World Meteorological Organization
Weather • Climate • Water
Vol. 58 (3) - July 2009

Bulletin

Feature articles | Interviews | News | Book reviews | Calendar
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World Climate Conference-3

31 August–4 September 2009

WCC-3

The major expected outcome of World Climate Conference-3 is an international framework facilitating efforts to reduce the risks and realize the benefits associated with current and future climate conditions by incorporating climate prediction and information services into decision-making.

Bulletin

The journal of the World Meteorological Organization

Volume 58 (3) - July 2009

The *WMO Bulletin* is published quarterly (January, April, July, October) in English, French, Russian and Spanish editions.

Subscription rates

	Surface mail	Air mail
1 year	CHF 60	CHF 85
2 years	CHF 110	CHF 150
3 years	CHF 145	CHF 195

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WMO Bulletin

www.wmo.int/bulletin_en

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World Climate Conference-3

Better climate information for a better future

World Climate Conference-3 (WCC-3) will bring together scientists, high-level policy-makers and global business leaders and decision-makers to push forward global actions that enable society to become more resilient to current and future changes in climate. The focus is on the development and use of seasonal to multidecadal climate predictions for decision-making in socio-economic sectors. These sectors include food and agriculture, water, health, disaster preparedness and risk management, environment, forestry and fishery, tourism, transportation and energy, among others. Presentations will include information about advancements in climate predictions and services. WCC-3 follows the successes of the first and second World Climate Conferences, which mobilized global awareness of climate change and eventually led to the establishment of the Nobel-Peace-Prize-winning Intergovernmental Panel on Climate Change and the United Nations Framework Convention on Climate Change.

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WCC·3

Geneva, Switzerland
31 August–4 September 2009

Geneva International Conference Centre

UN SYSTEM
DELIVERING AS ONE ON
CLIMATE KNOWLEDGE

World
Meteorological
Organization
Weather • Climate • Water

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Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Die Bundesregierung

Canada

EUROPEAN COMMUNITY

GOBIERNO DE ESPAÑA

MINISTRY FOR FOREIGN AFFAIRS OF FINLAND

Australian Government

NORWEGIAN MINISTRY OF FOREIGN AFFAIRS

RUSSIAN FEDERATION

Japan

Saudi Arabia

REPUBLIC OF KENYA

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PEOPLE'S REPUBLIC OF CHINA

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RÉPUBLIQUE FRANÇAISE

Government of India, Ministries of Science and Technology and Earth Sciences

In this issue

There is little doubt now that climate change has serious development impacts. Factoring climate change into the development process is not only a fundamental necessity in terms of guiding the international development policy framework but also an invaluable opportunity to reappraise the most pressing needs of a highly inequitable global society, with greatly differing social, environmental and economic levels of development.

The international debate on climate change has focused largely on the commitment—or failure to commit—to emissions reductions. This emphasis omits the pressing need to focus on the costs of present and future climate variability and its adverse impacts on vulnerable groups and climate-sensitive ecosystems. Both technological equity and efficiency (mitigation) and the capacity of communities to prepare themselves for climate change (adaptation) are fundamental to advancing international climate change negotiations.

It is encouraging that recent trends in negotiations incorporate concerns for actions in support of adaptation to climate variability. Adaptation to current climate variability would address not only present situations but also the challenges of future climate change in terms of building capacity. Early action will bring clear economic benefits. There is an urgent need to focus on helping climate-vulnerable countries and communities deal with this issue effectively.

World Climate Conference-3 (WCC-3) takes place in Geneva, from 31 August to 4 September 2009 on the theme "Better climate information for a better future" to address these concerns.

Zillman traces the history of activities that have resulted in greater awareness, both at political and scientific level, about climate change. The article links various events over the past 50 years that have led to increasing cooperation among countries and international institutions that, in turn, has led to international arrangements such as the Intergovernmental Panel on Climate Change assessments and the United Nations Framework Convention on Climate Change negotiation process. It looks at the way climate science and international cooperation could further help address climate challenges.

Busalacchi and Asrar point out that the World Climate Research Programme (WCRP) was established in 1980 by WMO and partners to determine the predictability of climate and to determine the effect of human activities on climate. These fundamental objectives have laid the groundwork for society's present adaptation and mitigation response strategies to changes in climate. Thanks to WCRP efforts, it is now possible for climate scientists to monitor, simulate and project global climate so that climate information can be used for governance in decision-making and in support of a wide range of practical applications.

Climate science today provides seasonal-to-interannual predictions on various climatic parameters. Short- and medium-range climate predictions are essential for adapting to climate variations and mitigating their impacts. The Global Framework for Climate Services that is likely to emerge from WCC-3 would form the foundation for science-based climate information at different time-scales, thereby building the ability of countries to adapt to evolving climate phenomena more effectively. The Framework would provide such information at different scales from global to local in user-friendly format and fulfil the needs of decision-making processes in various sectors.

The frequency and intensity of major large-scale disasters related to climatic events such as fires, heat-waves, droughts, landslides, floods and outbreaks of disease will increase. Disaster prevention, preparedness, response and recovery should become an even greater priority for WMO Members. Rapid response capacities to climate change would need to be accompanied by a strategy for disaster prevention and alert at global to local levels. Wahlström explores the linkages between climate change, disaster risk reduction and national development. She underscores the important role that National Meteorological and Hydrological Services have played—and continue to play—in providing early warnings ranging from short-term weather events to long-term climate variations and change. She forcefully highlights the important role that WCC-3 and its expected outcome, the Global Framework, can play in disaster risk reduction and recovery.

The need for climate change information at the regional-to-local scale is one of the central issues within the global change debate. Georgi, Jones and Asrar describe the status and plans for the Coordinated Regional climate Downscaling Experiment (CORDEX), which will help fulfil this need.

Ogallo and Oludhe describe how the provision of climate information through Regional Climate Outlooks Forums helps deal with ongoing climate variability and develop adaptation strategies in the Greater Horn of Africa. They point out the need for national monitoring and preparedness programmes that respond to specific local needs and the role that regional institutions play in making such information available from regional to national level. They identify the challenges that need to be surmounted in order to face the increasing demand for climate information of all kinds and incorporate it in the decision-support systems and climate risk management practices in various socio-economic sectors.

Martínez and Mascarenhas provide a glimpse of the activities of the International Centre on El Niño research and how it provides climate information for climate risk management in western South America. It meets the climate-related needs of the various socio-economic sectors through climate system monitoring, predictions of critical climatic elements on monthly and seasonal timescales, including user liaison and practical applications, and services tailored to users' needs. The Centre also addresses the training of experts in the region.

Water is one of the major sectors through which climate variability and change manifest their impacts in different sectors of development. It is, therefore, important to understand the impacts of climate variability, particularly extreme events (floods and droughts), on the availability of water resources management plans to adapt to consequences of such events. Calver explores the interrelation of climate change, that is expected to alter hydrological regimes, and the patterns of freshwater availability. She emphasizes the need to address present climate variability and identifies some associated research challenges.

Understanding land and water linkages under a changing climate is fundamental to livelihoods, food security and water-related ecosystem services. With intensifying competition for water resources, agriculture, inland fisheries and aquaculture are expected to be significantly impacted. Hideki discusses various aspects of food security under the new paradigm of climate change but stresses the need to give priority to present climate variability. He points to the need of addressing the problems faced by small land holders who are most vulnerable and the role that climate prediction can play in building their resilience.

Experience and expertise in designing effective adaptation strategies and implementing policies are still limited. It is important that the capacities be developed to make use of climate information in various sectors to be able to use this information in long-term planning and their day-to-day operation and thereby manage the risks of extreme climate through sharing such experiences. It is hoped that the articles in this issue will blaze a trail in sharing such experiences.

A history of climate activities

by John W. Zillman*

Introduction

The third WMO (World Meteorological Organization)-convened World Climate Conference, which will be held in Geneva from 31 August to 4 September 2009, should be viewed both as an end and as a beginning. As an end, it represents the culmination of some 30 years of remarkable progress in climate research, monitoring, applications and impact assessment under the World Climate Programme, which was established in the wake of the First World Climate Conference in 1979 and reconstituted, underpinned and refocused following the Second World Climate Conference in 1990. It also seems likely to mark the beginning of a new and more integrated approach to the application of climate science to societal needs through the establishment of a new global framework for climate services which will focus powerful new scientific capabilities on the formidable social, economic and environmental challenges of living with the large natural variability of climate and mitigating and adapting to human-induced climate change.

It is surprisingly little understood how comprehensively and how well WMO and its predecessor and partner organizations have worked together to provide the framework for international cooperation on climate matters since the establishment of the International Meteorological Organization (IMO) in 1873. The non-governmental IMO provided essential international coordination and standardization of climatological practices for more than 70 years, especially, since 1929, through its Commission for Climatology, which was re-established as an intergovernmental body by WMO in 1951 and has been maintained, albeit with a brief change of name to enhance its focus on applications, to the present day. Many of the National Meteorological Services (NMSs) of WMO's now 188 Member States and Territories owe their origins not so much to their more publicly visible role in daily weather forecasting as to their national responsibility for long-term observation, description and monitoring of climate.

In planning for a new global framework for climate service provision through World Climate Conference-3 (WCC-3), it will be critically important to focus the established and emerging scientific capabilities for climate prediction on the burgeoning societal needs of a world now concerned with climate issues as never before. But it will also be important that the new framework be based not just on a recognition of what is already in place but on a measure of historical insight into the issues explored, challenges met and lessons learned in putting the present international institutional arrangements in place. While there is not space, here, to retrace the fascinating history of international climate science and services in any detail, it may be of interest, as a starting point, to identify a few of the highlights of the past 50 years and especially of the 30 years since the establishment of the World Climate Programme in 1979. Figure 1 provides a schematic, albeit greatly simplified, summary of the milestones in the emergence of climate as an international scientific and political issue since the 1950s.

Origin of the climate issue

While climatology has always been recognized as an important branch of the science and practice of meteorology (Landsberg, 1945) and the basic physics of greenhouse warming has been understood for more than a century (Houghton, 2009), the present global concern with climate issues really dates from the convergence of five important scientific, technological and geopolitical developments of the 1950s:

- Post-World War II advances in basic atmospheric science

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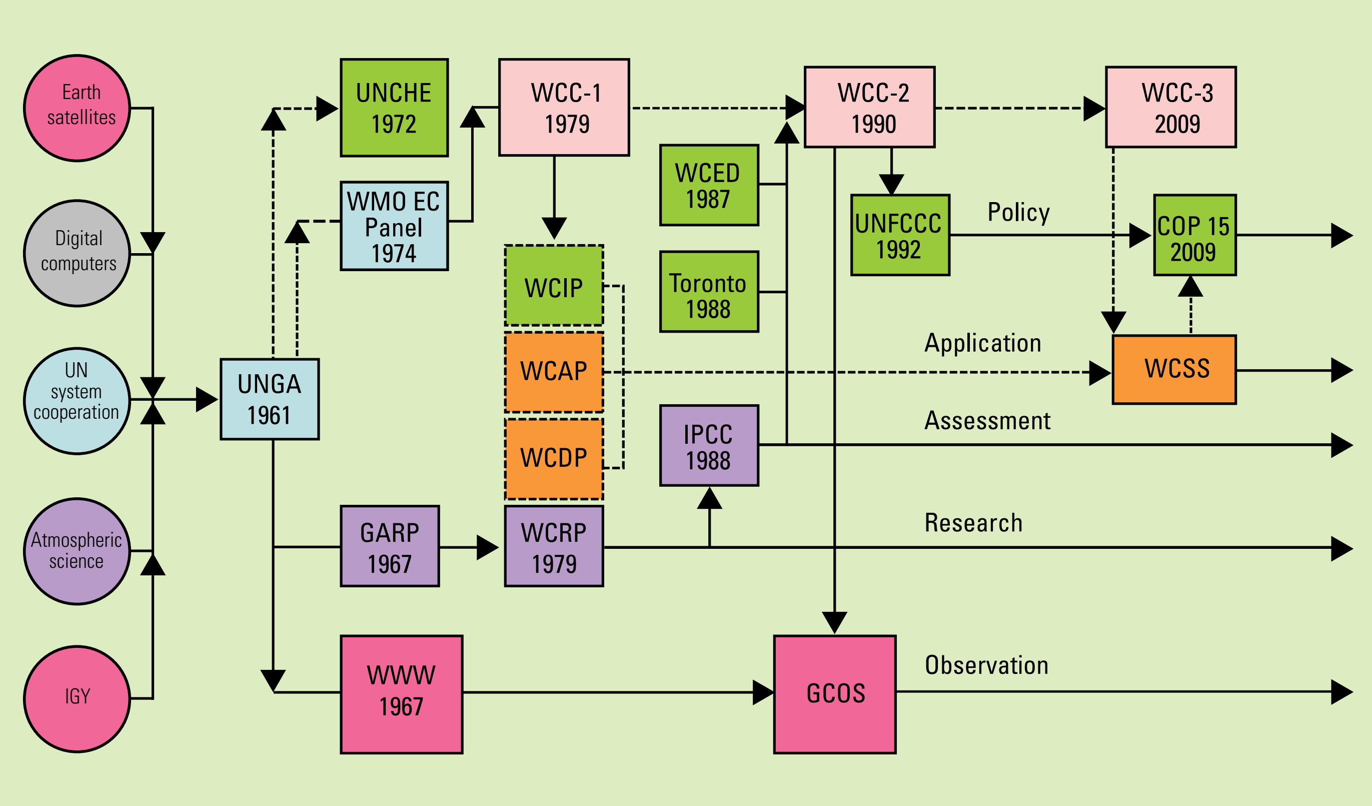

Figure 1 — The emergence of climate as an international scientific and policy issue: the five major scientific, technological and geopolitical developments on the left converged to inspire UN General Assembly (UNGA) Resolution 1721 (XVI) which triggered the establishment of the WMO World Weather Watch (WWW) and the WMO-ICSU Global Atmospheric Research Programme (GARP) and, later and less directly, the convening of the 1972 United Nations Conference on the Human Environment (UNCHE). The 1974-1977 WMO EC (Executive Committee) Panel of Experts on Climate Change, set up at the request of the sixth special session of the UNGA, triggered the convening of the 1979 World Climate Conference (WCC-1) and the establishment of the four-component World Climate Programme (WCP), including the WMO-ICSU World Climate Research Programme (WCRP). The 1987 report of the World Commission on Environment and Development (WCED), the 1988 Toronto Conference and the First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) shaped the agenda of the 1990 Second World Climate Conference (WCC-2), which led to the establishment of the Global Climate Observing System (GCOS) and the negotiation of the UN Framework Convention on Climate Change (UNFCCC). The chart also depicts the proposed evolution of the service-oriented components of the WCP into a more integrated World Climate Services System (WCSS), built on GCOS and WCRP, to produce a new Global Framework for Climate Services (see Figure 5).

that led to greatly increased understanding of the mechanisms of the large-scale circulation of the atmosphere;

- Initiation of a number of new geophysical observations (especially the Mauna Loa measurements of atmospheric carbon dioxide) during the 1957 International Geophysical Year;
- Recognition of the potential meteorological observing capabilities of Earth-orbiting satellites;
- The advent of digital computers; and
- The willingness of countries, even in the developing Cold War environment, to use the institutions of the United Nations System for cooperation in addressing important global problems;

which shaped the transition of climatology from a descriptive to a physical science (Flohn, 1970) and opened up the prospect of diagnostic and predictive modelling of the global climate system (Bolin, 2007).

