GLOBAL FRAMEWORK FOR CLIMATE SERVICES

The Global Climate for Framework Services – Innovation and Adaptation

Projecting Global and Regional Climate Impacts, Risks and Policy Implications

Weathering the risk of climate change

Partnerships for Success – The WMO Fellowship Programme

From ship to shore: Bringing real-time weather into the classroom

Drought and Desertification in Postage Stamps
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<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>1 year</td>
<td>CHF 30</td>
<td>CHF 43</td>
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<tr>
<td>2 years</td>
<td>CHF 55</td>
<td>CHF 75</td>
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Contents

In this issue ........................................... 3

The Global Climate for Framework Services – Innovation and Adaptation ................. 4

Projecting Global and Regional Climate Impacts, Risks and Policy Implications ............ 9

Weathering the risk of climate change by Chiemi Hayashi and Thomas Kerr ................. 15

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Partnerships for Success – The WMO Fellowship Programme

From ship to shore: Bringing real-time weather into the classroom
by Wilfried Jacobs and Peter Schmitt

Subseasonal to Seasonal Prediction Project: bridging the gap between weather and climate
by Frédéric Vitart, Andrew W. Robertson and David L. T. Anderson

Building Model Evaluation and Decision Support Capacity for CORDEX
by Kim Whitehall, Chris Mattmann, Duane Waliser, Jinwon Kim, Cameron Goodale, Andrew Hart, Paul Ramirez, Paul Zimdars, Dan Crichton, Gregory Jenkins, Colin Jones, Ghassam Asrar, Bruce Hewitson

Drought and Desertification in Postage Stamps
by Garry Toth and Donald Hillger

Is it now possible to blame extreme weather on global warming?
by Leo Hickman from The Guardian

18

21

23

29

35

40
WMO 2013 Calendar

WORLD METEOROLOGICAL ORGANIZATION – CELEBRATING THE INTERNATIONAL YEAR OF WATER COOPERATION

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In this issue

Humanity must be able to anticipate future climate with some reasonable degree of confidence in order to innovate and adapt successfully. The proposed Global Framework for Climate Services promises to meet the challenge of providing effective climate services for decision-making in four initial priority areas – agriculture and food security, disaster risk reduction, health and water – before expanding to provide such services to a broader spectrum of users. The first Extraordinary Session of the World Meteorological Congress, meeting in Geneva from 29 – 31 October, will decide on the implementation plan and governance model for the Global Framework for Climate Services, thus, this issue of Bulletin is dedicated to highlighting some of its principal aspects.

The lead article summarizes the Implementation Plan for the Global Framework for Climate Services – how it will bring existing initiatives together, fill gaps in observation, hone capacity in National Meteorological and Hydrological Services and open dialogue between the providers and users of climate services. In the articles that follow, we hear from Massachusetts Institute of Technology (MIT) then the World Economic Forum (WEF), both participants in the two-day Global Framework for Climate Services User Dialogue that will immediately precede Extraordinary Session. MIT introduces its model for Projecting Global and Regional Climate Impacts, Risks and Policy Implications while WEF discusses the economic global impacts associated with the risk of climate change.

Partnerships for Success – The WMO Fellowship Programme offers a glimpse at some of the more recent partnership success stories and demonstrates the potential of the WMO Fellowship Programme to contribute to the capacity development and training that will be required to implement the Global Framework for Climate Services. From ship to shore: Bringing real-time weather into the classroom highlights a recent Deutscher Wetterdienst initiative that offers students a unique opportunity to gain experience in forecasting and research.

A key issue to the success of the Global Framework for Climate Services is the provision of predictions in the sub-seasonal to seasonal time range where many management decisions in agriculture and food security, water, disaster risk reduction and health fall. However, this time scale has long been considered a “predictability desert”. This is the topic of Sub-seasonal to Seasonal Prediction Project: bridging the gap between weather and climate.

WMO through the co-sponsored World Climate Research Programme (WCRP) established the Coordinated Regional Downscaling Experiment (CORDEX) to facilitate coordination for regional climate downscaling. One important requirement of CORDEX is to improve access to existing long-term climate quality observations for the evaluation of regional climate projections in order to meet the high priority regional need of the Global Framework for Climate Services. Building Model Evaluation And Decision Support Capacity For CORDEX discusses the work currently underway in this area and the way forward.

Effective implementation of the Global Framework for Climate Services will require effective communication and outreach. Philately may be considered outmoded by some, but it remains an important means for outreach. Drought and Desertification in Postage Stamps examines how these life-threatening climate-related areas are portrayed on postage stamps and how those stamps have served to educate people on the issues and on the responses of international institutions.

Record high temperatures and drought affected large parts of the United States of America this summer, and headline and articles repeatedly pointed to climate change – global warming – as the cause. Though the Global Framework for Climate Services aims to provide sound scientific information to help users adapt to the effects of climate, can we now say that specific extreme weather events are caused, or at least exacerbated, by global warming? This is the question that Leo Hickman of The Guardian posed to several scientists in the article – Is it now possible to blame extreme weather on global warming?
The Global Framework for Climate Services - Innovation and Adaptation

Innovation and adaptation have permitted humanity to not only survive but to reach new heights. Innovation led to the development of new tools, industrialization, computerization and untold scientific advancements, with both positive and negative consequences. Adaptation has involved, amongst others, design of warmer, lighter or even camouflage clothes and shoes, construction of sturdier structures and migration. Today, with billions of mouths to feed and the risk that climate change will cause rapid and unprecedented impacts, the stakes are as high as ever and the need to innovate and adapt ever greater.

Living with, and adapting to, climate variability and change is an everyday challenge. What has changed is the measure of trust we can have in the basic assumption that past climatic and socio-economic conditions are indicative of current and future conditions. The combined effects of climate change, population growth, migration, infrastructural development and inappropriate land use present unprecedented challenges to society; populations are exposed to hazardous conditions and in positions of increasing vulnerability. Despite this, humanity must be able to anticipate the future climate with some reasonable degree of confidence in order to adapt successfully. Effective forecasts would, for example, facilitate climate-smart decisions that would reduce the impacts of climate-related disasters, improve food security and health, and enhance management of water resources.

Innovation – the advent of satellites, high-speed telecommunications, supercomputers and new scientific insights – has given the ability to provide such climate services. We can now peer further into the future than ever before. A growing understanding of how the oceans, the land, and the atmosphere interact to drive climate now makes it possible to provide seasonal and inter-annual forecasts of increasing reliability. Research into how humanity’s greenhouse gas emissions are changing the climate has led to forecasts and scenarios that project out to the end of this century and beyond.

However, although the innovation, foundational capabilities and infrastructure for effective climate services already exist, there is a lack of a coherent operational climate service, thus the need for the Global Framework for Climate Services.

Components for Implementation

The Global Framework for Climate Services, endorsed by the World Climate Conference-3 in 2009, will strengthen and coordinate existing initiatives, and develop new mechanisms where needed in order to meet today’s challenges as well as those ahead. The National Meteorological and Hydrological Services of WMO Member States, which are already providing weather and climate information, will provide a solid foundation for the Framework. Its implementation structure will include five components across which activities will be coordinated and integrated:

- User Interface Platform;
- Climate Services Information System;
- Observations and Monitoring;
- Research, Modelling and Prediction; and
- Capacity building.

These five components will form the pillars on which the Global Framework for Climate Services will be built. Focus will initially be placed on the four priority areas of the Framework – agriculture and food security, disaster risk reduction, health and water – then, as gaps are filled, will extend out in scope.
User Interface Platform

The User Interface Platform will provide a structured means for users, climate researchers and climate service providers to interact at the global, regional and national levels to ensure that the Framework meets user needs for climate services. Its objective is to promote effective decision-making in areas where climate is involved.

To achieve its objective, the User Interface Platform is aiming for four outcomes:

- Feedback - identify the optimal methods for obtaining feedback from user communities;
- Dialogue - build dialogue between climate service users and those responsible for the observation, research and information systems;
- Outreach - improve climate literacy in the user community through a range of public education initiatives and online training programmes; and
- Evaluation - develop monitoring and evaluation measures for the Framework that are agreed between users and providers.

Implementation during the first years will focus on the Framework’s priority areas – agriculture and food security, disaster risk reduction, health and water. However, these four areas are not mutually exclusive. Ongoing disasters, for example, can often present challenges in food security, health and water, so the User Interface Platform will, at times, have to deal across all the user communities. At other times, it will be more effective to deal with the stakeholder communities in the priority areas separately. An initial focus on the four priority areas will not, of course, preclude ongoing interest and activities in other areas of national, regional and global interest where there are sensitivities to climate variability and change.

Climate Services Information System

The Climate Services Information System is the principal mechanism through which information about climate – past, present and future – will be routinely collated, stored and processed to generate products and services that help to inform decision-making processes across a wide range of climate-sensitive activities and enterprises. It will comprise a physical infrastructure, together with professional human resources, and will develop, generate and distribute a wide range of climate information products and services. The WMO World Climate Services Programme will be the principal mechanism to implement the Climate Services Information System.

A substantial part of a fully operational Climate Services Information System already exists. Thus, its implementation strategy is based on a three-tiered structure of collaborating institutions that will ensure climate information and products are generated, exchanged and disseminated:

- Globally through a range of advanced centres;
- Regionally through a network of entities with regional mandates; and
- Nationally and locally by National Meteorological and Hydrological Services and their partners through national institutional arrangements.

The primary and high priority functions will include climate data rescue, management and mining, climate analysis and monitoring, climate prediction, and climate projection. These will encompass processes of data retrieval, analysis and assessment, re-analysis, diagnostics, interpretation, attribution, verification and communication over a global-regional-national system of inter-linked producers and providers. Formalized structures and procedures will be essential for standardization, sustainability, reliability, and adherence to established policies and procedures.

The Climate Services Information System will have to engage with the User Interface Platform in order to gain a clear understanding of user requirements and of how users will apply climate information. Regional Climate Outlook Forums will be effective for stimulating collaborative assessment to assist users in identifying robust climate signals, in understanding inherent uncertainties and in developing consensus. Users of climate information will benefit from having access to products that reflect expert
assessment and consensus, in addition to information from a variety of individual sources.

The Climate Services Information System will also engage with the Observations and Monitoring and Research, Modelling and Prediction for the inputs required for its operations.

Observations and Monitoring

For effective climate services to be delivered, observations of appropriate types and of adequate quality and quantity must be made, and these observations must be available at the right place and at the right time. Both surface-based and space-based observations are required of physical and chemical climate variables of the atmosphere, land, and oceans, including the hydrologic and carbon cycles and the cryosphere.

However, the delivery of useful climate services also requires the availability, for national use in particular, of socio-economic, biological and environmental data. Physical and chemical climate observations and complementary socio-economic and other data must be effectively integrated to develop and provide users of climate services—farmers, public health officials, disaster risk reduction managers, water resources administrators, and the like—with information that will help to minimize losses due to climate variability and change and to effectively manage natural and human systems.

Despite the fundamental importance of observations for the delivery of climate services, many key regions and climatic zones remain poorly observed. Significant gaps in observations exist, especially in developing countries, and timely access to observational data is still problematic in many locations. The requirement for complementary socio-economic, biological, and environmental data raises additional challenges in ensuring that such data are collected, quality assured, archived, and made accessible in standardized formats.

Observations and Monitoring proposes actions to address these gaps and requirements, placing particular emphasis on the areas of greatest need in Developing and Least Developed Countries and more specifically Small Island Developing States (SIDS). It presents an overview of existing observational programmes, activities and initiatives on which the Framework relies, and seeks to increase the focus of these on the data needed to support the provision of climate services to users, particularly in the key priority areas of the Framework. It targets the observational gaps, the enhancement of networks and data management and exchange systems, and highlights the need for monitoring of socio-economic, biological and environmental variables. The principle of free and open exchange of climate-relevant data will, of course, respect national and international policies.

While Observations and Monitoring may require some new types of physical or chemical climate variables, there is clearly a need for greater observational density in both space and time for those variables that are already being monitored. The initial focus will be on the rehabilitation of silent stations, the activation of key stations in data poor areas, and the sustaining of space-based observations in support of climate. Greater efforts to rescue historical data are also proposed in order to make use of all the observational data that already exists. To facilitate access, all data must be securely archived in electronic formats with at least basic data management capabilities.

Where socio-economic, biological and environmental data (and perhaps some additional physical and chemical observations) are concerned, more consultation is needed. The determination of needs will vary by sector and will be achieved through an interactive process with the key end users of climate information. Consequently, early activities will include the establishment of a formal consultation mechanism with users to assess the need for, and role of, climate observations for adaptation to climate change. Linkages to both the User Interface Platform and the Climate Services Information System will be vital to the success of these activities.

Implementation of Observations and Monitoring will require full engagement in the programmes and working mechanisms of partners at global, regional, and national levels. The observational contributions of non-governmental organizations and universities will also be of importance—there is a potential for greater

The main goal of the GFCS is to “enable better management of the risks of climate variability and change and adaptation to climate change, through the development and incorporation of science-based climate information and prediction into planning, policy and practice on the global, regional and national scale”.

(World Climate Conference-3)
engagement of non-governmental and private sector observational networks.

**Research, Modelling and Prediction**

Further expansion and strengthening of research on climate will be required for the implementation of the Framework. Existing climate knowledge will have to be systematically converted into practical solutions, and this will require a change in how climate research is conducted. Multiple applications of climate knowledge, targeting the need for science-based climate information in a wide range of socio-economic sectors, will have to be developed. New professional networks of research communities in various socio-economic sectors will have to be created to unite climate research, the diverse service providers and user communities.

To meet these objectives, Research, Modelling and Prediction proposes to:

- Proactively target research towards developing and improving practical applications and information products so that the initial requirements of climate information users can be satisfied at the current science and technology readiness level;

- Significantly enhance the interaction and cooperation of the corresponding research communities with climate information users and operators through the User Interface Platform;

- Enhance the science-readiness level for production of improved climate projections, predictions and user-tailored climate information products; and

- Continue to improve the understanding of the Earth's climate in the aspects that determine the impacts of its variability and change on people, ecosystems, and infrastructure.

