipitation anomalies for summer (JJA) 1998 by IAP-DCP, initiated from 1 to 28 February.

The high probability and low standard deviation indicate that the prediction is believable. **Figure 4** provides verification, as it shows that the climate prediction was successful. Both the predicted and observed patterns of summer rainfall anomalies for 1998 are very similar. The strength of the positive anomaly is unusually large in both the predictions and observations (although the predicted anomaly was less than the observed one).

In the example in **Figures 3-4**, the climate prediction indicated floods might occur in the middle to low reaches of the Yangtze River and along the Nen River (north-east China). Thus, a warning report was submitted at the beginning of March to the central and provincial governments, to begin preparation for flood prevention.

The floods subsequently occurred with unusual severity. The Yangtze River bank collapsed suddenly at Jiu Jiang, in an unexpected location. Emergency responders had to mobilize workforce and materials from across China. Chinese President Jiang Zemin went to Jiu Jiang to lead efforts on mitigating the flood damage and sealing the collapsed bank. Subsequent satellite monitoring and NWP were very helpful for engineers tasked with sealing the bank. Numerical climate prediction was therefore useful for early preparation to manage the flood, and satellite monitoring and NWP were important during management of the disaster.

Some shortcomings of the predictions were that the predicted summer rainfall was not strong enough and that sufficient attention was not paid to the prediction

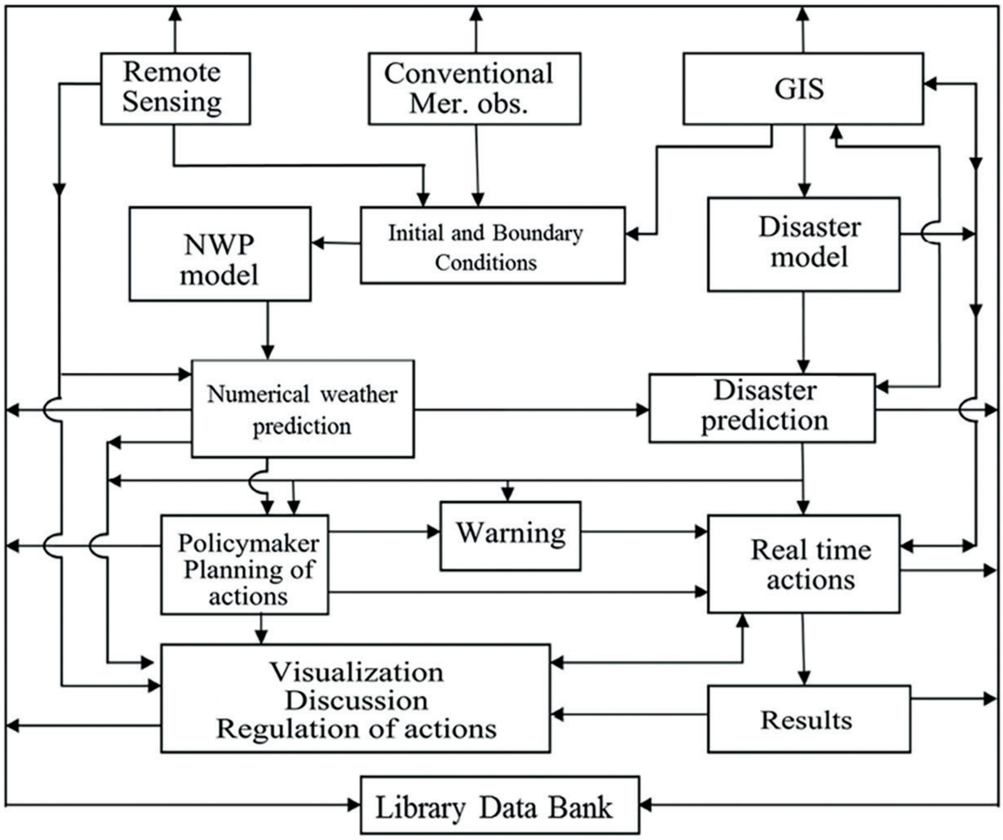


Figure 5. Flow diagram for monitoring, predicting and managing extreme meteorological events in order to minimize disasters risks