These influences were brought together in a 1961 United Nations General Assembly Resolution which called on WMO and the non-governmental International Council for Science (ICSU) to collaborate in developing the new scientific and technological opportunities for monitoring, predicting and eventually controlling, weather and climate and triggered the twin birth of the WMO World Weather Watch and the WMO/ICSU Global Atmospheric Research Programme (GARP). The World Weather Watch was aimed at providing the basic global infrastructure for supporting operational weather forecasting and for describing and monitoring climate, while GARP was focused on the dual objectives of improved weather forecasting and a scientific basis for climate prediction (Davies, 1990).

Already by the late 1960s, as the implementation of the World Weather Watch and GARP was getting underway, scientific concern was beginning to mount, reinforced by the increasing carbon dioxide concentrations evident from the early observations at Mauna Loa, that human activities could, in fact, already be starting to impact on the Earth's climate at global scales (SMIC, 1971). Then, in the 1970s, not for the first time and certainly not for the last, a counter view emerged, quickly sensationalized by the media (Calder, 1974) that, rather than just a manifestation of the large natural variability of climate superimposed on the expected slow greenhouse warming trend, the devastating Sahelian drought of the 1960s and the series of extremely cold winters in the northern hemisphere in the early 1970s could be the harbingers of the Earth's imminent descent into a new ice age.

They served to bring the implications of climate variability and change back to the attention of the United Nations, however, and, in 1974, the sixth special session of the General Assembly called on WMO to undertake a study of climate change. WMO established an Executive Committee Panel of Experts on Climate Change which, in its final report (Gibbs et al., 1977), largely dismissed the speculation on global cooling and reaffirmed the general scientific expectation of greenhouse warming but stressed the importance of making better use of existing climate knowledge in learning to live with the large natural variability of climate. It inspired the early WMO planning for an inter-agency World Climate Programme and triggered the WMO decision to convene a World Climate Conference in 1979.

The 1979 World Climate Conference

The 1979 World Climate Conference, now usually referred to as the First World Climate Conference (FWCC or WCC-1), was organized by a Committee chaired by Robert M. White of the USA and held in the International Conference Centre in Geneva from 12 to 23 February 1979 (Figure 2). It was convened by WMO, in collaboration with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), the United Nations Environment Programme (UNEP), ICSU and other scientific partners, as "a world conference of experts on climate and mankind". The first week was attended by some 350 specialists from 53 countries and 24 international organizations and from a wide range of disciplines including agriculture, water resources, fisheries, energy, environment, ecology, biology, medicine, sociology and economics (White, 1979).

At the end of the second week of deliberations in a smaller group of 100 invited experts from all parts of the world, the organizers issued a World Climate Conference Declaration as an appeal to nations in the following terms:

Figure 2 — The opening of the World Climate Conference in February 1979. From the left: R. Schneider, Deputy Secretary-General of WMO; F. Mayor, Deputy Director-General of UNESCO; R.W. Phillips, Deputy Director-General of FAO; M.K. Tolba, Executive Director of UNEP; H. Mahler, Director-General of WHO; K.K.S. Dadzie, Director-General for Development and International Economic Cooperation of the United Nations; D.A. Davies, Secretary-General of WMO; R.M. White, Conference Chairman; Ju.A. Izrael, Acting First Vice-President of WMO; E.K. Fedorov; Sir John Kendrew, Secretary-General of ICSU; O. Vasiliev, Deputy Director of IIASA; and H. Taba, Director, Programme Planning and UN Affairs in the WMO Secretariat

Having regard to the all-pervading influence of climate on human society and on many fields of human activities and endeavour, the Conference finds that it is now urgently necessary for the nations of the world:

(a) To take full advantage of man's [sic] present knowledge of climate;

(b) To take steps to improve significantly that knowledge;

(c) To foresee and prevent potential man-made changes in climate that might be adverse to the well-being of humanity.

The WCC-1 Declaration (WMO, 1979(a)) called on all nations to strongly support the proposed World Climate Programme and suggested immediate strategies to assist countries to make better use of climate information in planning for social and economic development.

Establishment of the World Climate Programme

Following the Conference, WMO moved swiftly to give effect to the call for a World Climate Programme. Eighth World Meteorological Congress (Geneva, April/May 1979) agreed that, as the UN specialized agency for meteorology embracing both weather and climate, WMO should take the lead in promoting studies of climate variability and change and their implications for society and the environment (WMO, 1979(b)).

It thus formally established the World Climate Programme with four components: the World Climate Data Programme (WCDP); the World Climate Applications Programme; the World Climate Research Programme (WCRP) (initially entitled Climate Change and Variability Research Programme); and the World Climate Impact Study Programme (WCIP), following fairly closely the recommendations of the World Climate Conference.

Congress recognized, however, that climate issues were already becoming highly interdisciplinary and that implementation of the proposed World Climate Programme would require the involvement of many other UN bodies such as UNESCO, FAO, WHO and UNEP, as well as the scientific community through ICSU.

It thus sought their co-sponsorship of the WCP as a whole and invited UNEP to take lead responsibility for the WCIP. It also agreed that WCRP should be implemented as a joint initiative of WMO and ICSU under the terms of an agreement that would follow seamlessly from the WMO-ICSU joint sponsorship of GARP, which had dated from 1967. The WCDP responsibility was passed to the Commission for Special Applications of Meteorology and Climatology (CoSAMC), the successor and predecessor of the WMO Commission for Climatology (CCl).

The Congress considered convening a ministerial conference and establishing an overall intergovernmental and interagency coordination mechanism for the WCP but concluded that this would be premature. It decided, instead, to foster prompt implementation of the four components with liaison through a WCP Office. It urged countries to establish their own national climate programmes under the overall umbrella of the WCP. It mapped out an ambitious implementation schedule for the WCP as a whole (Zillman, 1980).

The 1985 Villach Conference and the SCOPE report

The international and national planning and implementation of projects and activities within the framework of the four components of the WCP proceeded vigorously through the early 1980s with a particular focus in the research community on the role of increasing atmospheric concentrations of greenhouse gases in producing global warming. In October 1985, UNEP, WMO and ICSU convened an international assessment of the role of carbon dioxide and other greenhouse gases in climate variations and associated impacts. Now widely referred to as "the Villach Conference", it was attended by scientists from 29 countries who produced a highly influential statement foreshadowing temperature rises in the first half of the 21st century greater than any in human history (WMO, 1986). It drew heavily on a major scientific assessment then underway under the auspices of the ICSU Scientific Committee on Problems of the Environment (SCOPE) (Bolin et al., 1986)

The Villach Conference Statement included a set of recommendations to governments and funding institutions on the monitoring and research needed to further clarify the nature of the threat and, importantly, it also called on UNEP, WMO and ICSU to, inter alia:

- Ensure periodic assessments were undertaken of the state of scientific understanding and its practical implications; and
- Initiate, if deemed necessary, consideration of a global convention.

The 1987 WMO Congress

Tenth World Meteorological Congress in May 1987 considered both the outcome of the Villach Conference and an advance briefing on the conclusions of the World Commission on Environment and Development (the Brundtland Commission) which had drawn heavily on the Villach findings in highlighting global warming as a major threat to sustainable development (WCED, 1987). There were many calls from national delegations for WMO to provide authoritative information on the state of knowledge of human-induced climate change. Congress agreed with the Villach recommendation for periodic assessments of scientific knowledge but considered that the assessment mechanism should operate under the overall guidance of governments rather than solely through scientists serving in their personal capacities (WMO, 1987). It, and the immediately following session of the WMO Executive Council, authorized the Secretary-General to consult with the Executive Director of UNEP to establish what was soon to become the joint WMO-UNEP Intergovernmental Panel on Climate Change (IPCC).

The Toronto Conference

The World Conference on the Changing Atmosphere: Implications for Global Security (the Toronto Conference) was held in Toronto, Canada on 27-30 June 1988 with the participation of more than 300 scientists and policy-makers. The Conference called upon governments, the United Nations and its specialized agencies, industry, educational institutions, non-governmental organizations and individuals "to take specific actions to reduce the impending crisis caused by the pollution of the atmosphere".

The Toronto Conference Statement called, in particular, for increased resourcing for the research and monitoring efforts within the WCP, support for the work of the proposed IPCC and development of a comprehensive global convention as a framework for protocols on the protection of the atmosphere (Pearman et al., 1989; WMO, 1989).

The Intergovernmental Panel on Climate Change

The first session of the WMO-UNEP Intergovernmental Panel on Climate Change (IPCC) in Geneva in November 1988 elaborated its basic concept of operation as an intergovernmentally supervised expert assessment mechanism, established its three working group structure and initiated the work programme which was to lead to its highly influential First Assessment Report approved after long and difficult negotiation at its fourth session in Sundsvall, Sweden, in August 1990.

Under its three successive Chairmen and using increasingly rigorous and comprehensive assessment and review processes, the IPCC produced its Second Assessment Report in 1996, its Third Assessment Report in 2001 and its Fourth Assessment Report in 2007, as well as a number of Special Reports and Technical Papers along the way. It is now working on its Fifth Assessment Report.

Though criticized by some as too cautious and by others as too political and too alarmist, the IPCC has been widely accepted by its sponsors, governments and the competent bodies of the UN Framework Convention on Climate Change (see below) as the authoritative source of information on the science and impacts of climate change (Bolin, 2007; Zillman, 2007). Though formally constituted as a joint subsidiary mechanism of WMO and UNEP, and reporting regularly to the governing bodies of both its sponsors, it now operates essentially as an independent intergovernmental organization.

The Second World Climate Conference

The Second World Climate Conference (SWCC or WCC-2) took place, under the sponsorship of WMO, UNESCO, UNEP, FAO and ICSU, in Geneva from 29 October to 7 November 1990. It consisted of two parts: six days of scientific and technical presentations and discussions involving 747 participants from 116 countries; and two days of ministerial sessions attended by 908 participants from 137 countries. The Conference was held in the Geneva International Conference Centre but the opening of the ministerial sessions was held in the Palais des Nations with addresses from two Heads of State and four Prime Ministers (Jäger and Ferguson, 1991).

The original purpose of WCC-2, as envisaged when its planning began in 1986, was to review the first decade of progress under the WCP and the Conference programme included some excellent reviews of the WCP as a whole (Bruce, 1991) and its individual components (Boldirev, 1991) including major achievements in the application of climate information to the challenges of food, water, energy and urban and building design. The second purpose of the Conference, which emerged relatively late in the planning, was to undertake an initial international review of the First Assessment Report of the IPCC (Bolin, 1991; Coughlan and Nyenzi, 1991) as a lead-in to the negotiations for a UN Framework Convention on Climate Change, which were scheduled to begin in Washington DC in February 1991 and to conclude in time for signature at the Rio Earth Summit in June 1992.

The scientific part of WCC-2 included five specialist scientific panels and 12 task groups which produced recommendations for action in areas such as food, water, energy and land use. The resulting seven-page Conference Statement picked up many important issues that emerged from the group discussions, including a recommendation for the urgent establishment of a Global Climate Observing System (GCOS).

The five-page Ministerial Declaration from WCC-2, which was adopted by consensus, after lengthy negotiations on the final day, represented the most broadly based call thus far for cooperative international action on the climate change issue. It set the essential parameters for

Figure 3 — The Secretary-General of WMO, G.O.P. Obasi, addressing the opening of the ministerial sessions of the Second World Climate Conference in the Palais des Nations, Geneva, on 6 November 1990. Behind him (left to right) are the Hon. E. Fenech-Adami, Prime Minister of Malta; the Rt Hon. M. Thatcher, Prime Minister of the United Kingdom; HM King Hussein I of Jordan; Federal Councillor A. Köller, President of the Swiss Confederation; M. Rocard, Prime Minister of France; and the Rt Hon. B. Paeniu, Prime Minister of Tuvalu.

negotiation of the UNFCCC and invited the forthcoming Eleventh World Meteorological Congress to strengthen the WCP research and monitoring programmes in consultation with UNESCO, UNEP, FAO, ICSU and other relevant international organizations.

Establishment of the Global Climate Observing System

In the light of the WCC-2 Conference Statement and Declaration, the then Chairman of the Joint Scientific Committee (JSC) for the WCRP moved immediately to convene a meeting of experts to formulate a prospectus for the Global Climate Observing System. The meeting was hosted by the UK Meteorological Office at Winchester in January 1991 (Winchester Group, 1991), the concept and sponsorship arrangements were elaborated and agreed by the governing bodies of the proposed sponsors and, by early 1992, a Memorandum of Understanding was in place between WMO, IOC, UNEP and ICSU for the establishment of GCOS. A Joint Planning Office was established at WMO Headquarters in Geneva, a Joint Scientific and Technical Committee was appointed and, by mid-1995, a comprehensive GCOS plan had been finalized (GCOS, 1995).

The fundamental design concept for GCOS was that it be built as a system of climate relevant components of the established observing systems based on the WMO Global Observing System and Global Atmosphere Watch for the atmosphere and the then emerging Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS) which were also co-sponsored by several of the co-sponsors of WCC-2. The basic purpose of GCOS was to provide observational support for all components of the WCP, the IPCC and the UNFCCC.

GCOS has continued to evolve over the intervening years with a particularly strong focus on support of the UNFCCC (see below) since 1998 (GCOS, 2004). Although its concept of operation has been widely misunderstood and its implementation seriously under-resourced in both developed and developing countries, it is now widely seen as the appropriate international framework for ensuring the availability of all observations required for climate purposes at both the national and international levels and on all time and space scales (Sommeria et al., 2007).

Restructuring of the World Climate Programme

Eleventh World Meteorological Congress (May 1991) responded to the recommendations of WCC-2 by broadening and restructuring the WCP, establishing a broadly based Coordinating Committee for the World Climate Programme (CCWCP), institutionalizing the essential underpinning role of GCOS and foreshadowing an intergovernmental meeting to review the coordination arrangements and identify a resourcing strategy for both WCP and GCOS.

The four restructured components of the WCP became:

- The World Climate Data and Monitoring Programme (WCDMP):
- The World Climate Applications and Services Programme (WCASP);
- The World Climate Impact Assessment and Response Strategies Programme (WCIRP); and
- The World Climate Research Programme (WCRP).

with the former Advisory Committee on the World Climate Applications and Data Programmes (ACCAD) broadened to embrace all agencies involved with climate aspects of socio-economic development and IOC invited to join WMO and ICSU as co-sponsors of the WCRP (WMO, 1991).