Research, Modelling and Prediction will expand the practical dimension of climate research to make its outcomes valuable for informed decision-making. The overall approach will be to facilitate the transformation of the multitude of existing independent research activities into a more coherent, better supported, and more focused research process culminating in systematic generation, assessment, and improvement of valuable and timely climate-dependent information products. Success will be gauged based on improvements in timely delivery and usefulness of the science-based products and services offered through the Framework to the diverse socio-economic sectors.

To benefit from climate services, users and decision-makers will need to know the limits of current scientific understanding of climate, how to take into account the inherent uncertainty of provided information, and how to effectively and accurately communicate their needs.
to scientists. The research communities will need to assess the current and future ability of climate science to satisfy the requirements of users and accommodate corresponding needs in their observations, research, development, and communication priorities. Further targeted investments in research, modelling and prediction activities will be required in order to progress toward fulfilling decision makers' needs for science-based climate information.

Capacity Development

The Framework aims to develop the capacity of countries to apply and generate climate information and products relevant to their particular concerns, thus Capacity Development is an integral part of its implementation. The World Climate Conference-3 recognized that many countries lacked policies and institutions, or human resources with the right skills or practices, to enable them to take advantage of new or existing climate data and products or to create national user interface groups to establish national dialogue on these issues.

Capacity Development tackles two separate but related activity areas: the particular capacity development requirements identified in the other components and, more broadly, the basic requirements – national policies, legislation, institutions, infrastructure and personnel – to enable Framework related activities to occur.

By necessity plans for implementation for the Framework have, to date, been built top down using generalized capacities and assumptions to provide a first guess estimate of what is required, what can be implemented in a sustainable manner and how much it could cost. The implementation of specific projects at national or regional or sub-regional level will require that these generalized assumptions, capacities and costs are tested for the specific circumstances and projects, thus leading to a gap analysis or refinement for each project. This analysis will also need to determine the presence or absence of the underlying foundations for sustainable projects and identify what needs to be done if the foundations do not exist. The results of the analysis will determine the financial, human and institutional resources required for implementation of the related project on a sustainable basis and the collaboration and coordination mechanisms required between various players.

Fast tracked pilot projects will address specific needs of the countries in the priority areas of the Framework, especially in the Developing and Least Developed Countries and Small Island Developing States, and further refine the underlying assumptions. An estimated cost of approximately 300 million USD is required to implement the initial phase (2013 – 2017) of Capacity Development with the possibility for an additional similar amount in its last phase (2018 – 2023).

Mechanisms for agencies to work together and exchange relevant information on their activities will need to be refined or developed where they do not exist. Capacity Development will facilitate and strengthen, not duplicate, existing activities.

Governance and baseline budget

The Framework is expected to have a governance mechanism – an Intergovernmental Board – that will be accountable to the World Meteorological Congress. It aims to oversee the activities of the Secretariat and technical committees that will deal with the details of implementation of the Framework.

Cooperation is the key

Different institutions, organizations and entities carry out activities around the globe in the relevant areas of the Framework. Cooperation and collaboration with existing networks, projects and initiatives will be the key to the success of the Framework. At the global level, this includes a number of UN partners and the systems and institutions that these organizations co-sponsor. Non-governmental organizations and universities will also have an important role to play. To achieve its potential, the Framework must reach out and engage with all of these players.

Meeting the challenge of providing effective climate services for decision-making in the four initial priority areas of the Framework – agriculture and food security, disaster risk reduction, health and water – will require the full support of WMO Members. With the National Meteorological and Hydrological Services as the cornerstone of its foundation and the User Interface Platform, Climate Services Information System, Observations and Monitoring, Research, Modelling and Prediction, and Capacity Building as its central pillars, the Global Framework for Climate Services will deliver on its promise.
Projecting Global and Regional Climate Impacts, Risks and Policy Implications

By the Joint Program on the Science and Policy of Global Change of the Massachusetts Institute of Technology (MIT)

How effective and costly would a policy be in alleviating human-forced climate change? What are the advantages and risks of waiting for better scientific understanding? Which nations, regions and economic sectors face the greatest risks to unimpeded global change, and can we substantially reduce these risks through adaptation or mitigation?

Decisions made under these sorts of questions ultimately come down to an issue of risk. Policymakers, stakeholders, and local officials are increasingly relying on scientific climate information to help answer these questions. The MIT Integrated Global System Model (IGSM) is central to this effort of projecting the possible social, economic and environmental consequences of climate change.

The IGSM brings together the human, natural, and managed systems of our global environment. This “integrated” approach is critical because we often cannot directly measure the impacts of human development on the environment. Therefore, we must form computer models of the combined natural and human systems, compare the models with observations, and then apply the models in “numerical experiments” that assess the influence of human activities on the Earth system and how the response of the Earth system, in turn, will affect human systems.1

The IGSM framework has been developed and refined by the Joint Program on the Science and Policy of Global Change since the early 1990s. It’s currently being put to work in the developed world, and in developing nations through our work with the United Nations University-World Institute for Development Economics Research.

From Zambezi, Africa, to the state of Colorado in the United States of America, its insights assist nations, sectors and communities in learning how to grow more efficiently and adapt to vital present and future challenges such as water management and energy resources.2

Integrated Assessment: Two Components

The IGSM is a “framework” of linked sub-models of varying complexity. Depending on the issues and specific research questions being addressed, users can choose which sub-models to use and add layers of complexity where needed.3

The two primary components are:

1. The Emissions Predictions and Policy Analysis (EPPA) model, which analyzes human activity as it interacts with climate processes and assesses proposed policy measures; and

2. An Earth system model that couples dynamic and chemical atmosphere, ocean, and natural biogeophysical and biogeochemical exchange models within a Global Land System framework. It analyzes the terrestrial biosphere interactions and feedbacks.

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Economics, Emissions and Policy Analysis

The EPPA model is a multi-sector, multi-region computable general equilibrium (CGE) model of the world economy. It provides projections of world economic development and emissions, along with analysis of proposed emissions control measures. It is used to analyze the processes that produce emissions and to assess the consequences of policy proposals – providing estimates of the magnitude and distribution among nations of their costs and clarifying the ways that changes are mediated through international trade.

EPPA uses the Global Trade Analysis Project dataset (maintained at Purdue University), augmented by data on the emissions of greenhouse gases, aerosols and other relevant species, as well as taxes and details of selected economic sectors.4

The model projects economic variables – GDP, energy use, sectorial output, consumption, etc. – and emissions of greenhouse gases – CO₂, CH₄, N₂O, HFCs, PFCs and

SF₆ – and other air pollutants – CO, VOC, NOx, SOx, NH₃, black carbon, and organic carbon – from combustion of carbon-based fuels, industrial processes, waste handling, and agricultural activities. Different versions of the model have also been formulated for targeted studies to provide consistent treatment of feedbacks of climate change on the economy, such as effects on agriculture, forestry, biofuels and ecosystems, and interactions with urban air pollution and its health effects.

Earth-System Model

We utilize an efficient, flexible Earth system model with a hierarchy of complexities to facilitate investigations of feedbacks and uncertainties between model components and with human drivers and mitigation goals. It couples several submodels: atmospheric chemistry; atmospheric dynamics; oceanic dynamics; oceanic biogeochemistry; and terrestrial ecosystems. These model components are as close as possible to state-of-the-art – coupling together various configurations while maintaining computational efficiency, and enabling extensive testing of these phenomena. In one configuration, models of atmospheric dynamics and chemistry, thermodynamic sea-ice, land ecosystem and biogeochemistry, and a mixed-layer ocean representing the processes of heat and carbon uptake are combined. This configuration is MIT’s most computationally efficient Earth system model, and allows us to explore climate uncertainties by performing thousands of simulations. In another configuration, we employ a three-dimensional (3-D) model of ocean circulation, marine biology, and chemical processes that control the biogeochemical cycling of carbon, nutrients and alkalinity. In both of

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the configurations above, the Earth system component also includes an interactive atmospheric chemistry module, and an urban air chemistry component.

Changes in land ecosystems due to climate changes are important considerations in policy discussions. Additionally, climate-driven changes in the terrestrial biosphere affect climate dynamics through feedbacks on both the carbon cycle and the natural emissions of trace gases. The terrestrial component of the IGSM includes hydrologic and ecologic models in a Global Land System framework. Hydrologic processes and surface-heat fluxes are represented by the Community Land Model (CLM), which is based on a multi-institutional collaboration of land models. Within the IGSM, CLM is dynamically linked to the global Terrestrial Ecosystems Model (TEM), developed by The Ecosystems Center at the Marine Biology Laboratory.

TEM is used to simulate the carbon dynamics of terrestrial ecosystems. Driven by dynamic inputs from both TEM and CLM, methane and nitrogen exchange are considered through the Natural Emissions Model (NEM). The coupled CLM/TEM/NEM model system represents the geographical distribution of global land cover and plant diversity through a mosaic approach in which all major land cover types and plant functional types are considered over a given domain, and are area-weighted to obtain aggregate fluxes and storages.

Balancing Uncertainty

Central to the IGSM framework is the building in of uncertainty to account for key human influences, such as the growth of population and economic activity, the pace and direction of technical advance, and the response of the Earth system to these human drivers.

To investigate the feedbacks and uncertainties between model components and with human drivers and mitigation goals, the most efficient IGSM configuration of intermediate complexity is used and the model is run hundreds of times with each study. Every run is given slightly varied input parameters, selected so that each run has about an equal probability of being correct based on present observations and knowledge. Doing this gives a more realistic assessment of the range of potential future effects.
above which potential severe effects from climate warming ensue.\(^6\)

Even given this analysis, there is always a level of “deep uncertainty,” which describes physical relationships in the Earth system that are currently unknown. We cannot precisely predict some phenomena because the global environment involves complex and dynamic interacting processes that are not all fully understood, many of which have chaotic elements that fundamentally limit the predictability of the climate system. Even looking at the relationships we have expected and been measuring, we’ve experienced some surprises – such as the Arctic ice melting faster than any of the models predicted. Along with others in the field, we face the challenge that the changing climate may bring some significant costs that may not be evident until after we witness them.\(^7\)

Putting this approach into practice, we, for example, analyse temperatures and find that the world could warm from 3.5˚C to as much as 6.7˚C by the end of the century.\(^5\) To illustrate temperature uncertainty, we’ve developed roulette-style wheels known as the Greenhouse Gamble Wheels. The face of each wheel is divided into colored slices, with the size of each slice representing the estimated probability of the temperature change in the year 2100 falling within that range. One wheel represents an unconstrained emissions (“no policy”) outcome, while the other depicts the outcome “with policy.”

In making these analyses, we are able to help decision-makers compare the value of various mitigation policies, energy technologies and adaptation strategies to lower the risk of global climate warming. We can also assess the costs for stabilization of greenhouse gases at various levels, and how these costs can be justified by the expected benefits from avoided damages.

Looking at emissions-control scenarios, for example, we’ve found that even relatively modest emissions-control measures can have a large impact on reducing the odds of the most extreme warming outcomes. If we immediately reduce global emissions there is about a 50-50 chance of stabilizing the climate at a level of no more than a few tenths above the 2˚C target – a level that is considered likely to be a tipping-point, above which potential severe effects from climate warming ensue.\(^6\)

Even given this analysis, there is always a level of “deep uncertainty,” which describes physical relationships in the Earth system that are currently unknown. We cannot precisely predict some phenomena because the global environment involves complex and dynamic interacting processes that are not all fully understood, many of which have chaotic elements that fundamentally limit the predictability of the climate system. Even looking at the relationships we have expected and been measuring, we’ve experienced some surprises – such as the Arctic ice melting faster than any of the models predicted. Along with others in the field, we face the challenge that the changing climate may bring some significant costs that may not be evident until after we witness them.\(^7\)

**Incorporating a regional scale**

From this discussion, one can see how the model is useful at the global scale. But as the threat of climate change grows, the importance of assessing the regional impacts grows along with it. As stated at the beginning of this article, local officials depend on such analysis to guide them through critical decisions.

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Understanding the increased importance of determining the likelihood of regional climate effects, MIT has created a “hybridized” approach that widens the scope and flexibility of the analysis. By collecting emergent climate-change patterns from the community of climate-model projections analyzed from the Coupled Model Intercomparison Project (CMIP) in conjunction with the International Panel on Climate Change (IPCC), MIT has combined these with the IGSM to develop hybrid frequency distributions (HFDs) that can quantify the likelihood of particular regional outcomes. To characterize the prevailing climate patterns that alter human emissions, we characterize each climate models’ spatial responses, relative to their zonal mean, from transient increases in trace-gas concentrations and then normalize these responses against their corresponding transient global temperature responses. This procedure allows for the construction of meta-ensembles of regional climate outcomes, by combining these patterns to the aforementioned ensembles of the MIT IGSM’s zonal climate outcomes – which then produce climate projections, with uncertainty, under different global climate policy scenarios – with regionally-resolved patterns. This hybridization of the climate-model longitudinal projections with the global and latitudinal patterns projected by the IGSM can, in principle, be applied to any given state or flux variable that has the sufficient observational and modeled information (from the CMIP archives). The approach consistently ties together the socio-economic data of different emission scenarios and various levels of uncertainty in the global and regional Earth-system response.

