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Weather · Climate · Water

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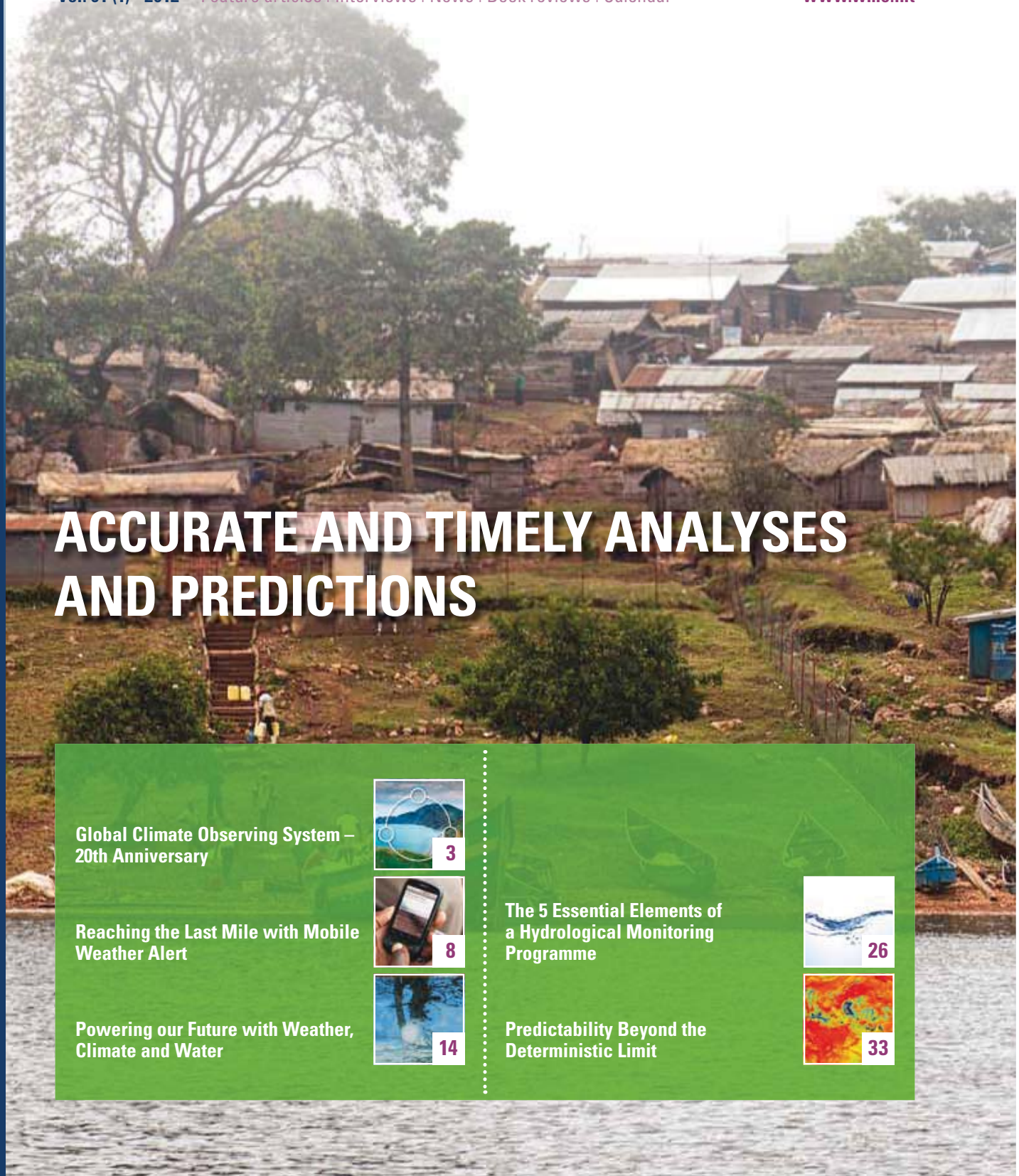

ACCURATE AND TIMELY ANALYSES AND PREDICTIONS

Bulletin

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In this issue

Sustainable development holds the promise for a better future for all. Information on weather, climate and water – important factors affecting all areas of human activity – is critical to decision-making for sustainable development. Thus, the Global Framework for Climate Services (the Framework), which provides the mechanism for the generation and use of climate knowledge, products and services, will bring us closer to achieving sustainable development.

One of the essential elements of the Framework, *the Global Climate Observing System (GCOS) celebrates its 20th Anniversary* in this issue. Established in 1992, the GCOS looks back at its accomplishment and forward to the challenge that implementation of the Framework will bring.

Accurate and timely analyses and predictions

The Framework will provide accurate and timely weather and climate analyses and predictions, which can further improve human safety, prosperity and livelihood, and preserve precious natural resources. The importance of such information to end-users is highlighted in *Reaching the last Mile with Mobile Weather Alerts*. The article brings out the practical aspect of delivering weather and climate services to farmers and fishermen in Uganda and the benefits that stem from such services in terms of lives saved and livelihoods improved.

Water Sector Industry Perspectives for Climate Services in turn highlights how weather and climate information and predictions are used in short and long-term decision-making concerning the delivery of safe drinking water and sanitation services to populations.

These articles demonstrate the value of accurate predictions to the diverse end-user communities. In *Predictability Beyond the Deterministic Limit*, the last article in this issue, Brian Hoskins questions the traditional idea of a deterministic limit by considering the possibility of some predictive skill on all time-scales from hours to decades.

World Meteorological Day

WMO was honoured to have two special guest speakers, United Nations Industrial Development Organization (UNIDO) Director General Kandeh Yumkella and French Meteorological Society President Jean Jouzel, for its World Meteorological Day celebration in Geneva on the afternoon of 23 March. In this issue, we publish articles based on their speeches:

- *The Sustainable Energy for All Initiative and Climate Change Mitigation* and
- *Evolution of climate in Response to Human Activity*.

The centrefold Photo Exhibition – "*One civilization. One planet*." also featured in World Meteorology Day.

Sustainable development

Water is life. But it can also take lives. From droughts to floods – it requires constant vigilance and monitoring. *The 5 Essential Elements of a Hydrological Monitoring Programme* highlights the best practices, industry standards and new technologies that optimize efficiencies and maximize effectiveness for the preservation of vital ecosystems, safety of citizens and sustainable development.

Without financial support and investments climate services would not be a reality. Part of the *Green Climate Fund* should be used to support such infrastructure development and other decision-support mechanisms such as the Framework and would help scale up scientific and technical capabilities, especially in developing countries.

The Global Climate Observing System – 20th Anniversary

by David Goodrich[1] and William Westermeyer[2]

April 2012 marked the 20th anniversary of the Global Climate Observing System (GCOS) Programme, which ensures provision of the observational data and information that is the foundation for decisions on climate. The Global Climate Observing System is built on existing operational and scientific observing, data management and information distribution systems. It is based on the climate-relevant components of the WMO Global Observing System, the Global Ocean Observing System, the Global Terrestrial Observing System, and on various programmes monitoring additional key components of the climate system, such as atmospheric constituents. GCOS is sponsored by WMO, the Intergovernmental Oceanographic Commission (IOC) of United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environmental Programme (UNEP), and the International Council for Science (ICSU). It formally came into being at the first meeting of the GCOS Joint Scientific and Technical Committee in Geneva in April 1992.

In the 1980s and early 1990s, several global research initiatives were set up to help scientists better understand and predict various climate phenomena. But these scientists soon become aware of major problems embedded in the long-term observational record of climate – a record that would be vital to understanding and addressing climate change. The First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published in 1990, touched on the issue. In addition to its findings on the state of the climate system, the IPCC Report made the following statement on the observing system:

> Systematic long-term observations of the system are of vital importance for understanding the natural variability of the Earth's climate system, detecting whether man's activities are changing it, parameterising key processes for models and verifying model simulations. Increased accuracy and coverage in many observations are required. Associated with expanded observations is the need to develop appropriate comprehensive global information bases for the rapid and efficient dissemination and utilization of data.

In addition, the Second World Climate Conference (WCC-2) in 1990 issued an invitation to the World Meteorological Congress to strengthen monitoring and research within the World Climate Programme (WCP). Following this invitation, an expert meeting, hosted by the UK Meteorological Office in January 1991, elaborated the concept and sponsorship arrangements for a Global Climate Observing System. By early 1992, a Memorandum of Understanding to establish the Global Climate Observing System was in place among the proposed sponsors. A Joint Planning Office (later renamed the GCOS Secretariat) was established at WMO Headquarters in Geneva, a Joint Scientific and Technical Committee (which eventually became the GCOS Steering Committee) was appointed, and, by mid-1995, a comprehensive GCOS Plan had been finalized.

The Global Climate Observing System supports all aspects of the World Climate Programme, the climate change assessment role of the IPCC, and the international climate policy role of the United Nations Framework Convention on Climate Change (UNFCCC). In particular, it was conceived to provide sustained, comprehensive, climate and climate-related observations to:

- Detect further climate change and determine its causes;

[1] Former Director, GCOS Secretariat (June 2005-July 2008)
[2] Senior Scientific Officer, GCOS Secretariat (through 31 December 2011)

- Model and predict the climate system;
- Assess impacts of climate variability and change;
- Monitor the effectiveness of policies for mitigating climate change;
- Support adaptation to climate change;
- Develop climate information services;
- Promote sustainable national economic development; and
- Meet other requirements of the UNFCCC and other international conventions and agreements.

Thus, the GCOS Programme aims to provide comprehensive information on the total climate system, involving a multi-disciplinary range of physical, chemical and biological variables across the atmospheric, oceanic and terrestrial domains, including hydrological and carbon cycles and the cryosphere. It is intended to meet the full range of national and international requirements for climate and climate-related observations on all scales – global, regional and national.

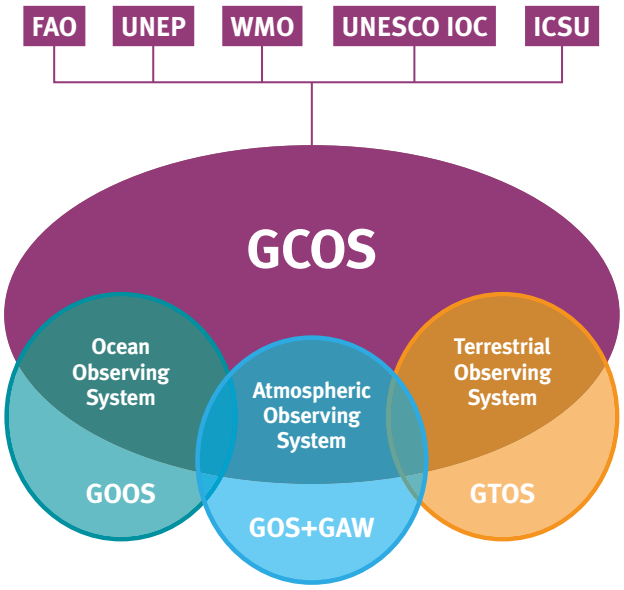
The GCOS Programme will formally celebrate the 20th anniversary of the Global Climate Observing System on Friday, 29 June 2012 during the 64th WMO Executive Council meeting in Geneva. The celebration will provide an opportunity to review the origins of the Global Climate Observing System, to take stock of the accomplishments of the GCOS Programme in the first twenty years of its existence, and to plan ahead for new opportunities and challenges.

Accomplishment to date

While there remain many gaps and deficiencies in climate-observing networks, there have been some notable accomplishments in the first two decades of the Global Climate Observing System. In the atmospheric domain the GCOS Surface Network (GSN) and GCOS Upper Air Network (GUAN) were created from the larger World Weather Watch network. GSN and GUAN consist of high-quality, long-duration stations especially appropriate for climate purposes. To assist in upgrading and/or renovating the stations in these networks, the GCOS Secretariat created the GCOS Cooperation Mechanism in 2001. This is a mechanism by which developed countries can make contributions toward the resolution of problems at priority climate stations in developing countries. As a result, the dedicated GCOS System Improvement Programme has renovated over 30 GSN and 20 GUAN stations and provided over 25 station-years of radiosondes to date. Another notable accomplishment in this domain has been the launch of a reference network for upper-air observations, the GCOS Reference Upper Air Network (GRUAN). This network is a hybrid observing system, combining operational upper-air measurements sites with research sites and providing high-quality reference data for atmospheric profiles.

A significant example of progress in the ocean domain is the creation of the global Argo float network. The Argo Programme reached its goal of 3 000 floats in 2007 and currently has over 3 500 floats in the water, providing one of the key data sets for monitoring ocean temperature and salinity. With Argo in mind, the global expendable bathythermograph (XBT) network was redesigned to consist of frequently repeated and high density lines.

Inaugural Meeting of the GCOS Joint Scientific & Technical Steering Committee, April 13 – 15, 1992, at the World Meteorological Organization, Geneva, Switzerland



The fundamental design concept for the GCOS was to build it as a system of climate relevant components of the established observing systems

In addition to the broad coverage provided by these networks, a worldwide system of reference stations, known as OceanSITES, has been deployed, providing full-depth coverage at 60 sites for dozens of variables. Overall, the number of in situ oceanographic reports has gone from roughly 4.5 million in 1999 to more than 16 million in 2009. Taken as a whole, these platforms provide a rich and complementary perspective on the global ocean.

There has also been progress in terrestrial networks for climate since the Global Climate Observing System was founded, although progress has not been as rapid as in other domains. Examples include the increased commitment of space agencies to produce fundamental climate data records from existing systems, which has led to improved availability of global datasets, such as of burned area, fraction of absorbed photosynthetically active radiation, and land cover; the improved overall performance of in situ glacier monitoring networks; and the increasing collection of permafrost data as a result of a focus on this data during the 2008-2009 International Polar Year.