The sponsorship and organizational arrangements for the re-structured World Climate Programme and associated activities following the 1991 Congress (Zillman, 1995) are shown schematically in Figure 4.

Negotiation of the UNFCCC

On the basis of the scientific evidence summarized in the First Assessment Report of IPCC and in line with the guidance from WCC-2, the Intergovernmental Negotiating Committee (INC) for a Framework Convention on Climate Change, which was established by the 1990 (45th) session of the UN General Assembly, commenced two years of hectic negotiations which ended with an agreed text for the UN Framework Convention on Climate Change on 9 May 1992. The Convention, whose Articles 4 and 5 include specific commitments to systematic observation and research in support of its ultimate objective ("…..stabilization of greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"), was signed by 155 countries at the Rio Earth Summit in June 1992 and came into force on 21 March 1994 (Mintzer and Leonard, 1994).

The first session of the Conference of the Parties to the UNFCCC reached agreement on the establishment of its subsidiary bodies, including the Subsidiary Body for Scientific and Technological Advice, which serves as the main link between the scientific and technical work of GCOS, WCRP and IPCC and the international policy role of COP.

The Article 4 and 5 link between GCOS and UNFCCC was greatly strengthened following the response of the 1997 third (Kyoto) session of the COP to the findings of the 1997 International Conference on WCRP. This was then further reinforced, in conjunction with the research role of WCRP, by the requirements of the 2007 COP-13 Bali Action Plan for comprehensive scientific information in support of both mitigation of, and adaptation to, climate change.

The Climate Agenda

The April 1993 Intergovernmental Meeting on the World Climate Programme, which had been called for by WMO Congress in 1991 to put in place a broadly based intergovernmental framework for the further development and resourcing of WCP and GCOS (WMO, 1993), was co-sponsored by the established sponsors of WCP

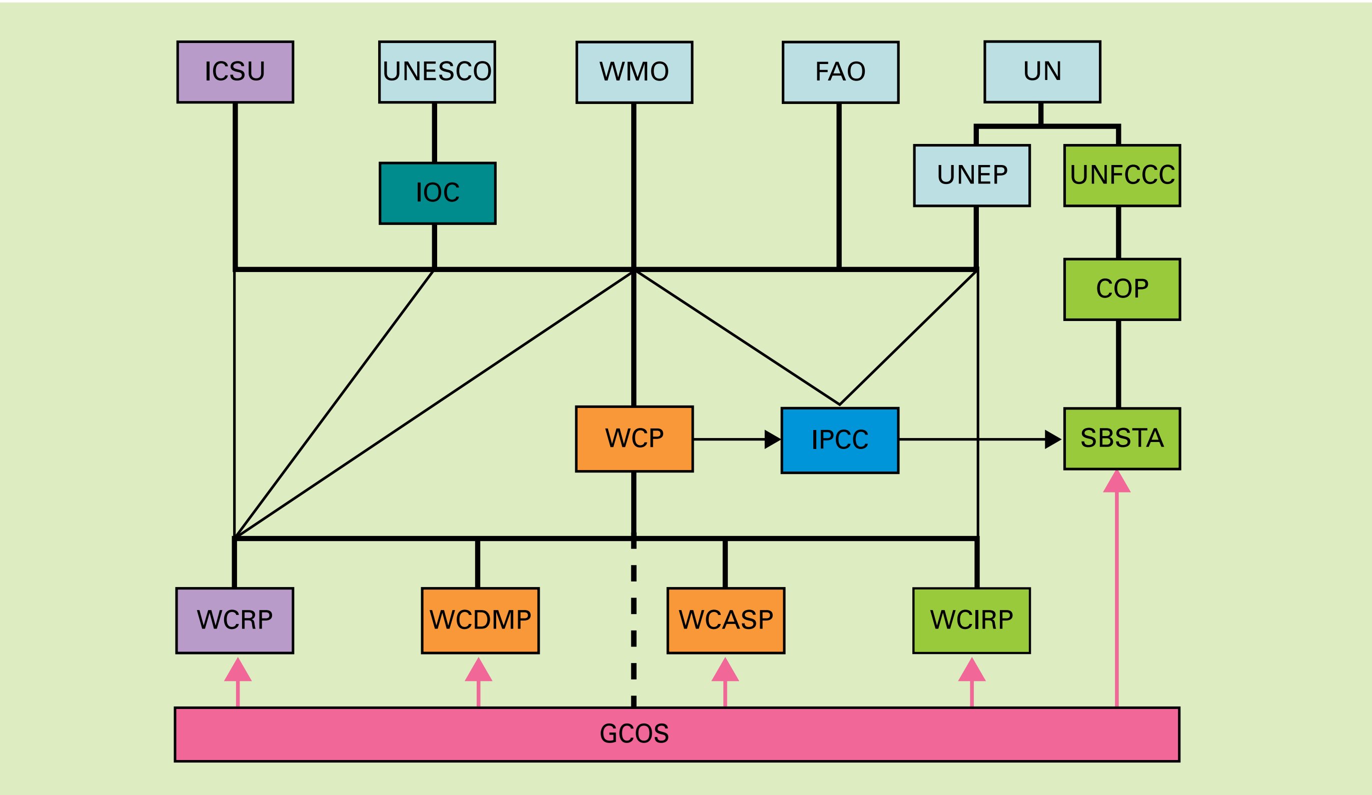

Figure 4 — Organizational structure and sponsorship arrangements for the World Climate Programme (WCP) following the Second World Climate Conference, showing also the underpinning role of the Global Climate Observing System (GCOS) and the link to the Intergovernmental Panel on Climate Change (IPCC) and the UN Subsidiary Body for Scientific and Technological Advice (SBSTA) of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC)

(WMO, UNESCO and its IOC, UNEP, FAO and ICSU) along with the United Nations Development Programme. It was attended by 360 delegates from 134 countries and 83 experts from 37 intergovernmental and non-governmental international organizations. It endorsed the concept of The Climate Agenda and, through its nine-page "Statement on the Climate Agenda", called for development of an integrated proposal to governments with four key thrusts on:

- Dedicated observations of the climate system;
- New frontiers in climate science and prediction;
- Studies for climate impact assessments and response strategies to reduce vulnerability; and
- Climate services for sustainable development.

It called especially for the establishment of National Climate Programmes in all countries as a basis for accelerated implementation of WCP and achievement of the agreed objectives of The Climate Agenda.

As part of its follow-up to the Intergovernmental Meeting, Eleventh World Meteorological Congress (1995) authorized the establishment of an Interagency Committee for the Climate Agenda (IACCA), which served as the peak coordination mechanism for GCOS, IPCC, WCP and other international climate-related programmes and activities through the remainder of the 1990s. The development of detailed proposals for resourcing GCOS, WCP and The Climate Agenda, was, however, largely left in abeyance, pending agreement on a new framework for international coordination of climate activities and consideration of proposals for the organization of a third World Climate Conference.

The call for a third World Climate Conference

Already in the second half of the 1990s and in response to growing concern at the failure of the 1993 Intergovernmental Meeting to mobilize the additional resources that were urgently needed for strengthening climate observing networks and climate research and service provision in support of both the specific needs of the UNFCCC and the broader global challenge of living with climate variability and change, pressure developed in WMO and other circles for WMO to convene a third World Climate Conference towards the end of the decade. This did not, however, find universal support and several of those who had been instrumental in shaping the earlier WMO-convened conferences moved instead to support the preparations for the World Climate Change Conference which was held in Moscow in September/October 2003 (Izrael et al., 2004). But, eventually, under the leadership of its Advisory Group on Climate and Environment, which had been established by the WMO Executive Council in 1999, specific proposals were developed for consideration by Thirteenth World Meteorological Congress in 2003 .

The convening of a third World Climate Conference was, however, strongly opposed by some countries and the Congress decided, instead, simply to request the Executive Council to keep the matter under consideration.

The growing emphasis on adaptation

Under the influence of the 2001 Third Assessment Report of the IPCC, the 2002 Johannesburg World Summit on Sustainable Development and the growing realization in UNFCCC and other circles that the global challenge of climate change would have to be addressed through a balance of mitigation and adaptation, international awareness began to increase rapidly of the need for comprehensive climate information in support of national and international strategy for reducing greenhouse gas emissions and adapting to unavoidable climate change. The focus moved strongly to the need for "downscaling" climate change projections in support of adaptation at the regional, national and local levels.

This, in turn, underscored the continuing importance of such earlier international initiatives as the Climate Information and Prediction Services project of the World Climate Applications and Services Programme as a framework for meeting the expanding need for the full range of climate services in all countries. The scientific and practical challenges of making better use of climate information to live with climate variability and change were comprehensively addressed in two important WMO-sponsored Conferences in 2006 and 2007:

- The July 2006 Espoo (Finland) Conference on Living with Climate Variability and Change: Understanding the Uncertainties and Managing the Risks (WMO, 2009(a)); and
- The March 2007 Madrid Conference on Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services (WMO, 2009(b));

and the information needs for adaptation have been comprehensively identified through a series of initiatives under the Nairobi Work Programme of the UNFCCC.

Planning for WCC-3

In the light of the growing international pressure for more detailed and more reliable climate prediction and information and

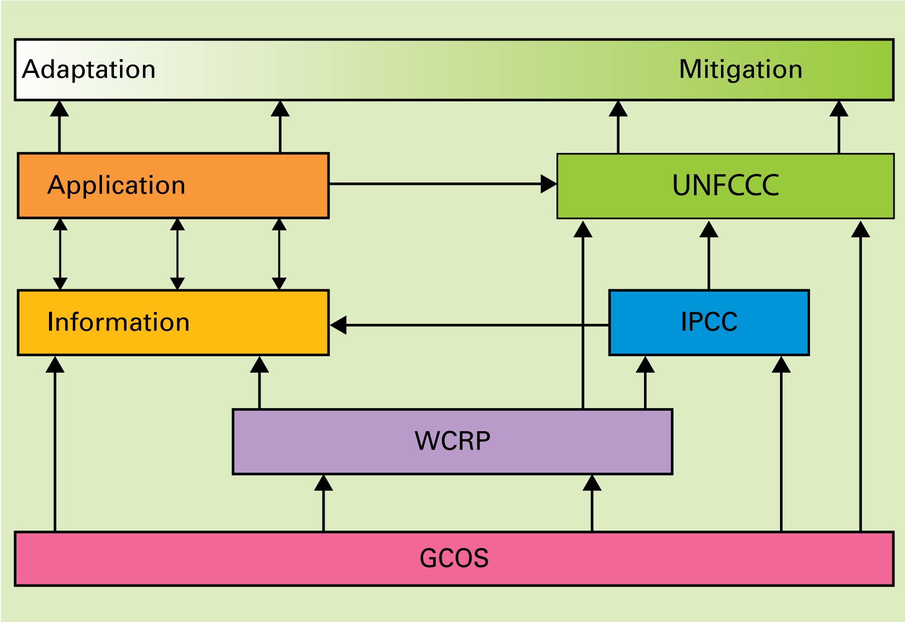

Figure 5 — The proposed new Global Framework for Climate Services consisting of a strengthened Global Climate Observing System (GCOS) and World Climate Research Programme (WCRP) supporting closely coupled Information and Application components of a World Climate Services System to complement and support the climate change assessment and policy roles of the IPCC and UNFCCC in achieving mitigation of, and adaptation to, climate change

nearly a decade after the need was first identified within the WMO community, Fifteenth World Meteorological Congress (2007) endorsed the organization of World Climate Conference-3 (WCC-3), by late October 2009, around the theme "Climate prediction for decision-making, focusing on seasonal to interannual time scales, taking into account multi-decadal prediction".

At the request of Congress and the Executive Council, the Secretary-General of WMO established a WCC-3 International Organizing Committee (WIOC) of some 24 members supported by representatives of 27 co-sponsoring and partner organizations. The Committee met in February and September 2008 and March 2009 to develop the concept and guide the planning, for WCC-3 with a Conference vision for "an international framework for climate services that links science-based climate predictions and information with the management of climate-related risks and opportunities in support of adaptation to climate variability and change in both developed and developing countries".

The UN System delivering as one

Following the December 2007 UNFCCC adoption of the Bali Action Plan and a series of UN General Assembly and other resolutions, the UN Secretary-General, through the UN Chief Executives Board and its High-Level Committee on Programmes initiated a process to ensure a coherent and coordinated UN System response to the challenge of climate variability and change. In the first instance, this involved the identification of five focus areas (adaptation, capacity-building, finance, reducing emissions from deforestation and degradation, and technology transfer) and four cross-cutting areas of UN System action, one of which, to be co-convened by WMO and UNESCO, was identified as "science, assessment, monitoring and early warning" ("climate knowledge").

As the first major initiative of the "UN System delivering as one on climate knowledge", WCC-3 has been designed to guide the establishment of a new global framework for climate services to meet the rapidly growing needs for information in support of the 21st century response to the challenge of climate variability and change. WMO successfully established and operates the international framework for provision of a wide range of meteorological and related services. The successes and lessons learned will motivate and guide the establishment of a wide range of new and improved climate services to support adaptation to climate variability and change.

Conclusion

The new global framework for climate services proposed as the significant concrete outcome from WCC-3 is well placed to build on the remarkable scientific progress of the past 50 years and the solid institutional foundation provided by the international climate observation, research and assessment mechanisms put in place by WMO and its partner organizations over the 30 years since the historic First World Climate Conference of February 1979.

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World Climate Research Programme: achievements, activities and challenges

by Antonio J. Busalacchi[1] and Ghassem R. Asrar[2]

In the wake of World War II, owing to advances in our observing and understanding of the dynamics of the atmospheric circulation, together with nascent digital computing and telecommunication technologies, the new field of numerical weather prediction was ushered in. The societal benefit of these scientific discoveries and technological innovations is manifest in present-day routine daily and weekly weather predictions.

Today, as a result of advances in climate science during the past 30 years, we are now seeing major advances in our ability to predict seasonal-to-interannual variability in Earth's climate and project climate change on centennial timescales for major regions of the world. Looking to the future, we find ourselves at the beginning of a new era of predicting Earth System behaviour with tremendous potential to serve global society's need for climate and environmental information from days to seasons, years to decades and longer. Coordination and collaboration among the nations around the world have been and will continue to be a hallmark of such progress.

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The World Climate Research Programme (WCRP) was established in 1980 under the joint sponsorship of WMO and the International Council for Science (ICSU) and, since 1993, the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The main objectives for WCRP since its inception are, to determine the predictability of climate and to determine the effect of human activities on climate. These fundamental objectives have laid the groundwork for present society's adaptation and mitigation response strategies to changes in climate. Thanks to WCRP efforts, it is now possible for climate scientists to monitor, simulate and project global climate so that climate information can be used for governance, in decision-making and in support of a wide range of practical applications.

Over these 30 years, new disciplines of climate science have arisen that transcend traditional fields of atmosphere, ocean and land sciences and have led to routine seasonal-to-interannual climate predictions and longer-term climate projections. In parallel with such studies of natural fluctuations of the coupled climate system, the WCRP development of coupled climate models, driven by changes in the radiative forcing of greenhouse-gas emissions, has provided the climate change projections that have underpinned the assessments of the Intergovernmental Panel on Climate Change (IPCC) and the United Nations programme on assessment of atmospheric ozone depletion/recovery.