In our initial study using this approach, we find that by the middle of this century – while some regions are affected by emission reduction measures more than others – when comparing business-as-usual with a greenhouse gas stabilization scenario, lowering emissions does reduce the odds of regional warming. In fact, the most extreme warming outcome from

the business-as-usual case is eliminated entirely. At the same time, the odds of regional precipitation changes are seen to both increase and decrease by the middle of this century. However, when greenhouse gas concentrations are lowered through the stabilization scenario, the greatest likelihood of regional precipitation change moves toward more benign values by the end of the century. Stabilization also reduces the chances of more extreme precipitation changes.8

Specifically, these distributions of regional climate outcomes have been directly applied to assessments of climate risk for developing countries and have most recently focused on the Zambezi river basin. In this study, we consider the odds (i.e. the distribution) of changes that could be expected in important hydro-climate variables – precipitation (shown below) and surface-air temperature – under unconstrained emissions and global economic growth, as well as a modest stabilization scenario (Level 2 stabilization achieves 660 CO2 equivalent concentration by 2100). Changes in these quantities during the spring and summer have notable impacts on agricultural productivity as well as transportation infrastructure (i.e. roads, bridges, etc.). The unconstrained emissions outcome shows the "most likely" outcome (seen by the mode of the distribution) to convey a dry and warmer (not shown) situation – with a small chance (about 10 per cent) of conditions at least twice as dry as the most likely outcome. However, there is also a small chance that very wet conditions may occur – and these conditions present the greater risk in damage to the transportation infrastructure. In the stabilization case, the occurrence of these extreme outcomes are removed from the distributions – and the most likely outcome (nearly 50 per cent of the distribution, more than twice as likely in the unconstrained case) now lies at half of the drying (i.e. reduced precipitation) seen in the unconstrained case.

This hybridized approach is an immediate way to apply the full capabilities of the IGSM – that is, a probability analysis of the integrated natural and human systems – to a regional scale. Overall, this approach helps decision and policy makers make long-term decisions that will impact the future direction of planning in their nations. While the hybridized method brings much-needed progress in projecting the regional impacts of climate change, MIT’s ongoing improvements of the IGSM will include more explicit modelling of these regional features. We hope such added complexity will further build upon the capabilities toward fine-tuned regional assessments.

Drought is widely recognized as a slow creeping natural hazard that occurs due to natural climatic variability. In recent years, concern has grown world-wide that droughts may be increasing in frequency due to climate change. Responses to droughts in most parts of the world are generally reactive in terms of crisis management and are known to be untimely, poorly coordinated and disintegrated. Consequently, the economic, social and environmental impacts of drought are by far the most damaging of all natural disasters.

Integrated Drought Management (IDM) is a critical component of disaster risk reduction programmes, climate adaptation strategies and national water resources policies, bringing together the needs of the different stakeholders affected by droughts. In order to address drought issues more effectively, WMO and the Global Water Partnership are jointly launching the Integrated Drought Management Programme. By working together with other partners, the Integrated Drought Management Programme aims to provide preventive and demand-driven support mechanisms for the communities, countries and regions affected by drought.

In order to address the drought issue WMO, the Secretariat of the United Nations Convention to Combat Desertification (UNCCD) and the Food and Agriculture Organization of the United Nations (FAO), in collaboration with a number of UN agencies, international and regional organizations and key national agencies, plan to organize the High-Level Meeting on National Drought Policy in Geneva from 11 to 15 March 2013.

WMO Drought Initiatives: High-Level Meeting on National Drought Policy (HMNDP) and Integrated Drought Management Programme (IDMP)
Weathering the risk of climate change

by Chiemi Hayashi\(^1\) and Thomas Kerr\(^2\)

Climate change is as hard on the economy as it is on society. Extreme weather and climate events have exacted a heavy toll in recent years, taking hundreds of thousands of lives and causing upward of US$ 380 billion in economic losses – a tally that is expected to double every 12 years\(^3\). But beyond the grim figures, the effects of “catastrophic convergence” are far more devastating where droughts, floods and other climate events directly correlate with violent outbreaks, political upheaval and even civil war.

The World Economic Forum’s *Global Risks 2012* report listed water supply and food shortage crises, as well as extreme volatility in energy and agriculture prices, as three of the top five risks in terms of global impact. Determined by nearly 500 experts from industry, government, academia and civil society, these risks also scored high in terms of likelihood. More than a straightforward inconvenience, disruptions in food supply and volatile prices can be directly linked to social unrest. In areas that do not have sufficient domestic grain production, and which are thus dependent on imports, the problem is quickly exacerbated as grain prices rise. For example, the 2007 – 2008 food protests in Tunisia, Yemen, Egypt and Morocco, among others, are considered a major factor in the Arab Spring.

This year, record low rainfall in the United States has decimated crops such as corn and soybeans. Their prices have more than doubled in the past year, prompting warnings of knock-on effects in the developing world.

Better managing environmental risks would contribute to more resilience, which the Forum defines as the capacity of an organization, community or country to continually evolve and adapt to gradual changes and sudden shocks while remaining able to fulfil its core function. Yet, progress on this front has been hindered by a lack of collaboration between weather data and science experts, as well as between the public and private sector. Coordination is particularly important as weather affects everyone. Further, greater collaboration among stakeholders is needed to improve access to climate-related data and prediction tools.

While meteorologists currently excel in short- and very long-range weather forecasting, mid-range (six to nine months) forecasting techniques have not been sufficiently developed. Improvements here would allow concerned industries and governments precious time to implement mitigation measures. The algorithms and complex mechanisms for gleaning this kind of data exist; but society needs better cooperation and shared investment in order to put them to use.

Given the world’s interdependence, the first line of defence is to build resilience collectively. This is an endeavour best carried out in a multi-stakeholder and interdisciplinary setting such as the World Economic Forum’s Risk Response Network, which is comprised of over 1 000 international leaders and experts from government, industry, academia and international organizations. Further, given the interconnectedness of global risks, any comprehensive effort to understand their interdependence is typically beyond the resources and capacity of any single organization or stakeholder. The Risk Response Network’s annual *Global Risks* report maps the 50 most prevalent global risks and analyses

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their perceived likelihood and impact over a 10-year time horizon. It defines global risks as having “global geographic scope, cross-industry relevance, uncertainty as to how and when they will occur, and high levels of economic and/or social impact”. Global risks, it stresses, require a multi-stakeholder response.

Africa suffers from some of the highest levels of climate vulnerability in the world. According to the Pan African Climate Justice Alliance, more than 50 per cent of the continent’s total export value and 21 per cent of its total GDP rely on agriculture. Given increasingly frequent weather and climate extremes, the risk to African coastal cities of flooding and deaths from extreme heat exposure and disease is rising. At the same time, the Horn of Africa and other key agricultural regions are more at risk of severe drought and floods. Kenya, for example, has recently seen a devastating impact on food production affecting both its population and economy. Businesses in the region will experience higher costs due to a decrease in worker productivity, supply chain disruptions and insurance losses. Earlier this year, the World Economic Forum on Africa, in Addis Ababa, brought together a variety of industry peers who were keen to better understand their risks and share new ideas; such collaboration will become increasingly crucial.

**Improving risk management and reducing impacts**

A Vision for Managing Natural Disaster Risk (2011), a World Economic Forum publication, outlines recommendations to improve risk management and reduce the impact of natural disasters. The report, written in collaboration with the Arup Group Ltd., Lloyds of London and Swiss Re, among other companies, encourages preparedness by using the resources of both the public and private sectors. As we examine the consequences of natural disasters and climate change, including food security, several issues must be considered. Many countries lack the knowledge, capacity and resources to deal with natural disasters. Unfortunately, when these disasters occur the public sector is often paralyzed by damaged infrastructure and unable to cover the costs of emergency and relief efforts.

Lack of overall risk planning and investment in resilience measures, with too much focus on post-disaster response, leads to increased loss of life, suffering and damages. People in developing countries are generally more exposed to natural disasters, particularly through a higher dependency on agriculture and increased

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4 Pan African Climate Justice Alliance, 2009: The Economic Cost of Climate Change in Africa (Practical Action Consulting)
vulnerability to the natural environment. However, these countries are not capable of protecting themselves, due to lower levels of physical and financial preparedness as a result of low income and insurance penetration.

Implementation of the following prevention and mitigation measures can have a significant impact on the extent of suffering after a natural disaster:

1. Increase knowledge and awareness of the population at large, the private sector and policy-makers to achieve behaviour change.

2. Take preventative steps to reduce risk through physical measures, such as enhanced resilience. This is the only way to directly reduce the loss of life and the number of people affected.

3. Mitigate residual risks through a variety of methods using both public and private means.

4. Apply post-catastrophe rebuilding processes to increase recovery speed and lessen follow-on effects.

The Global Framework for Climate Services, which includes the mitigation of disaster risks as one of its priorities, will have an important role to play here. Its User Interface Platform will provide the structure for the population at large, the private sector, policy-makers, climate researchers and climate service providers, to interact and achieve change. Such an exchange is essential to enhance preparedness for disasters and coordinate efforts and initiative across both the public and private sectors.

Despite the worst-case scenarios, improved risk assessment and mitigation practices can minimize financial loss, increase social stability, and improve disaster-response efficiency in the face of droughts, flooding and other climate events. For example, a major reforestation project to restore China’s environmentally degraded Loess Plateau helped to lift 2.5 million people out of poverty and secure food supplies in the face of frequent droughts.

What can governments and businesses do to manage climate risks and disasters whether in Africa, North America or elsewhere in the world? While the situation is serious, there are, after all, silver linings of opportunity to the heavy clouds.

Leaders must bolster existing risk management measures to prepare for the future. This includes implementing early warning systems, land use planning, the development and enforcement of building codes, improvements to health surveillance, and ecosystem management. It also requires better cooperation between environmental and planning agencies to develop a comprehensive climate disaster plan. Another crucial step is to pursue investment opportunities related to climate adaptation, including improving building construction and efficiency, initiating water resource planning and efficiency, and developing new insurance products to mitigate risks.

In order to specifically address these issues, leading companies from the finance, infrastructure, energy and agriculture sectors joined with public finance institutions to launch the Green Growth Action Alliance (G2A2). With a secretariat hosted by the World Economic Forum, it focuses on a wealth of opportunities for combating climate change, including: advancing country pilots, unlocking financing for key technology development in the areas of sustainable/renewable energy, water infrastructure, energy efficiency and agriculture/aviation biofuels. Collaboration activities include convening government leaders, Chief Executive Officers and Alliance members to review progress and launch investments at the UNFCCC COP 18 in Qatar this December and at the World Economic Forum’s annual January meeting in Davos. Additionally, the World Economic Forum’s Global Agenda Council (GAC) on Climate Change is advancing a roadmap for public and private investment regarding adaptation strategies to help shape this agenda as it moves forward.

As climate change transforms the world and we grapple with its many consequences, we should bear in mind that it is an issue that concerns us all. When it is too late for prevention, focusing joint efforts on mitigation and adaptation can help to alleviate the pressure imposed by highly interdependent risks.
Partnerships for Success –
The WMO Fellowship Programme

Since its inception about 50 years ago, the WMO Fellowship Programme has assisted countless National Meteorological and Hydrological Service of WMO Members, providing them with experts whom have gone on to play key roles in the fields of weather, climate and water. Until about a decade ago, WMO partnered with the UN Development Programme (UNDP) to fund and implement the Fellowship Programme. When the arrangement ended, the WMO budget and trust funds from Members provided the resources to continue the Programme, but it could barely meet demand, much less fund a capacity increase to cover new areas and provide more fellowships. An urgent solution was needed, so WMO reinvigorated its effort to reach out to new partners.

WMO had already been running successful partnerships in education and training since the 1960s, establishing WMO Regional Training Centres in national institutions, primarily in developing countries. These institutions would open their doors to foreign students in the fields of weather, climate and water. A number of them, or the National Meteorological and Hydrological Services that support them, had been successful in attracting support from governments, who waived fees, provided consular assistance and offered help with student accommodation. In some cases, complementary national bursaries were also provided toward covering the cost of courses. WMO focused its effort for the Fellowship Programme on renewing such partnerships and seeking out new ones.

By doing so, the Organisation was able to increase the numbers of fellows and the range and breadth of topics covered. Even more notable, it achieved this success while ensuring that fellowships had a wide geographic distribution, reflected gender equity and addressed the needs of developing and least developed countries (LDC). This article offers a glimpse of some of the more recent partnership success stories and demonstrates the potential of the WMO Fellowship Programme to deliver the capacity development and training that will be required to implement the Global Framework for Climate Services.

Doing more with partners

China

In April 2007, WMO and the Ministry of Education of the People’s Republic of China signed a Memorandum of Understanding (MoU) for cooperation on the implementation of long-term fellowships in the fields of meteorology and operational hydrology at the Bachelor and Master of Science level. This cost-sharing arrangement would cover basic education and specialized training in Chinese institutions and universities, including the WMO Regional Training Centres in Beijing and Nanjing, for candidates from African countries. In 2011, an additional

New Fellowship Opportunities

Every year, the WMO Secretary-General circulates a comprehensive letter to Members detailing the fellowship opportunities that are coming up over the next 12 months. In addition to the core offers of education and training at WMO Regional Training Centres, there are now opportunities, usually at Master’s degree level, for study in multi-disciplinary themes in Germany, Japan, Korea and the United Kingdom of Great Britain and Northern Ireland. These new offers are designed to support Members in the high priority activity areas of the Global Framework for Climate Services – agriculture and food security, disaster risk reduction, health and water.
five fellowships were added to the initial agreement for candidates to be selected from LDCs and Small Island Developing States (SIDS), particularly in Asia and the Pacific Regions. Since the signing of the initial MoU, 54 fellowships have been offered to students from 35 countries.

As of August 2012, the training of fellows in China has further expanded to include four months of specialized training through affiliation with experienced forecasters in Beijing. This training will consolidate the meteorological expertise of fellows graduating from the Nanjing University of Information Science and Technology (NUIST). This forecasting programme will be reviewed at the end of the inaugural attachment and is expected to run on an annual basis for all graduate fellows. Furthermore, a full Doctor of Philosophy scholarship at NUIST will be awarded to at least one fellow who demonstrated excellence in his/her postgraduate studies. Discussions are ongoing between WMO and the Ministry of Education to identify how this initiative could be made into a regular occurrence.

All students undertaking meteorology studies in China attend NUIST. In 2011, NUIST offered, with some support from WMO, a further five full fellowships for students from WMO Members. The first five students commenced their studies in September 2012.