Aside from facilitating improvements in specific networks, the GCOS Programme has been active in a number of other ways that have facilitated improvements in the long-term climate record. An important example is the formulation of the GCOS Climate Monitoring Principles. Today, these principles provide the framework for the design and operation of climate networks globally, both satellite and in situ. The GCOS Programme has also established important links with the UNFCCC, becoming the respected voice of the climate-observing community in this forum. It reports regularly to the UNFCCC's Subsidiary Body on Scientific and Technological Advice and is frequently asked by the Conference of the Parties to the UNFCCC to assess the status of climate observing networks and to report on progress in implementing needed improvements. Thus, the GCOS Programme, drawing on its large network of experts, produced the *Report on the Adequacy of the Global Climate Observing Systems* in 1998, which it updated in 2003. It was then asked by the UNFCCC to prepare an implementation plan addressing the needs identified in the "Adequacy Report." The *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* was first prepared in 2004 then updated in 2010, following the release of a progress report in 2009. The UNFCCC has found these documents very useful, and the GCOS Programme plans to update them at regular intervals every five or six years.

In addition, in 1999 the UNFCCC asked the GCOS Programme to organize a Regional Workshop Programme to identify priority observing system needs in developing countries. Conducted between 2000 and 2006, this Programme led to the preparation of Regional Action Plans in ten regions of the world. However, implementation of the project proposals has proved more difficult than preparation of the Plans. While some have been implemented, many remain to be carried out. In an attempt to assist African regions in identifying funding for implementation, the GCOS Secretariat helped organize a meeting in Ethiopia in 2006 that led to the establishment of the Climate for Development in Africa Programme. This important programme is now poised to assist funding of African observing system needs. The GCOS Programme will continue to work with other regions to help them mobilize resources for addressing priority needs.

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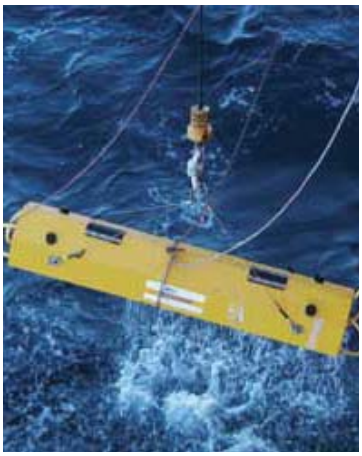
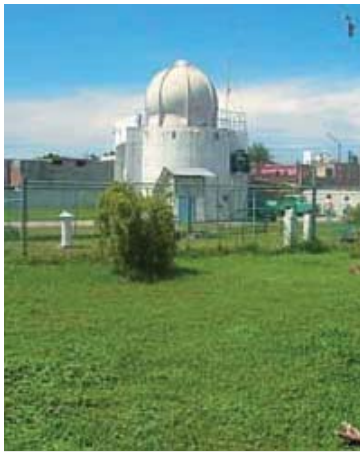
An Argo float is deployed in the Southern Ocean (left). It then pops out of the water to signal it is working (right).



Sabrina Speich



Roger Pielke | Richard Thigpen

A surface station in Mazatlan, Mexico (left) and the launch of an upper-air station during a GUAN upper-air training workshop in Windhoek, Namibia (right).

M. Hoelzle/University of Zurich

Density measurements in a snow pit in a glacier accumulation zone.

Finally, the GCOS Programme can take satisfaction in its promotion of the development of satellite observing systems for climate. There has been direct and intense interaction between the GCOS Programme and the satellite community over the 20-year history of the Global Climate Observing System. One of the highlights of this interaction has been the development of a strong working relationship between the GCOS Programme and the Committee on Earth Observing Satellites, the primary international forum for coordination of space-based Earth observations. In 2006, for example, space agencies, through the Committee on Earth Observing Satellites, responded to the GCOS climate requirements across the atmospheric, oceanic, and terrestrial domains identifying 58 separate actions to be undertaken. In addition, the Committee on Earth Observing Satellites requested a more detailed analysis of satellite climate observing needs. This was provided in 2006 as the so-called Satellite Supplement to the GCOS Implementation Plan and again in 2011, following the release of the updated Implementation Plan.

Future opportunities and challenges

Despite these key accomplishments in the last 20 years, there are still a significant number of needs to be met. This is especially the case in developing countries, where some networks have been deteriorating, rather than improving, despite the efforts of the GCOS Programme and others.

As the GCOS Programme looks to the future, some important new challenges have come into focus. The expert segment of the World Climate Conference-3 in 2009 identified the Global Climate Observing System as one of the essential elements for a new Global Framework for Climate Services. New climate services are being demanded by important user sectors, including water resources, agriculture, health and disaster risk management. The Global Climate Observing System must be capable of meeting the needs for these new services at global, regional and local scales. Indeed, the effectiveness of climate services will depend at least partly on the adequacy of the component observing networks on

which the Global Climate Observing System is built.

The GCOS Programme has been an active participant in preparing the Implementation Plan for the Global Framework for Climate Services. With the WMO Observing and Information Systems Department and with other UN agencies and interested parties, it is assisting in the preparation of the Observations and Monitoring Annex to the Plan. It is anticipated that the Global Framework for Climate Services Implementation Plan and its Annexes will be approved at the Extraordinary Session of the WMO Congress in October 2012.

In addition to a new need for climate observations to support the development and use of climate services, there is a related need for climate observations for climate risk management and adaptation to climate change. A prerequisite for effective climate risk management and adaptation is the availability of reliable information about how regional climate is likely to vary in the future on seasonal and interannual time scales or change on decadal and longer time scales. In the near future, the GCOS Programme plans to organize a major workshop to better understand observing system requirements to support the design of effective adaptation measures. In the longer term, it will work to ensure that those requirements are met.

To summarize, much has been accomplished by the GCOS Programme in the last 20 years in support of the Global Climate Observing System. However, the challenge of creating and sustaining a fully functioning climate observing system that can meet the need for observations of the climate for science, policy, services, and assessment continues.

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Reaching the Last Mile with Mobile Weather Alert

User-interface platform in action

Hundreds of thousands of lives, and livelihoods, are threatened and lost every year in Africa due to the impacts of climate variability and severe weather conditions. Some, if not most, of such losses could be avoided if populations had access to reliable and localised weather information in a timely manner.

Many essential economic activities could also be better planned, and food security improved, if people were well informed of seasonal climate predications and could take appropriate actions. Agriculture, for example, would vastly benefit if farmers had seasonal information on rainfall and temperatures to help them decide which seeds to plant – yields would improve and, with it, the livelihood of the entire community.

Significant technological advances and analytical breakthroughs in the prediction of global climate and severe weather have led to the development of reliable weather and climate information products and services. But few in the developing countries, where the information is often most needed, have access to high-quality weather and climate products. Where such information is available, it is uncertain that it reaches the end-users who need it most and whose livelihoods depend on it. And, if it does reach them, it is uncertain that the users are able to understand the information and make decisions based on it.

WMO, through its network of National Meteorological and Hydrological Services around the world, is working to improve this situation by bridging the "last mile." With support from the Norwegian Government and the World Bank, the WMO Mobile Weather Alert project pilots the dissemination of weather and climate information directly to end-users in Uganda, taking advantage of the widespread availability of mobile phones.

Targeting farmers and fishermen

Over the past decade Africa has experienced an incredible boom in mobile phone use. According to International Telecommunications Union (ITU), Africa has had the fastest expanding mobile telephone market – growing at twice the rate of the global market – over the last five years. In sub-Saharan Africa, 9 out of 10 inhabitants with access to a telephone are using cellular telephony. In Uganda, 13 million people, about 38 per cent of the population, own a mobile phone. And there too the number is growing.

The WMO Mobile Weather Alert pilot projects launched in Uganda have two components, one targeting farmers, the other fishermen on Lake Victoria. Both emphasize the importance of continuous interactions between service providers and end-users. To be relevant, it is essential that service provider understand the real, on-the-ground, needs of end-users and are certain that those users understand the meteorological information that will be sent to them and can use it to make sound decisions.

Will it rain soon? That's what we need to know!

In Kasese District, in the south-west of Uganda near the boarder of the Democratic Republic of Congo, rain usually starts falling in the period from late February to early March, converting dry, red soil into green vistas. Farmers plan their ploughing and sowing activities on this long-standing temporal pattern of precipitation. But this is changing.

Some time ago on a late-March day, when Bithibanji Adidas, a farmer in Kasese, looked up the sky, there was still no sign of rain. In the previous weeks, clouds had covered the sky several times but only a few drops had

fallen. The local farmers were worried and kept turning to him for advice, but he had none.

Bithibanji is the "Community Knowledge Worker" of the Grameen Foundation, an organization that helps local microfinance institutions to become more effective and that provides innovative mobile phone-based solutions to the poor. He has a smart phone, given to him by the Grameen Foundation, on which he can access a range of valuable information regarding agriculture. On it, for example, he can see the buying prices for various agriculture products at the different marketplaces in the region, information he shares with the local farmers, which helps them to determine where to bring their crops to market. It also gives him access to other practical information, such as how to deal with damages diseases and harmful insects cause to crops. The Grameen team in Kampala works with various partners to keep the information he receives up-to-date.

So Bithibanji's friends, fellow farmers, were used to coming to him whenever they needed more information than what they could observe themselves on which to base the decisions to be made on their farms. Bithibanji used his "magical" phone to answer their inquiries. In so doing, he acted as an information intermediary, responsible to help other farmers in his community with the mobile devise entrusted to him by the Grameen Foundation.

But the question he was asked most frequently, "When will it rain?", remained unanswered. On that most important question, his magical phone was silent.

Launch of the farmers' weather alert module

Some 90 per cent of Uganda's rural population survives on subsistence farming, which is mostly rain fed, so it is not only Bithibanji and farmers in his community who long to know what weather and climate to expect for the next season. To increase their resilience to changing climatic conditions and improve their livelihoods, all Ugandan farmers need to access such information and use it in decision-making.

Thus, in February 2012, the Uganda Department of Meteorology launched the agricultural component of the Mobile Weather Alert pilot project in Kasese District in close collaboration with the Grameen Foundation and WMO. The project aims to enhance the end-to-end process in agro-meteorological services and to deliver agricultural advisories in conjunction with 10-day, monthly and seasonal forecasts more directly to farmers in Kasese District through Community Knowledge Workers.

The success of the project depends on effective two-way communication between the service provider and end-users. A training workshop, organized for the 21 Community Knowledge Workers in Kasese District at the launch of the project, offered an ideal opportunity for enhancing interaction between the two groups. During the workshop, a meteorologist from the Uganda Department of Meteorology offered an explanation of how to interpret weather and climate information and agricultural advice, and Community Knowledge Workers openly discussed what types of information products they would like to receive and what would be most helpful.

For the first time, Bithibanji spoke directly with a "weather man". He was able to gain understanding of their work and of the different parameters measured at the weather station at the Kasese Airfield.

The farmers' component of the Mobile Weather Alert project in Kasese District also duplicated an initiative that had already proven successful in West Africa: plastic rain gauges were distributed to the Community Knowledge Workers so that they too – like the meteorologist – could record daily precipitation and participate in data collection. The Community Knowledge Workers were instructed on how to use the gauges and how to send the information to the Uganda Department of Meteorology with their cell phones. The data they collected would improve the quality of the weather and climate information products that the Uganda Department of Meteorology would provide back to them.

So, when will it rain? The Kasese Community Knowledge Workers received the first seasonal forecast and agricultural advisory in the first week of March 2012. Now, Bithibanji can tell his fellow farmers when the rain is likely to start.

The Kasese pilot project will run until the end of 2012, when it is expected to roll out to a wider audience across Uganda.

Fishermen on Lake Victoria

Lake Victoria, the largest lake in African, is divided between Kenya, Tanzania and Uganda. Some 200 000 fishermen depend on the Lake for their livelihood. The fishing is usually carried out in small, overloaded, wooden boats. Lake Victoria is also extensively used for transport and trade. But most of those accessing the Lake cannot swim, and life jackets are not readily available to them. As a result, sudden strong winds, which bring high waves that capsize the wooden boats, have been estimated to cause the death of some 5 000 fishermen every year on Lake Victoria.

Thus up-to-date, accurate and easily accessible weather information is critical for the millions living from and along Lake Victoria. The use of mobile phones could improve the dissemination of storm warnings and prevent unnecessary loss of lives on the Lake. Fishermen would be able to make more informed decisions on when and where to fish if they received weather information and warnings on their cellular phones. Even if they were already out on the water when the information came in, they could use it to decide whether to stay on the Lake or seek shelter in safe havens. Weather information would help to save many lives and would enhance the livelihoods of the communities around the Lake, where many fishermen are the sole providers for large families.

The Uganda Department of Meteorology and WMO, together with Ericsson Communications, MTN Mobile and the National Lake Rescue Institute, piloted the Mobile Weather Alert service for fishermen in Kalangala District in south-western Uganda in May 2011. Since then, one thousand fishermen from various communities in the Ssese Islands have registered for the service.

During the pilot project, tailored local weather forecasts were sent to registered fishermen every day by SMS (short messaging service). The forecast were provided by the Uganda Department of Meteorology, which is also responsible for providing severe weather warnings over the islands' part of Lake Victoria. The Uganda Department of Meteorology links to MTN Mobile through an application developed by Ericsson, which ensures forecasts are captured in an appropriate way and delivered through the SMS platform to the fishermen in the islands.

An important part of Mobile Weather Alert project was, again, the establishment an interchange between the pilot communities and service providers in order to collect feedback on the service. The National Lake Rescue Institute played a key role in this as they have a long history of interaction with the fishing communities. In addition to the continuous feedback on the usability of the service, two surveys were carried out in order to gain a better understanding of the acceptability and usefulness of the service amongst the communities as well as how the service could be improved in the future.