Past achievements

Modern climate science began with the creation of physically based numerical models of atmospheric and oceanic circulations in the 1950s and 1960s. In the 1960s and 1970s, observations from new Earth-orbiting satellites, ostensibly in support of weather prediction, began providing an unprecedented perspective of the Earth as an interconnected system of atmosphere, oceans, continents and life and temporal changes in this system much longer than that of day-to-day weather phenomena.

This first global perspective of the Earth's atmospheric circulation and climate system enabled global climate studies and identified the important physical climate system processes. The idea of an international research programme on climate change came into being at Eighth World Meteorological Congress in May 1979, which formally established WCRP, inclusive of a climate research component (to be jointly managed by WMO and ICSU), as well as activities in gathering, managing and applying climate data and assessment of the potential impacts of climate change (to be managed by the United Nations Environment Programme (UNEP)).

WCRP from the outset had two major foci: climate predictability and human influence.

WCRP identified the scientific complexity and breadth of the climate system: the Scientific Plan for the programme, prepared in 1984, recognized clearly the role of radiation, cloudiness, the ocean, the hydrological cycle and the biosphere. Oceans, land surfaces, the cryosphere and biosphere all needed to be represented realistically in global climate models. The extensive model development and numerical experimentation required the exploration of the sensitivity of the climate to changes in atmospheric carbon dioxide concentration (as well as other gases and aerosols). Early work on the assessment of research into carbon dioxide effects on climate anticipated IPCC needs. In view of the critical role of oceans in the climate system, close cooperation was established with the oceanographic community, with IOC joining as co-sponsor of the WCRP in 1993.

The first WCRP coupled atmosphere-ocean initiative, the Tropical Ocean and Global Atmosphere (TOGA) project, began in 1984. TOGA studied the influence of the slowly varying thermal inertia of tropical oceans on the large-scale atmospheric circulation. Recognition of the longer timescale or memory inherent to the oceans enabled short-term climate forecasts beyond the lead time of daily weather prediction. The requirement for ocean observations to initialize coupled forecasts established the prototype of the ocean observing system now in place.

During the TOGA decade, routine observations of the air-sea interface and upper-ocean thermal structure in the tropical Pacific Ocean were provided in real-time by the Tropical Atmosphere Ocean (TAO) array. These mooring observations have since been sustained in the Pacific and extended to the Atlantic and Indian Oceans, thus building a solid foundation for today's ocean observing system.

Ocean data assimilation proved to be a key element to the initialization of seasonal-to-interannual climate forecasts. Coupled ocean-atmosphere prediction models were implemented at many of the world's major weather prediction centres (Figure 1). This led to key breakthroughs in seasonal climate forecasts based on observations, understanding and modelling of worldwide anomalies in the global atmospheric circulation, temperature and precipitation patterns linked via teleconnections to El Niño. This was the beginning of the concept of climate products and services.

In addition, the overall approach to climate science evolved during TOGA. Prior to TOGA, in the early to mid-1980s, oceanographers and meteorologists were often in separate and distinct communities. As part of TOGA, these communities came together to form a new discipline of climate science realizing that there are modes of variability that occur in the coupled ocean-atmosphere system that do not exist in the uncoupled ocean or atmosphere.

Just as TOGA left behind a legacy upon which the subsequent Climate Variability and Predictability (CLIVAR) programme was established, so too did the WCRP World Ocean Circulation Experiment (WOCE) establish a solid foundation to study the ocean's role in climate. WOCE was the largest and most successful global ocean research programme ever undertaken. Between 1990 and 1997, WOCE collected oceanographic data of unprecedented quality and coverage. These data, contributed by more than 30 nations, were fundamental in the development of basin-scale ocean models and have shaped our current understanding of mixing processes for energy and nutrients in the oceans. WOCE left a significant imprint on our knowledge of the global oceans, changes in the technology used by oceanographers and overall changes to the scientific methods for ocean research. During WOCE, a global perspective for the time-varying nature of the world's oceans, from top to bottom, was realized.

The notion of a steady general ocean circulation or "snapshot" approach to observing the ocean was refuted by the repeat sections of the WOCE global hydrographic survey. This survey established a baseline to assess changes in time and evaluate anthropogenic effects on the global

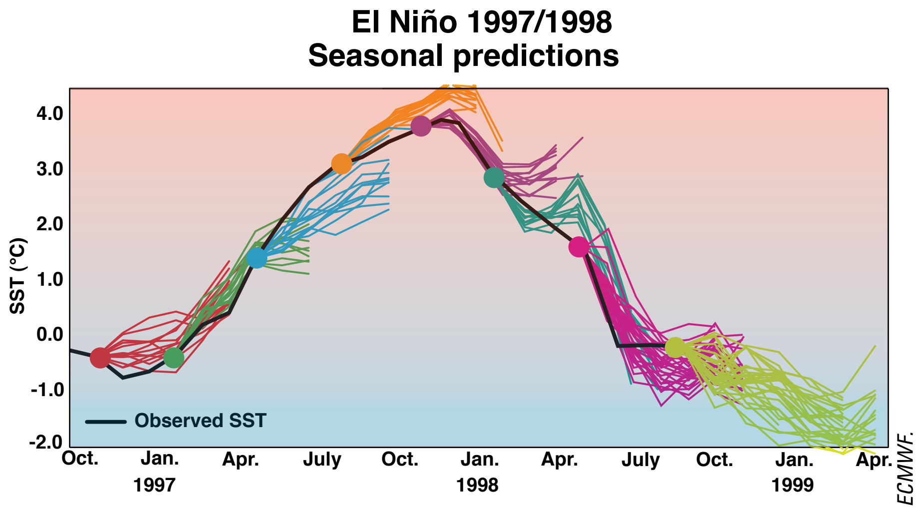

Figure 1 — Demonstration of successful ENSO forecasts such as displayed here for the 1997/1998 event have been possible through intensive research efforts in the field of seasonal prediction. The physical basis for understanding and predicting El Niño temperature signals and associated changes in the global atmospheric circulation from a season to a year in advance was laid during the WCRP project on Tropical Ocean and Global Atmosphere (TOGA, 1985-1994).

ocean circulation. In partnership with the US Joint Global Ocean Flux Study, a carbon dioxide and trace chemistry survey was enabled. Regional process studies and focused observational campaigns improved our knowledge of the Southern Ocean, deepwater formation in the Greenland-Iceland-Norwegian and Labrador Seas, and refinements to our understanding of the global thermohaline circulation and the meridional transport of heat from Equator to pole.

Advances in ocean technology played a major role in permitting a global ocean perspective. Continuous observations of global sea-surface height were provided by the TOPEX/Poseidon and European remote-sensing satellite radar altimeters. Active and passive microwave satellite sensors provided all-weather retrievals of the ocean surface wind velocity. Improved instrumentation and calibration led to refinements in air-sea flux measurement capabilities from both ship- and mooring-based platforms. Within the ocean, the WOCE float programme led to the ARGO programme and the concept of a global deployment of profiling floats. Experimental devices such as gliders demonstrated the potential for performing repeat sections in historically difficult-to-observe regions of the ocean such as western boundary currents.

Initiated by the WOCE Community Modelling Effort and fuelled by advances in computer technology, global ocean models now exist which can resolve energetic boundary currents and associated instability processes and provide a dynamically consistent description of many observed aspects of the ocean circulation that contribute to understanding the role of oceans in the Earth's climate system. WOCE also changed the way the scientific community studies the ocean's role in climate. The idea of an ocean synthesis in which in situ observations and/or remotely sensed observations are brought together with data-assimilation methodologies revolutionized the approach to global oceanography. Real-time global ocean observations have ushered in the possibility of operational oceanography on a global scale; an important theme of the upcoming Ocean Observations '09 Conference (Venice, Italy, September 2009). We are now at the point that the oceanographic equivalent of a World Weather Watch is not a folly limited by logistics, but is in fact on the verge of reality.

Present activities

Other important initiatives of WCRP were the International Satellite Cloud Climatology Project in 1982, the compilation of a Surface Radiation Budget dataset from 1985, and the Global Precipitation Climatology Project in 1985. These were based on exciting new techniques, developed to blend optimally remotely-sensed and in situ observations, providing for the first time new insights into the role of clouds in the climate system and the interaction of clouds with both radiation and the hydrological cycle. These activities formed the starting point for the comprehensive Global Energy and Water Cycle EXperiment (GEWEX) established in 1988, which is still one of the largest worldwide energy and water cycle experiments. As such, GEWEX leads the WCRP studies of the dynamics and thermodynamics of the atmosphere, the atmosphere's interactions with the Earth's surface (especially over land) and the global water cycle. The goal of GEWEX is to reproduce and predict by means of observations and suitable models the variations of the global hydrological regime, its impact on atmospheric and surface dynamics, and variations in regional hydrological processes and water resources and their response to changes in the environment, such as the increase in greenhouse gases.

GEWEX strives to provide an order-of-magnitude improvement in the ability to model global precipitation and evaporation, as well as accurately assess the feedback between atmospheric radiation, clouds, land use and climate change. To date, GEWEX has developed high-resolution, next-generation hydrologic land surface and regional climate models by improving parameterizations and applying them for experimental predictions. GEWEX has developed global datasets on clouds, radiation, precipitation and other parameters that are invaluable in understanding and predicting global energy and water cycles processes,

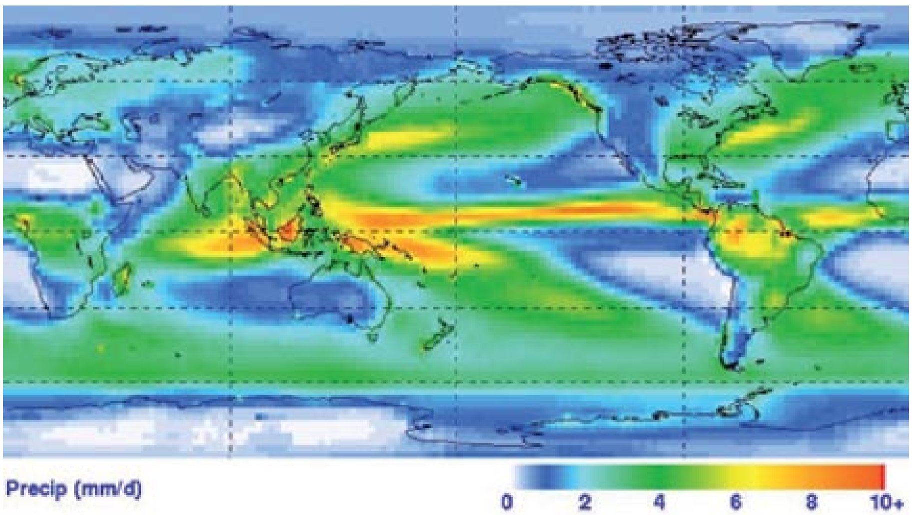

Figure 2 — Satellite-gauge combined precipitation product of the GEWEX Global Precipitation Climatology Project averaged for the 30 years 1979-2008, in mm per day. Data courtesy of GEWEX/GPCP; image by David Bolvin (SSAI), 5 June 2009, NASA/Goddard Space Flight Center, Greenbelt, MD.

and for their proper representation in the climate system models (Figure 2). Modelling studies and coordinated field experiments have identified key land-surface processes and conditions that contribute most significantly to the predictability of precipitation. GEWEX is developing land-data assimilation systems that will resolve land-surface features at resolutions as small as 1 km that will prove invaluable in studies and assessments of regional climate variability and change.

Climate Variability and Predictability (CLIVAR), founded in the year 1995, is the main focus in WCRP for studies of climate variability. Monsoons, El Niño/Southern Oscillation and other global coupled atmosphere-ocean phenomena are investigated by CLIVAR on seasonal, interannual, decadal and centennial timescales. CLIVAR builds on—and is advancing—the findings of WCRP's successfully completed TOGA and WOCE projects. CLIVAR further examines the detection and attribution of anthropogenic climate change based on high-quality climatic records.

Its mission is to observe, simulate and predict the Earth's climate system, with a focus on ocean-atmosphere interactions enabling better understanding of climate variability, predictability and change for the benefit of society and the environment in which we live. CLIVAR seeks to encourage analysis of observations of climate variations and change on seasonal-to-centennial and longer timescales. It collaborates closely with GEWEX in studying and ultimately predicting the monsoon systems worldwide. It also encourages and helps to coordinate observational studies of climate processes, particularly for the ocean, but also over the monsoon land areas, encouraging their feed through into improvements in models.

CLIVAR promotes the development of a sustained ocean observing system both regional and globally. In collaboration with other WCRP projects, it is attempting particularly to understand and predict the coupled behaviour of the rapidly changing atmosphere and more slowly varying land surface, oceans and ice masses as they respond to natural processes, human influences and changes in the Earth's chemistry and biota, while refining the estimates of anthropogenic climate change and our understanding of climate variability.

CLIVAR provides scientific input to the WCRP crosscutting topics on seasonal and decadal prediction and (with GEWEX) on monsoons and climate extremes. It also contributes to those on anthropogenic climate change and atmospheric chemistry (with Stratospheric Processes and their Role in Climate (SPARC)) and sea-level variability and change (with the Climate and Cryosphere (CliC) project, and cross-cutting scientific climate themes. CLIVAR achievements include the development of improved understanding and prediction of climate variability and change.

CLIVAR has provided coordination of climate model scenario experiments for IPCC, as well as key inputs on changes in climate extremes to the IPCC Fourth Assessment Report. Model intercomparison activities aimed at improving seasonal predictions and ocean model performance have been led by CLIVAR. Study of the ocean's role in climate has been a major focus for coordination of field studies to help improve parameterization schemes for atmosphere and ocean climate models, synthesis of ocean data and advocacy for real-time ocean observations and high-quality delayed mode observations for ocean operations and research.

CLIVAR has organized major training workshops on seasonal prediction in Africa, climate impacts on ocean ecosystems, climate data and extremes and El Niño/Southern Oscillation. One specific example is the development of an electronic African Climate Atlas, as a tool for research on African climate.

Since 1993, the role of the stratosphere in the Earth's climate system has been the focus of the WCRP project on SPARC. SPARC concentrates on the interaction of the atmosphere's dynamical, radiative and chemical processes. Activities organized by SPARC include the construction of a stratospheric reference climatology and the improvement of understanding of trends in temperature, ozone and water vapour in the stratosphere. Gravity-wave processes, their role in stratospheric dynamics and how these may be parameterized in models are other current topics.