Philippines
In 2012 the Government of the Philippines supported six fellows from the South-West Pacific (WMO Regional Association V) to undertake courses at the WMO Regional Training Centre in the Philippines for meteorological technicians and meteorologists. The fellowships were organized in collaboration with the Philippines Atmospheric Geophysical Astronomical Services (PAGASA) in cooperation with the University of the Philippines and WMO. PAGASA are negotiating with the Government of the Philippines to run similar courses in the future. Support from Governments such as the Philippines is critical for many getting expert training for Members in the Pacific who are reliant on air transport and tourism, vulnerable to the damaging effects of tropical cyclones, storm surges and flooding and who are anticipating rising sea levels associate with climate change. For these countries to benefit from weather, climate and water services it is essential to have qualified and competent staff which it will only be possible to provide through partnerships such as this one.

Russian Federation
The Government of the Russian Federation, in conjunction with WMO, offers assistance annually to fellows in meteorology and hydrology, which includes aspects of ecology, economics and management, and oceanography. Over the last forty years more than 170 WMO Fellows – 50 in the last 10 years – have successfully completed studies at the Russian State Hydrometeorological University in St. Petersburg. Many have gone on to influential, senior positions in their National Meteorological and Hydrological Services.

United Kingdom of Great Britain and Northern Ireland (UK)
Over the years, the UK Met Office has sponsored students to complete university courses across a broad spectrum of subjects – from meteorology to business. The strength of the partnership between the Met Office and WMO was demonstrated in 2011 when the University of Reading created a Master of Science in Applied Meteorology and Climate with Management programme specifically aimed at WMO Members. An MoU signed between WMO and the UK Met Office in March 2012 formalized the working arrangements between the two organizations. Six fellows successfully completed the first course in September 2012 and a further five fellows from different parts of the globe will be undertaking the 2012 Master of Science course.

Gender Equity
WMO ensures gender equity in the development and delivery of its programmes. Gender is a key consideration in the selection of beneficiaries of WMO fellowships. Women in developing countries need knowledge and skills to be properly represented and fully integrated into decision-making processes regarding weather, climate and water issues. In 2012 Ewha Womans University in the Republic of Korea started a graduate programme in Meteorology in its Department of Atmospheric Science and Engineering, which will award Master Science and

“...the knowledge and skills I acquired during the fellowship programme has brought positive impacts on the quality of weather and climate services of my country” - Ms Irene Bernard KALUMBETE, Tanzania
Doctor of Philosophy degrees. English will be the medium of instruction. In May 2012 WMO entered into an agreement with Ewha to jointly promote the education of women in meteorology. Under this arrangement, Ewha, through WMO, shall provide up to two scholarships per year for study in its Master’s programmes.

### Intensifying the scope of knowledge

Much of the activity in the fellowship area is centered on assisting Members to develop a pool of qualified staff, however, hands-on training skills are not neglected. WMO is partnering with a growing number of institutions to provide on-the-job training opportunities.

On-the-job training for fellowship graduates from NUIST at China Meteorological Administration was already mentioned. Countries such as Austria, Germany, Norway, Romania, Spain, France and Switzerland have also been assisting with such training. These programmes deepen the networks that link the meteorological and climatological community, exposing both the hosts and the fellows to different ways of working and help them to identify common issues and concerns.

The National Oceanic and Atmospheric Administration (NOAA) of the United States of America has been providing fellows with hands-on experience and training in operational weather and climate services for more than 20 years.

The NOAA-WMO cooperation falls into four categories:

- **Africa Desk** - Fellowships are granted to professional African meteorologists and scientists training in the Climate Prediction Center for periods of four months. The Africa Desk operates both weather and climate sections. Candidates must commit to return to their duty stations in their home countries for at least one year immediately upon completion of their training;

- **South American and Tropical Desk** - The four month programme is tailored to meet the operational needs of a modern forecast office, and to make the best use of available tools/objective forecasting in applied tropical meteorology, hydrology and climate;

- **Pacific Desk** - Six-week fellowships are granted to forecasters from South Pacific. Like the South America and Tropical programme this one is also tailored to meet the operational needs of a modern forecast office, and to make the best use of available tools/objective forecasting in applied tropical meteorology, hydrology and climate; and

- **Short attachments to the Hurricane Warning Centre** for forecasters from the Caribbean.

### The Global Framework for Climate Services

The WMO Fellowship Programme has already started to put partnerships in place to increase the training of experts as required by the Global Framework for Climate Services. It is for this reason that an arrangement was put in place with the UK Met Office for the training of experts from developing countries and LDCs at Master’s level, in the field of applied meteorology and management at the University of Reading. This Master of Science in Applied Meteorology and Climate with Management (AMCM) aims to help participants to develop skills to assist with the provision of effective weather and climate applications/services. This programme has been developed for, and is currently confined to, applicants from developing countries, in particular those who work for National Meteorological Services in the LDCs. It combines the majority of the meteorological and climate science modules of the Applied Meteorology programme with management training. Feedback from the first group of graduates has been very positive.

WMO has also commenced work with Kyoto University, Japan, in its Global Centre of Excellence, on an experimental programme on “Sustainability/survivability Science for a Resilient Society Adaptable to Extreme Weather conditions.” The programme focuses on adaptation to climate change and changes in the frequency, intensity and extent of extreme weather phenomena that seriously affect people and societies around the world. It combines course work with intensive research activities under the close supervision of one or more professors. WMO will continue to work with Kyoto University to ensure the continuation of this programme for considerable length of time.

Sustained human resource development through education and training is a key ingredient of viable meteorological services. Education and training is important in technical matters but also on planning, management, communication and public affairs, and other administrative and support functions. The Fellowship Programme will make a significant contribution to the Global Framework for Climate Service. It addresses the need for development of human capacity with adequate expertise on science and policy issues relating to climate change. This aspect is fulfilled through training of meteorologists, climatologists and hydrologists and specialized training such as that offered at the University of Reading and Kyoto University. Priority needs to be given to the human resource development issues that impact the capacity of the National Meteorological and Hydrological Services to have influence within their governments and societies, and better serve national development goals.
From ship to shore: Bringing real-time weather into the classroom

by Wilfried Jacobs and Peter Schmitt

An important component of the Global Framework for Climate Services is the development of weather and climate scientific skills. In order to deliver effective meteorological and climatological services, all countries need well-trained professionals. The honing of professional skills in its staff is the goal of Deutscher Wetterdienst, the Meteorological Training and Conference Centre of the German Meteorological Service in Langen. One of its most recent initiatives offers students a unique opportunity to gain experience in forecasting and research by bringing real-time weather into the classroom.

Seagoing vessels have long been used by weather services and scientific researchers to gain insight into oceanic weather phenomena, climatic change and the interaction between the atmosphere and oceans. The vessels may only cover a small area compared to the vastness of the oceans but each delivers a wide range of data: Observations and measurements of weather and oceanographic parameters, radio soundings, weather reports and forecasts, written documentations of specific weather phenomena and images. This comprehensive data can be linked to satellite products and numerical weather prediction output to give a more encompassing view of the atmosphere at any one time. Yet, this type of investigation is only open to the most highly qualified meteorologists as it demands mental dexterity to assay data from multiple sources as well as experience with a wide variety of analytical tools. Until now, it was also difficult for German students to gain the experience required as surface ocean observations were not readily available to them.

Since 2011 Deutscher Wetterdienst students have been following the voyage of Polarstern, a research and resupply vessel that traces a route from Bremerhaven, Germany, to Antarctica or the Arctic every year. Meteorologists aboard ship provide observations as well as written and visual commentary on meteorological and oceanographic conditions throughout the voyage. This real-time information is transmitted to the EUMeTrain Website where students monitoring the progress of the ship – using synoptic analysis, satellite imagery and numerical model outputs, including wave models – can access it. Students can thus visualize the impacts the various weather systems traversed have on the ship and gain first-hand knowledge of how weather conditions change during the ship’s journey.

Students learn a lot from these data and improve their skills in climatology and oceanography, the interpretation of satellite images, radio soundings, synoptic observations and the use of numerical weather

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\[2\] An international meteorological training project sponsored by EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites)
prediction products. The programme also improves their transferable (soft) skills, teaching them how to follow a routine, to communicate with other students and to exchange and learn from experience.

The training project is the result of coordinated efforts between Deutscher Wetterdienst, the Alfred-Wegner-Institute (owner of the ship), Instituto Português do Mar e da Atmosfera (I.P. Portugal) (processor of the data from the JASON satellite) and EUMeTrain. The satellite imagery is coordinated by Meteosat (polar meteorological satellites operated by EUMETSAT), NOAA (the US National Oceanic and Atmospheric Administration), MetOp (Meteorological Operational satellite) and JASON, a satellite oceanography mission that monitors global ocean circulation and wave heights.

**Anchor’s away**

The project was an immediate success, garnering the enthusiasm of students and researchers alike. Thus in April 2012, the project partners decided to increase its scope by adding the commentary in English, opening the way for students from other National Meteorological and Hydrological Services training centres to join their German counterparts. When Polarstern set a course from Punta Arenas, Chile, back to Bremerhaven from 11 April to 15 May, meteorological students from around the world could follow the ship’s progress and get first-hand reports of atmospheric and oceanographic conditions in English.

For example, in the period from 30 April to 1 May, the ship crossed an area of dust near the Cape Verde Islands. The violet to pink areas in the satellite imagery seen by the students in Langen and other National Meteorological and Hydrological Services training centres indicated that there was dust near the ship. The corresponding surface pressure field showed them that the Southeast trade wind had transported the dust from the Sahara to the ship. The students could easily relate this information in real-time with the onboard data: On the EUMeTrain site, they could click on “Polarstern”, opening a page where the temperatures, speed and direction of the wind, diverse satellite imagery, the weather report and onboard photos could all be consulted.

The data and materials collected by the meteorologists and researchers during the voyage will remain available for students to consult on the EUMeTrain server at any time.

A number of research institutions and organizations have expressed interest in the project: Met Office College, United Kingdom, South African Weather Service, University of the Free State, South Africa, Bureau of Meteorology, Australia, Instituto de Ciências Atmosféricas (ICAT), Brazil, Departamento de Ciencias de la Atmosfera y los Océanos (UBA), Argentina, Lithuanian Hydrometeorological Service, Lithuania, and I.P., Portugal.

**Improving service**

Training is, and will continue to be, of utmost importance to Deutscher Wetterdienst. Together with its partners, Deutscher Wetterdienst aims to be at the forefront of training for meteorologists in areas such as meeting the imminent deadline for competency standards for all aeronautical weather forecasters and observers (1 December 2013); developing the human capacity needed in the Global Framework for Climate Services such as reviewing the education qualifications, skill requirements and job training required for climate specialists; and, ongoing support for disaster risk reduction activities.

Projects such as the Polarstern show that it is possible to link operational work (even remote operational work) to classroom activities to enable trainees to build a more complete understanding of what their job entails and how their work impacts upon the daily lives of people and activities.

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2 If you are interested in participating in the virtual voyage for the 2012/2013 Southern Summer season visit www.eumetrain.org and “Polarstern” for further details.
Subseasonal to Seasonal Prediction Project: bridging the gap between weather and climate

by Frédéric Vitart1, Andrew W. Robertson2 and David L. T. Anderson1

Great progress has been made in recent decades on development and applications of medium-range weather forecasts and seasonal climate predictions. The subseasonal to seasonal project will bring the weather and climate communities together to tackle the intervening time range, harnessing shared and complementary experience and expertise in forecasting, research and applications, toward more seamless weather/climate prediction systems and more integrated weather and climate services.

From the societal perspective, many management decisions in agriculture and food security, water, disaster risk reduction and health fall into the subseasonal to seasonal time range. However, this time scale has long been considered a “predictability desert”, and forecasting for this range has received much less attention than medium-range and seasonal prediction. Recently, research has indicated important potential sources of predictability in this time range through better understanding and representation of atmospheric phenomena such as the Madden–Julian Oscillation, improved coupling with, and initialization of, the land–ocean–cryosphere and stratosphere, new model developments, more comprehensive and reliable observational networks, enhanced data assimilation techniques and increasing computing resources. These improvements are expected to translate into more accurate forecasts.

A number of recent publications (e.g. Brunet et al. 2010) have stressed the importance of, and need for, collaboration between the weather and climate communities to better tackle shared critical issues, and most especially to advance subseasonal to seasonal prediction. At its fifteenth session in November 2009, the WMO Commission for Atmospheric Sciences (CAS) requested that the Joint Scientific Committees of the World Weather Research Programme (WWRP) and the World Climate Research Programme (WCRP) and the THORPEX3 International Core Steering Committee set up an appropriate collaborative structure to carry out an international research initiative on this topic and recommended that it be coordinated with future developments in the Global Framework for Climate Services. An Implementation Plan4 has been written-up on which this article is based.

Needs from applications

Weather and climate events continue to exact a toll on society despite the tremendous advances and investment in prediction science and operational forecasting over the past century. Weather-related hazards, including early/late onset of rainy seasons and chronic events such as drought and extended periods of extreme cold or heat, trigger and account for a great proportion of disaster losses. From the end-user perspective, the sub-seasonal time scale is important because it lies between the well-established and routine application of weather forecasts in diverse user sectors on the one hand, and the increasing use of seasonal forecasts on the other. Many management decisions, such as in agriculture, fall into the intervening two-weekly to two-monthly time scale, so the development of more seamless weather-to-climate forecasts promises to be of significant societal value, and will augment the regions/situations where there is actionable forecast information. As such, this activity is regarded as a significant contribution of

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1 European Centre for Medium-Range Weather Forecasts, United Kingdom of Great Britain and Northern Ireland
2 International Research Institute for Climate and Society, Columbia University’s Earth Institute, United States of America
3 THe Observing system Research and Predictability EXperiment (THORPEX)
both WCRP and WWRP to the Global Framework for Climate Services.