Fishermen highly valued the accurate and specific information delivered to their mobile phones. The service is in provided in the local language, Luganda, and messages are easy to understand. Abubakar Mutyaba, a fisherman from Bubeke Island commented, "The Mobile Weather Alert has enhanced our lives in many different ways. It has helped by informing us of the weather conditions on the lake and has reduced accidents."

"The Mobile Weather Alert has done a very good job," also noted Robert Ssebalamu, a fisherman and trader from Kalangala District. He explained, "Before we would go on the lake without knowing if the weather would change or not, but now it is just a matter of looking at my phone in the morning and I am informed on how

the conditions are going to be during the day and I can decide whether to go onto the lake or not."

The pilot project demonstrated the clear demand, and need, for these types of services in Uganda.

Improving the delivery of climate and weather services

Behind the Mobile Weather Alert project lies regional initiatives such as the long-standing Greater Horn of Africa Climate Outlook Forum, which issues the consensus based seasonal climate outlook twice a year, and the Severe Weather Forecasting Project (SWFP) for Eastern Africa, which is aimed at strengthening the capacity of the National Meteorological Services in the region and improving the confidence of forecasters in respect to severe weather events.

The Mobile Weather Alert also aims to enhance the weather observation network of Uganda to support the provision of higher quality weather and climate information products. For the farmers' part of the project, in addition to the one currently deployed at the Kasese Airfield, two new weather stations have been installed in Kasese District, which will be integrated into the national observation network.

Observations of the lake surface temperature are of particular importance in forecasting severe weather in the Lake Victoria region. Differences between the temperature of the lake surface and the surrounding land surface generate convective weather processes that produce thunderstorms, which bring heavy precipitation and strong winds. The UK Met Office is helping to install observations on the Lake and is supporting the forecast team in Uganda in order to improve severe weather forecasting.

While the lack of weather information is starkest in Africa, mobile telephone solutions are suitable for expansion to other regions. The services provided in the Mobile Weather Alert project are designed to be replicable and scalable to any community and can be adapted to fit other user needs that rely on weather in decision-making.

The February Mobile Weather Alert workshop facilitated communication between the service providers and end-users. The two groups gained an appreciation of each other's work and information needs.

Green Climate Fund

What is it and what are its aims?

The Green Climate Fund is being set up as the global channel through which most climate finance will flow. It is the intended distribution mechanism for US$ 100 billion in assistance, which developed countries have pledged to mobilise for developing nations annually by 2020. The new fund is intended to simplify the current complex network of funding mechanisms and bilateral agreements that provide low carbon and climate adaptation investment for developing countries.

The aims of the Green Climate Fund are:

Mitigation

- Establish clear goals and a timely schedule for reducing human-generated greenhouse gas emissions over time to keep the global average temperature rise below two degrees;
- Encourage the participation of all countries in reducing these emissions, in accordance with each country's responsibilities and capabilities to do so; and
- Review progress made towards the 2°C objective, with a review by 2015 on whether the objective needs to be strengthened in the future. This will include the consideration of a 1.5°C goal.

Transparency of actions

- Ensure international transparency of the climate change actions taken by countries, and ensure that global progress towards the 2°C goal is reviewed in a timely way.

Technology

- Mobilize the development and transfer of clean technology to boost efforts to address climate change, getting it to the right place at the right time and for the best effect on both adaptation and mitigation.

Finance

- Mobilize and provide scaled-up funds in the short and long term to enable developing countries to take more effective action; and
- Set up the Green Climate Fund to disburse US$ 100 billion per year by 2020 to developing countries to assist them in mitigating climate change and adapting to its impacts.

Adaptation

- Assist the particularly vulnerable people in the world to adapt to the inevitable impacts of climate change by taking a coordinated approach to adaptation.

Forests

- Protect the world's forests, which are a major repository of carbon. Governments have agreed to launch concrete action on forests in developing nations, which will increase going forward.

Capacity building

- Build up global capacity, especially in developing countries, to meet the overall challenge; and
- Establish effective institutions and systems that will ensure these objectives are implemented successfully.

Development of the Green Climate Fund

The 194 parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed on the formal launch of the Green Climate Fund at the Durban

2011 Conference of the Parties (COP) in December. The Copenhagen 2009 COP had first committed to provide developing countries with up to US$ 100 billion a year in funding from 2020 onwards to help them decarbonise their economies and adapt to climate change. Then, following the Cancun 2010 COP, which agreed that work would begin on the creation of a Green Climate Fund, the UNFCC appointed a "Transitional Committee" to the task. The Transitional Committee, supported by seconded staff from the United Nations and other international institutions, provided the impetus for the formal launch of the Green Climate Fund in Durban.

An interim Green Climate Fund Secretariat has now commenced work and regional groups are negotiating on who will represent them on the Governing Board, which will include 12 seats for representatives of developing countries and 12 for developed countries. Nominations for membership of the Board were submitted during the first Board meeting held from 31 May to 2 June 2012 in Geneva, Switzerland.

WMO Members Encouraged to Support Green Climate Fund at Rio+20

WMO encouraged its Members to support the Green Climate Fund at the United Nations Conference on Sustainable Development (Rio+20), held in Rio, Brazil, from 20–22 June 2012.

WMO recognizes the importance of strengthening the scientific, technological and innovation capacities of countries to promote sustainable development. However, further investments must be made into improving infrastructure at both national and regional and/or sub-regional levels as appropriate for observation, data management and processing, as well as the downscaling of climate predictions, to name but a few investment needs.

The Green Climate Fund should be used to support such infrastructure development and would help scale up scientific and technical capabilities and use of technology transfer especially in developing countries.

How will the fund be financed?

Financing is a major issue. The actual volume of finance that will be available through the Green Climate Fund mechanism remains uncertain. The Republic of Korea, Denmark, Switzerland and Germany have pledged assistance, including financing totalling more than EUR 55 million in contributions, to the start-up costs of the Fund.

The Durban COP did not secure commitments for sustained financial contributions – long-term financing is still addressed in general terms. The Durban agreement does not create any obligations for developed countries to contribute funding (Report of the High Level Advisory Group on Climate Finance).

Governance

Once established, the Board of the Green Climate Fund will be accountable to the UNFCCC COP and will includes seats (the number has not yet been determined) for private sector and civil society observers. A UNFCCC standing committee will be created to review activities and provide independent guidance.

How will the Green Climate Fund be accessed?

Like the Adaptation Fund[1], recipient countries will designate national authorities to review and endorse proposed projects. The Green Climate Fund will allow recipient countries access through accredited National Implementing Entities, but also work through Multilateral Implementing Entities. A private sector facility that can provide financing directly to private business will also be created.

WMO became accredited to the Adaptation Fund as a Multilateral Implementing Entity in December 2010. The accreditation authorizes WMO to propose adaptation projects on the behalf of its eligible Members. Eligible Members are those countries included in the list of "Non Annex 1 Parties to the Convention."

Information adapted from content of reports and statements made through UNFCCC www.unfccc.int and www.business-green.com.

1 The Adaptation Fund was established by the Parties to the Kyoto Protocol of the UNFCCC to finance concrete adaptation projects and programmes in developing countries that are Parties to the Kyoto Protocol. The Fund is financed with 2 per cent of the Certified Emission Reduction (CERs) issued for projects of the Clean Development Mechanism (CDM) and other sources of funding.

Powering our Future with Weather, Climate and Water

Each year, on 23 March, World Meteorological Day commemorates the entry into force, in 1950, of the WMO Convention creating the Organization. The 2012 theme for World Meteorological Day was *Powering our future with weather, climate and water*. This focuses on the critical roles of weather, climate and water services in powering a sustainable future for us and for generations to come.

Every moment, every day, National Meteorological and Hydrological Services around the world gather and analyse data on weather, climate and water and convert it to value-added information that protects lives and livelihoods and is fundamental to the present and future well-being of our society and our planet. The examples of this are myriads. Our food and farming supply must be tailored to the climate of a region and the available water. Industrial processes need ample water and energy. Cities need clean air and protection from storms and floods. International trade and tourism depend on safe and efficient transportation.

WMO Private Sector Forum

WMO hosted its first Private Sector Forum on the morning of World Meteorological Day. The Global Framework for Climate Services provides an excellent opportunity for the private sector to benefit from enhanced, and more accessible, climate services and information. It also promises to make full use of private sector expertise. During the Forum four speakers from the private sector discussed their needs for climate services. The forum provided a platform for interaction between WMO and key private sector agencies. The event was webcast live from the WMO. (The webcast is available at www.wmo.int/pages/prog/wcp/WMO-PrivateSectorForum_Webcastoff.html.)

We rely on up-to-the minute, reliable weather forecasts for everything ranging from social activities to multi-million dollar decisions. According to one recent study, US economic output varies by up to US$ 485 billion a year – about 3.4 per cent of Gross Domestic Product – owing to weather variability.

Human activities increasingly impact on our weather, climate and water. National Meteorological and Hydrological Services are at the fore of efforts to observe and understand this complex inter-relationship. Now more than ever, we need climate projections for the future. And we need to increase our knowledge about how global climate phenomena play out at regional, national and local level.

This rationale forms the basis of the Global Framework for Climate Services. This far-reaching initiative will help countries – especially those most vulnerable – manage the risks and seize the benefits of a changing climate. It will unleash the potential of the billions of dollars invested in climate observations, research and information management systems. Disaster risk reduction, water management, food security and health are its top priorities.

National Meteorological and Hydrological Services have an important role to play in *Powering our future with weather, climate and water* through the Global Framework for Climate Services. The various activities organized at WMO headquarters to mark World Meteorological Day highlighted that role. The three articles that follow are based on presentations made that day. The first two are by the guest speakers at the official WMO ceremony and the last is by a speaker participating in the first WMO Private Sector Forum. We have also published a series of photographs in our centrefold from the movie "One planet. One civilization.", by Gaël Derive, an extract of which was shown at the WMO ceremony.

The Sustainable Energy for All Initiative and Climate Change Mitigation

by Kandeh Yumkella[1], Nebojša Nakicenović[2], Morgan Bazilian[3] and Jessica Jewell[4]

This paper briefly explores the climate change mitigation benefits from the goals of the United Nations Sustainable Energy for All Initiative. In doing so, it relies on the analytical work and scenarios of the forthcoming Global Energy Assessment.[5]

Energy powers human progress, from job generation to economic competitiveness, from strengthening security to empowering women, energy is the great integrator: it cuts across all sectors and lies at the heart of all countries' core interests. Now more than ever, the world needs to ensure that the benefits of modern energy are available to all and that energy is provided as cleanly and efficiently as possible. This is a matter of equity, first and foremost, but it is also an issue of urgent practical importance – this is the impetus for the UN Secretary-General's *Sustainable Energy for All Initiative*.

This initiative was launched in a time of great economic uncertainty, great inequity, high urbanisation, and high youth unemployment. It is also a time where there is emerging consensus on the need to act cohesively and urgently towards global issues such as sustainable development and climate change. How we capture opportunities for wealth and job creation, for education and local manufacturing will be the key to unlock any real revolution. Addressing a transition to a radically different, and inclusive, energy system is a generational challenge. To this end, Economist Jeremy Rifkin cites[6] numerous interacting crises as the impetus for, "a new economic narrative."

The UN responds

Three linked objectives underpin the goal of achieving *Sustainable Energy for All* by 2030:

1. Ensuring universal access to modern energy services
2. Doubling the rate of improvement in energy efficiency
3. Doubling the share of renewable energy in the global energy mix

These three objectives are mutually reinforcing. Increasingly affordable renewable energy technologies are bringing modern energy services to rural communities where extension of the conventional electric power grid would be prohibitively expensive and impractical. More efficient devices for lighting and other applications require less energy and thus reduce the amount of power needed to support them. And finally, the alternative – unconstrained expansion of today's conventional fossil fuel-based energy systems – would lock-in a long-term infrastructure commitment to an unsustainable emissions path for the world's climate.

Climate impacts of Sustainable Energy for All

Although the primary focus of the *Sustainable Energy for All Initiative* is not climate change mitigation, achieving the three objectives is consistent with limiting the increase in mean global temperature to below two degrees Celsius in the long run. The International Energy Agency's (IEA's) *World Energy Outlook 2011* finds that early investments in

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5 *Global Energy Assessment – Toward a Sustainable Future, 2012*, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria & Cambridge UP, Cambridge, UK and New York, NY, USA. ISBN: 9781107005198.
6 MakingIt Magazine, Q1, 2012.

sustainable energy pays off: for every US$ 1 of investment undertaken in the power sector before 2020, US$ 4.30 in spending to compensate for increased emissions can be avoided after 2020. In addition, to enable at least basic levels of energy access for all has minimal implications for greenhouse gas (GHG) emissions (Figure 1).[7]

The *Sustainable Energy for All* objectives are aligned with pathways that would stabilize global temperature. Figures 2 and 3 show an energy future where all the *Sustainable Energy for All* objectives are met. We can compare this scenario to a hypothetical energy system development, based on current trends and to six scenarios from the *Global Energy Assessment* that, in addition to meeting the Sustainable Energy for All objectives, stabilize climate change to less than 2°C. The forthcoming Global Energy Assessment is the largest cross-disciplinary study on energy systems and their futures. Its analytics help us quantify the impacts of the *Sustainable Energy for All* objectives, their multiple benefits and also their contribution toward climate change mitigation.[8]

In the baseline, energy increases by about 50 per cent and GHG emissions by about 60 per cent. This is because the baseline is fossil intensive – basically not fundamentally different from the IEA's *World Energy Outlook* reference case through 2030. In the S*ustainable Energy for All* scenario, final energy use increases by about 10 per cent between 2010 and 2030 while for the six *Global Energy Assessment* scenarios final energy demand increases by less than 2 per cent over that period.[9] At the same time, emissions stay constant in the *Sustainable Energy for All* scenario while in the *Global Energy Assessment* scenarios they decrease between 16-35 per cent. The change in the *Sustainable Energy for All* scenario compared to the baseline shows energy-related emissions down about 30 per cent (Figure 3).