Research on stratospheric-tropospheric interactions have led to new understanding of tropospheric temperature changes initiated from the stratosphere. SPARC has organized model simulations and analyses that were a central element of the WMO/UNEP Scientific Assessments of Ozone Depletion and now recovery (Figure 3). SPARC-affiliated scientists have served on the WMO/UNEP Assessment Steering Committee, as lead and contributing authors and reviewers. In addition, SPARC comprehensive peer-reviewed reports include: "Trends in the vertical distribution of ozone"; "Upper tropospheric and stratospheric water vapour"; "Intercomparison of middle atmosphere climatologies"; and "Stratospheric aerosol properties". WCRP researchers have also provided much of the scientific basis for the ozone protocols and carbon-dioxide- and aerosol-emission scenarios used by the United Nations Framework Convention on Climate Change (UNFCCC).

In 1993, the Arctic Climate System Study (ACSYS) opened up a polar perspective with the examination of key processes in the Arctic that have an important role in global climate. The scope of this study was broadened to the whole of the global cryosphere with the establishment of the Climate and Cryosphere (CliC) project in 2000. CliC was established to stimulate, support and coordinate

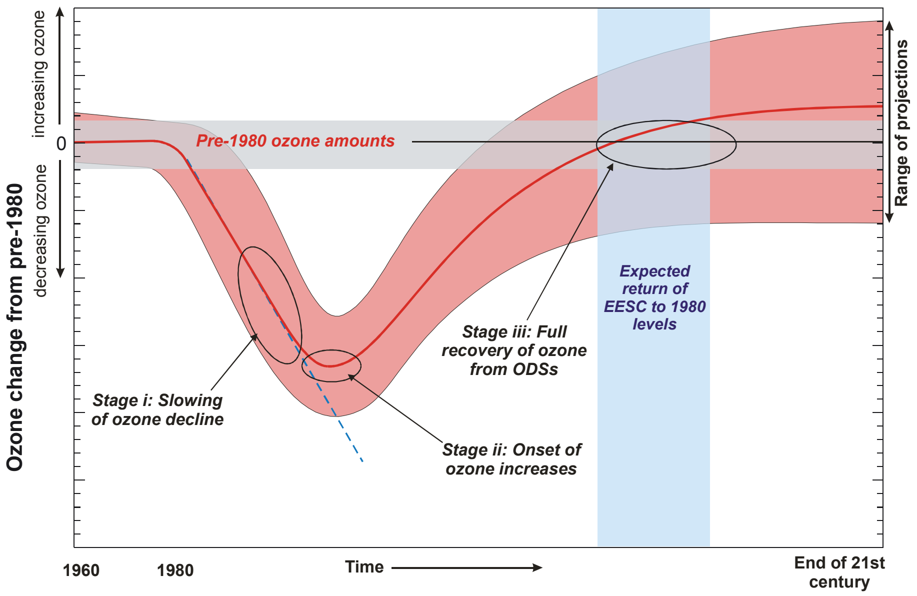

Figure 3 — Through its project on Stratospheric Processes and their Role in Climate (SPARC), WCRP-related scientists have served on the WMO/UNEP Scientific Assessment Panel for Ozone Depletion as lead and contributing authors and reviewers. The schematic diagram shows the temporal evolution of observed and expected global ozone amounts. Image source: WMO/UNEP Scientific Assessment of Ozone Depletion 2006.

research into the processes by which the cryosphere interacts with the rest of the climate system. The cryosphere consists of the frozen portions of the globe and includes ice sheets, glaciers, ice caps, icebergs, sea ice, snow cover and snowfall, permafrost and seasonally frozen ground, as well as lake- and river-ice. As a sensitive component of the climate system, the cryosphere provides key indicators of climate change (e.g. sea level rise, Figure 4), and CliC focuses on identifying patterns and rates of change in cryospheric parameters. CliC encompasses four themes, covering the following areas of climate and cryosphere science: The terrestrial cryosphere and hydrometeorology of cold regions; Ice masses and sea level; The marine cryosphere and climate; and Global prediction of the cryosphere.

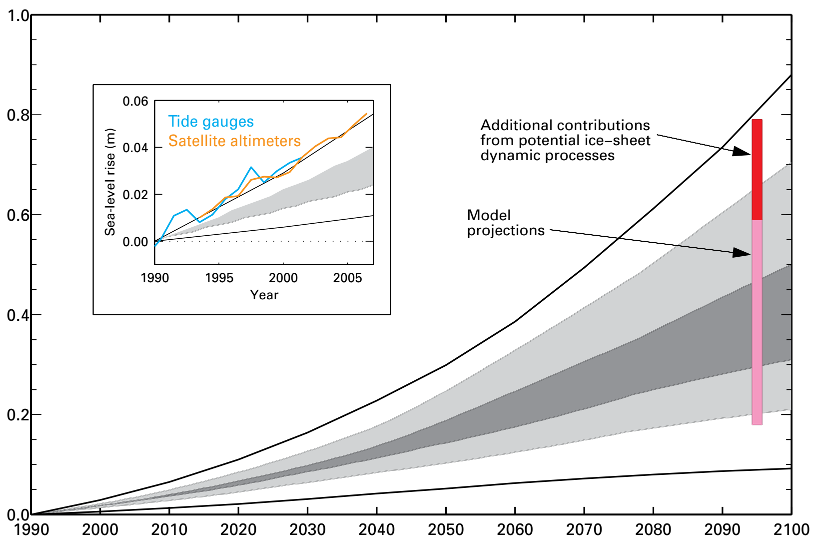

Figure 4 — The climate knowledge and understanding we gain from research has to be made available to decision-makers in an open and timely manner in order to become beneficial to human society and the environment. For example, vulnerability assessments of coastal settlements and low-lying areas such as Pacific Islands and other island States prone to a rising sea level are based on the reconstructed and projected sea-level rise for the 21st century (m). A new WCRP activity within the Climate and Cryosphere (CliC) project now focuses on assessing the contribution of ice caps and glaciers on global sea level. Image source: modified and updated by J. Church, based on Church et al. 2001 in IPCC Fourth Assessment Report.

CliC generated strong input from the climate research community to the scientific programme of the International Polar Year 2007-2008. This included the concept of a polar satellite snapshot aimed at obtaining unprecedented coverage of both polar regions. CliC was one of the key scientific programmes that drew the attention of the world's scientific community to the cryosphere. For the first time, a chapter on snow, ice and frozen ground was prepared in the IPCC Fourth Assessment Report. As detailed there, the contribution of melted water to recent sea-level change is now known with considerably increased accuracy.

The development and evaluation of global climate models is an important unifying component of WCRP, building on scientific and technical advances in the more discipline-oriented activities. These models are the fundamental tool for understanding and predicting natural climate variations and providing reliable predictions of natural and anthropogenic climate change. Models also provide an essential means of exploiting and synthesizing, in a synergistic manner, all relevant atmospheric, oceanographic, cryospheric and land-surface data collected in WCRP and other programmes. The Working Group on Numerical Experimentation (WGNE), jointly sponsored by WCRP and the WMO Commission for Atmospheric Sciences (CAS), leads the development of atmospheric models for both climate studies and numerical weather prediction.

The WCRP modelling programme has provided essential input to the four published assessments of the IPCC and is once again providing input to the next round of IPCC assessments. The WCRP Working Group on Coupled Modelling (WGCM) leads the development of coupled ocean/atmosphere/land models used for climate studies on longer timescales. WGCM is also WCRP's link to the International Geosphere-Biosphere Programme's (IGBP) Analysis, Integration and Modelling of the Earth System and to the IPCC. Activities in this area concentrate on the identification of errors in model climate simulations and exploring the means for their reduction by organizing coordinated model experiments under standard conditions. Under the purview of WCRP, the Atmospheric Model Intercomparison Project has facilitated controlled simulations by 30 different atmospheric models under specified conditions. The comparison of the results with observations has shown the capability of many models to represent adequately mean seasonal states and large-scale interannual variability.

Moreover, WGCM has initiated a series of Coupled Model Intercomparison Projects (CMIP). In 2005, WCRP facilitated the collection, archival and access to all the global climate model simulations undertaken for the IPCC Fourth Assessment Report. This third phase of CMIP (CMIP3) involved an unprecedented set of 20th- and 21st-century coordinated climate change experiments from 16 groups in 11 countries with 23 global coupled climate models. About 31 terabytes of model data were collected at the Program for Climate Model Diagnosis and Intercomparison. The model data are freely available and have been accessed by more than 1 200 scientists who have produced over 200 peer-reviewed papers, to date.

The first WCRP Seasonal Prediction Workshop was held in June 2007 in Barcelona, Spain, bringing together climate researchers, forecast providers and application experts to address the current status of seasonal forecasting and the application of seasonal forecasts by decision-makers. Workshop participants outlined recommendations and identified best practices in the science of seasonal prediction. During the workshop, the WCRP Climate-system Historical Forecast Project was launched. That project is a multi-model, multi-institutional experimental framework for assessing state-of-the-science seasonal forecast systems and for evaluating the potential for untapped predictability due to interactions of components of the climate system that are currently not fully accounted for in seasonal forecasts.

The World Modelling Summit for Climate Prediction, jointly sponsored by WCRP, IGBP and the WMO World Weather Research Programme (6-9 May 2008, Reading, United Kingdom) was organized to develop a strategy to revolutionize prediction of the climate through the 21st century to help address the threat of climate change. A key outcome of the Summit was the indisputable identification that our ability as a research community to make the transition from studies of global climate variability and change to application at the regional level has tremendous ramifications for present and future climate models, observations and needed infrastructure, such as high-performance computing.

Throughout its history, WCRP has had extensive interactions with many groups concerned with climate and climate research and has collaborated widely with other international scientific organizations on aspects of climate research that involve biogeochemistry, as well as physics. Multiple examples of active collaboration between WCRP and IGBP can be found in the GEWEX, SPARC and CLIVAR projects. Furthermore, WCRP strongly supported WMO's establishment of the Global Climate Observing System (GCOS) in 1992 in cooperation with ICSU, UNEP and IOC. WCRP is also a co-sponsor of the international global change SysTem for Analysis, Research and Training (START) that promotes environmental research capacities in developing countries. In 2001, projections of possible future climate change and of increasing variations in climate stimulated the establishment of the Earth System Science Partnership between WCRP, IGBP, the International Human Dimensions Programme and the international programme of biodiversity science, DIVERSITAS. This partnership is promoting a coordinated focus on important global issues of common concern, namely the carbon budget, food systems, water systems and human health and similar important themes to human activities that could be affected by possible future climate change and increasing climate variability.

Future challenges/ opportunities

Looking to the future, the WCRP Strategic Framework for 2005-2015 period aims to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. A key focus of this Strategic Framework is towards seamless prediction of weather, climate and, ultimately, the whole Earth system. There are many theoretical and practical reasons for this approach to be pursued by the weather and climate community in adopting a seamless or unified approach to environmental prediction.

Extension of climate prediction to more encompassing environmental prediction requires recognition that the climate system is inextricably linked to the Earth's biogeochemistry and to human activities. For WCRP to achieve its goals of understanding and predicting climate variability and change and their effect on society at large, it must, and will, contribute to studies of the fully integrated Earth system.

Developing a unified approach to weather, climate, water and environmental prediction requires a broadened Earth system perspective beyond the traditional atmospheric science disciplines. The development of climate prediction and ultimately environmental prediction is not a rote extension of numerical weather prediction. For example, the scientific disciplines required to support weather, climate and environmental prediction across these timescales span meteorology, atmospheric chemistry, hydrology, oceanography and marine and terrestrial ecosystems.

While atmospheric nowcasting and very short-range weather forecasting are primarily initial value problems, extension to short-, medium- and extended-range weather forecasting begins to bring in the coupling of land-surface processes and the role of soil moisture feedback and other surface-atmosphere processes. Long-range forecasting through seasonal climate forecasting involves atmosphere-ocean coupling with the initial conditions of the memory inherent in the upper ocean leading to longer lead-time predictive skill.

Decadal climate prediction is determined by both initial values and boundary-value forcing. On these timescales, deeper oceanic information and changes to radiative forcing from greenhouse gases and aerosols play determinant roles. When considering interdecadal to centennial climate projections, not only do future concentrations of greenhouse gases need to be taken into account, but also changes in land cover/dynamic vegetation and carbon sequestration governed by both marine and terrestrial ecosystems. In addition, regionally specific predictive information will be required across these timescales for environmental parameters such as air and water quality.

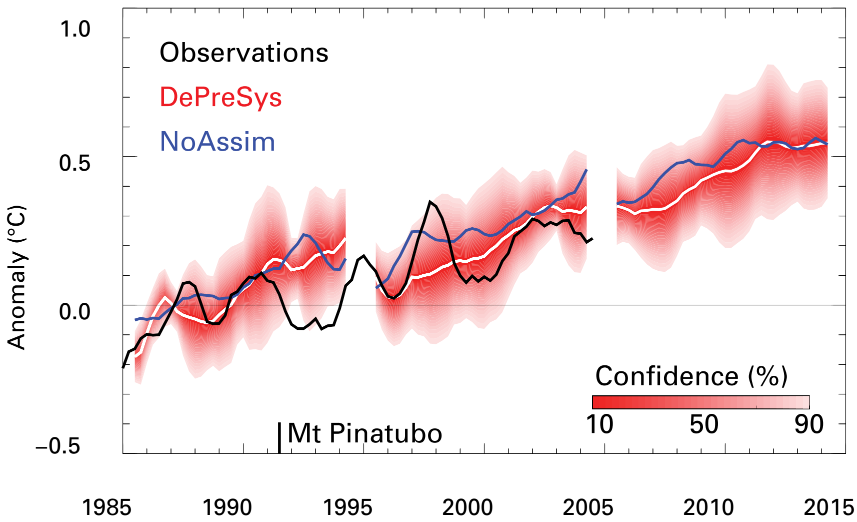

Figure 5 — Global average of annual-mean Earth surface temperature anomaly (1979-2001) forecast by the UK Met Office Decadal Prediction System (DePreSys) beginning in June 2005. The confidence interval (red shading) is diagnosed from the standard deviation of the DePreSys ensemble mean (white curve). The blue curve is an equivalent forecast with no initialization with observations. The black curve is the hindcasts beginning from June 1985 together with observations. Source: Smith et al. (2008, Science 317)

One of WCRP's major challenges is to determine the limits to predictability on the decadal timescale. Within the concept of a unified suite of forecasts, decadal prediction bridges the gap between predicting seasonal-to-interannual climate variability and change and the externally forced climate change projections over very long periods, i.e. a century. The climate-change community is typically focused on the problem of estimating anthropogenically induced climate change on centennial timescales. For this community, the provision of accurate initial conditions is not a major concern, since the level of predictability of the first kind is believed to be small on century timescales.

By contrast, although the numerical weather prediction and seasonal forecast community have well-developed data-assimilation schemes to determine initial conditions, the models do not incorporate many of the cryospheric and biogeochemical processes believed to be important on timescales of centuries. A focus on decadal prediction by the two groups may help expedite the development of data-assimilation schemes in Earth system models and the use of Earth system models for shorter-range prediction, e.g. seasonal. For example, seasonal predictions can be used to calibrate probabilistic climate-change projections in a seamless prediction system. Hence, there is common ground over which to base a cooperation of the two communities in order to develop seamless predictions.