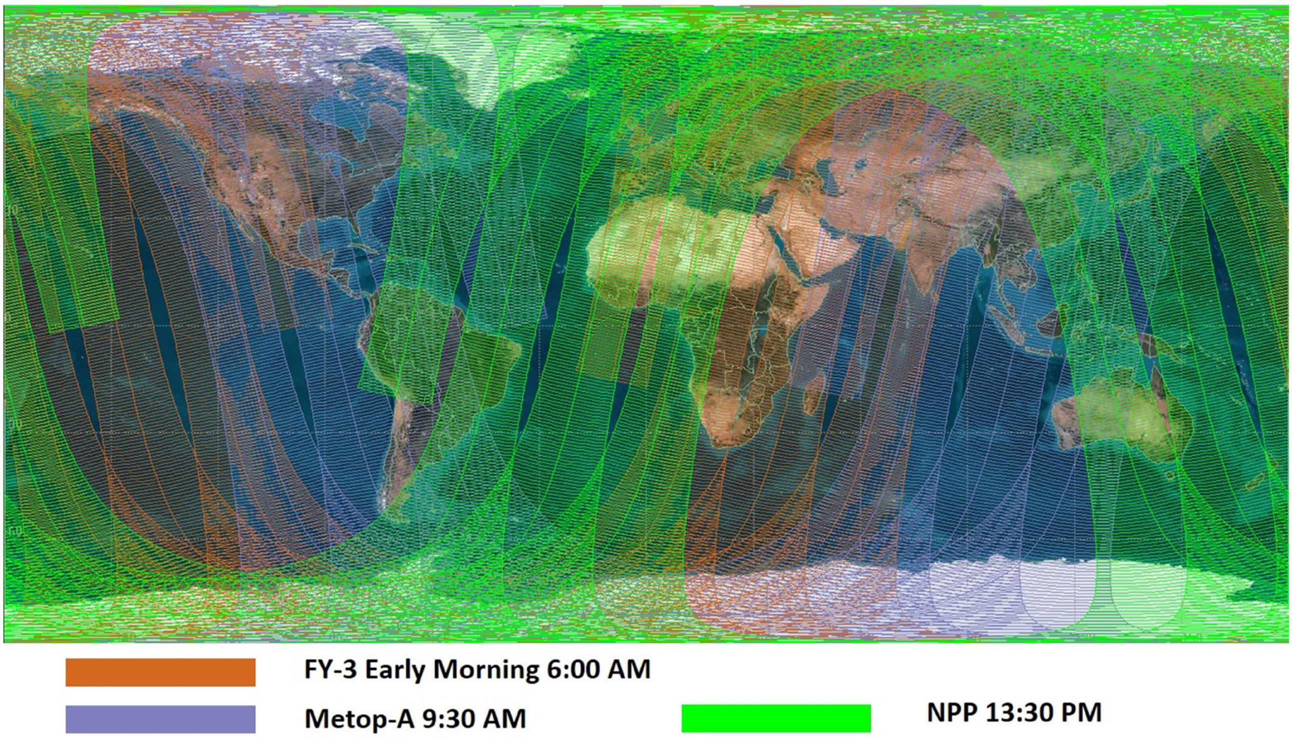


Figure 6. Satellite orbit options: FengYun-3 (FY-3) early morning, NPP (afternoon) and Metop (mid-morning)

of disaster situations (especially the affected area, depth of floods, and the time and place of bank collapse, which was a serious problem).

Managing meteorological-related disasters

In summary, the following steps are important in the management of disasters risks during extreme meteorological events:

1. Monitoring and predicting the weather/climate situation and its evolution
2. Predicting impacts or disaster situations and making projections of loss estimates
3. Issuing warnings
4. Establishing a strategic prevention plan
5. Implementing the plan and real-time regulations (updated by real-time monitoring of weather and disaster situations)
6. Verifying and assessing actual losses (based on data and experiences)
7. Storing the data and documents in related (or special) databanks and libraries

Every step in the process of disaster management and mitigation should be improved to address specific scenarios and demands, especially steps (2), (4) and (5). Close cooperation among meteorologists and scientists of other disciplines is necessary for continued success.

Future improvements

The following are some suggestions for the way forward, based on Chinese experiences, plans and thinking.