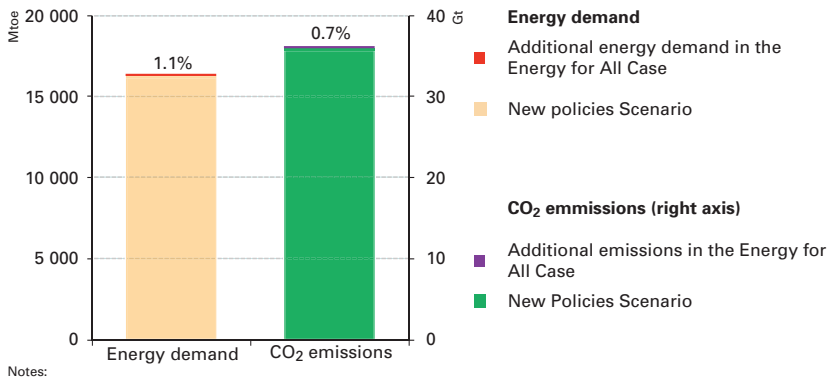
The decrease in GHG emissions reductions from the *Sustainable Energy for All* objectives significantly contributes to a temperature-stabilization profile with likely climate stabilization at 2.0°C.

Figure 4 highlights one of the *Global Energy Assessment* scenarios that meet the *Sustainable Energy for All* objectives. The light gray area in the main graph

[7] Of course, this would vary according to assumptions about per capita consumption levels.

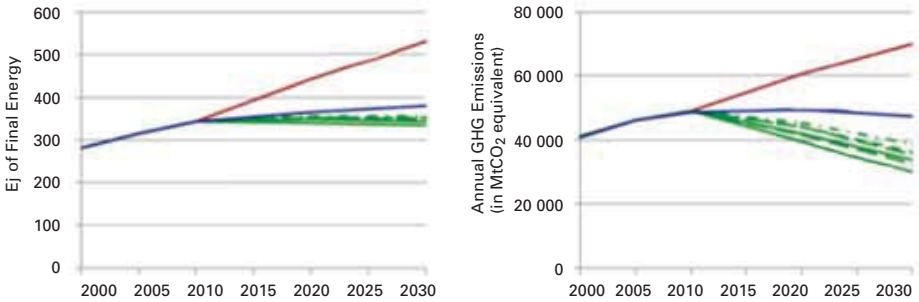
[8] These scenarios focus on analysing energy system transformations, and thus, other drivers of change such as population and Gross Domestic Product (GDP) do not vary across the six scenarios. Population increases by 20 per cent to 2030 (by about 1.3 billion) and GDP by 80 per cent.

[9] This is much more "humble" compared to the roughly 50 per cent reduction one would have by simplistically applying the objectives to the current system (all else being equal).



Notes:
Percentages are calculated as a share of the total energy demand or CO_2 emissions respectively in 2030.
Gt = gigatonnes
Mtoe = Million tons of oil equivalent

Figure 1 – Additional energy demand and CO_2 emissions from the IEA's Energy for All Case compared with the New Policies Scenario (IEA, 2011)



Notes:
Ej = Exajoule
Mt = millions metric tonnes

Figure 2 – Final energy demand and GHG Emissions in the Global Energy Assessment scenarios (blue lines) and compared to a business as usual case (red line)

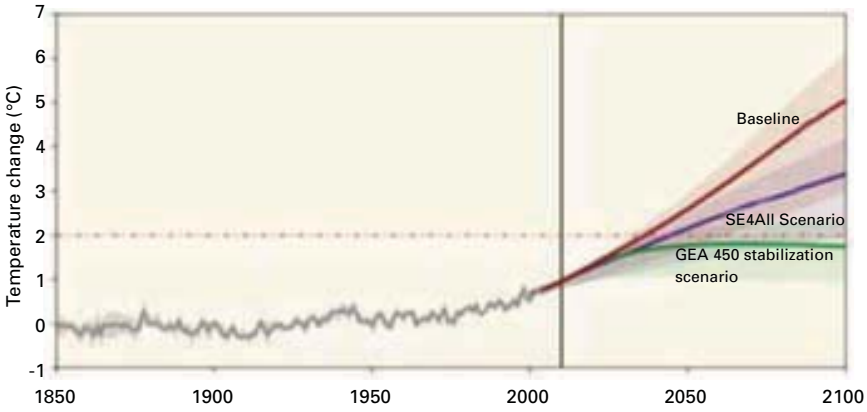


Figure 3 – Temperature profiles for the Sustainable Energy for All scenario as well as a baseline case and one of the Global Energy Assessment scenarios.

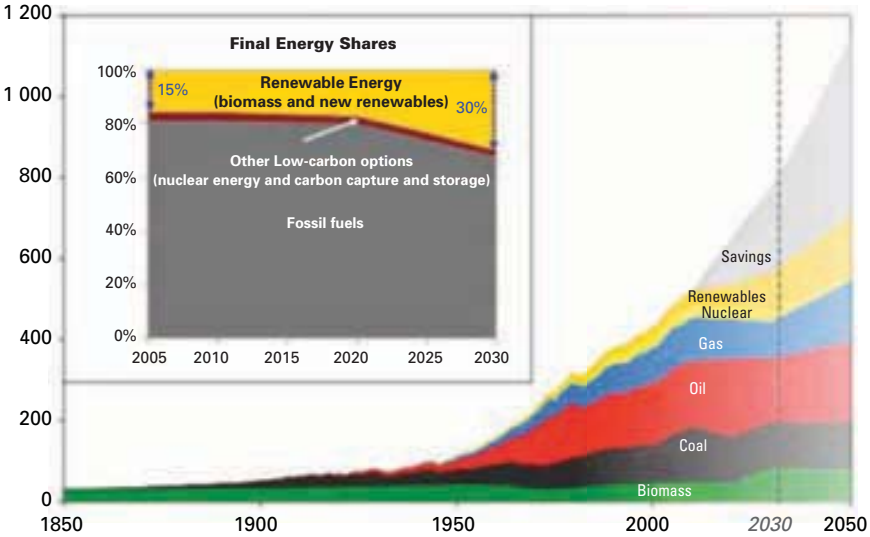


Figure 4 – One of the Global Energy Assessment scenarios that meets the Sustainable Energy for All objectives shown with the historical context.

illustrates the central role of efficiency in both reducing demand and enabling renewable energy. This illustrates how 'negawatts' – or avoided energy demand – are a critical lever in achieving the *Sustainable Energy for All* objectives. Doubling the share of renewable energy is possible with commercially-available technologies but only if current energy efficiency improvement rates are dramatically increased. Figure 4 also shows the two historical transformations that the world has experienced. First, the industrial revolution when horse-power was replaced by machines, and second, the age of diversification when energy technologies multiplied as a result of increasing energy demand from the introduction of the light bulb, internal combustion engine, aircraft and most recently, the Internet.

Achieving the *Sustainable Energy for All* objectives would bring social, health, environmental, economic and security benefits. Ensuring universal energy access would foster development for the world's poorest and drastically reduce negative health impacts associated with traditional forms of energy in developing countries. The three objectives are also consistent with avoiding climate change and would reduce local air pollution. Finally, the dramatic changes to the clean energy sector that the *Sustainable Energy for All* objectives imply have the potential to support the global economy by providing growth and job opportunities in rapidly growing industries.

An important year

The UN General Assembly named (Resolution 67/151) 2012 the *International Year of Sustainable Energy for All*– thus placing energy at the heart of the multilateral process for the first time. It represents, inter alia, a significant opportunity to share models that work, are scalable and can help fill gaps in existing funding or capacity. It is also a chance to ensure that the political momentum currently focused on this area is maintained. We must do considerably more than scratch the surface for an issue that deeply impacts all of our lives. This means firm commitments from many different stakeholders, well-planned country actions, a dedicated set of funding and financial tools, and ways to track progress. To begin, go to www.sustainableenergyforall.org, and join us!

Photo Exhibition – “One planet. One civilization.”

A film by Gaël Derive

People from Ethiopia, Nepal, Kiribati, Brazil, Nunavut and Bangladesh – their common link: they share the same planet and civilization. Each has a unique lifestyle, based on their experiences in diverse climates throughout the planet, be they equatorial, semi-arid, monsoon, mountain, oceanic or polar. “One plant. One civilization.” discussed their present situation – agriculture, food, water and climate – and debates their future in a changing climate. The stakes are high. How can we ensure access to food while protecting the climate and ecosystems?

There will be another two billion people on the planet in 40 years, and climate conditions are changing fast. Each encounter in the film brings a unique perspective. Each has an answer to the question: What kind of civilization do we want?

www.gaelderive.fr

Evolution of Climate in Response to Human Activity

by Jean Jouzel[1]

It is useful to recall what scientists have said about the evolution of our climate in response to the increased greenhouse effect caused by human activity. I will, therefore, recall the findings of the Fourth Report of the Intergovernmental Panel on Climate Change (IPCC) published in 2007 (AR4) and of the Special Report on Extreme Events (SREX)[2]. The conclusions presented in the summary report for decision-makers, entitled *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, were approved in spring 2011; they seem particularly relevant in the context of our symposium.

The fourth IPCC report confirms some of the truths about climate change, but it also clearly reiterates that questions remain and that major uncertainties surround many aspects of our climate.

The first thing we can be sure of is this: the composition of the atmosphere is definitively affected by human activities. Since 1750, the quantity of methane in the air has multiplied by 2.5, due essentially to the intensification of agriculture and cattle-raising. The use of fossil fuels – together with deforestation – is largely responsible for the observed increase in carbon dioxide, which since the beginning of the industrial era (around 1750) to 2012 has increased 40 per cent, whereas fossil fuels – together with agricultural/farming practices – have caused a nearly 20 per cent increase in nitrous oxide. By absorbing infrared radiation, those gases increase the greenhouse effect, also aggravated by other compounds such as ozone and chlorofluorocarbons. There is no doubt about the anthropogenic origin of the changes observed, which are very well-documented (water vapour is also a greenhouse gas but its concentration in the atmosphere is not directly affected by human activities).

The second AR4 finding is also a certainty: "warming of the climate system is unequivocal." Apart from 1996, each year between 1995 and 2007 has been warmer than any other in over 140 years. This global warming has occurred in two stages: from 1910 and 1945, then the second began in 1976. Since then, temperatures have increased at a rate three times faster than that recorded in the rest of the twentieth century. The plateau observed in the last ten years does not reopen the question of global warming – 2010 was the warmest year on record and though temperatures did drop slightly in 2011 that was only due to a significant La Niña event (Figure 1). A number of observed phenomena – such as the warming of ocean waters, increased water vapour in the atmosphere, the accelerated melting of most mountain glaciers, rising sea levels due also to the melting of the Greenland and West Antarctic ice sheets, and the retraction of the maximum snow cover in the northern hemisphere and of the minimum Arctic Ocean ice surface – confirm unequivocally that the Earth is getting warmer.

This double statement – the greenhouse effect is increasing and global warming is real – does not imply a causal relationship. In order to establish a link between global warming and human activity, we must distinguish between climate changes due to natural causes, which have always existed and will always exist, and those possibly caused by human activities. Have we already changed the Earth's climate? The IPCC has studied this question and the answer has evolved with each new report, following confirmation of global warming and thanks to a better understanding of its causes in the scientific community. No link was established in the first report published in 1990, but it was suggested for

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1 Researcher, Laboratory for Climate and Environment Sciences (LSCE/IPSL, CEA Saclay, 91191, Gif-sur-Yvette, France), and President, French Meteorological Society

2 Special Report from the Intergovernmental Panel on Climate Change – Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

the first time in 1995: "a number of elements suggest a perceptible influence of human activity on global climate". This diagnosis was confirmed in 2007: "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." A slight doubt remains, but for the meteorological scientific community no doubt subsists that we are definitely living in a world where human activities have already changed the climate.

Another certainty: the climate will continue to get warmer. Without underestimating the impact of other compounds, we cannot but note that the Earth's net radiation depends largely on emissions of carbon dioxide (CO_2). Apart from being the main cause of the increased greenhouse effect, carbon dioxide remains in the atmosphere for a long time. Economists have suggested different future scenarios that would take into account all greenhouse gases and sulphurous aerosols whose radiative effect is negative. By 2100, the lowest emissions scenario would feature an average warming of approximately 1.8°C; this figure would rise to 4°C in the highest emission scenario. With regard to a specific economic scenario, significant uncertainties remain because of our, still, limited knowledge of certain climatic processes. Therefore, in the highest emission scenario, the average warming would be between 2.4 and 6.4°C, while the full prediction range would be between 1.1 and 6.4°C.

Though we know that global warming is inevitable, there is still a lot we do not understand about how it will happen. Many aspects remain unclear: the role of aerosols, the regional characteristics of climate change and climate variability, the occurrence of extreme events, the importance of sea level rise, the risk of unknown climatic events, and the interactions between biogeochemical cycles and climatic change. However, the IPCC deems the projections on other climatic variables reliable: increased precipitation at high latitudes and decreased precipitation in subtropical regions, wind changes, a likely intensification of tropical cyclones, heat waves, heavy rainfalls, retraction of the snow cover, decrease of sea ice, irreversible sea-level rise … if we are not careful, that is what our world will look like at the end of the century and beyond. The sea level could thus rise by 60 cm or more by 2100.