Over the past 20 years, the link between WCRP observational and modelling efforts has been atmospheric reanalyses that have greatly improved our ability to analyse the past climate variability. The Third WCRP International Conference on Reanalysis was held in Tokyo from 28 January to 1 February 2008 to showcase results of progress in reanalysis products and research and to discuss future goals and developments. The climate record is made up of analyses of observations taken for many other purposes, such as weather forecasting in the atmosphere or core oceanographic research. It is now recognized that global climate can be understood only by ensuring that there are climate-quality observations taken in the atmosphere, ocean and land surface, including the cryosphere.

A consequence of past practices is that the climate record often displays biases that mask long-term variations. Many climate datasets are inhomogeneous: the record length is either too short to provide decadal-scale information or the record is inconsistent, owing to operational changes and absence of adequate metadata. Hence, major efforts have been required to homogenize the observed data for them to be useful for climate purposes. Reanalysis of atmospheric observations using a constant state-of-the-art assimilation model has helped enormously in making the historical record more homogeneous and useful for many studies. Indeed, in the 20 years since reanalysis was first proposed, there have been great advances in our ability to generate high-quality, temporally homogeneous estimates of past climate. WCRP and GCOS have provided leadership in promoting the underpinning research and observational needs for reanalysis. With the ongoing development of analysis and reanalysis in the ocean, land and sea ice domains, there is huge potential for further progress and improved knowledge of the past climate record.

From the Conference, it was apparent that much future work remains to be done to address outstanding issues in reanalyses, especially those related to the changing observational data base. These issues adversely affect decadal and longer variability and limit applications of reanalyses at present. Moreover, while the origins of reanalysis have been in atmospheric climate and weather, there have been significant studies of reanalysis (or synthesis) of ocean data. Because of the limited size of the historical ocean datasets, it has been necessary to develop novel techniques for increased homogeneity of ocean reanalysis. Other promising developments are occurring in sea ice, Arctic and land surface reanalysis. There has also been initial development of coupled atmosphere-ocean data assimilation, which is laying the foundation for future coupled reanalysis studies that may lead to more consistent representations of the energy and water cycles. A challenge is to improve estimates of uncertainty in the reanalysis products.

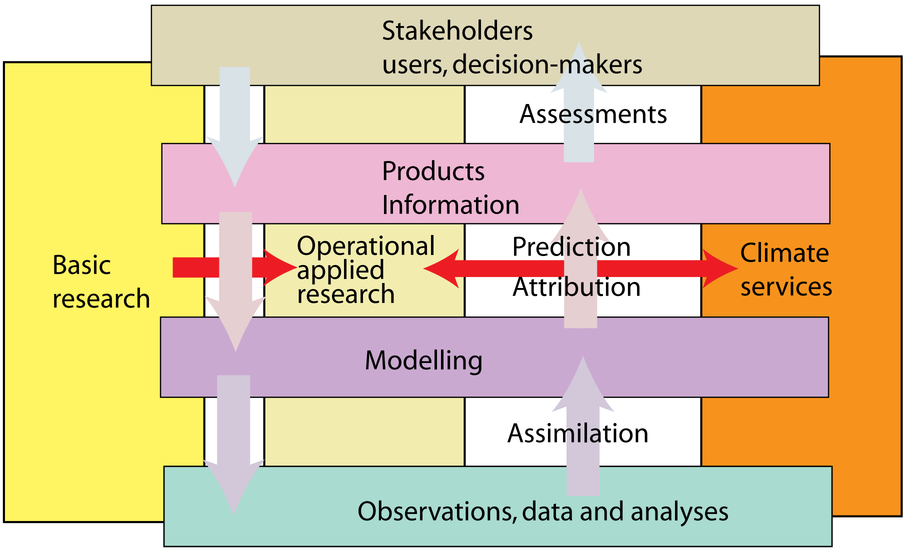

Figure 6 — A conceptual framework for a climate information system which begins with observations, research and analysis and results in information required by the decision-makers. The decisions on priorities and coordination among component of the system are informed by the need for scientific understanding together with the type of climate information required by the decision-makers. Source: Trenberth (2008), WMO Bulletin 57 (1), January 2008, slightly modified by G. Asrar

Global atmospheric reanalysis results in high-quality and consistent estimates of the short-term or synoptic-scale variations of the atmosphere, but variability on longer timescales (especially decadal) is not so well captured by current reanalyses. The primary causes of this deficiency are the quality and homogeneity of the fundamental datasets that make up the climate record and the quality of the data-assimilation systems used to produce reanalyses. Research into bias corrections and advanced reanalysis techniques is showing promise, however, and further reanalysis efforts are needed. In the future, it will prove important that next-generation global reanalyses are coordinated and, if possible, staggered to ensure that the basic observational data record is improved before each reanalysis, so that there is time to analyse and hence learn from the output of past efforts. Further improvements to reanalyses, including expansion to encompass key trace constituents and the ocean, land and sea-ice domains, hold promise for extending their use in climate-change studies, research and applications.

Another challenge confronting the climate research community is the provision of climate information on the regional level that investors, business leaders, natural resources managers and policy-makers need to help prepare for the adverse impacts of potential climate change on industries, communities, ecosystems and entire nations (Figure 6). While global mean metrics of temperature, precipitation and sea-level rise are convenient for tracking global climate change, many sectors of society require actionable information on considerably finer spatial scales. The increased confidence in attribution of global-scale climate change to human-induced greenhouse-gas emissions, and the expectation that such changes will increase in future, has lead to an increased demand in predictions of regional climate change to guide adaptation. Although there is some confidence in the large-scale patterns of changes in some parameters, the skill in regional prediction is much more limited and indeed difficult to assess, given that we do not have data for a selection of different climates against which to test models.

Much research is being done to improve model predictions but progress is likely to be slow. In the meantime, WCRP recognizes that governments and businesses are faced with making decisions now and require the best available climate advice today. Despite their limitations, climate models provide the most promising means of providing information on climate change and WCRP has encouraged making data available from climate predictions to guide decisions, provided the limitations of such predictions are made clear. This will include assessments of the ability of the models used to predict current climate, and the range of predictions from as large a number of different models as possible.

Toward this end, WCRP has begun to develop a framework to evaluate regional climate downscaling (RCD) techniques for use in downscaling global climate projections (Giorgi et al., 2009). Such a framework would be conceptually similar to the successful coupled model intercomparisons undertaken by WGCM and would have the goal of quantifying the performance of regional climate modelling techniques and assessing their relative merits. An international coordinated effort is envisioned to develop improved downscaling techniques and to provide feedback to the global climate modelling community. A specific objective will be to produce improved multi-model RCD-based high-resolution climate information over regions worldwide for input to impact/adaptation work and to the IPCC Fifth Assessment Report (AR5). This would promote greater interactions between climate modellers, those producing downscaled information and end-users to better support impact/adaptation activities and to better communicate the scientific uncertainty inherent in climate projections and climate information. An important theme in this activity will be the greater involvement of scientists from developing countries.

Over the next few years, WCRP will continue to provide the scientific leadership for major international climate assessment activities. Currently, under the leadership of WCRP's WGCM, the fifth phase of CMIP (CMIP5) is under development in support of IPCC AR5. The grand challenge of the new set of climate models examined in CMIP5 is to resolve regional climate changes, particularly in the next few decades, to which human societies will have to adapt, and to quantify the magnitudes of the feedbacks in the climate system, such as in the carbon cycle.

The scientific community has formulated the proposed CMIP5 coordinated experiments to address key science questions. Since these experiments will be the major activity of the international climate change modelling community over the next few years, the results will be eligible for assessment by AR5. The new suite of coupled model experiments is based on the use of two classes of model to address two time frames and two sets of science questions. For longer timescale projections (to 2100 and beyond) (Figure 7), and as an extension to previous WGCM modelling supporting IPCC, intermediate resolution (~200 km) coupled climate models will incorporate the carbon cycle, specified/simple chemistry and aerosols, forced by new mitigation scenarios (referred

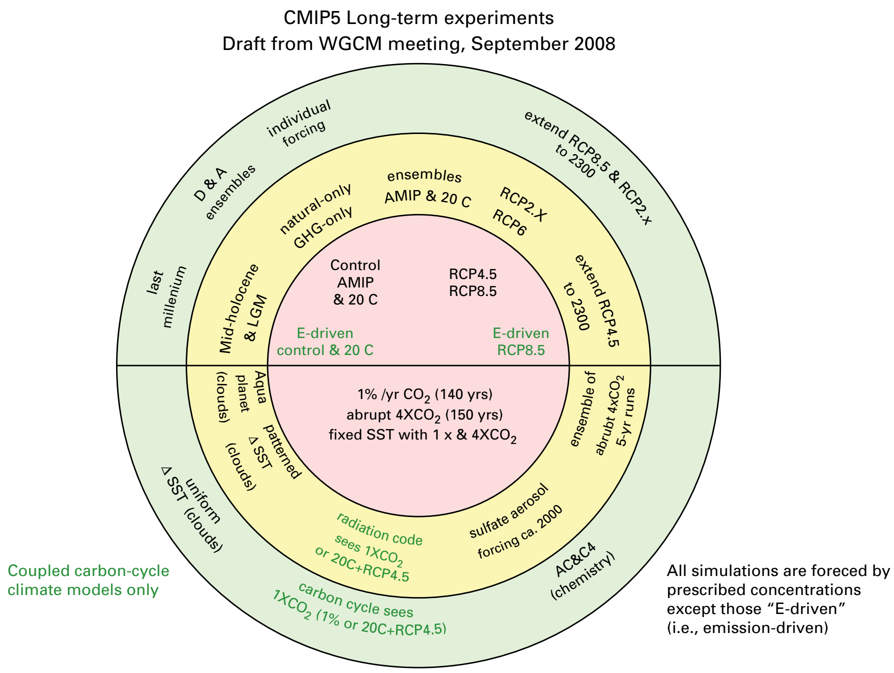

Figure 7 — WCRP and the International Geosphere-Biosphere Programme have joined expertise to advance climate model development and, hence, prediction capabilities. Future climate modelling activities include a set of experiments that "compare" existing climate models and evaluate their strengths and weaknesses and improve climate simulations, using a defined suite of emission scenarios. By incorporating the global carbon cycle, more complex Earth system models are also being tested for their response to different forcings. Within WCRP, the Working Group on Coupled Modelling leads the development of coupled ocean-atmosphere-land models used for climate studies on longer timescales. Image source: Taylor et al (2008)

to as "representative concentration pathways". The science questions to be addressed relate to the magnitude of feedbacks in the coupled climate system. Mitigation and adaptation scenarios with permissible emissions levels that allow the system to hit stabilized concentration targets are to be used (in place of the previous IPCC Special Report on Emissions Scenarios). The new scenarios will have implicit policy actions to target future levels of climate change. Since we can only mitigate part of the problem and we will have to adapt to the remaining climate change, the challenge is to use climate models to quantify time-evolving regional climate changes to which human societies will have to adapt.

A new focus area for CMIP5 is a set of near-term projections that encompass 10- and 30-year prediction studies and high-resolution time-slice experiments, as summarized in Taylor et al., 2008. WCRP research has indicated there are reasonable prospects for producing decadal forecasts of sufficient skill to be used by planners and decision-makers, as well as being of considerable scientific interest. The CMIP5 experimental design provides an opportunity for the international coordination of research and experimentation in this area.

There are two aspects to the decadal problem; the externally forced signal (greenhouse gases and aerosols, volcanoes, solar, etc.) and the predictable part of the internally generated signal from intrinsic oceanic mechanisms, coupled ocean-atmosphere processes, modulation of climate modes of variability (e.g. El Niño/Southern Oscillation) and, potentially, land and cryospheric processes. To date, climate projections have generally treated internal variability as a statistical component of uncertainty. Though there is no marked decadal peak in the spectrum of the climate system, long timescales exist and are potentially predictable. The challenge of prediction/predictability studies is to identify the mechanisms associated with regions/modes of predictability, to better understand the connection between oceanic modes and terrestrial climate variability and to investigate predictive skill by means of prognostic (including multi-model) decadal predictions.

The results of predictability studies and demonstrations of forecast skill provide the foundations for initiating a coordinated WCRP study of decadal prediction/predictability. There are abundant scientific opportunities to improve and extend models and for the analysis of variability and of modes of variability. Future challenges include the need to develop improved analysis methods, especially in the ocean, and for model initialization, verification and development, as well as in ensemble generation and the use of multi-model ensembles for prediction on decadal timescales.

In addition to its support of the IPCC assessment process, WCRP will continue to support the quadrennial WMO/UNEP Ozone Assessment. The SPARC Chemistry Climate Model Validation Activity (CCMVal) is the main model-based analysis for the connection between atmospheric chemistry and climate. CCMVal provides strategic modelling support to the ozone assessment process that is mandated by the Montreal Protocol. Ozone is a major constituent in radiative processes and is also affected by dynamics and transport. Only CCMs can simulate the feedback of chemical processes on the dynamics and transport of trace gases.

Under the direction of WCRP SPARC, CCM simulations will be conducted as a major contribution to the WMO/UNEP Scientific Assessment of Ozone Depletion: 2010. The main focus will lie on model validation against observations, as well as on assessments of the future development of stratospheric ozone. At present, ozone recovery is expected to take place until mid-century (WMO, 2007; Eyring et al., 2007), when column ozone is expected to reach 1980 values in southern polar latitudes. This development is determined on the one hand by a decrease in ozone depleting substances and on the other hand by a decrease in stratospheric temperatures due to enhanced greenhouse-gas concentrations in the atmosphere, which affects polar stratospheric cloud formation and heterogeneous ozone destruction.

An important issue is how the changes in the tropospheric abundances of ozone depleting substances translate to changes in the ozone-depleting active chemicals in the stratosphere. Dynamical processes that control transport and dynamical issues related to vortex formation and maintenance need to be carefully taken into consideration when predicting the long-term evolution of polar ozone. The influences of the changes in stratospheric ozone and composition on the Earth's climate that need to be evaluated include those that can influence the composition of the troposphere. For studies of the future development of stratospheric ozone, it is of great importance to take into account the interactions of radiation, dynamics and chemical composition of the atmosphere.

In summary, WCRP has made great strides in advancing understanding of the coupled climate system on timescales ranging from seasonal to centennial. WCRP research efforts resulted in the reality of operational climate forecasting, products and services. WCRP has had a major role in transferring the resultant scientific information and knowledge about the Earth's climate system for policy decisions through the IPCC, the UNFCCC Conference of Parties and its Subsidiary Body on Scientific and Technological Advice. More than one half of the scientific and technical contributions used in the IPCC assessments were provided by WCRP-affiliated scientists. WCRP made a concerted effort to provide worldwide access to its model predictions/

projections and research results for use by scientists from developing and Least Developed Countries to assess the consequences of potential climate variability and change on major economic sectors (e.g. food, water, energy, health), for their country or geographic region.