Weather and climate span a continuum of time scales, and forecast information with different lead times is relevant to different sorts of decisions and early-warning. Extending downward from a seasonal forecast, which might inform a crop-planting choice, a sub-seasonal forecast could help optimize the irrigation scheduling and pesticide/fertilizer application with collateral benefits for the environment. In situations where seasonal forecasts are already in use, sub-seasonal ones could be used as updates, such as for estimating end-of-season crop yields. Extending upward from user-applications of numerical weather predictions, there is a potential opportunity, for example, to extend flood forecasting with rainfall-runoff hydraulic models to longer lead times. In the context of humanitarian aid and disaster preparedness, the Red Cross Climate Centre’s International Research Institute for Climate and Society (IRI) have proposed a “Ready-Set-Go” concept for making use of forecasts from weather for seasonal forecasts. It uses seasonal forecasts to begin monitoring of sub-seasonal and short-range forecasts, update contingency plans, train volunteers, and enable early warning systems (“Ready”); sub-monthly forecasts are used to alert volunteers, and alert communities (“Set”); weather forecasts are then used to issue warnings, activate volunteers, distribute instructions to communities, and evacuate if needed (“Go”).

Success, even where there is already a measure of predictive skill, will depend crucially on the active involvement of the climate and applications communities, and co-development with stakeholders. Important topical areas will include the evaluation of past and current experience, and the demonstration of applications with emphasis on communication and evaluation, including building upon on-going applications activities at operational centres.

Research priorities

The subseasonal to seasonal prediction initiative will give high priority to the following research activities:

- Understanding the mechanisms of subseasonal to seasonal predictability.
- Evaluating the skill of subseasonal forecasts, including identifying windows of opportunity for increased forecast skill, with special emphasis on the associated high-impact weather events.
- Understanding model physics and how well the important interaction processes in the Earth system are represented.
- Comparing, verifying and testing multi-model combinations from these forecasts and quantifying their uncertainty.
- Understanding systematic errors and biases in the subseasonal to seasonal forecast range.
- Developing and evaluating approaches to integrate subseasonal to seasonal forecasts into applications.

Forecasting day-to-day weather is primarily an atmospheric initial condition problem, although there can be an influence from ocean and land conditions. Forecasting at the seasonal to inter-annual range, in contrast, depends strongly on slowly-evolving components of the Earth system, especially the sea-surface temperatures (SST). In between these two time scales is subseasonal variability, which is defined here as the time range between two weeks and two months. Subseasonal to seasonal forecasting is at a relatively early stage of development. Many issues remain to be resolved and procedures improved before the full potential of sub-seasonal prediction can be realized. There are glimpses of potential predictability well beyond the range of normal numerical weather prediction (~10 days), but the range of processes involved is not well understood (Hoskins 2012a,b).

Sources of subseasonal to seasonal predictability come from various processes in the atmosphere, ocean and land. A few examples of such processes are:

- The Madden-Julian Oscillation: as the dominant mode of intraseasonal variability in the tropics that modulates organized convective activity, the Madden-Julian Oscillation has a considerable impact not only in the tropics, but also in the middle and high latitudes, and is considered as a major source of global predictability on the subseasonal time scale (e.g. Waliser 2011);
- Soil moisture: inertial memory in soil moisture can last several weeks, which can influence the atmosphere through changes in evaporation and surface energy budget and can affect the forecast of air temperature and precipitation in certain areas during certain times of the year on intraseasonal time scales (e.g. Koster et al. 2010);
- Snow cover: The radiative and thermal properties of widespread snow cover anomalies have the potential to modulate local and remote climate variability over monthly to seasonal time scales (e.g. Sobolowski et al. 2010);
- Stratosphere-troposphere interaction: signals of changes in the polar vortex and the Northern Annular Mode/Arctic Oscillation (NAM/AO) are often seen to come from the stratosphere, with the anomalous
tropospheric flow lasting up to about two months (Baldwin et al. 2003); and

- Ocean conditions: anomalies in upper-ocean thermal structure, in particular sea-surface temperature, lead to changes in air-sea heat flux and convection, which affect atmospheric circulation. The tropical intraseasonal variability forecast skill is improved when a coupled model is used (e.g., Woolnough et al. 2007), while coupled modes of ocean-atmosphere interaction, including the El Niño–Southern Oscillation in particular, can yield substantial forecast skill even within the first month.

In addition to the above, the topics of teleconnections, monsoon variability, tropical storms, polar prediction and sea ice have high relevance in the subseasonal to seasonal range, and linkages with the respective research communities will be emphasised by the project. It is likely that predictive skill will be higher in certain “windows of opportunity”, for example where strong signals from several of these processes interact constructively, but exactly how this occurs and what these windows are, or how to recognize them, is still unclear.

Major issues from a climate perspective include the occurrence of extreme events, from heatwaves to hurricanes, how seasonal-to-interannual variability affects their probability of occurrence, and whether such climatic variations are usefully predictable. Many of the extreme events with the largest impacts have a strong subseasonal/weather character, reinforcing the importance of subseasonal time scales for advancing both understanding and predictions of extreme events in a variable and changing climate. Assessing how subseasonal to seasonal variations may alter the frequencies, intensity and locations of high impact events will be a high priority area of research from the societal decision-making perspective.

The probabilistic nature of weather and climate, and extreme events in particular, makes the development and use of ensemble-based modelling a requirement to improve estimates of the likelihood of high-impact events. In general, an ensemble prediction system (EPS) based on several models, rather than a single model, a so-called multi-model ensemble prediction system (MEPS) approach, provides more useful probability density functions than those obtained from a single EPS when using models of comparable skill (e.g., Hagendorn 2010). The majority of the current subseasonal to seasonal operational forecasting systems are based on ensembles of coupled ocean-atmosphere integrations because realistic representation of ocean-atmosphere coupling is likely to be important on the subseasonal to seasonal time range. However, several important modelling issues still need to be addressed:

- What is the optimal way to initialize a coupled ocean-atmosphere system for successful subseasonal to seasonal prediction?
- What is the best forecast system configuration for representing uncertainty to achieve successful subseasonal to seasonal forecasts?
- What is the impact of increasing horizontal or vertical atmospheric and oceanic resolution?
- What are the main sources of systematic errors at this time range?
- What is the impact of coupling the atmosphere to an ocean, land surface and cryosphere model?
- What is the spread-skill relationship at this time range?
- What is the benefit of multi-model combinations?

Forecast verification activities will be crucial and serve numerous purposes, including: (i) providing information and guidance regarding deficiencies and benefits associated with changes in subseasonal prediction systems, which can feed back into system improvements; (ii) evaluating the impacts of components of
the subseasonal prediction systems such as land data assimilation system impacts, the ability to predict the Madden-Julian Oscillation and other subseasonal phenomena (e.g., blocking, storm track variations, etc.), and the dependence on the El Niño–Southern Oscillation; (iii) evaluating the benefits of multi-model ensemble configurations; and (iv) providing linkages with users and applications of the predictions (e.g., to provide meaningful skill estimates for decision making).

Research activities will also focus on some specific extreme event case studies, to demonstrate that using subseasonal predictions could be of benefit to society. The case studies will be chosen for their high societal impact, but should also represent important research topics, for instance, the Russian heatwave of 2010, the floods in Pakistan in 2010 and Australia in 2011, or the European cold spell of 2012. An important outcome of these demonstration projects would be a better understanding of the causes of some extreme events. Some recent subseasonal to seasonal forecasts have already shown promise in predicting some of these high-impact extreme events. For instance, some seasonal forecasting systems have been successful in predicting higher precipitation over north-west Australia during the Southern Hemisphere summer of 2010-2011 (See example in Figure 1). Another example is the prediction by some extended range forecasts of the heat wave over the United States of America in July 2012 (See example in Figure 2). Therefore, it is timely to evaluate the ability of the state-of-the-art extended range forecasting systems to predict high-impact extreme events. This would be of interest to the climate community for the attribution of extreme events to global warming or to natural low frequency variability and would help to generate additional coordination between the weather and climate communities.

Implementation

Over the past years, a few multi-model ensemble prediction systems have been set up for medium-range weather and seasonal forecasting: the THORPEX Interactive Grand Global Ensemble (TIGGE) for forecasts up to two weeks, the WMO lead centre for long-range forecasts and the Climate-System Historical Forecast Project (CHFP) for seasonal forecasts. However, these databases were not designed to study subseasonal prediction. Therefore, an important goal of this project is to produce a MEPS database from the current operational subseasonal forecasts (most of the Global Producing Centres are now producing operational subseasonal to seasonal forecasts). The multi-model database will consist of ensembles of subseasonal (up to 60 days) forecasts, and will follow the TIGGE protocols, to capitalize on the existing infrastructure.

The proposed database will provide a powerful community resource for investigating the mechanisms of subseasonal to seasonal predictability, and assessing their skill and the usefulness of state-of-the-art subseasonal forecasts for applications. Seasonal forecast practice and the TIGGE project have both recognized that the calibration of ensemble forecasts, correcting for model biases in the ensemble mean and spread and allowing downscaling, can provide an important complement to multi-model ensembling in improving the probabilistic reliability and skill of forecasts. In TIGGE it was shown that a calibrated forecast from a single model could be as skilful as a multi-model ensemble of uncalibrated models, while constructing a multi-model ensemble of calibrated forecasts has been shown to improve overall skill of seasonal forecasts (e.g. Robertson et al. 2004). For numerical weather prediction forecasts, model error is not usually so large that a reforecast set is needed, but for the subseasonal to seasonal range model error is too large to be ignored. Therefore, an extensive reforecast set spanning a sizeable number of years is needed to calculate model bias, which in some cases can also be used to evaluate skill.

An important aspect will be to promote use of these forecasts and their uncertainty estimates by the applications community. Truly actionable science for a wide range of decision makers will require interdisciplinary researchers engaged in developing risk-management strategies and tools for establishing climate services. Extensive multi-model reforecast sets will also be used to build statistical models to tailor climate forecasts for use in sector specific applications. However, the fact that some of the reforecasts are produced on the fly and include only a limited number of years may be an issue for some applications.
In order to attract a maximum number of applications and users of the database, it is desirable to release the forecasts as close as possible to real-time. However, this conflicts with the data policy of some operational centres. It is, therefore, proposed to start with a forecast release date that is a few weeks behind real-time. However, for some demonstration projects, it may be possible to allow near real-time access for a limited amount of time to the research and application communities, possibly including archiving a larger set of variables and at a higher resolution.

Open access to forecast data and user-friendly databases are important requirements for broad community uptake. The database will underpin the research that can shape the scope of developing operational products to be provided by the WMO Global Producing Centres as coordinated by the Commission for Basis Systems (CBS). The demonstration projects will provide an important mechanism to promote the use of subseasonal prediction by application users and foster relationships with partners and provide common focussed objectives. More details on the proposed database can be found in the implementation plan.

### Linkages

The subseasonal to seasonal time range falls within the remit of the Global Framework for Climate Services and the output from this project aims to provide an important contribution to its first (near-term) phase. Collaborations and linkages will be established with other WMO working groups.

Through the intersection with disaster risk management, food security and markets, the subseasonal timescale is of relevance to development agencies such as the World Bank, USAID, UK Department for International Development, and food security organizations such as the World Food Programme, and the Consultative Group on International Agricultural Research’s Program on Climate Change, Agriculture and Food Security. Improved forecasts of extremes on this timescale have the potential to mitigate disasters, and thus improve resilience of vulnerable communities to climate shocks, and help them better adapt to climate change. Importantly, the two-way flow of information between development/food security organizations and the climate community will be crucial to the creation...
Usefulness to society

Subseasonal forecasting has not received as much attention as weather forecasting or seasonal forecasting because it was thought to be a difficult time range that is not as well defined as weather and seasonal forecasting. However, there are reasons to think that there are opportunities for making forecasts for this time range that would be very useful to society.

To achieve success will require considerable improvement in scientific understanding of sources of predictability, together with the development of improved high resolution coupled atmosphere ocean ice models, improved initialization strategies of the coupled system and representation of longer-lived atmospheric phenomena such as the Madden-Julian Oscillation. Several operational weather centres are now either making, or planning to make, forecasts for the subseasonal range, and some climate models could also be brought to bear on this time range, opening the opportunity to compare model forecasts, to understand which processes are robust and which not, as well as to develop strategies for combining the various model forecasts.

This could include multi-model forecasts, but other approaches are possible. Such rigorous analysis and assessment of the forecast will offer greater confidence to the users of such information for decisions relating to agriculture and food production, water resources management, energy and transportation, etc. Establishing an effective feedback mechanism on adequacy and efficacy of the resulting information by the users will also ensure greater focus on improving such forecasts based on the users’ perspective.

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Building Model Evaluation and Decision Support Capacity for CORDEX

by Kim Whitehall1,3, Chris Mattmann1,2,4, Duane Waliser1,2, Jinwon Kim2, Cameron Goodale1, Andrew Hart1, Paul Ramirez1, Paul Zimdars1, Dan Crichton1, Gregory Jenkins3, Colin Jones5, Ghassam Asrar6, Bruce Hewitson7

State, national and international climate assessment reports are important to provide a scientific basis for the understanding and assessment of impacts of climate variability and change on economic sectors such as agriculture and food, water resources, energy and transport. A core element of these assessment reports is future climate projections based on models that not only provide a foretelling of physical indicators of future climate but also indirectly provide information on societal impacts of such changes. Thus they are a key source of science-based information for addressing climate policy, adaptation issues, mitigation planning and risk management strategies.

These quantitative climate projections are usually based on ensembles of multi-component, coupled dynamical global and regional climate models. It is of utmost importance to bring as much observational scrutiny as possible to their simulations of past and present climates, to build confidence in their future projections. While systematic multi-model experimentation and evaluation have been undertaken in many facets for global-scale assessments during the past two decades, for example by the Intergovernmental Panel on Climate Change (IPCC), the development and application of infrastructure for regional-scale models has been somewhat limited due to lack of international coordination. The World Climate Research Programme (WCRP) established the Coordinated Regional Downscaling Experiment (CORDEX; Giorgi et al. 2009, Jones et al. 2011) to facilitate such coordination for regional climate downscaling. One important requirement of the CORDEX framework is to improve access to existing long-term climate quality observations for the evaluation of regional climate projections. A schematic depiction of the roles of models and observations, and the connections between global and regional models, for informing decision-making related to climate impacts is provided in Figure 1 (see page 30).