The multiple effects of these changes will increase with rising temperatures, and so will various extreme events, which will cause greater damage. The first findings of the SREX, which focuses on extreme events, rely on observations made since 1950. These suggest,

Hydro-meteorological Information: a Tool for Social and Economic Development?

The French Meteorological Society held a two-day international symposium at WMO headquarters on 21 and 22 March entitled "Hydro-meteorological Information: a Tool for Social and Economic Development?"

Recent studies have underlined that hydro-meteorological information can yield economic and social benefits and gains in terms of security and quality of life. This is true for industrialized countries as well as for developing and emerging countries. However, weather forecasts and hydrological information, though a part of daily life in industrial countries, are largely absent from developing countries. Investing in the hydro-meteorological sector thus would be a good way of accelerating economic development and growth, and of alleviating poverty.

The symposium gathered experts and operational managers to discuss the financial and technical needs to produce quality hydro-meteorological information (observations and forecast) and to assess the social and economic benefits of these services to various economic sectors, such as health, risk management, insurance, industry, energy and agriculture. Presentations also looked at the solutions and options for developing sustainable hydro-meteorological services.

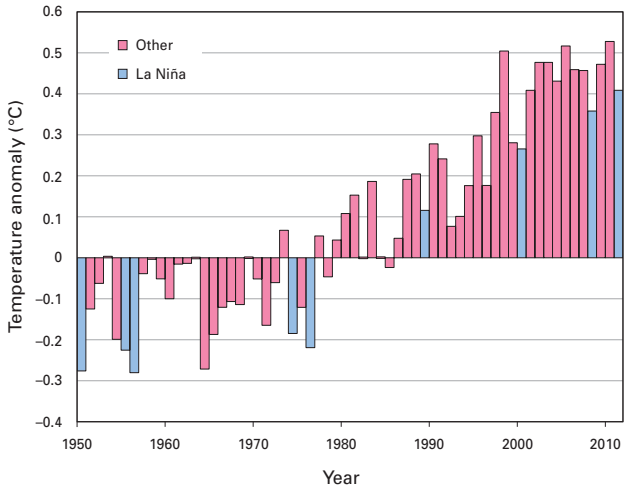


Figure 1 – Global surface temperature anomalies (relative to 1961–1990) for the period 1950– 2011; years that started with a moderate or strong La Niña already in place shown in blue

albeit with a limited degree of certainty, that certain extreme values are changing. Thus, on a global scale, the number of cold days and nights has decreased whereas that of warm days and nights has increased and, depending on the region, more heat waves, more severe droughts and a greater number of heavy rainfall episodes have been observed. Moreover the SREX indicates that there are reasons to believe that some of these changes are due to human activities.

A significant part of the report covers future trends in extreme climatic events for different emission scenarios. Thus, models project a noticeable rise in extreme temperatures resulting in the increased duration, frequency and/or intensity of heat waves. As Figure 2 shows, an extremely hot day, which once recurred every 20 years, will recur every 2 years from now until the end of the century (A1B and A2 scenarios). By then the frequency of heavy precipitation, or their incidence in the torrential rainfall, will probably have increased in most regions while in other areas droughts will become more severe in certain seasons due to decreased rainfall and/or to higher evapotranspiration. The maximum average wind speed associated with tropical cyclones will probably also increase.

The SREX does not deal exclusively with the observations and projections related to extreme climatic events. It also looks at their impact on sectors that are closely connected with climate, such as water resources, agriculture and food production, forestry, health and tourism as well as at losses resulting from the disasters caused by those extreme events. Finally, the report mentions the many strategies to adapt to global warming and deal with the risk of climatic extremes and disasters.

To conclude, I would like to mention that hazards induced by global warming and related extreme events should be easier to manage since we will be able to check future warming by adopting an ambitious worldwide strategy to curb and, subsequently, cut emissions of greenhouse gases.

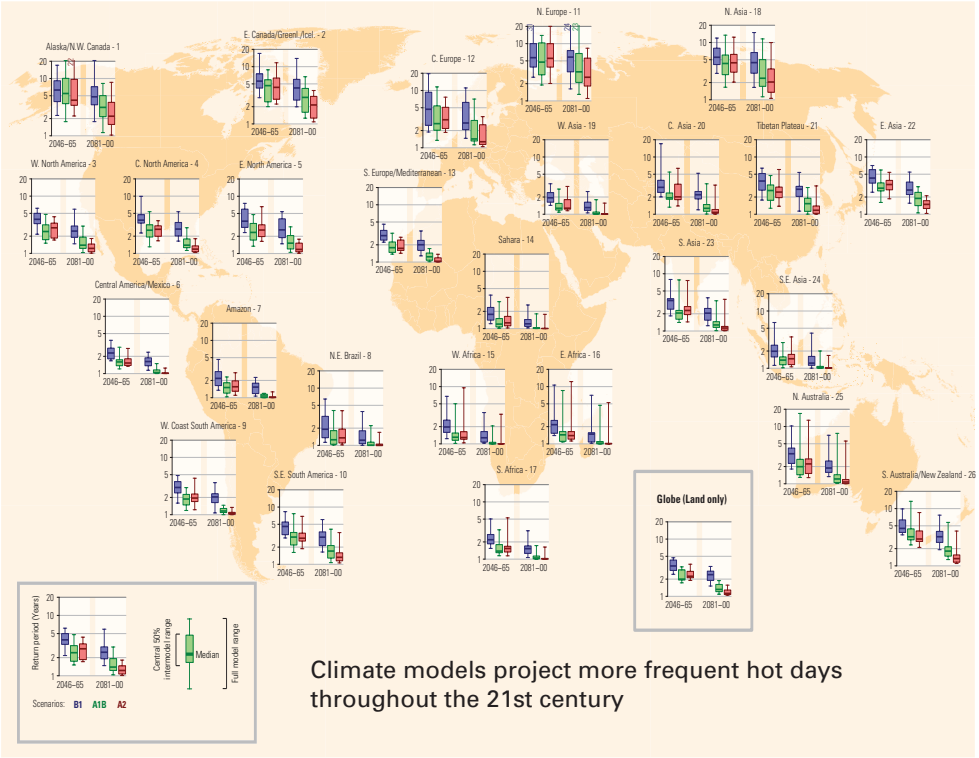


Figure 2 – In many regions, the time between "20-year" (unusually) warm days will decrease

Water Sector Industry Perspectives for Climate Services[1]

Xavier Maitrerobert[2]

AquaFed, the International Federation of Private Water Operators, represents private companies that deliver water supply or sanitation services under the direction of public authorities. Its members, local and international companies of all sizes, operate in some 40 countries. The majority of people who get water from private companies – mandated and regulated by governments – receive that service from members of AquaFed. Some supply water and sanitation daily to a few thousand people, others to hundreds of thousands and still others to millions or even tens of millions.

AquaFed's members operate public drinking water and sanitation services entrusted to them through public-private partnership contracts or licenses. They are under the instruction and control of the public authorities. Simply put, the private operators are tools public authorities use to implement water policies. Thus, AquaFed members are instruments for public policies. Their position is not unique. Many local, national and regional governments have sought out private-public partnerships called PPPs for the construction and/or operation of large projects. It is a prevalent practice in, for example, the energy sector for supplying electricity to the population.

AquaFed's global mission is to connect private water operators, international public institutions and civil society organisations. To achieve this goal, Aquafed has positioned itself as a channel between private water and wastewater providers and international stakeholders and has promoted the exchange of expertise within the two communities. Part of this work, involves explaining the various forms of Private Sector Participation models available to public authorities.

The European Commission of the European Union and the Economic and Social Council of the United Nations have both accredited AquaFed.

The operation of public water services

Private sector participation in the delivery of municipal public water and sanitation services covers less than 10 per cent of the world's population, if only formal arrangements are considered. However, an informal business sector of significant size has sprung up in developing countries where public water services are not provided or unavailable. For instance, evidence shows that up to 40 per cent of the urban population of Africa receives water from informal Small Scale Water Services Providers.

Public and private water service providers face the same operational, technical, economic and financial constraints no matter where they operate. Bear in mind that only 10 per cent of the "blue water" abstracted[3] worldwide is used for public water and sanitation services. The main share goes to agriculture – 70 per cent of the total volume.

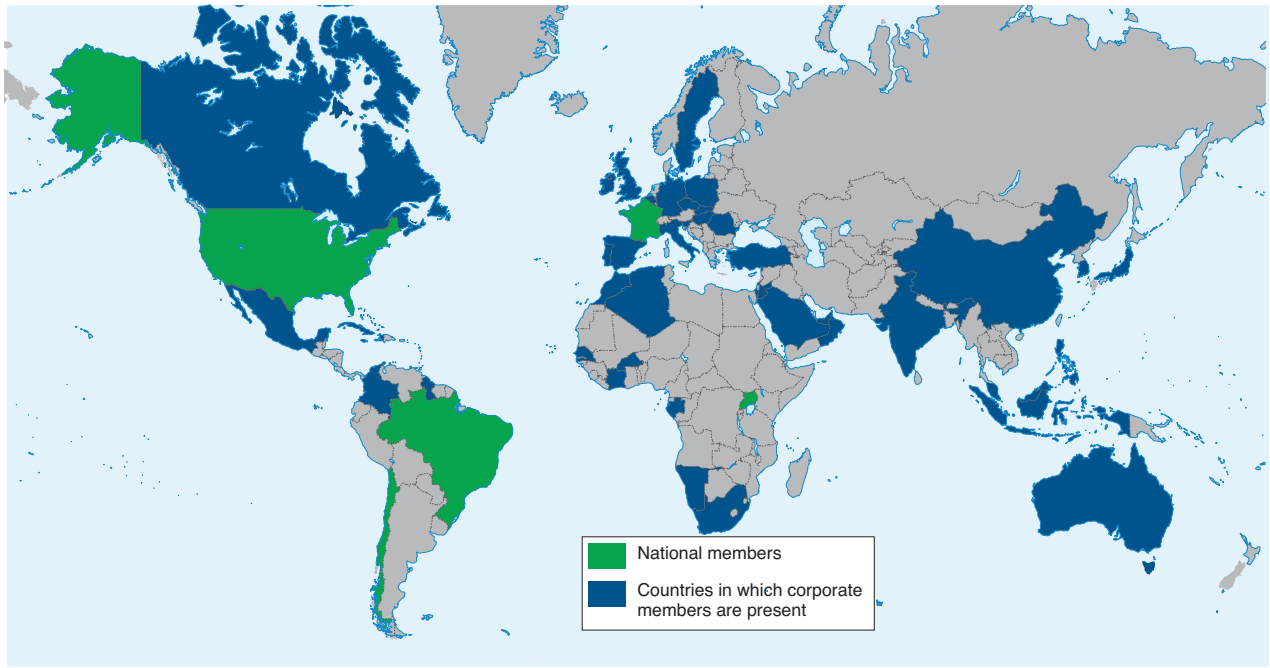
Meteorological data – requirements based on time horizons

Water operators/utilities as well as public authorities and regulators need meteorological information and data to fulfil their mission to provide satisfactory water and sanitation services to the population. In the water

[1] Article drawn from the presentation at WMO Private Sector Forum held on World Meteorological Day 2012 in Geneva

[2] Xavier Maitrerobert is an economist and engineer and has been the Senior Water Adviser within the team of water professionals of AquaFed

[3] Water abstraction, water extraction, or groundwater abstraction is the process of taking water from any source, either temporarily or permanently.



AquaFed membership

supply and sanitation sectors the information needed differs and depends on the time horizon.

Over the medium and short term – a year, a season, a week, a day or even in real-time – the perspectives and the corresponding need for meteorological data differs:

Supply side factors impacting municipal water services

- Infrastructure policies: dams, transfer of water, storage facilities
- Competition for use: other abstraction permits that might deplete aquifers
- Pollution of aquifers/sources: man-made industrial or agricultural pollutants
- Rainfall patterns impact aquifers/groundwater, surface water, temperature, climate change
- Saline intrusion caused by a rise in sea level and/or the depletion of local aquifers by over abstraction
- Urban and planning policies: draining of wetlands, faster run-off of rainwater, lower recharge of groundwater
- Ecological constraints.

- Year/season: Meteorological data are needed for budgeting processes and, more importantly, for revenue variation analysis. They are also required to predict the level of aquifers, groundwater and surface water and to provide useful input for the management of fresh raw water reservoirs on a seasonal basis.

- Week/Day: Weather – rain and temperature – have an immediate impact on water demand. Extreme rainfall forecasts are important to plan the potential consequences on urban sewerage networks and assess the risk of local flooding. Frost and defrost forecasts are used for the preparation of the operational ground teams who will have to handle the main breaks in the distribution network that such weather can cause. Such information is essential to anticipate potential problem and to better prepare for them.

- Real time: Supervisory Control and Data Acquisition[4] (SCADA) type systems are now being implemented more and more often by large urban water and sewerage services to manage drainage networks.

[4] AquaFed members have developed SCADA-type tools, examples include the RAMSES software developed by Suez Environnement which is used to manage the urban drainage network of Bordeaux, France, (see: http://www.lyonnaise-des-eaux.fr/collectivites/enjeux-leau-et-lassainissement/optimiser-gerer-anticiper) and a similar tool by Veolia Water - Kruger that provides real time control using weather radar (see: web.sbe.hw.ac.uk/staffprofiles/bdgsa/temp/12th%20ICUD/PDF/PAP005239.pdf and web.sbe.hw.ac.uk/staffprofiles/bdgsa/temp/12th%20ICUD/PDF/PAP005541.pdf).

These systems accurately monitor heavy rainfall by directly accessing weather radar type information from the local meteorological organization/office. SCADA contributes to better flood risk management and pollution control by providing early warning signals, alerting civil society to risks, allowing for better management and optimization of water storage and triggering on-site interventions. Most SCADA systems include hydraulic modelling of drainage networks.