Improve monitoring, observation and remote sensing

The WMO Integrated Global Observing System (WIGOS) is comprehensive and essential for continued improvements in the integration and sharing of observational data. China will make contributions to the space component of WIGOS by launching an early morning polar-orbiting satellite in the FengYun-3 series and new-generation geostationary satellites, the FengYun-4 series, with high spatial and temporal resolutions and enhanced monitoring capabilities (e.g. vertical profiles of temperature and humidity, finer cloud structure and lightning). WIGOS will have three polar-orbiting satellite sets (FengYun-3 early morning, NPP afternoon and Metop mid-morning) in its space component in the future. This will constitute an orbit fleet for observing the entire globe and providing the data needed for NWP data assimilation every 6 hours (**Figure 6**).

The FengYun-4 satellite series will be helpful for monitoring and predicting tropical weather systems such as typhoons, Madden–Julian oscillations, strong thunderstorm activity, heavy rains or floods over Pacific and Indian ocean regions. Preliminary results of monitoring thunderstorm and lightning processes using FengYun-4A (the first experimental satellite of FengYun-4, launched in 2016) have already demonstrated their usefulness.

Chinese scientists are also considering new applications of small satellites and high-resolution satellites to explore and monitor weather systems. Preliminary results obtained by a Chinese scientific research satellite, Gao Fen-4 (launched in 2016), showed that Typhoon *Nepartak* (2016) had an eye with very fine structure. In contrast, the eye of a typhoon has been considered to be a region of calm weather in the past.

CMA is building the Longmen Integrated Ground-based Station in Guangdong Province for observing cloud and rain microphysics, their vertical profiles, and droplet spectra provided by radars, lasers and other methods. The purpose is to develop observational- and physical-based parameterization schemes to improve NWP.

Improve meteorological prediction models and data assimilation

There has been significant progress in NWP with data assimilation over the past 20 years. But the complicated models for climate prediction, heavy rain prediction, typhoon structure prediction and so on should be seriously improved for future demand. Special data assimilation can also pose challenges.

China has a network of surface automatic stations with very high resolution, providing a nearly continuous meteorological dataset in space and time. For example, there are 5 256 automatic surface meteorological stations in three provinces of southern China: Guangdong, Guangxi and Hainan. Assimilating these very useful but inhomogeneous data into NWP models is a problem yet to be solved. Some schemes have been experimented with, but further improvements are necessary to enable routine application.

Design numerical models for disaster prediction, and models for optimal management of disasters and real-time regulation

Meteorologists can currently make routine predictions of disaster situations based on past experiences and case studies of previous events. However, this is not purely objective, and big data need to be processed, especially those obtained from geographical information systems (GIS).

A prediction (priori estimation) of losses may be made using digital data or maps to represent disaster situations and data from GIS to represent the social situation. Then, the predicted disaster situation and priori-estimated losses can be provided to policymakers for management of disaster risks. Real-time management of disaster events is conducted by policymakers according to their experiences and collective discussions.

It is desirable to carry out these activities objectively, using supercomputing to help meet future demands. The design of numerical (quantitative) models for predicting disaster situations and models for optimal management of disasters and real-time regulation is necessary and important.

Flooding models, slide models and other models are currently under development, but they require additional improvements so that they may be applied in the near future. This can be accomplished by combining supercomputing and relevant science and technology.

Optimal management means that the management plan should be made according to some principles, for example, minimum workforce and financial consumption for the actions and minimum losses due to the mitigated disaster. Actions consist of evacuation of residents, mobilization of workforce and materials, assessment of labour and engineering required, transportation, control and regulation of water levels and flow (for flooding cases), and so on. Optimal management is therefore associated with complicated mathematical problems, which can be solved only using supercomputing.

Data communication and visualization are important during real-time regulation of actions. Using such methods, techniques and facilities, the evolutionary processes of weather and disaster situations, as well as the results of actions, can be visualized in real time, and policymakers can make their decisions.

Construct a scientific platform

There is a need to build a bridge – a scientific platform – to accelerate research through to routine application, to address the required improvements listed above. Such platforms have been already established in Europe, Japan, Germany, United Kingdom and USA.