To meet this CORDEX objective and the high priority regional need, the Jet Propulsion Laboratory, California Institute of Technology (JPL), and their Joint Institute for Regional Earth System Science and Engineering (JIFRESSE) with the University of California, Los Angeles (UCLA), have developed the Regional Climate Model Evaluation System (RCMES). This is one of several regional evaluation activities that WCRP is promoting that targets 10 continental-size focus regions, for example, Africa, S. Asia, Central America, Arctic, Australia. In parallel, the WCRP in partnership with other sister programmes and organizations is establishing a network of regional experts to carry out such evaluations and ultimately assist with interpretation of the scientifically based climate assessments for decision-makers in economic sectors of interest to their region.

The goal of this paper is to introduce RCMES to the broader climate modelling and decision-support communities, recognizing that the Global Framework for Climate Services (GFCS) offers a major opportunity for greater use of RCMES.

Meeting Climate Modelling Needs

Success in remote sensing and climate modelling has led to massive amounts of data being generated at numerous climate/weather observation and modelling centers around the world. These datasets are of various formats, resolutions and coverage. As an example, the total data
volume of Coupled Model Intercomparison Project 3 (CMIP3), which supported the IPCC Fourth Assessment Report: Climate Change 2007 (AR4), was 10’s of terabytes, while Coupled Model Intercomparison Project 5 (CMIP5) is expected to be a few petabytes – that is orders of magnitude larger in size and complexity. Similarly, the amount of satellite data, as evidenced by the successful launches of the international Earth Observing System (EOS), grew by nearly two orders of magnitude from 1997 to 2005. Thus, archiving, distributing and processing of these large datasets whilst maintaining data integrity and expedient workflow capabilities have become a major challenge for climate scientists and other users.

Historically, the global climate community has openly shared datasets and the methodologies for handling and analyzing data with each other via numerous portals such as NASA’s Distributed Active Archive Centers (DAACs) for satellite data or the University Corporation for Atmospheric Research (UCAR) Climate Data Guide for many modelling and in-situ based data sets. Climate scientists have tackled some of the aforementioned challenges by developing systematic frameworks for model experimentation and comparison. Iconic examples are the Atmospheric Model Intercomparison Project (AMIP; Gates et al. 1999) from the early 1990s, followed by the Coupled Model Intercomparison Project (CMIP; Covey et al. 2003). The latter served as the modelling basis for IPCC assessment reports under the auspices of the WCRP. In fact, the success of the early CMIPs demanded a more tailored and high capacity Information Technology (IT) solution to address archiving and distribution needs, particularly starting with CMIP3. The Earth System Grid Federation (ESGF; Williams et al. 2009), sponsored primarily by the US Department of Energy, was adopted and further developed to address these challenges. Having met the terabyte needs of CMIP3, and now in a more distributed and capable fashion, the petabyte needs of CMIP5, it has been deemed a significant success.

Beyond the need for systematic frameworks for model experimentation, and IT capabilities to carry out global climate model intercomparisons and evaluations, is the need for some community standards for evaluation metrics. Having such standard, and community-accepted, metrics are crucial to gauge and track model development as well as provide overall non-biased performance skill measures for the models. While standardized skill metrics have been adopted and utilized by the weather forecast communities for some time, they have only recently been promoted within the climate modelling community. Notable among them is the Madden-Julian Oscillation Working Group (e.g., Waliser et al., 2009), and the Climate Metrics Panel jointly sponsored by the Working Group on Coupled Modelling (WGCM) and Working Group on Numerical Experimentation (WGNE) to define a set of multi-variate, multi-process metrics for climate models (e.g. Gleckler et al. 2008). A primary target for the application of such metrics is the CMIPs.

New Focus on Regional Climate Needs

The resources, capabilities and frameworks that have come together to service the global modelling community bring it closer to its goals of improving the fidelity of climate models and the projections resulting from these models. Thanks to these, users will be provided with better assessments of climate impacts, vulnerabilities and risks to major global economic sectors. However, in response to an urgent request by the participating countries in the UN Framework Convention on Climate Change (UNFCCC) for regional, seasonal to decadal climate information for decision-makers, there are major efforts under way by international research coordination programmes such as the WCRP.

This is most evident in the additions of the decadal and regional climate prediction/projection in the CMIP5 experimental design and in the CORDEX framework. CORDEX provides a common framework through which systematic regional downscaling experiments can
follow from the CMIP5 decadal or century scale climate projections. This coordinated framework contributes greatly to the considerable challenge, and multi-step process, of carrying out well-prepared climate projections and translating the resulting information into a format understandable to end-users/decision-makers.

The progress in facilitating the developing, archiving and access to model data has not eliminated the formidable computational resources needed for evaluation and analysis of such data, which typically also involve equally capable resources for the observations and their databases. Given the much higher spatial resolution required, regional model output archiving and dissemination are as demanding as global models, despite the savings from their limited area of coverage. The Earth System Grid Federation has identified this as a major challenge to address in its future activities. Although its nascent capabilities are being applied to the regional problem, there are still key gaps in delivering model-based climate change/projection information to the end-user:

- Having observations and model output in close enough proximity in form/format and accessibility to provide a feasible means for robust model evaluation capabilities from which credible future climate projections/assessments will result, and from which model improvements are expected to emerge;

- As with the global models, there is a need for a robust set of standard model evaluation metrics;

- Acknowledging that the regional problem is strongly tied to decision support issues and questions at a local level – these capabilities need to be available at local levels and not only accessible to the top tier institutes, universities and laboratories. This is an important concern because many of the nations/communities that do not have the institutional capacity to produce or handle large datasets are among the most susceptible to climate variability and change (IPCC, 2007).

The RCMES development effort (see Acknowledgements for support) derives from combined knowledge and expertise in climate science, regional modelling, remote sensing, and a number of information technology areas, including archiving, processing, distributing, and visualizing massive datasets. The overarching objective of RCMES is to provide a science-based, climate information system that is well grounded in state-of-the-art technology capabilities and tools and is usable by a diverse regional community on affordable workstations, with capabilities to compare climate models output with high-quality observation datasets, using existing and/or user-developed computational tools via user-friendly interfaces. This will relieve regional users from major difficulties in climate research and applications by alleviating the need for expensive computational equipment and the computational experts to administer such a system. These are:

- Addressing data format and metadata heterogeneities foremost in observation datasets, but also model datasets;

- Identifying and making available state-of-the-art and most well accepted climate observations, including what are often perceived to be as less tractable satellite datasets;

- Overcoming spatial and temporal differences between datasets through established transformation and re-gridding methods;

- Expediting data access especially during multiple user projects;

- Eliminating the need for large computational resources for archiving and analyzing observation and model datasets.

Such capabilities will greatly facilitate regional community efforts around the globe that are in sore need of information on regional climate change that will aid in their planning and implementing adaptation strategies optimized for their region.

The Regional Climate Model Evaluation System

RCMES is a platform that simplifies the process of jointly using observational and/or model datasets to support regional assessments of climate variability, change and impacts. RCMES provides remote access to available satellite, re-analysis and in-situ datasets stored with similar formats within a single repository, whilst offering basic statistical metrics, data manipulation and visualization capabilities to make their inter-comparison easier and user-friendly for scientists and other users. Through these capabilities, RCMES expedites the model evaluation process for climate researchers, by permitting them to spend less time finding, transferring, converting and manipulating data, thus allowing more time for evaluation and analysis. Based on its advanced software architecture (see box), RCMES reduces the institutional computer resources required for climate model evaluation and analysis, facilitates larger community participation in climate research and impact assessments, and increases use of these capabilities especially by scientists and users from developing nations/regions.
IT View of RCMES

RCMES consists of two components, the Regional Climate Model Evaluation Database (RCMED) and the Regional Climate Model Evaluation Toolkit (RCMET) as illustrated in Figure 1. These two components may be viewed as the data server (RCMED), which is installed at a data center that users interact with remotely, and the client component (RCMET), which is installed on the users’ local system and optionally becomes customized by the user.

RCMED is a large, scalable database of observation datasets residing at JPL. It utilizes cloud-computing software, which facilitate efficient data storage and expedite data access. The data in RCMED has been extracted and transformed from the original formats to a common format. Users may query the data in RCMED through a web-service layer based on URLs from their system. The query returns data to their systems that are stored in a compressed format for subsequent use should a similar query be made. Much of the architecture was designed to benefit users with modest Internet speeds. The table opposite provides an excerpt of the datasets currently stored in RCMED.

The RCMET is a collection of Python functions. These functions provide users with input/output, conversion, analysis and services including: loading user-defined data from other sources, re-gridding datasets to spatial and temporal homogeneity, spatial and temporal decomposition of datasets, as well as dataset analyses and visualization. Encapsulated in RCMET are basic common statistical metrics for analysis such as means, bias, standard deviation, and correlations. Visualization of these metrics is also available.

Users are allowed to personalize RCMES for their purposes with regards to workflow, defining subroutines for increased functionality and defining various visualization options. The RCMET component is also able to service a diverse computer-literate community through a web-based graphical user interface whereby the Python functions are available via Bottle services (a Python web Framework) or accessed via command line and scripting mechanisms.

The RCMES team is working with JPL and NASA to make RCMET (and RCMES) open source software, thus users are encouraged to create and share their personalized functions with the community, using the open source software for NASA as a guide.

Figure 1 – Schematic of RCMES
### Datasets available in RCMED

<table>
<thead>
<tr>
<th>Dataset Name</th>
<th>Abbreviation</th>
<th>Variables</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCEP/CPC Daily Precipitation</td>
<td>URD</td>
<td>Precipitation</td>
<td>Gridded analysis of daily station data at a 0.25-deg resolution over the conterminous US and northern Mexico. Daily and monthly data.</td>
</tr>
<tr>
<td>AIRS L3 Standard daily product (AIRS/AMSU) version 5</td>
<td>AIRS</td>
<td>Surface air temperature; atmospheric temperature; geopotential height</td>
<td>Satellite-based retrievals using Atmospheric Infrared Sounder (AIRS IR) and Advanced Microwave Sounding Unit (AMSU), without Humidity Sounder for Brazil (HSB). Daily and monthly data.</td>
</tr>
<tr>
<td>ERA-Interim Reanalysis</td>
<td>ERA</td>
<td>Temperature; dew-point temperature; geopotential height</td>
<td>Global reanalysis product from ECMWF. Daily and monthly data.</td>
</tr>
<tr>
<td>Moderate Resolution Imaging Spectro-radiometer</td>
<td>MODIS</td>
<td>Cloudiness</td>
<td>Satellite-based retrievals. Daily and monthly data.</td>
</tr>
<tr>
<td>Climate Research Unit TS3.0</td>
<td>CRU</td>
<td>Precipitation; daily-mean, max and min surface air temperatures</td>
<td>Gridded analysis of surface station observation over the global land surfaces at 0.5-deg horizontal resolutions. Daily and monthly data.</td>
</tr>
<tr>
<td>Climate Research Unit TS3.1</td>
<td>CRU_TS_3.1</td>
<td>Precipitation; daily-mean, max and min surface air temperatures; cloudiness</td>
<td>Updated version of the CRU 3.0 data. Daily and monthly data.</td>
</tr>
<tr>
<td>Sierra Nevada Snow-water equivalent</td>
<td>SWE</td>
<td>Snow-water equivalent</td>
<td>Blended satellite retrieval and surface observations over the Sierra Nevada range. Monthly data.</td>
</tr>
<tr>
<td>MERRA DAS3d analyzed state on pressure</td>
<td>MAI6NPANA</td>
<td>MSLP; Surface pressure</td>
<td>NASA-GMAO Global Reanalysis Monthly data.</td>
</tr>
<tr>
<td>CERES Radiation</td>
<td>CERES</td>
<td>Short- and longwave irradiances for all sky, clear sky, TOA, and surface</td>
<td>Satellite retrieved radiation product Monthly data.</td>
</tr>
</tbody>
</table>

**Figure 2** – Example of a bias analysis using RCMES for annual-mean daily maximum temperature from 1989 to 2006. The observation dataset is CRU surface station analysis (left) and the model data are from the climate hindcast using the Second-generation Regional Climate Model (RACMO2) of Royal Dutch Meteorological Institute (KNMI) driven by the large-scale forcing data derived from the ERA-Interim reanalysis (right).
At present, RCMES is being utilized for model evaluations associated with the WCRP’s CORDEX programme and the US National Climate Assessment (NCA). CORDEX-Africa and CORDEX-N. America (aka NARCCAP, used for US NCA) have been the first tangible uses of RCMES, with collaborations and users now rapidly developing for CORDEX-S. Asia, CORDEX-E. Asia and CORDEX-Arctic.

Targeting Climate and Social Scientists

RCMES objectives include a commitment to providing a tool that can be applied without pre-defined approaches. Thus far, communities of users have utilized RCMES in two very distinct ways. Firstly as a data management and model evaluation tool, for example in regional projects involving CORDEX, such as CORDEX Africa and NARCCAP - the N. American component of CORDEX. The RCMES team is also participating in three more CORDEX regions including the Arctic, South Asia, and East Asia. To date this has included attending the organizational workshops and developing collaborations and RCMES improvements that would further enhance its utilities for the given CORDEX region. Regional RCMES users report that the key advantages of using RCMES are the accessibility to various observation datasets, the ease of inserting their own data, availability of built-in re-gridding functions for datasets (local or remote), and general ease of use.