Balancing supply and demand on longer horizons

Long term foresight – an ability to analyze data and predictions in an environment of uncertainty – is required for proper water investment planning given the long life and initial investment costs of such assets.

Over terms longer than 10 years, it is the duty of water operators and authorities to make sure that demand for drinking water in the area they service is met by the supply available from the assets they manage – boreholes, water treatment plants and networks of distribution pipes. This process is known as the supply/demand balance and applies equally for sewerage services. This balance, which most developed countries have achieved, has to be reassessed continuously in an ever-changing environment affected, amongst others, by economic and technical variations on the demand side and ecological and environmental variations on the supply side.

For instance, the volume of water resources available to supply drinking water to the population might be affected by the pollution of the aquifers they tap into. Some pollution may be man-made, for example, from industry or agriculture. These have to be monitored from the moment they are detected. Others may be the result of climate change, for example, saline intrusion due a rise in sea level and/or the depletion of local aquifer by over-abstraction. Models used in the decision-making process of water authorities and regulatory bodies take all of these parameters into account. They help water regulator to make decisions based on scientific predictions of the water that will be available for use under average and extreme conditions, taking into account all possible allocations of water.

England's well-documented and regulated water sector offers a clear demonstration of the benefits to be gained from considering and adjusting to factors that affect the supply and demand curves. The authorities have optimized investments and minimized costs by making sure that the two curves run closely along the same line. Investments are planned using the least costly options available on either the supply or demand side.

Demand side factors impacting municipal water services

- Per capita consumption
- Access to water (connection to municipal services)
- Network efficiency (leakages, state of the assets, etc.) and efficiency of water appliances
- Soft issues such as education, behaviour, impact of media messages about water scarcity
- Urban policies: population density, demographic trends, urbanisation, re-use, rainwater harvesting
- Tariff/price of water, including the sewage services often billed with water
- Temperature
- Rainfall patterns, for example, demand for garden water is greater in dry weather

"Water Resource Plans" and "Supply/Demand balance" are mandatory processes for private water companies in England and Wales. They are required by both the Environment Agency and the Water Services Regulation Authority and have to be updated on a rolling basis, 25 years sliding, in coherence with the comprehensive regulatory "Periodic Review" process for water tariffs every 5 years. The clear and detailed methodologies used to assess both side of the supply and demand balance even adjusts to reflect miscellaneous factors – such as headroom, outage, etc. – as per the frameworks designed by the sector in accord with regulatory bodies.

The methodological frameworks fully captures climate change factors and provides guidance on the assessment process to deal with average and extreme events and the risk of water shortage.

Conclusion

The management and operation of water utilities requires close collaboration with providers of meteorological information at the local, regional and global levels. It is AquaFed's view that WMO has an important role to play in improving the level of services public water and sanitation utilities provide to populations in the short and long term.

The 5 Essential Elements of a Hydrological Monitoring Programme

by Stuart Hamilton[1]

Water is the natural capital of the growing world population. Services built on our natural capital are the currency of the 21st century. The timing and spatial distribution of surface water quantity – and the variability in quality of that water – define how we design and build the infrastructure necessary for our energy, agriculture, mining, transportation and industrial sectors.

But water can also take lives. Droughts and floods are threats that require constant vigilance. Our ability to predict flooding, plan for droughts and support healthy ecosystems are challenged by land-use and climate change. Safe drinking water sources and entire ecosystems depend on continuous improvements in our understanding of, and efforts to protect, our water resources.

In fact, it is difficult to overstate the importance of the availability, reliability, and accuracy of data from water monitoring. Today's hydrometric monitoring networks range from volunteer stewardship of small watersheds to continental-scale initiatives. Collectively, they are the basis for every action taken to support beneficial uses of water and to minimize threats from water.

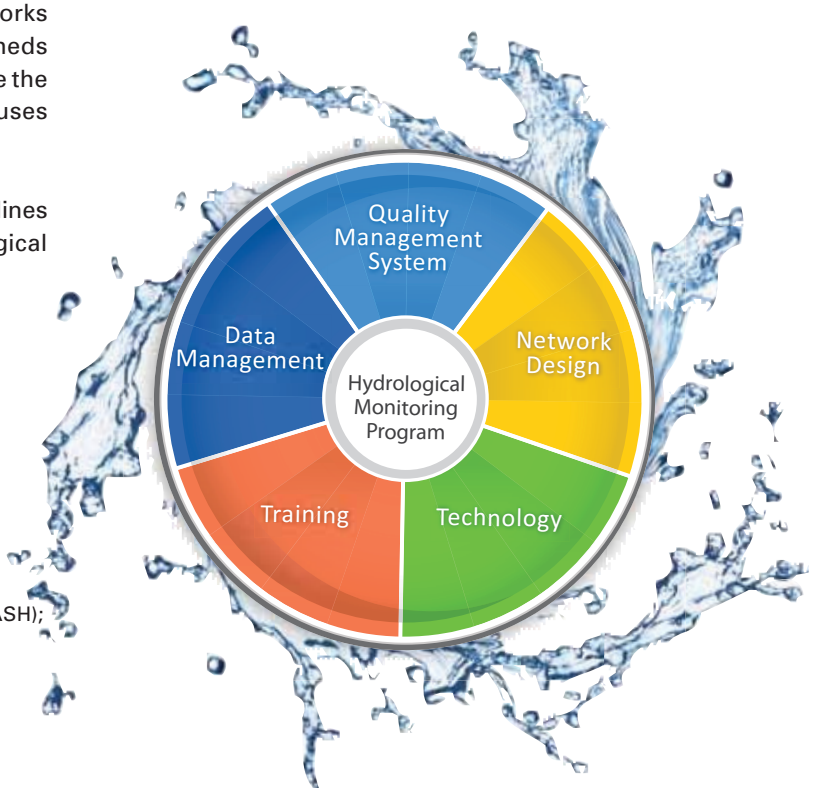
Written for water resource managers, this paper outlines the five essential elements of a successful hydrological monitoring programme:

1) Quality Management System
2) Network Design
3) Technology
4) Training
5) Data Management

The day-to-day work of the stream hydrographer has changed substantially from even a decade ago. It is time to review how these changes impact the end-to-end system for collecting and publishing credible and valid data. This document presents a modern 'best practices' approach to hydrometric monitoring. The practices are fully scalable to any size of network and can improve the availability, reliability, and accuracy of all water information assets.

1 Quality Management System

A Quality Management System includes a set of standard operating procedures that govern the data production process to ensure that the data are of consistent, known quality. Every monitoring programme requires clear objectives for (1) data quality, (2) service, and (3) security that are closely linked with the needs of



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the end users. The Quality Management System provides rules to direct and control an organization towards meeting these quality management objectives.

In evaluating or creating a Quality Management System, water resource managers must keep in mind the concept of "Fitness for Purpose." Data adequate to order an evacuation of a floodplain, for example, may be inadequate for testing a hypothesis about a trend. End-users of data develop a trust relationship with data providers based on their confidence that the quality management objectives – for data quality, service, and security – have been met with respect to their intended purpose.

Quality Objectives

Quality is a result of observation and information production processes. These processes need to be enforced by formal compliance with documented standard operating procedures. There are several industry sources for hydrometric standards, including:

- Techniques & Methods Reports published by the US Geological Survey (USGS);
- USGS Technique of Water-Resources Investigations Reports;
- International Organization for Standardization (ISO) Technical Committees 113 and 147;
- WMO publications prepared as part of the Quality Management Framework – Hydrology (No. 49 "*Technical Regulations* Vol. III Hydrology" - 2006 edition, publication No. 168 "*Guide to Hydrological Practices*" - 6th edition, and various manuals including the second edition of the *Manual on Stream Gauging*). (All these can be downloaded from the WMO Website free of charge.)

A commitment to internationally accepted technical standards provides a basis for inter-comparability of data. Data produced by different agencies (or even by different hydrographers within the same agency) should have similar accuracy and precision. This means that if hydrographers were to independently monitor the same gauge, the resultant discharge hydrographs would be very similar and without systematic bias.

Service Objectives

The service objectives address the completeness of the data (for given levels of quality assurance at different lag times since observation). Historically, hydrometric data was published annually, as aggregated daily values and extreme statistics. Today, the focus is on real-time, continuous publication of unit value data. A modern hydrometric service needs to address evolving expectations for data reliability and timeliness.

Achieving the desired service objectives is primarily a function of the balance between:

- Staffing (e.g. response time for instrument failure);
- Equipment specifications (i.e. instrument reliability);
- Life-cycle management of equipment (i.e. calibration and control procedures);
- Efficiencies in data production (e.g. automated notifications, auto-corrections, and auto-publication); and,
- Feedback from the data production process (e.g. sufficient metadata to support a continuous improvement process).

There is also an increasing expectation that data should be openly discoverable, searchable and accessible. Harmonized standards for data inter-operability are provided by the Open Geospatial Consortium. For example, the Water ML2.0 standard provides for the exchange of (1) point-based time series data, (2) processed values such as forecasts and aggregations, and (3) relevant information on monitoring points, procedures and context. By working within the Open Geospatial Consortium framework, water resource managers ensure that observations can be provided in the context of relevant coverages and features.

Security Objectives

Hydrometric data are valuable, demanding important capital, human and operational investments to obtain. The security objectives aim to protect these investments over the life of the data. In a well-maintained data management environment, the value of the data accrues with time.

But any information legacy is vulnerable to neglect, loss and destruction. Technological advancements can result in fragmented records and incompatible formats. Continuity between modern systems and historical archives must be managed with care and diligence.

The Global Climate Observing System (GCOS) Principles provide several best practices for maintaining data integrity when managing time series data. In particular: "The details and history of local conditions, instruments, operating procedures, data processing algorithms, and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data."

Best practices for data curating ensure that (1) the data are secure and stored out of harm's way, (2) metadata are complete, and (3) documentation is available for any changes in methods that could potentially impact the integrity of the data.

Results Focus

It is one thing to clearly articulate the desired data quality, service and security objectives. However, the Quality Management System must also verify that the product meets the needs of end-users. Any departure from expected results should provide feedback, creating a loop of continuous improvement. The needs of end-users change with time so the Quality Management System has to be adaptive.

Verifying that the quality objectives have been met is a two-step process. Quality Control is a system of routine and consistent checks to ensure data integrity, completeness, and compliance with stated standard operating procedures. Quality Assurance is a system of independent review procedures to verify that the data quality objectives are met.

Most National Hydrometric Services have developed their own Quality Management System, however, some are choosing to become certified in the standardized ISO 9000 method.

2 Network Design

Network design is an ongoing process with new stations being established and existing stations being discontinued as priorities and funding evolve. This process must be managed with selective thinning and pruning, while nurturing new growth to fill data voids. Updating the design of a network is fundamentally a sampling problem. The challenge is to find the right balance between hydrometric monitoring objectives and site desirability.

Sampling the Phenomena of Interest

How will the information be used? The design process must begin with the end in mind. Locations upstream and downstream of dams or diversions are both useful, but for very different purposes. An upstream location is an integration of all runoff process occurring in the contributing watershed, whereas a downstream location is rich in information about what will be happening in receiving aquatic and riparian ecosystems. A good location is one where the variation in discharge is sensitive to the phenomena of interest.

The monitoring objectives determine which parameters need to be included in the network design. If the objective is regulatory compliance or to develop statistics for engineering design, then perhaps the only parameter needed is discharge. However, if the purpose is to understand runoff processes, to develop water management policies, or to calibrate predictive models, then network design should consider all relevant components of the water cycle, including stores (e.g. groundwater, snowpack, and lake levels) and flux (e.g. temperature, evaporation, and precipitation). The measurement of some parameters (e.g. sediment and water quality) must be co-located with discharge gauging if loadings are a requirement. Jurisdictional collaboration is integral to the network design process and ensures an efficient, coordinated approach to monitoring within a watershed.

Sampling the Hydroscape

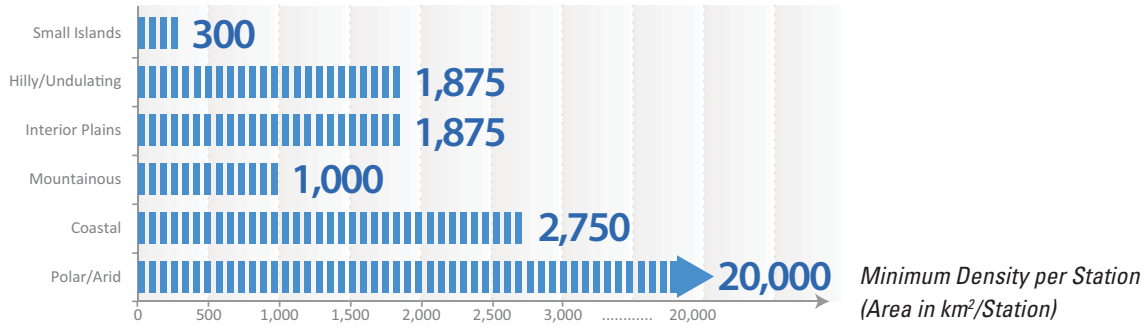
The design of a successful hydrometric monitoring network must next consider how the variability in space needs to be sampled so that the variability in time can be effectively monitored. In other words, the location of gauges should reflect the geophysical complexity of the landscape. In order to satisfy the assumption that the data are scalable and representative, gauges must be located across the scale of the geophysical variability of the watershed.

Ultimately the pragmatic station density in a region is a function of risk tolerance. These regional-scale density recommendations may be inadequate to fully characterize local-scale threats from flooding or to provide the needed guidance for local-scale water supply management. Risk tolerance is often particularly high in the developing world; resulting in a perpetual need to react to, rather than prevent, water related crises.