WCRP's accomplishments and progress were all made possible by the generous and sustained contributions of its sponsors: WMO, ICSU and IOC, and their network of more than 190 Member countries. The entire WCRP community is grateful for this sponsorship and support and is excited about the many opportunities that have made possible major contributions to understanding the causes and consequences of climate change and variability, assessing their impact on major sectors of the world economy and enabling the use of resulting knowledge for managing the risks associated with these changes for our generation, our children and those who will follow them in this century and beyond.

WCRP work has established, unequivocally, that the Earth System will experience real climate change over the next 50 years, exceeding the scope of natural climate variability. A question of paramount importance confronting nations is how to adapt to this certainty of climate variability and change in the next half century. The needs for coping with climate variability and adapting to climate change therefore represent a real challenge to society. In response, the upcoming World Climate Conference-3 will consider how comprehensive climate services would best inform decisions about adaptation.

The delivery of climate observations and services involves the transition across basic research, applied research, operations, applications and engagement with the user community. Yet, most of the effort to date has been focused on the physical climate system and has not been product-driven. However, climate impacts and services involve sectors such as business, finance, agriculture, engineering, public health, public policy, national security, etc. In order to satisfy the needs of society for climate services, a climate information system is called for by decision-makers to support policy, budget and investment decisions. Such a system would build upon reliable climate predictions over timescales of seasons to decades, tailored forecasts for regions and localities, integration of atmospheric, oceanic, terrestrial and social data into a comprehensive "Earth System" prediction model and decision-support interfaces that can be adjusted to provide user-specified "if-then" scenarios.

The realization of a climate information system will require the coupling of models across the physical climate system, biogeochemical cycles and socio-economic systems, synthesis of disparate datasets from in situ and space-based observations, new terrestrial and orbital sensor systems, dedicated high-performance computer infrastructure and software and unprecedented synergy between the climate research community, the operational delivery arm of climate services, and the end users. Much akin to the situation 60 years ago with the advent of numerical weather prediction, we now find ourselves on the brink of a new era of climate information and services underpinned by climate research striving to improve, expand and refine our understanding and ability to predict the coupled climate system.

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World Climate Conference-3: towards a Global Framework for Climate Services

Introduction

The climate challenge is enormous and requires a comprehensive and coordinated response from the world community. In the tradition of the two earlier World Climate Conferences, World Climate Conference-3 (WCC-3) is expected to create a mechanism to provide "better climate information for a better future". Considerable work has already been done in formulating a Global Framework for Climate Services (GFCS) to achieve exactly this.

A global framework for climate services is proposed as the significant concrete outcome from WCC-3. It is well placed to build on the remarkable scientific progress of the past 50 years and the solid institutional foundation provided by the international climate observation, research and assessment mechanisms put in place by WMO and its partner organizations over the 30 years since the historic First World Climate Conference of February 1979.

Why is a Global Framework for Climate Services necessary?

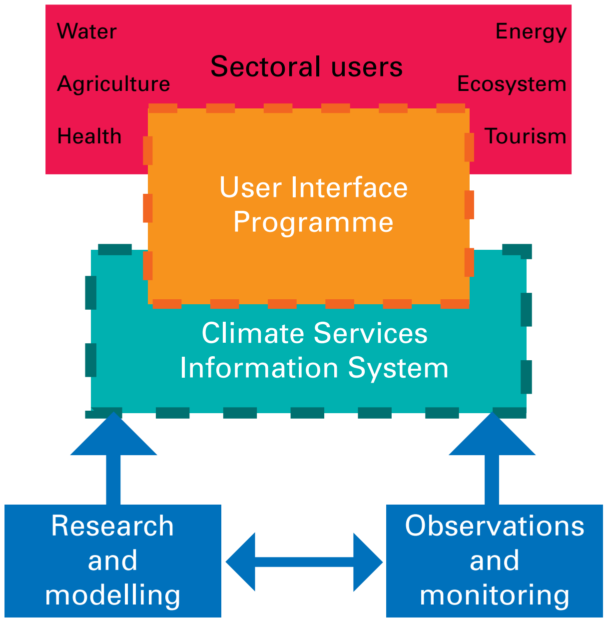
Decision-makers in many climate–sensitive sectors—water, agriculture, fisheries, health, forestry, transport, tourism, energy, disaster risk management—are increasingly concerned by the growing adverse impacts of climate risks, but are ill-equipped to make use of the available climate information. There is an urgent need for a global framework that defines the interface between the providers and users of climate services to ensure that relevant climate information is integrated into policy development and decision-making.

Recent advances in science and technology offer the prospect of continued improvement in climate information and prediction services. In particular, integrating seasonal to decadal predictions and long-term climate projections into decision-making in all socio-economic sectors will ensure that adaptation decisions are smarter, more effective and better targeted.

In order to address the need for improved climate information and an effective interface between scientists and decision-makers, WMO and its partner organizations, which are co-sponsoring WCC-3, propose the development and establishment of a new Global Framework for Climate Services whose goal is to:

> Enable climate adaptation and climate risk management through the incorporation of science-based climate information and prediction into policy and practice at all levels.

What is the Global Framework for Climate Services?



Components of the Global Framework for Climate Services

The Framework will have four major components: Observation and monitoring; Research and Modelling; a Climate Services Information System; and a Climate Services Application Programme. The first two components are already well established but are in need of strengthening. The third component, the Climate Services Information System, builds on, and expands, existing components of the World Climate Programme among others. The fourth component, the Climate Services Application Programme, is entirely new and will require an extensive partnership among a range of international and national organizations in order to make climate information effectively reach decision-makers in all socio-economic sectors.

The Climate Services Information System will be built on established global programmes such as the World Climate Programme and its various elements and will reinforce and further develop, existing institutions, their infrastructure and mechanisms. It will synthesize information streaming from the first two components through a network of global, regional and national institutions and ensure the development and delivery of user-oriented climate information and prediction services. It will focus, in particular, on standardization, exchange and quality assurance of information and delivering them to decision-makers from global to local scales. The System will also build capacity among national and regional meteorological service providers in developing and Least Developed Countries, whose contributions are essential for improved climate information products at both global regional and national scales.

The new Climate Services Application Programme is the interface between the providers and users of climate information. It will bridge the gap between the climate information being developed by climate scientists and service providers on the one hand and the practical needs of information users—decision-makers—on the other. It will support and foster necessary institutional partnerships, cross-disciplinary research, innovation, development of decision-support tools and climate risk management practices, capture of knowledge, evaluation and establishment of best practices, education, capacity-building and service application for decision-making.

What will be achieved through the Global Framework for Climate Services?

A successful Framework will support disaster risk management and the alleviation of poverty and help to achieve internationally agreed upon goals, including the United Nations Millennium Development Goals. Effective implementation of the Framework would further lead to:

- Strengthened national observational networks and information-management systems for climate and climate-related variables;
- Enhanced climate modelling and prediction capabilities through strengthened international climate research focused on seasonal-to-decadal timescales;
- Improved national climate service provision arrangements based on enhanced observation networks and prediction models, and greatly increased user interaction;
- More effective use of global, regional and national climate information and prediction services in climate-sensitive sectors in all countries; and
- Widespread social, economic and environmental benefits through better informed climate risk management and capacities for adaptation to climate variability and change.

Who will participate in the Global Framework for Climate Services?

In addition to the development of climate data products, for which

WMO is the unassailable world leader, the Global Framework requires extensive collaboration and outreach to communities in all socio-economic sectors which will benefit from the application of climate data and information in policy development and decision-making. This outreach will be facilitated if it includes consultations with a broad base of participants from diverse organizations both within and outside the UN system, as well as governments.

Implementing the Framework will require broad collaboration and partnerships. National and local governments, agencies, non-governmental organizations, civil society, the private sector, as well as universities and research institutions, will all need to contribute to the success of the Framework. In addition, the Framework is supported by the entire United Nations System and other organizations contributing to the climate knowledge component of "the United Nations System Delivering as One" initiative.

How will the Global Framework for Climate Services be financed?

Financial support for the implementation of the Global Framework within a stipulated time will need to be established through a range of mechanisms. The expectation is that specific commitments and support from developing, as well as developed, countries will be required to maintain appropriate national and regional institutions. The developed countries would be expected to facilitate the participation of the Least Developed Countries and developing countries as service providers and users.

What are the next steps in developing a Global Framework for Climate Services?

While a successful Framework will support disaster risk management and the alleviation of poverty and help achieve internationally agreed upon goals, including the UN Millennium Development Goals, it may be difficult for a new initiative to gain traction in the midst of other global crises. For this reason, and to gain access to decision-makers with the greatest influence, the WCC-3 International Organizing Committee determined that a task force made up of high-level individuals representing a broad spectrum of socio-economic sectors and regions could act as "champions" in reaching out to world experts in all sectors.

Following high-level endorsement of the concept of the Framework, it is proposed that a task force of independent advisers, supported by a broad-based group of experts, will further develop the Framework along the lines of the Global Framework Concept Note approved by the WCC-3 International Organizing Committee and in wide consultation with all relevant partners within nine months of WCC-3. Within the same timeframe, it would develop an action plan, measurable indicators and a timeline for the establishment and implementation of the Framework, including the identification of an overarching organizational body for the Framework and an indication of funding requirements. The task force would report back to the UN system, governments and other relevant organizations on the proposed next steps for establishing the Framework and implementing it within their respective organizations.

The Framework will contribute to the UN Framework Convention on Climate Change (UNFCCC) Bali Action Plan, especially the Nairobi Work Programme, and inform discussion at the 15th session of the Conference of Parties to the UNFCCC in Copenhagen, Denmark, in December 2009, as a possible mechanism for building the individual and collective capacities of nations to adapt to climate change.

Disaster risk reduction, climate risk management and sustainable development

by Margareta Wahlström*

Introduction

Disaster risks have risen over recent decades, and more extreme weather conditions in future are likely to increase the number and scale of disasters.

At the same time, the existing methods and tools of disaster risk reduction, and climate risk management in particular, provide powerful capacities for substantially reducing risks and adapting to climate change.

Climate change is no longer in doubt. The science has been thoroughly elaborated and assessed in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), [1,2] even if some details remain to be researched. Furthermore, new evidence is accumulating of changes around us, such as Arctic ice melting that is happening faster than was predicted by the IPCC reports. It seems that the more we know from new evidence, the more serious and challenging our future is.

Over the period 1991-2005, 3 470 million people were affected by disasters, 960 000 people died and economic losses amounted to US$ 1.193 billion [3]. Poor countries are disproportionately affected, because of intrinsic vulnerabilities to hazards and comparatively low capacities for risk-reduction measures, and they will suffer the most from climate change. Small countries are also particularly vulnerable: Grenada's losses of US$ 919 million as a result of Hurricane *Ivan* in 2004 were equal to 2.5 times its gross domestic product (GDP). By contrast, the largest and wealthiest countries have diversified economies and risk transfer mechanisms and while losses may amount to billions, such economies can cope overall, as was the case with the USA and Hurricane *Katrina* in 2005. Over the last two decades (1988-2007), 76 per cent of all disaster events were hydrological, meteorological or climatological in nature; these accounted for 45 per cent of the deaths and 79 per cent of the economic losses caused by natural hazards.

According to the landmark Global Assessment Report on Disaster Risk Reduction *Risk and Poverty in a Changing Climate* [4], which was launched on 17 May 2009, our exposure and vulnerability to weather and climate hazards are growing, resulting in continued rises in the numbers and costs of disasters. Disaster risk is accumulating largely as a result of unplanned settlements and environmental degradation, though climate change is also beginning to show its hand. The poor have the most to lose in a disaster, both as individuals and as countries, as they lack the information, resources, capacities and social safety nets needed to protect their assets and livelihoods.

Concentrations of people and assets are growing in urban areas, often in high-risk areas such as storm-exposed coasts, flooding river deltas, earthquake-prone valleys and volcanic slopes. Cities may not have proper drainage and flood protection, may not apply effective building codes and are often dependent on vulnerable sources of essential water and energy supplies. Environmental buffers may be badly damaged and overuse of natural resources can lead to their depletion and pollution. When a major hazard event strikes, this concentration of vulnerability can cause severe impacts and the destruction of hard-won development gains. These, in turn, may destabilize public order, leading to political instability. Climate change is the new factor in risk for this millennium and is a direct result of the same processes that have led to the accumulation of disaster risk.

At the global level, there is concern by humanitarian actors that the demands and costs for response actions are increasing beyond their capacities to effectively assist, and that this

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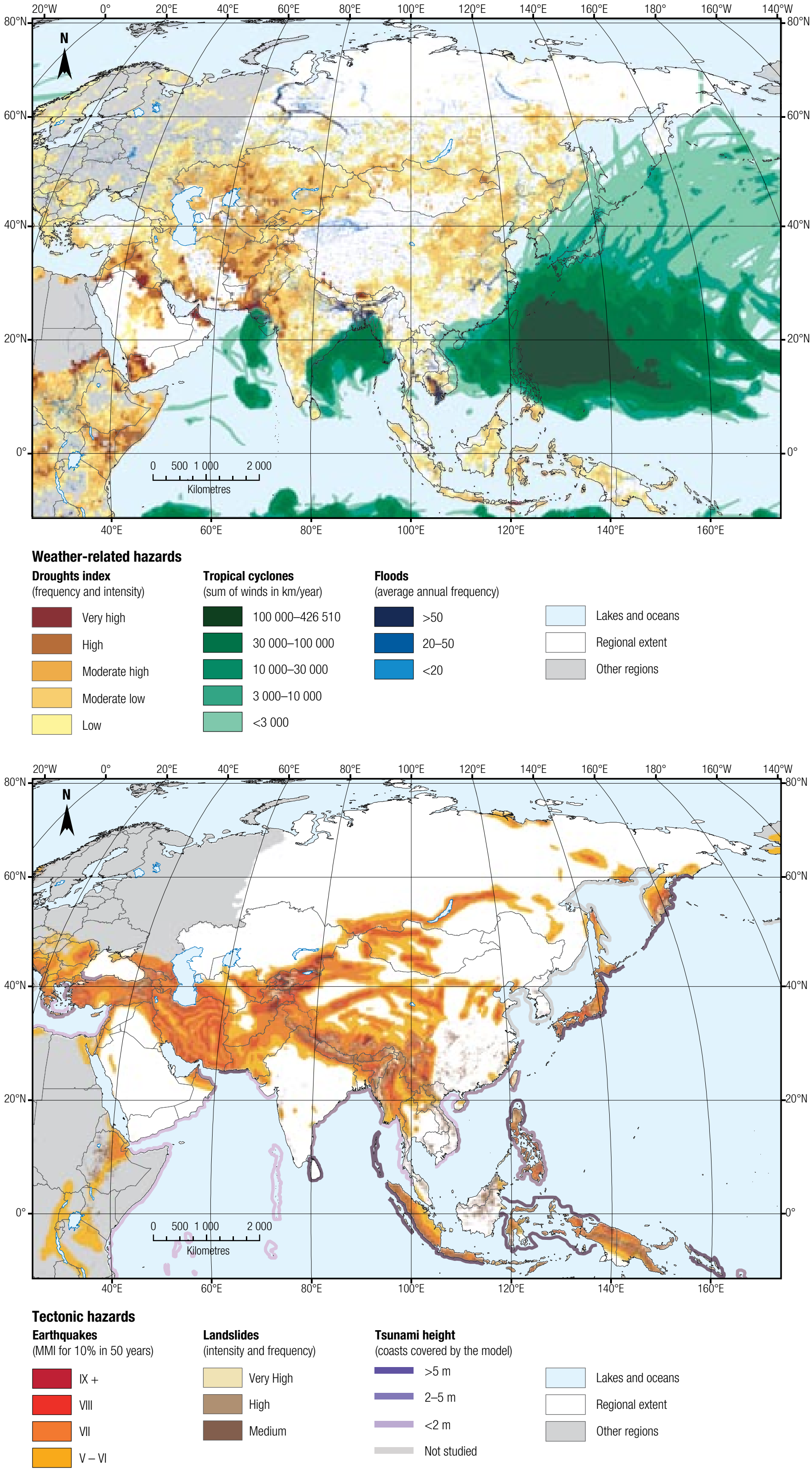


Multi-hazard map of Asia (United Nations Global Assessment Report on Disaster Risk Reduction (2009), page 23)

will worsen with climate change. A record number of 13 international humanitarian "flash appeals", mostly for climate-related events, were made in 2007. These appeals to donors are initiated by the United Nations in response to disasters and other sudden humanitarian crises. The humanitarian community has two roles—firstly, to respond to crises and disasters when they occur and, secondly, to work to reduce the root causes of crises and disasters. There is a new commitment by humanitarians to pay attention to disaster risk reduction and climate change, and some donors have targeted 10 per cent of their humanitarian budgets for investment in disaster risk reduction.