Secondly, RCMES has been used as a metric and visualization tool in science-based environmental assessment projects. The users of RCMES in this regard report key advantages in the ability to access multiple observation datasets, visualization of data, basic model evaluation metrics and ease of use. Through the Climate and Development Knowledge Network (CDKN) project, we are exploring the use and integration of RCMES with the University of Cape Town, South Africa, and its Climate Information Portal (CIP). RCMES has also been introduced to groups such as Leadership for Environment and Development (LEAD) in Africa, as a means of aiding assessments.

The Way Forward

The next steps for RCMES involve incorporating: (1) additional observation datasets – those suited for model evaluation as well as those relevant to new decision-support systems; (2) additional methods for quantifying statistically the robustness of the analyses results; (3) functions and visualization capabilities that are commonly used in climate and environmental Geographical Information System applications; and (4) promoting its greater use in other regional activities that will emerge as a part of the Global Framework for Climate Services. Arrangements are also underway make RCMES available through the Earth System Grid Federation.

The RCMES team looks forward to continued and enhanced engagement with CORDEX and, where possible, to providing climate analysis resources and even a training platform to the Global Framework for Climate Services through the WMO network of National Meteorological and Hydrological Services (NMHSs). Through wider collaboration, and the team’s efforts to make RCMES open source software, capabilities will grow.

(Please visit http://rcmes.jpl.nasa.gov for capability updates, collaborative activities, and application outcomes. We welcome your suggestions and feedback.)

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34 | WMO Bulletin 61 (2) - 2012
Drought and Desertification in Postage Stamps

by Garry Toth¹ and Donald Hillger²

Introduction

The Global Framework for Climate Services (GFCS) identifies four initial priority areas: water, food security, health and disaster risk reduction. Drought and desertification (henceforth referred to as D+D) are important issues in all of these areas. Whether due to natural climate variability or climate change, there is an urgent need to develop better D+D management strategies that are based on scientific knowledge, and to ensure broader social responses to manage the risks and mitigate the effects of D+D. Communication and outreach on such issues are key to the success of the GFCS. Philately may be considered by some as outmoded in the world of e-mail and the Internet, but it remains an important means for outreach. In particular, a surprisingly large number of stamps with depictions or themes related to D+D have been issued by countries from around the world. This article examines how D+D have been portrayed on postage stamps and how those stamps have served, in their own way, to educate people on the existence of the problem and on some of the international institutional responses to it.

Philatelists keep track of postage stamps through the information included in various catalogues. In what follows, stamps are identified for the convenience of readers from around the world using numbers from the Scott catalogue, published in the United States, and the Michel catalogue, published in Germany.

Drought as Depicted on Stamps

Drought can be defined as a prolonged period of abnormally low precipitation which creates a shortage of water for different uses – such as for sanitation and drinking, agriculture, hydrological needs, industry, forests, recreation, cities and power generation. There is no life without water so the impacts of droughts can be significant. Drought is one element of climate, and comes and goes with the natural variability of climate. For example, a large part of North America endured a debilitating drought in the “Dust Bowl” years of the 1930s.

However, it appears that the climate is now changing in various ways as a result of the recent anthropogenic global warming. Scientists are coming to the conclusion that in a warming world, there will be an increased probability of droughts that are more intense and/or of longer duration. It follows that in a warming world, the impacts of droughts will increase as well.

In postage stamps, drought is often represented by a depiction of parched and cracked ground. One example is the United Nations New York Scott 968e (Michel

Drought and Desertification

WMO is implementing two initiatives to address drought issues: the High-level Meeting on National Drought Policy to be held in collaboration with the UN Convention to Combat Desertification in March 2013 and the Integrated Drought Management Programme with the Global Water Partnership. (For more information see the Concept Paper, November 2011, at www.wmo.int/pages/prog/wcp/drought/idmp/documents/IDMP_Concept_Note.pdf).

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1105-1108 minisheet of four), from 2008, one of several sheets of four stamps found in a deluxe stamp booklet that treats the topic of climate change (Figure 1). The “Climate Change” cancellation on that sheet links the desertification theme to the climate change theme. The other two UN postal administrations (Geneva and Vienna) also issued similar booklets. Other stamps include dramatic designs with mention of drought, or refer to drought impacts. Mauritius Scott 418 (Michel 410), from 1976 (Figure 2) is an example of the former category, with its stark illustration of the theme of “Drought in Africa” while Niger Scott 737 (Michel 997), from 1986 (Figure 3) falls in the latter group. Its theme, “trucks of hope”, refers to the famine caused by droughts in Africa. Some stamps and postal items relate forest fires to drought. Mauritius Scott 694 (Michel 792), issued in 1983 (Figure 4), mentions the “fight against drought” and depicts a dead forest after a fire that occurred, presumably, during a drought. A Trinidad and Tobago 1969 cancellation (Figure 5) states “forest fires cause drought”, unfortunately confusing cause and effect: drought can lead to more forest fires, rather than the other way around.

Desertification as Depicted on Stamps

Desertification is a more complex concept than drought, since several factors can contribute to it. A basic working definition is that desertification is the process by which drylands (lands with naturally low amounts of soil water) become even drier and more desert-like, sometimes because of drought, but also at times because of inappropriate land use, agriculture, deforestation, loss of biodiversity or other pressures due to increasing population. Indeed, the human element is at times the principal factor in desertification. Human actions can create desertification of vulnerable land in the absence of a drought, or can feed back to intensify (or, with correct management, to lessen) the impacts of drought. Up to 40 per cent of the Earth’s land mass is composed of drylands; the area of Africa just south of the Sahara desert is perhaps the best-known example, but such areas are found around the world.

Stamps related to desertification often mention the term directly or illustrate some of its impacts. For example, what can happen if the land gets very dry? If the land care is inappropriate, or if there is poor erosion control, then, as in the text in Australia Scott 1267c (Michel 1308) from 1992, “the soil blows away” (Figure 6). In the same vein, a set of four stamps from Transkei from 1984 (Scott 155-158, Michel 163-166) has for its theme “Save the Soil”. The 11c value (Figure 7) illustrates what can happen with bad land use practices: land degradation and possible desertification. The 50c value (Figure 8) show the same scene in which the land has been well-managed.
Forests are important: cutting them down is one route to desertification. This is emphasized in many stamps, including Congo Republic Scott 810 (Michel 1136) from 1988, which mentions “stop deforestation” as part of the “fight against desertification” (Figure 9). In countries where the desert is encroaching on dryland areas, some attempts have been made to stabilize the sand dunes to slow them down or stop them. Niger Scott 790 (Michel 1055), issued in 1988, shows one such dune stabilization project (Figure 10). Russia Scott 5967 (Michel 6171), from 1991, shows what used to be the Aral Sea (Figure 11). The waters in the rivers that used to flow into it were diverted for irrigation, and in an extreme example of desertification, it has almost completely dried up.

Drought, Desertification and Water

If there is adequate water then there is no drought, and often there is no desertification either. Some postage stamps take advantage of this contrast to emphasize the problem of D+D. For example, New Caledonia Scott 492 (Michel 723), from 1983, with the theme “water, a vital resource”, contrasts a healthy environment inside a water drop with dying trees and extremely dry conditions in the absence of water (Figure 12). Uruguay Scott 2097 (Michel 2849), issued in 1984, with the theme “water, a scarce resource”, does much the same thing, with a symbolic pond against a background of parched and cracked ground (Figure 13). Other countries chose to focus on international water conferences that dealt with a lack of water such as the World Water Forums, from the first one in Buenos Aires in 1977 through the fifth and most recent in Istanbul in 2009. Stamps have been issued to commemorate both of those conferences.

Drought and Desertification Maps

Maps of regions of D+D are found on some stamps. They draw attention to vulnerable areas and to those that have already suffered. The cachet and cancellation of a first-day cover (FDC) issued by the Geneva office of the UN present a vivid reminder of the areas of Africa that were affected by drought in 1986 (Figure 14). The stamp (UN Geneva Scott 140, Michel 137) sets the scene with its illustration of “Afrique en Crise” (Africa in crisis). In 1977, Iraq issued two stamps (Scott 826-827, Michel 919-920) that highlighted areas of North Africa and the Middle East susceptible to desertification (Figure 15 shows the 30 Iraqi fils stamp in this set). On the other side of the Atlantic, Brazil’s Caatinga Nordestina is a dryland in the north eastern part of the country that is at risk for desertification. The region is highlighted in a map in a souvenir sheet of one stamp (SS1) issued in 2002 (Scott 2849, Michel Block 119, Figure 16). Ethiopia Scott 1711 (Michel 1847), from 2006, presents worldwide areas that are susceptible to desertification (Figure 17).
Fundraising for Drought Relief through Semi-Postal Stamps

Many countries gather funds for various causes by issuing postage stamps with surcharges that are in addition to the regular postal face value. A few of them are known to be for drought relief. For example, a series of USSR stamps (Scott B14-B23, Michel 165-168, 174, 174b, 174c, 175, 175b, 175c, not shown) was issued in 1921 and 1922 to raise money for famine relief in the Volga area (the famine was caused in part by a drought in 1921). More recently (in 1999, no catalogue number), the People’s Republic of China issued a postal card with a surcharge (in red at the lower left in Figure 17) for drought relief in parts of the Qinghai province.

Sécheresse-Solidarité africaine

In 1972 and 1973 West Africa suffered through a serious drought, probably the worst since the drought of 1911-1914. Fifteen African countries, mostly in 1973, issued revalued stamps overprinted with the words Sécheresse-Solidarité africaine (African solidarity in drought). This was apparently a programme of mutual support and cooperation, though documentation to back this claim could not be found. In any case, the message of cooperation among the affected nations in time of emergency is an important one. Figure 18 shows one such stamp (Mauritania Scott 303, Michel 462).

The Sahel

The Sahel is an African dryland transition region between the Sahara desert and the savannah grasslands to the south. It has a long history of periods of drought. Harsh droughts in the 1970s and again in the 1980s caused desertification and so led to major famines. Many African stamps were issued in the context of those droughts. For example, Upper Volta Scott 538 (Michel 793), issued in 1980, shows a green hand symbolically holding back the desert (Figure 19). The phrase “Opération Sahel Vert” (Green Sahel Operation) is found in many of the Sahel-related stamps from this period, as reforestation is a common theme in many of these stamps. One example is Senegal Scott 431 (Michel 594), from 1976 (Figure 20). In 1984 some countries issued revalued stamps overprinted “Aide au Sahel ’84” (Aid the Sahel ’84). An example is Niger Scott 668 (Michel 915), which also includes the reforestation theme (Figure 21).

International Conferences Related to Drought and Desertification

Many climate conferences have focused on D+D. The Iraq stamp in Figure 15, already referred to for its map, was issued to mark the UN Conference on Desertification held in Nairobi in 1977. It was the first major international conference dedicated to desertification and four countries commemorated the event with postage stamps. Pakistan Scott 435 (Michel 438) is another example (Figure 22). More recently, in 2003, Cuba Scott 4326 (Michel 4537) marked the Sixth Session of the Conference of the Parties to the UN Convention to Combat Desertification (UNCCD-COP-6), which was held in Havana (Figure 23). The Convention is an international framework designed to address the problem of desertification, following a recommendation from the Rio Earth Summit of 1992. (As an aside, many postage stamps were issued to commemorate the Rio Summit). One confirmation of the global nature of D+D is that almost 200 countries now belong to the Convention. The UNCCD-COP-10, which took place in South Korea in October 2010, is the most recent desertification conference to be commemorated on a postage stamp (South Korea Scott 2371, Michel 2841, issued in 2011; see Figure 24).

The World Day to Combat Desertification

Sponsored by the UNCCD, the World Day to Combat Desertification has been celebrated each 17 June since 1995. It is designed to promote public awareness about D+D and to publicize the international efforts to
mitigate their effects. To the authors’ knowledge, six countries have issued stamps for the World Day to Combat Desertification. Figure 25 presents a souvenir sheet of one stamp from Brazil (Scott 2592, Michel Block 103) issued in 1996 for the second World Day to Combat Desertification.

The International Year of Deserts and Desertification (IYDD)

The UN General Assembly declared 2006 the International Year of Deserts and Desertification with the goal of creating public awareness of the principal causes of desertification and the threats that it poses. At least 17 countries issued stamps for the event. Mexico Scott 2523 (Michel 3267) shows a desert scene and carries the International Year of Deserts and Desertification logo (Figure 26). Ethiopia issued a set of four stamps (Scott 1708-1711, Michel 1844-1847), three showing various areas around the world that are vulnerable to desertification. Figure 27 presents one of them (Scott 1711/Michel 1847).

Programmes and Agencies Involved in the Fight Against Drought and Desertification

Several programmes and agencies that work in the area of D+D have been commemorated on postage stamps. Ethiopia, hard-hit by droughts over the years, issued a set of four stamps (Scott 1413-1416, Michel 1539-1542) in 1995 for the 10th anniversary of the Intergovernmental Authority on Drought and Development (IGADD). Figure 28 presents Scott 1413/Michel 1539 from this set, which also includes the theme of deforestation. In another example, UN Geneva Scott 449 (Michel 528), issued in 2005, shows a World Food Programme aircraft dropping supplies to a North African area in need (Figure 29). The theme, “des vivres pour vivre”, can be roughly translated as “supplies for survival”.

The Science of Drought and Desertification

A few postage stamps refer to the science of D+D. One, a Norway minisheet of two stamps issued in 2009 (Scott 1570, Michel Block 37), states that global warming “sucks moisture out of the soil, leading to increasing desertification”. Another, Marshall Islands Scott 678 (Michel Block 24), a souvenir sheet of one stamp issued in 1998, refers to “the unprecedented and devastating drought brought on by El Niño” (Figure 30). We now know that El Niño events have a variety of effects, including above-normal precipitation in the eastern Pacific and below-normal precipitation in the western south Pacific. The very strong 1997-1998 El Niño in fact did cause a drought in some parts of the western south Pacific.