Selecting the Site

Once the monitoring objectives and criteria for geophysical representativeness

The WMO Guide to Hydrological Practices recommends the following station densities:



are established, then a specific reach of river can be selected for monitoring. A desirable location is one with (1) uniform, gradually varying flow, (2) inexpensive site access, (3) stable geophysical features for vertical control benchmarks and for channel control, and (4) safe stream gauging conditions.

Monitoring objectives often restrict the choice of possible locations to those with adverse monitoring conditions. A mismatch between local conditions and appropriate technology results in poor quality data and high maintenance requirements for both field and office procedures. Technologies are available to mitigate for almost any compromise needed in site selection, but the most reliable and affordable solutions are predicated on good site selection.

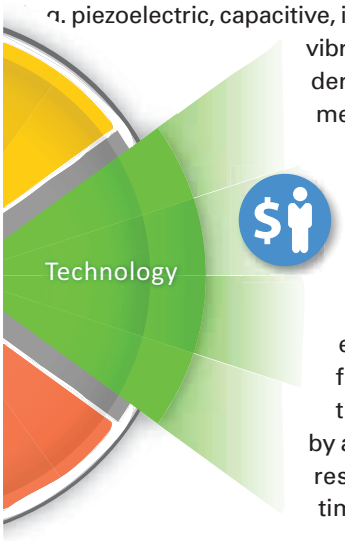
Site selection affects the following outcomes:

- Data persistence (i.e. a well selected location should produce data for generations to come),
- Data quality (e.g. conformance with underlying assumptions),
- Data representativeness (i.e. relevance to ungauged locations),
- Operational costs (e.g. site access),
- Liability risks (i.e. occupational and/or public safety),
- Selection of methods (e.g. use of rating curve vs. index velocity method), and
- Reliability risks (e.g. exposure to vandalism).

With so much at stake, a significant investigation is warranted for any change in network size. Unfortunately, water resource managers often come under pressure from management to expand or contract the network on short notice (for example, to make the change by fiscal year end). Thus, many important decisions are made in haste. As a best practice, network design should be an ongoing process with preparedness to make wise choices on short notice.

3 Technology

Selecting the best technology for a given location is more complex than ever before. Even when choosing a simple pressure transducer, a hydrologist must consider the type of piezoelectric, capacitive, inductive, potentiometric, vibrating wire, vibrating cylinder, or strain-gauge) and the method of deployment (e.g. bubbler, vented or compensated). For each combination of these technologies there are numerous vendors and products available – and each product has a performance specification that can be characterized by an error band, hysteresis, resolution, sensitivity and time constant.



Hydrometric network operators must consider several additional factors:

- Reliability requirements – an acceptable mean time between failures.
- Accuracy in the deployed setting – the blanking distance of some Acoustic Doppler Current Profilers (ADCPs), for example, may be too great to correctly measure discharge for some stream geometries.
- Cost of site access – for remote sites, the incremental costs of an Acoustic Doppler Velocity Meters (ADVMs) for use with an index-velocity model may be easily recouped by reduced site visits.

- Local site factors – high sediment transport, algal blooms, and river ice are all factors that warn against deploying expensive submersible technology.

- Instrument sensitivity and precision – relates to the time and effort spent on post-processing of the data.

- Training and familiarity – limiting the variety of products deployed in a region can greatly reduce both the training burden and the likelihood of mistakes caused by a lack of familiarity with a specific device.

Total Cost of Ownership

Factors that affect the total cost of ownership of technology include: the initial capital cost; field calibration and service frequency requirements; unscheduled field visits to repair or replace; time and effort spent on corrections and post-processing of the data; data lost due to sensor failure; amount of data degraded by high uncertainty; and supplies (e.g. compressed gas and/or power source). Money saved at the time of purchase can be easily exceeded by operations and maintenance costs.

Low-cost monitoring equipment does, nonetheless, have its place. For example, in monitoring a high-risk location (e.g. during a dynamic river ice breakup), one needs to get as much data as possible before the sensor is inevitably lost or destroyed. There can be as much as an order of magnitude of difference in the cost of sensors. Low-cost sensors have also led to the concept of "a network as a sensor" where several redundant sensors can be deployed at a gauge. In some cases, it is advantageous to use the average of these independent, if imprecise, measurements and also get a measure of the aggregate uncertainty. This concept also lends itself to deploying many low-cost sensors to sample landscapes at the scale of space-based observation systems.

In the context of total cost of operation, telecommunication technologies offer a significant improvement in data reliability as a result of real-time station health monitoring and improvements in the timing of stream gauging activities.

4 Training

No investment in technology can compensate for poor choices in data collection and data handling. Errors caused by procedural mistakes are the most difficult to detect and correct in data post-processing. Training accelerates the rate at which competencies are gained while simultaneously reducing the frequency of mistakes. Training is, arguably, more important than ever as the demographic in many monitoring agencies today has a double hump of new recruits and pre-retirees, creating an urgent need to compensate for loss of experience with improvements in knowledge.

Stream hydrographers must be skilled in many disciplines to be truly effective. The measurement of flowing water is a sophisticated application of science and engineering principles. Decisions made in the field and for data interpretation require a basic understanding of physics, chemistry, biology, hydrology, hydrodynamics, fluvial geomorphology, math and statistics.

Additionally, the installation and operation of hydrometric monitoring equipment requires skills in plumbing, wiring and programming. Stream gauging requires expert interpretation of quality management protocols with respect to the selection and application of methodologies while considering the specific context of the measurement conditions. The stream hydrographer must make decisions to limit adverse environmental effects and to preserve both personal and public safety.

While there are limited options for training, some National Hydrometric Services (e.g. USGS) offer courses to the general public. Short courses in hydrometric methods are also available from hardware and software vendors.

Investments in training improve data quality, increase productivity, improve gauge reliability, and enhance safety. Training in stream hydrography must be a continuous process to keep current with best practices as they apply to new and emerging technologies.

5 Data Management

Improvements to hydrological monitoring programmes often focus on field-based technologies. What is frequently ignored is how the data are managed after acquisition. Hydrological data are complex. Stream hydrographers are responsible for storing, validating, analysing and reporting on vast amounts of water data.

Specialized Hydrological Data Management Systems are available to meet the evolving needs of hydrologists and to support current industry standards for water information management. Software designed specifically

for hydrologists is required to achieve excellence and effectiveness in hydrological monitoring.

Auditable & Defensible Data

As discussed, the Quality Management System establishes the credibility of the data production process. One important role of the Data Management System is to establish the defensibility of the data by providing evidence of compliance with the Quality Management System. This means the Data Management System must preserve the full history of the data, including who did what, when, how and why.

As a best practice, raw data must be preserved intact and all changes must be recorded and be reversible, if needed. This means that data can be rolled back in time to show exactly what edits, corrections, approvals or notes were applied at any point in time. This is particularly important when dynamically publishing data using web pages or web services as opposed to static documents. The complete history (of who did what, when, where, how, and why) supports peer quality control and supervisory quality assurance. This history confirms the second half of the quality management mantra: "Say What You Do, Do What You Say."

Centralized & Accessible Data

Hydrologists must manage many types of data in all kinds of formats, for example: lab data in Excel, time series in CSV, gauging data in hardware vendor software, and station data in GIS. As a best practice, all of this data and supporting metadata are consolidated and managed as a secure, coherent collection. The best solutions support relational queries of this data collection. Web service connections to this database mean that data and metadata are accessible from anywhere, at any time.

Real-Time Data & Automation

A modern hydrometric monitoring system delivers data dynamically in real-time. Ideally, the best data are continuously available and can be served using international standards for interoperability. This means that end-users benefit as soon as new data are appended, erroneous values are filtered, corrections are applied, rating curves updated or shift corrections applied. The best solutions also provide end-users with informative metadata about the quality and status of the data. Data can be filtered based on the state of the data in the Quality Management System process. Archival quality data are clearly identified and 'locked' from further editing.

Automated notifications provide timely warnings about hydrological events and alert hydrographers to any faults or station health indicators that require immediate attention. Automated data correction algorithms censor invalid values and correct persistent and/or predictable errors in real-time. This eliminates some of the most onerous and repetitive tasks, allowing the stream hydrographer to focus on high value interpretive analysis. Automated reporting provides high value data products to water resources professionals and decision makers on an event-driven or scheduled basis.

Credible Rating Curves

The best solutions for developing and validating rating curves are engineered from basic hydraulic principles. The full suite of information gathered in the field is relevant to the calibration process, not just the x, y coordinates of the rating measurements. This includes consideration of site photos, cross sections, field notes, measurement quality, control conditions, historical ratings, and the time series of stage data. It has been shown to be less work and more accurate to use an evidence-based approach to curve-fitting rather than to be forever 'chasing' the curve using statistical regression techniques.

With modern hydrometric monitoring systems, discharge derivation models are calibrated with respect to underlying hydraulic science and engineering principles. The result is:

- Improved confidence in extrapolation (within the range of known channel geometry),
- Improved agreement on a solution (i.e. different hydrographers will independently produce similar results), and
- Improved defensibility of results (i.e. rating curve parameters help to constrain the solution).

It is often necessary to accommodate shifting channel control conditions with corrections to the stage-discharge model. The best solutions for managing shift corrections include the inspection and interpretation of field observations, residuals plot, and time series visualizations.

Data Visualization, Correction, & Markup

Advanced visual interpretation and analysis of the data is needed to identify errors that cannot be detected automatically. Sophisticated graphical tools available with Data Management Systems make it easier to calibrate time series data using field observations from a reference gauge. Specialized corrections can be made for many of the common, often repetitive, errors typical of the technologies used for hydrometric monitoring. Sophisticated methods are needed to estimate longer gaps in the data and for periods of ice effect. Extensive and comprehensive abilities are required to comment on these actions and to add event markers, quality grades, and to change the status of the data.

Reporting and Publication

The best Data Management Systems provide for continuity in reporting with customizable report templates that can be tailored to match legacy reports. New high-value reports can be developed from scratch or by modifying templates for industry standard reports. The content for the reports can be filtered according to status in the Quality Management System so that reports of archival quality data can be readily produced for conventional publication. Access to web services provides the ability to dynamically publish data, based on metadata filters, using industry-wide standards.

Modern Hydrological Monitoring Programmes

Starting from clearly defined water data quality objectives and ending with the timely publication of credible information, the five essential elements presented in this paper are fundamental to any modern hydrometric monitoring programme. Best practices, industry standards, and technologies for hydrometric monitoring have changed substantially in the last decade. A new 'normal' is emerging out of this change and it is time to re-engineer hydrometric programmes to improve the availability, reliability, and accuracy of water information assets.

Changes made to optimize efficiencies and maximize effectiveness in the delivery of critical hydrologic data products and services will ensure the success of mega-projects, the preservation of vital ecosystems, and the safety of citizens. Improvements in water data interoperability and accessibility will support evidence-based decision-making for water related problems from the scale of culvert design up to global environmental policy-making that will ultimately make the world a better place for generations to come.

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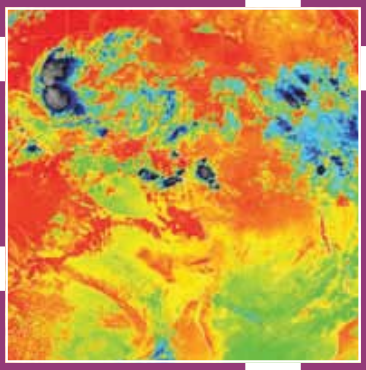
Predictability Beyond the Deterministic Limit



Brian Hoskins

The traditional idea of a deterministic limit is questioned by considering the possibility of some predictive skill on all time-scales from hours to decades. The discussion is framed in terms of the seamless weather-climate prediction problem. The focus is on phenomena that evolve on the time-scales of interest and the predictability associated with them, as well as the bias produced by longer time-scale conditions.

How can there be prediction beyond the deterministic limit?

The title given to me for this talk reflects the seeming contradiction between the fact that predictions are increasingly being attempted for months, seasons and longer and the idea that the atmosphere is essentially unpredictable beyond about two weeks. The latter idea is well-based on theory and arose from the work of Lorenz (1969). The sensitivity to initial conditions found by him and developed in the theory of chaos means that inevitable initial condition errors must eventually influence the flow on all length scales. Turbulence arguments, based on the observed relatively slow decrease in energy as smaller scales are considered, envisage inevitable uncertainty on small scales influencing motions on larger and larger scale such that all scales reflect this uncertainty in a finite time. Experiments with high resolution global forecast models suggest that two weeks is the outside limit for deterministic prediction of even the largest scales in the atmosphere.

However there are also indications of phenomena and structures that exhibit robustness beyond what might be expected based on chaos and turbulence arguments. Every 26 months or so the equatorial winds in the stratosphere change from westerly to easterly and back again. Blocking highs in middle latitudes tend to persist with little change in structure over many typical life-cycles of synoptic lows and highs. In such cases, the dynamics in the atmosphere appears to be crucial in extending potentially predictable behaviour rather than leading to its demise.

The idea of a deterministic prediction is one based in middle latitude synoptic weather forecasting and refers to explicit determination of the synoptic scale flow. It was never expected that each convective shower would be predicted: there would always have been the notion of a probability of their occurrence. In more recent years there has been a realisation that forecasts on all scales should be probabilistic. Ensemble prediction systems have been developed based on a number of runs of the forecast model with varied initial conditions within the observational analysis error. Inevitable randomness in the representation of sub-grid-scale processes is being mimicked by adding some statistical noise (e.g. Slingo and Palmer, 2011). On longer time-scales variations in the parameters in the representations of sub-grid-scale processes are now starting to be used.