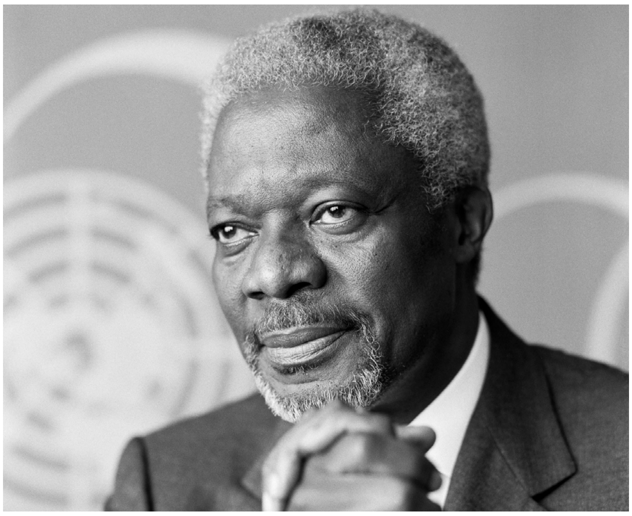
China is developing a scientific platform, the Earth Numerical Modelling System (ENMS), through cooperation of the Chinese Academy of Sciences, CMA and several Chinese universities.

The goals of ENMS are to:

1. Develop an earth system model to study global climate environment change and its regional impact
2. Develop seamless numerical prediction models (from climate to weather predictions to nowcasting), as well as disaster prediction models, optimal management models and real-time regulation methods
3. Develop numerical simulations of the design of future observing systems
4. Develop methods for big data applications (exploring big data and artificial intelligence).

China has been producing and accumulating large amounts of data and valuable datasets (big data) during long-term meteorological observation, prediction and management of related disasters. Developing methods and technologies for treating big data will be important and helpful, especially for prediction and management of disasters in certain areas. Scientists are developing new theoretical and practical methods, in addition to existing statistical methods. These new methods include so-called rigorous and quantitative causality analysis methods. It will be interesting to try these innovative methods in practice.

Obituary: Kofi Annan (1938-2018)



It was a shock to learn of the unexpected passing away of Kofi Annan. I had the privilege to interact with him and to learn from him for more than 20 years.

Kofi Annan was the ultimate incarnation of a true Statesman, always looking at the big picture. His perspective would stretch as far as possible into the future and with a remarkable skill for linking complex issues in very different fields. Although there are innumerous illustrations of this, I shall always remember his decisive role in the development and adoption of the Millenium Development Goals, without which it would have been impossible to reach the universal consensus on the Agenda for Sustainable Development and the associated SDGs a few years later. He was a true believer in multilateralism.

His personality was exceptional. Despite raising to the highest possible responsibilities, he remained himself, never showing any trace of arrogance and with a disarming humility. He had a unique way of making people interacting or working with him feel special. Invariably, he would ask the most thought provoking questions. When thinking about him, many words come to the mind: vision, wisdom, courage, elegance, compassion... When faced with a difficult situation, one would often reflect and ask oneself: what would he have done in such a situation?

From the WMO perspective, so many things come to mind that it is not possible to pay tribute to all. I remember in particular the first Chief Executive Board (ACC at the time) meeting of the United Nations, that WMO hosted in its new (still unfinished) headquarters building in April 1999. He referred to WMO as "the original networker." WMO will also always be grateful for the outstanding support he provided to the fight against climate change and natural disaster risk reduction in particular. His personal support for the 3rd World Climate Conference organised by WMO in Geneva in 2009 was decisive. On this occasion he stressed that the WMO "mission was now more important than those who established it 60 years ago could ever have imagined..." The Conference led to the development of the Global Framework for Climate Services (GFCS), which he actively supported. WMO was also privileged to benefit from his advice and support in other critical areas. For example, when WMO engaged to strengthen its approach on administrative and ethical issues. We should also very grateful to Kofi Annan for the attention he paid to water issues, in particular, his critical role in the establishment of UN-Water, one of the most effective coordination mechanism in the UN system. Just a few months ago he addressed WMO Executive Council with powerful words stressing the important role of WMO in the water area.

I had the privilege to attend, in different capacities, CEB (or ACC) meetings under three UN Secretary Generals. Kofi Annan was unique in the way he listened to all point of views, accepted different opinions and led in a quiet, but firm way. He was highly respected by all his CEB colleagues as the "primus inter pares." He was always passionate for the UN to demonstrate it could make a difference and contribute to make the world a better place. He was never discouraged by the many obstacles encountered. He was in many respects the voice of the voiceless and he relentlessly put his power at the service of the powerless.

We at WMO have lost a true friend. We shall miss him greatly, but at the same time he will continue to inspire us.

Thank you Kofi!

Michel Jarraud
Secretary-General Emeritus
World Meteorological Organization


Attend the AMS 99th
Annual Meeting in
Phoenix, AZ from
6–10 January 2019

World Meteorological Organization

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ISSN 0042-9767