Conclusion

We have seen that a wide variety of themes related to D+D is found in postage stamps. As such, those stamps can be considered to publicize various aspects of D+D: causes, extent, impacts, mitigation programmes and regional and international cooperation. In short, since the 1970s these stamps have served in their own small way as an outreach programme for the public on the subject of D+D.

Will the Global Framework for Climate Services be able to capture this visual means of communicating and reaching out to diverse audiences? This will be up to its members, but as the examples in this article show, one small postage stamp can speak a 1000 words.

The Authors

The authors have researched and written extensively on the subjects of weather, climate, and un-manned satellites on stamps and covers. Their Weather and Climatology philatelic website is found at http://rammb.cira.colostate.edu/dev/hillger/weather.htm. A separate page in that site has a complete listing of all known philatelic items related to drought and desertification is found at http://rammb.cira.colostate.edu/dev/hillger/drought.htm.
Is it now possible to blame extreme weather on global warming?

Whenever an episode of extreme weather – heatwave, flood, drought, etc. – hits the headlines, someone somewhere is sure to point the finger of blame at human-induced climate change. Such claims are normally slapped down with the much-aired mantra: “You cannot blame a single episode of bad weather on global warming.” But with the record high temperatures affecting large parts of the United States of America (US), there seems to be a noticeable reduction in such caveats and notes of caution.

In July, scientists seemed to be queuing up to explain how the wildfires in Colorado, the heatwave across the eastern seaboard and the super derecho are all indicative of “what global warming looks like.” Most pulled back, though, from directly blaming global warming for such weather events.

“In the future you would expect larger, longer more intense heatwaves and we’ve seen that in the last few summers,” Derek Arndt of the National Oceanic Atmospheric Administration (NOAA) Climate Monitoring told the Associated Press. The same report added: “At least 15 climate scientists told the Associated Press that this long hot US summer is consistent with what is to be expected in global warming.”

So, can we now say that specific extreme weather events are caused, or at least exacerbated, by global warming? Has anything changed in climate scientists’ understanding of the attribution – or “anthropogenic fingerprint” – of such events? Are they now more confident about making such links? I put this question to a number of climate scientists...

Kerry Emanuel, Professor of Atmospheric Science, Massachusetts Institute of Technology:

In my view, the only responsible statement scientists can make about this regards the probabilities of such events with and without climate change. We should be able to say something like “the annual probability of a heatwave of magnitude A and duration B before the advent of climate change was x but as a result of climate change has increased to y and is expected to further increase to between z1 and z2”. It would take some work to actually fill in the numbers x, y, z1, and z2, but there are studies along these lines for events such as the 2003 European heatwave.

In my view, any statement that goes appreciably beyond statements like this one probably involves spin of one kind or another. In addition, one could talk about the particular routes by which climate change affects particular events. For example, the fires in the Rockies have apparently been affected by the ill health of many trees, owing to a population explosion among pine beetles, which is in turn partly owing to climate change.

Dr Peter Stott, Head, Climate Monitoring and Attribution, Met Office Hadley Centre:

Unusual or extreme weather events are of great public concern and interest, yet there are often conflicting messages from scientists about whether such events can be linked to climate change. While it is clear that across the globe there has been an increase in the frequency of extreme heatwaves and of episodes of heavy rainfall, this does not mean that human-induced climate change is to blame for every instance of such damaging weather. However climate change could be changing the odds and it is becoming increasingly clear that it is doing so in...
such a way as to increase the chances of extremely warm temperatures and to reduce the chances of extremely cold temperatures in many places.

At the Met Office, in collaboration with international colleagues, we have formed the Attribution of Climate-related Events (ACE) initiative to develop the tools needed to quantify the changed risks of extreme weather. Extreme rainfall and flooding is a particular challenge. The globally warmer atmosphere now carries four per cent more moisture over the oceans than in the 1970s and in many places this extra moisture would be expected to lead to increased rainfall when storms form over land. But in some regions, weather patterns as a whole could change due to natural as well as human causes. For example, if there were a systematic shift in the jet stream, the fast flowing ribbon of air high in the atmosphere that steers storm systems, this could reduce the risk of extreme rainfall in some places. The next meeting of the ACE group, took place in Oxford last September, will discuss the development of authoritative assessments of extreme weather risk that can be produced shortly after the extreme weather events in question when interest is at its height.

Professor Michael Mann, Director, Earth System Science Centre, Department of Meteorology, Penn State:

I like to use the analogy of loaded dice. Here in the US, we’ve seen a doubling in the frequency of record-breaking heat, relative to what we would expect from chance alone. So far this year, we’re seeing those records broken at nearly 10 times the rate we would expect without global warming. So there is no question in my mind that the “signal” of climate change has now emerged in our day-to-day weather. We are seeing the loading of the random weather dice toward more “sixes”. We are seeing and feeling climate change in the more extreme heat we are witnessing this summer, the outbreak of massive forest fires like the one that engulfed Colorado, and more extreme weather events like the derecho that knocked out power for millions in the eastern US during a record-breaking heat spell.

Dr Clare Goodess, Senior Researcher, Climatic Research Unit, University of East Anglia:

On 28 June 2012, wildfires raged across the western US. The Waldo Canyon fire in Colorado attracted the most attention as it charred hundreds of homes, but large wildfires also burned throughout Utah, Wyoming, Montana, New Mexico and Arizona.

Over the last five years or so, a growing number of peer-reviewed studies have provided convincing evidence of a detectable human influence in the increases in high temperature extremes, which have been observed over the last few decades over the globe as a whole and over large-scale regions such as Europe. Attribution of observed trends to human influences (anthropogenic climate change) requires a clear signal of change, which is stronger than the inherent natural variability of climate (so-called ‘noise’), where the different driving mechanisms of change can be separated out. Thus it is a more challenging task for rainfall and other weather variables than for temperature, and for areas smaller than continents. An anthropogenic influence has, however, recently been detected over Northern Hemisphere land areas in the largest daily rainfall events experienced each year.

These approaches to what climate scientists refer to as detection and attribution do not, however, address the questions that are uppermost in people’s minds when they are personally affected by an extreme weather event. Unfortunately, I do not believe that it will ever be
possible to look at a single event and say definitively if it would or would not have occurred in the absence of human influence. However, what can be, and has been, done is to estimate the extent to which human activity has increased the risk of such events occurring. It has, for example, been demonstrated that human influence has more than doubled the risk of a hot European summer like that of 2003 occurring, and substantially increased the risk of flooding which occurred in England and Wales in autumn 2000.

Dr Doug Smith, Decadal Climate Prediction Research and Development, Met Office Hadley Centre:

I think it is inevitable that climate change will affect the frequency and intensity of extreme events. Weather can be characterised in terms of a mean value (the climate) and variability around the mean. Climate change will shift the mean value (by definition), and hence change the probability of extremes unless the variability also changes to compensate exactly (and there is no reason to expect this). The difficulty is in calculating the contribution of climate change to an individual extreme event. This is currently an active research area, known as operational attribution, in which many climate model simulations are made with and without forcing due to climate change in order to compute differences in the probabilities of particular events.

Michael Oppenheimer, Professor of Geosciences and International Affairs, Department of Geosciences, Woodrow Wilson School, Princeton University:

The link between extreme events which have occurred recently and the build-up of the greenhouse gases is best represented by the “loading the dice” analogy – as the world warms, the likelihood of occurrence (frequency), intensity, and/or geographic extent of many types of extreme events is increasing. The events are individual data points in a broader pattern, akin to pixels on a computer screen. You can’t say much from any one pixel, but a picture emerges when you step back and look at the pattern. That said, for a few types of extreme events, particularly heatwaves, it is sometimes possible to connect the pixel to the bigger picture more directly. The best case is the European heatwave of 2003. According to computer simulations of climate, the likelihood that such an event would occur was almost doubled by the build-up of greenhouse gases. A few other events have been examined using similar techniques, including the 2010 heatwave in Russia.

As for the willingness of scientists to make such statements as the climate signal due to the ever-increasing greenhouse effect strengthens and emerges more and more from the noise in the system, and as statistical techniques for doing such “fingerprinting” studies as I mention above improves: scientists have become more confident in making such claims, which is to be expected.

Harold Brooks, Head, Mesoscale Applications Group, National Severe Storms Laboratory, NOAA:

Attribution of extremes is challenging. We’re faced with separate, but related, questions. First, how much did the warming of the planet contribute directly to the extreme event? Second, how much more likely was the event because of a warmer planet? For things that are closely related to temperature (for example, heatwaves, fires), the first question can be addressed in a relatively straightforward manner and, typically, the answers are conservative. Even with a degree or two of global warming, the direct contribution to extreme heat, such as in the southern plains of the US in 2011 and in much of the US in 2012, is small.

The second question is more challenging to address. There are two issues that need to be considered. First is a statistical problem about how the likelihood of low probability events changes as the average condition changes. For example, if you flip a fair coin 100 times, on average you get 50 heads, but 95 per cent of the time you’ll get between 40 and 60 heads and 2 or 3 times you’ll get 65 heads. If you get a weighted coin that is 55 per cent likely to be heads, it will be 10 times as likely that you’ll get 65 heads. The small change in the average chance means the chance of an extreme becomes much more likely. The same thing happens for temperature extremes, but there’s another issue. Did the change in the average temperature make it more likely that the flow in the atmosphere was even more likely to occur than just by chance? For instance, when it doesn’t rain much...
over a large area, the ground dries out and heats up. The atmosphere responds to this by flowing around the area of hot air in a way that makes rain even less likely in the hot area, leading to more heating of the ground, reinforcing the flow around that area.

For things that aren’t temperature, we have to work to understand the relationship between the global temperature and the phenomenon in question. For instance, we understand that warming the planet will likely lead to a more intense water cycle, with heavier rain when it rains and longer periods without rain in between. On the other hand, our understanding of how global scale atmospheric changes affect things like tornadoes and severe thunderstorms is that global warming will make some of the ingredients for them more likely and others less likely. As a result, it appears that long-term trends in tornado occurrence or intensity are unlikely to be large. Even without the planet warming, we would expect to see some years with many tornadoes and others with few tornadoes.

Michael F. Wehner, Staff Scientist, Lawrence Berkeley National Laboratory:

Whenever an extreme weather event occurs, it is natural for the public to ask, “Is this event a result of global warming?” That is not quite the right. To date, all the individual weather events observed could have happened prior to human intervention in the climate system, however unlikely that may have been. The more relevant question is “How has the risk of this event changed because of climate change?”

This risk of extreme weather, particularly very severe heatwaves, has already changed significantly due to human induced global warming. For instance, the chances of the 2003 European summer heatwave, responsible for as many as 70,000 additional deaths, at least doubled and likely increased by a factor of 4 to 10. The chances of the 2010 Russian and 2011 Texas events also undoubtedly increased. While these events could have occurred without the human changes to the climate, it is important to know that the amount of climate change that we have experienced so far is very small compared to what is projected to occur by the middle and end of this century. By 2100, today’s most extreme weather events will seem relatively normal.

Connect the Dots

U.N. Framework Convention on Climate Change (UNFCCC) Executive Secretary Christiana Figueres expressed optimism that scientific scepticism on global warming is waning in the United States as reported by the E2 Wire blog on 1 October. “You see both trends,” she said, “both understanding that the climate is changing and that it is manmade. Both trends are moving in the right direction.”

In an earlier speech at Swarthmore College on 28 September, she stated, “January through August were the warmest eight months of any year on record in the US. This country just experienced one of the worst droughts on record, a heatwave extending from the Rocky Mountains to the Ohio Valley, with devastating effects on the farmers of the entire region. (...) It doesn’t take a scientist to connect the dots. While none of these events can be exclusively linked to climate change, taken together they indicate we’re already in the midst of climate unpredictability, of a profound disruption of the Earth’s hydrological cycle the effect of which is still unknown.”

Children play in a water fountain in downtown Silver Spring, Maryland 21 June 2012. On that day, a heatwave blanketed the US Mid-Atlantic and Northeast, forcing utilities across the region to ask customers to conserve electricity.
Milestones

1853  First International Meteorological Conference (Brussels)
1873  WMO predecessor, the International Meteorological Organization (IMO) established
1947  WMO Convention agreed unanimously by Conference of Directors
1950  WMO Convention entered into force on 23 March
1951  WMO became a specialized agency of the United Nations
1957  Global Ozone Observing System set up
1957/1958  Participation in the International Geophysical Year
1963  World Weather Watch launched
1971  Tropical Cyclone project established (upgraded to Tropical Cyclone Programme in 1980)
1972  Operational Hydrology Programme established
1976  WMO issues first international assessment of the state of global ozone
1977  Integrated Global Ocean Services System established jointly by WMO and the Intergovernmental Oceanographic Commission of UNESCO
1978/1979  Global Weather Experiment and Monsoon Experiments under the Global Atmospheric Research Programme
1979  First World Climate Conference, which led to the establishment of the Intergovernmental Panel on Climate Change (IPCC), the World Climate Programme and the World Climate Research Programme
1980  World Climate Research Programme established
1985  Vienna Convention on the Protection of the Ozone Layer
1987  Montreal Protocol on Substances that Deplete the Ozone Layer
1988  WMO/UNEP Intergovernmental Panel on Climate Change established
1989  Global Atmosphere Watch established
1990  Second World Climate Conference, which initiated the Global Climate Observing System; the International Decade for Natural Disaster Reduction; First IPCC Assessment Report released
1991  WMO/UNEP convened first meeting of the Intergovernmental Negotiating Committee of the United Nations Framework Convention on Climate Change
1992  The Global Climate Observing System established
1993  World Hydrological Cycle Observing System launched
1995  Climate Information and Prediction Services established; Second IPCC Assessment Report released
1999  WMO celebrates 50 years of service
2000  Third IPCC Assessment Report released
2001  Natural Disaster Prevention and Mitigation Programme, Space Programme and Programme for the Least Developed Countries launched
2005  Fourth IPCC Assessment Report released; IPCC is awarded the Nobel Peace Prize
2007  World Climate Conference-3
2009  WMO celebrates 60 years
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