Such techniques can be applied on all time-scales with the aim of determining the likelihood of differing outcomes of phenomena evolving on the time-scale of interest and the statistical characteristics of phenomena on shorter time-scales. Over the many years since the pioneering studies of Charney & Shukla (1981), it has also been shown that conditions in parts of the interacting Earth system external to the atmosphere, such as tropical sea surface temperatures or land surface soil moisture, may evolve slowly or in predictable ways. Consequently they are able to give a bias to the subsequent behaviour of the atmosphere, and therefore provide the basis for some predictive power. Solar variability and volcanic eruptions are truly external to the interacting system and can provide possible predictive power, though

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volcanic eruptions during the forecast period might diminish predictive skill.

The major focus here is on the phenomena whose evolution on the time-scale of interest give hope of some predictive power. The behaviour of the atmosphere can often seem like noise, but we are looking for the patterns of behaviour: the music. The discussion is framed in terms of the seamless weather-climate prediction problem illustrated in Figure 1. Potentially predictable phenomena occur on all time-scales. Each time-scale evolves in the context of the longer time-scales and truly external conditions that may bias their evolution. Smaller scale phenomena that cannot be represented explicitly may be partially "slave" to the retained scales, like general regions of convection to a front, in which case aspects of their feedback on the retained scales may be well determined by those retained scales. They may also be "free" such as the location and nature of individual convective towers, in which case some statistical element will be required.

As indicated in Figure 1, the breadth and complexity of the Earth system model required for prediction will depend on the time-scale of that prediction. In addition to the physical atmosphere, the extent to which the ocean, land, atmospheric chemistry and ice sheets have to be included explicitly in the forecast system will depend on the time-scale of interest. Understanding, and improved simulation and prediction at one scale, can provide valuable support for prediction on longer time-scales. For example the improvement in the forecasting of individual blocking events in recent years should help in giving an improvement of the simulation of their frequency and characteristics over the 20th century by climate models, and therefore more confidence in projections for changes in blocking at the end of the 21st century.

Examples of potential predictive skill on a wide range of time-scales

Day 1 – There is good progress on developing forecast systems for the first day using kilometre scale models embedded in regional or global models. As an example, the UK Met Office has embedded a 1.5 km model covering the United Kingdom of Great Britain and Northern Ireland in various members of an ensemble forecast system based on a 24 km model for an extreme local precipitation event in October 2008. The larger scale system gives various locations for a front and the fine-scale system gives evidence that very high rainfall event can be expected somewhere within a region dictated by the larger-scale front. Designing a fine resolution ensemble which is able to provide useful predictive power for these and other events is a current challenge.

Week 1 – In the past 30 years there has been great progress in predictions on the synoptic scale in middle latitudes, which were made possible by forecast model and observational and initial data analysis improvements. In the tropics there is potential predictability associated with phenomena that are not currently well captured by forecast models. As an example, equatorial waves coupled with convection are found in data to have typical structures, to move in a coherent manner and to evolve over this one week time-scale.

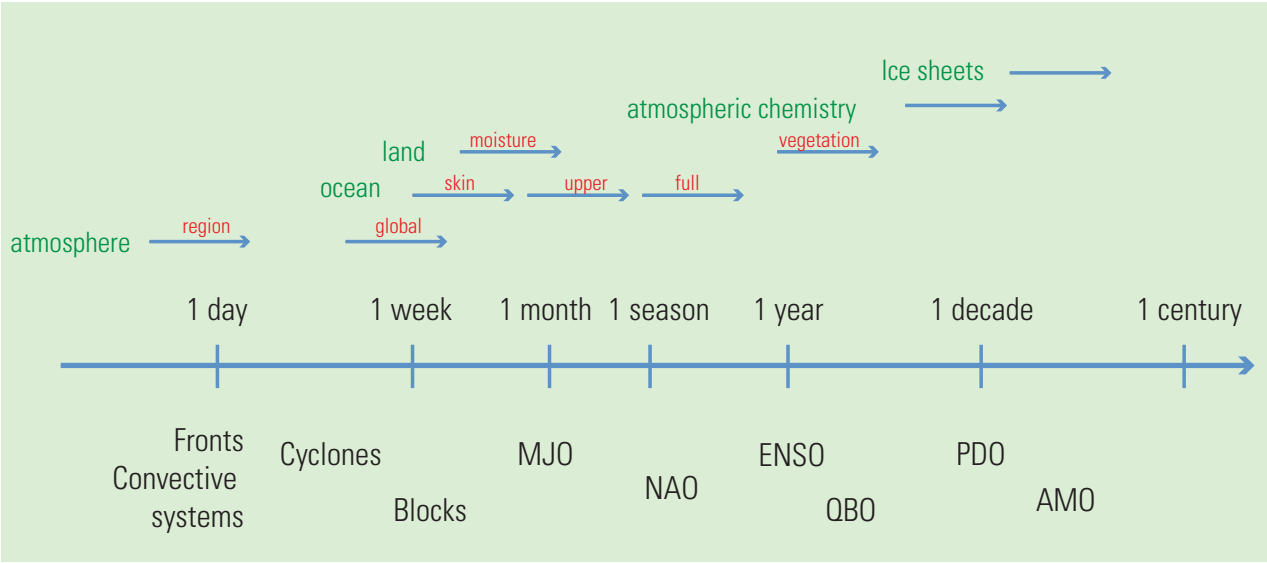

Figure 1 – The seamless weather-climate prediction problem. The time-scales are marked along the axis in the middle and below it some phenomena that occur on the different time-scales are given. At the top are indicated the components of the Earth system that need to be represented and the extent to which this needs to be done. For time-scales to the right of the arrows even more completeness in this representation may be required.

Deutscher Wetterdienst

Advances in modelling and seamless prediction

1 week to 1 month – Almost all the members of the ensemble prediction system of the Japanese Meteorological Agency initialised in the middle of December 2010 showed a very cold spell starting late December and continuing through early January 2011 that actually occurred. The floods in north west Pakistan were associated with a succession of major rainfall events from July to early August. Each one of these was picked up by the European Centre for Medium-Range Weather Forecasts ensemble prediction system more than 10 days before it occurred. The predictive power in both cases was associated with the same two phenomena, a propagating Rossby wave and a blocking high. In the winter case, the wave was present in the initial conditions and propagated along the subtropical jet before reaching the Japanese region. Here the wave extended in latitude and broke to form a blocking high which persisted. In the summer case each rainfall event was initiated by a trough in a wave that propagated from near the UK along the westerlies well to the south of the blocking high over Russia which led to the heat wave there. The rainfall events occurred when the trough reached the entrance region of the strong jet near Pakistan.

In both cases it is again the predictable evolution of phenomena that underlies the predictive power. Similarly, the evolution of the Madden Julian Oscillation (MJO) gives promise of significant predictive power for the tropics and into both hemispheres. However this predictive power is not yet realised because of limitations in the simulation of the MJO.

1 month-seasons – The well-known El Niño-Southern Oscillation (ENSO) is a phenomenon associated with the coupled evolution of the tropical Pacific Ocean and the atmosphere. It has been the basis of predictive skill on seasonal time-scales in the tropics and to a greater or lesser extent in higher latitude regions. Winds associated with MJO events are important for ENSO evolution, and so better simulation of the MJO may also lead to increased skill in ENSO prediction. Also promising, but more elusive than for ENSO, is skill in predicting the North Atlantic oscillation (NAO). There have been some indications of predictability through interactions with the stratosphere, and more recently through the impact of Arctic sea ice and Asian snow cover. The impact of the NAO in the atmosphere on the underlying ocean is clear, but the reverse impact that could help in providing predictive power is less clear.

Some extreme seasons such as the European summer heat wave in 2003 and the cold winter of 2009/10 were not predicted, but some hindcasts now appear promising. However the real test will be on the prediction of future extreme seasons.

1 year to 1 decade – A number of the phenomena that are almost stationary on seasonal time-scales and give

potential predictability on that time-scale may also do this on longer time-scales because of their slow, potentially predictable evolution. The NAO appears to have some persistence on these time-scales. The stratosphere also has multi-annual and perhaps decadal time-scales associated with persistent composition changes. The predictable evolution of solar activity through its impact on very short-wave radiation that is absorbed by the stratosphere is likely to influence its temperature. There is increasing evidence that such changes in the stratosphere can influence the statistics of the weather.

Skill has been demonstrated for predicting the temperature of the upper layer of the North Atlantic Ocean. In general, as said before, it is not yet clear whether this implies any predictability for the atmosphere. However tropical cyclones are strongly influenced by upper ocean temperatures and it has been shown that there is predictive skill for the 5-year average of their frequency in the North Atlantic region.

1 decade to 1 century – On these time-scales the trend implied by increasing greenhouse gases become important and should give predictive power. The focus until recent years was on changes in mean quantities, but there is now increasing interest in the possible impact on phenomena such as blocking or ENSO, or on patterns of variability such as the NAO. This impact might be seen in changing amplitude or frequency, or in changing structure.

There is variation in the NAO on multi-decadal time-scales and there are phenomena such as the Atlantic Multi-decadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO) whose evolution is on these time-scales. Current models can represent structures and their evolution that have some similarity to the observed AMO and PDO. When these representations improve and the behaviour of the NAO is better understood, it can be hoped that these phenomena will be the source of some predictive skill. To realise this will require suitable observational data and analysis and initialisation procedures. In the past these phenomena have tended to be perceived as noise that acts to obscure the climate change signal. In future they will become a major component of the projections for future decades.

Concluding comments

The background provided by the longer time-scales and by external conditions, and the phenomena that occur on each range of time-scales in the seamless weather-climate prediction problem, give the promise of some predictive power on all time-scales. The actual usefulness of this predictive power will not be clear for many time-scales before the relevant science has been done and techniques for using predictions in particular applications have been explored. I believe that a crucial aspect of the scientific approach will need to be an increased focus on the phenomena and their evolution: searching for and appreciating the music amongst all the noise of the weather-climate system. The challenge is a huge one for our science but the benefits for society may be immense.

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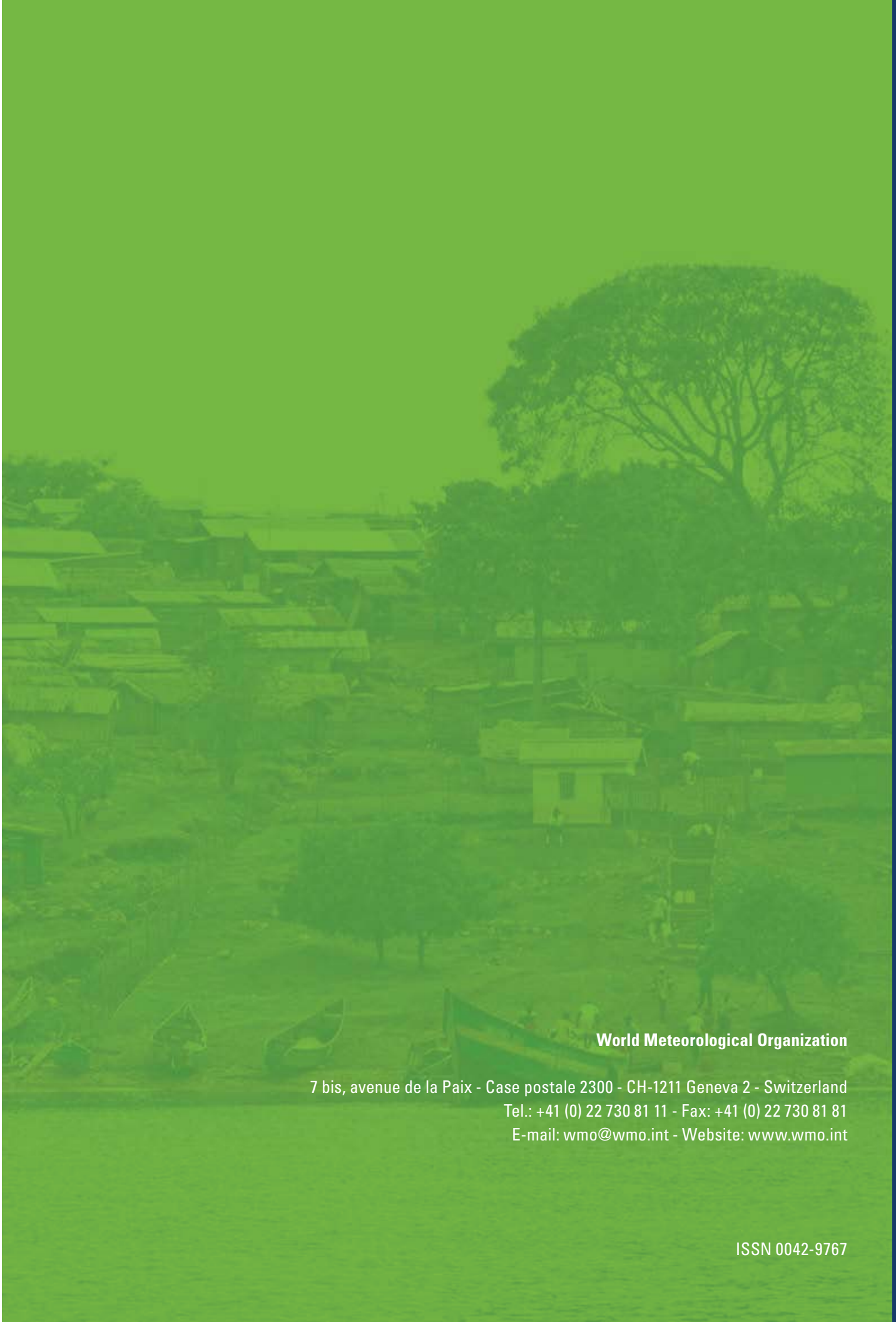

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