Disaster risk reduction is defined in the UN International Strategy for Disaster Reduction (UNISDR) terminology as "action taken to reduce the risk of disasters and the adverse impacts of natural hazards, through systematic efforts to analyse and manage the causes of disasters, including through avoidance of hazards, reduced social and economic vulnerability to hazards, and improved preparedness for adverse events" [5]. It is therefore tailor-made to help counteract the added risks arising from climate change.

It is human nature to be somewhat resistant to change as long as people are comfortable in their current situations. We do not want to believe or accept changes that might bring us uncertain or possibly negative impacts. Even if affected by some anxiety, we tend to think until the last moment that our house and family and we ourselves, will be all right and that it will be others who are affected. This tendency is quite common in most cultures, but it is an enemy of action to adapt to changing environments and risks, both at the individual and collective levels.

Nevertheless, more people than ever before are aware of the threats associated with climate change and of the need for both mitigation (of greenhouse-gas emissions) and adaptation (to the inevitable changes in the climate). Radical changes in our socio-economic models and behaviour are needed if we are to substantially reduce greenhouse-gas emissions and, for this reason, mitigation occupies the bulk of climate negotiators' attention at present.

Irrespective of our success at this task, however, the legacy of historical emissions means that we will increasingly face changes in climate and increases in disaster risks in the coming years. For poor countries, which have contributed so little to the problem, but face the largest impacts, the issue of adaptation is a particularly critical issue. Many significant steps need to be taken, with serious commitment and concrete actions, if we are to properly address the climate change problem. It is vital to vigorously propagate the culture "be prepared and have no regrets" in the contexts of climate change and growing disaster risk.

Climate change and adaptation

Main projections for climate change

The projections of future climate patterns are largely based on computer-based models of the climate system that incorporate the important factors and processes of the atmosphere and the oceans, including the expected growth in greenhouse gases from various socio-economic scenarios for the coming decades. The IPCC has examined the published results from many different models and on the basis of the evidence as at 2007 has estimated that by 2100:

- The global average surface warming (surface air temperature change), will increase by 1.1°C-6.4°C;
- Sea level will rise between 18 and 59 cm;
- The oceans will become more acidic;
- It is very likely that heat extremes, heatwaves and heavy precipitation events will continue to become more frequent;
- It is very likely that there will be more precipitation at higher latitudes and it is likely that there will be less precipitation in most sub-tropical land areas;
- It is likely that tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures.

How climate change will affect key sectors

In the absence of countermeasures, climate change will affect many sectors that are directly relevant to disaster risks, including water management, food and agriculture, industry, human settlement and land use, health and even national security. The main effects expected are as follows.

Water

Drought-affected areas will likely become more widely distributed. Heavier precipitation events are very likely to increase in frequency, leading to higher flood risks. By mid-century, water availability will likely decrease in mid-latitudes, in the dry tropics and in other regions supplied by meltwater from mountain ranges. More than one-sixth of the world's population is currently dependent on meltwater from mountain ranges.

Food

While some mid- and high-latitude areas will initially benefit from higher agricultural production, for many others at lower latitudes, especially in seasonally dry and tropical regions, the increases in temperature and the frequency of droughts and floods are likely to affect crop production negatively, which could increase the number of people at risk from hunger, as well as the levels of displacement and migration.

Industry, settlement and society

The most vulnerable industries, settlements and societies are generally those located in coastal areas and river floodplains and those whose economies are closely linked with climate-sensitive resources. This applies particularly to locations already prone to extreme weather events and, especially, areas undergoing rapid urbanization. Where extreme weather events become more intense or more frequent, the associated economic and social costs will increase.

Health

The projected changes in climate are likely to alter the health status of millions of people through, among others, increased deaths, disease and injury due to heatwaves, floods, storms, fires and droughts. Increased malnutrition, diarrhoeal disease and malaria in some areas will increase vulnerability to extreme public health and development goals will be threatened by longer-term damage to health systems from disasters.

Security

The impacts of climate change on security are uncertain and speculative, but may become significant in some circumstances. Potential concerns include: competition for scarce and depleting water resources; particularly in trans-border settings; migration and competition for food-growing land in low rainfall regions; mass migration from flooded coastal zones or small islands; civil disorder associated with severe disaster events, especially in urban areas; and political frustration of groups or countries who perceive they are unfairly affected by climate change.

Climate change and disasters

Natural hazards by themselves do not cause disasters—it is the combination of an exposed, vulnerable and ill-

prepared population or community with a hazard event that results in a disaster. Climate change will therefore affect disaster risks in two ways: firstly, through the likely increase in weather and climate hazards and effects of sea-level rise; and, secondly, through the increases in vulnerability of communities to natural hazards resulting from ecosystem degradation, reductions in water and food availability and changes to livelihoods. Climate change will thus add another stress to those of environmental degradation and rapid, unplanned urban growth, further reducing communities' abilities to cope with even the existing levels of weather hazards.

There is already evidence of increases in extreme conditions for some weather elements in some regions. The IPCC conclusions on changes in extreme conditions relevant to disaster occurrence are as follows.

Many long-term precipitation trends (1900-2005) have been observed, including significant increases in eastern parts of North and South America, northern Europe and northern and central Asia, and more dry conditions in the Sahel and southern Africa, throughout the Mediterranean region and in parts of southern Asia. The frequency of heavy precipitation events has increased over most land areas, which is consistent with global warming and the observed increases of atmospheric water vapour.

More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Higher temperatures and decreased precipitation have increased the prevalence of drier conditions, as well as contributing to changes in the distribution of droughts. Changes in sea-surface temperatures, wind patterns and decreased snow pack and snow cover have also been linked to changing drought occurrence.

Widespread changes in extreme temperatures have been observed in many regions of the world over the last 50 years; most notably the higher frequency of high-temperature days and nights.

There is good evidence for an increase of the more damaging intense tropical cyclone activity in the North Atlantic since about 1970, which is correlated with increases in tropical sea-surface temperatures. However, according to the IPCC, there is no clear trend evident to date in the global annual number of tropical cyclones.

It is difficult to provide projections of all the disaster-related effects of climate change, owing to the intrinsic uncertainty in the climate projections, the diverse and rapidly changing nature of community vulnerability, and the random nature of individual extreme events. However, there is a great deal of information from past events that can be extrapolated to the conditions projected by the IPCC to estimate the likely disaster-related consequences in general terms, as follows:

- More heatwaves will increase the number of deaths, particularly among the elderly, the very young or among people who are chronically ill, socially isolated or otherwise especially vulnerable;

- Increased drought in some regions will likely lead to land degradation, damage to crops or reduced yields, more livestock deaths and an increased risk of wildfire. Such conditions will increase the risks for populations dependent on subsistence agriculture, through food and water shortage and higher incidence of malnutrition and water- and food-borne diseases, and may lead to displacements of populations;

- Increased frequency of high precipitation in some regions will trigger floods and landslides, with potentially large losses of life and assets. These events will disrupt agriculture, settlements, commerce and transport and may further increase pressures on urban and rural infrastructure;

- Possible increases in the number and intensity of very strong tropical cyclones will affect coastal regions, with potentially additional large losses of lives and assets;

- Sea-level rise, coupled with coastal storms, will increase the impacts of storm surge and river flooding and damage livelihood systems and protective ecosystems. Low-lying settlements may become unviable, which may result in increased potential for movement of population and loss of infrastructure;

- Higher temperatures and melting glaciers may cause glacial lake outbursts that could flood downstream settlements.

With a view to providing a better definition of future disaster risks and of the available methods to manage and reduce them, the UNISDR and the Government of Norway jointly developed a proposal over 2008 and 2009 for a new IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [6]. The IPCC decided in April 2009 to go ahead with this report process. The Special Report will provide an authoritative assessment of disaster risk reduction and management policies and practices, including their effectiveness and costs, and will provide a sounder basis for action on adaptation and disaster risk reduction. Its preparation will involve hundreds of experts worldwide and will be completed by mid-2011. The meteorological and hydrological science communities are encouraged to actively contribute to this assessment process.

Disaster risk reduction in the UNFCCC process and the Bali Action Plan

The Bali Action Plan, agreed at the 13th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) held in Bali, Indonesia, December 2007, provided the guide for the negotiations on the global climate agreement that is expected to apply from 2012 [7]. Its directions for adaptation call for the consideration of:

> Risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance; Disaster reduction strategies and means to address loss and damage associated with climate change impacts in developing countries that are particularly vulnerable to the adverse effects of climate change.

The inclusion of these concepts is a major advance that will have positive repercussions for reducing disaster risks and improving risk management in the future. The ISDR system partners and Secretariat assisted this step through inputs to the internal UN preparatory processes coordinated by the UN Secretary-General in 2007 and to the activities of the UNFCCC Secretariat. Many of the general principles and requirements for adaptation that are listed in the Bali Action Plan are also highly relevant to reducing disaster risk, particularly vulnerability assessments, capacity-building and response strategies, as well as integration of actions into sectoral and national planning.

In support of the Bali Action Plan, and based on consultation with ISDR system partners and UNFCCC Parties, the UNISDR has arranged for the participation of developing country disaster risk experts in the UNFCCC meetings and, similarly, has invited climate change experts to participate in sessions of the Global Platform for Disaster Risk Reduction. At the 14th session of the Conference of the Parties in Poznan, Poland, December 2008, UNISDR was invited to provide a presentation on disaster risk reduction at an official workshop of UNFCCC Parties held on these issues. At the national level, UNISDR has identified and promoted the following two tasks that are particularly relevant to National Meteorological and Hydrological Services.

The first is to improve the interactions and coordination within countries to link disaster risk reduction and adaptation policies. This can be assisted, for example, through such things as: convening interdepartmental and national consultation meetings with personnel and experts from disaster risk reduction, climate change and development fields; formally cross-linking the national platform for disaster risk reduction and the national climate change team through systematic dialogue and information exchange; and conducting joint baseline assessments on the status of disaster risk reduction and adaptation efforts.

The second is to prepare adaptation plans drawing on the Hyogo Framework. Based on the assessment of needs and gaps, this task could include the joint development of a disaster reduction plan and an adaptation plan. These activities should capitalize on National Adaptation Plans of Action where present and other adaptation initiatives and should use the concepts and language of the Hyogo Framework where appropriate, ideally with action on all five of the Hyogo Framework's priorities (see "Priorities for action and practical examples", below) to ensure a comprehensive, integrated and systematic approach to adaptation.

Risk transfer mechanisms including insurance are noted in the Bali Action Plan as potential elements in a new climate agreement. Insurance and other risk transfer mechanisms have been long used to manage risks that would be too large for individual people and companies to bear on their own, by transferring some exposure to third parties with a more stable financial basis in exchange of a premium. Among the poor, however, especially in developing countries, insurance is not widely used. One question is whether insurance can be used as a tool to encourage risk-reducing behaviours. A recent study of the linkages between insurance and disaster risk reduction by a group of leading experts has been published by UNISDR [8].

There is some experience in developing countries with index-based climate micro-insurance, for example among low-income households, with financial coverage for climate risks, in Bolivia, Ethiopia, India, Malawi, Mongolia and Sudan. A multi-country index-based catastrophe insurance pool has recently been established among Caribbean island States. Index-based systems usually require a basis of quality meteorological data for calculating the risks and deciding on payout thresholds.

While these insurance schemes indicate some potential to provide improved security to vulnerable people and countries facing climate change, few programmes to date have a disaster reduction perspective or specific incentives to reduce disaster losses. Moreover, insurance and other risk transfer methods will be challenged by the increasingly frequent and intense events and hence growth of potential losses, and are unlikely to be able to deal with slow longer-term foreseeable changes like sea-level rise and desertification.

Nevertheless, collaboration between the insurance industry and public sector authorities can potentially help to promote risk reduction through, for example: data sharing; joint awareness raising and risk education; cooperation to ensure accurate risk pricing; collaborative improvement of enabling conditions and regulations such as legislation and financial oversight and monitoring; and the joint development of specific risk-reducing activities by policy-holders as a prerequisite for insurance cover.

Adaptation through disaster risk reduction and the role of the Hyogo Framework

The Hyogo Framework for Action

The Hyogo Framework for Action provides the global foundation for the implementation of disaster risk reduction [9]. Agreed at the World Conference on Disaster Reduction in January 2005, in Kobe, Japan, by 168 governments, its intended outcome for the decade is "the substantial reduction of losses, in lives and in the social, economic and environmental assets of communities and countries". It specifically identifies the need to "promote the integration of risk reduction associated with existing climate variability and future climate change into strategies for the reduction of disaster risk and adaptation to climate change...".

Mixed progress is being made in implementing the Hyogo Framework. A reporting process developed by UNISDR has resulted in systematic reports from about 100 countries. These have been summarized in the Global Assessment Report on Disaster Risk Reduction, which provides a comprehensive assessment of disaster risk, its relation to poverty and the progress towards implementing the Hyogo Framework. In general, progress has been greatest in the areas of institutional development and early warning and preparedness, and for middle- and higher-income countries. Progress has been least in the areas of environmental and sectoral concerns (which are often the sources of vulnerability and risk) and among the lowest-income countries (where the intrinsic risks are often highest). This shows that much needs to be done to address the real causes of risk and to integrate risk reduction into ongoing development policies and programmes.

The Global Platform for Disaster Risk Reduction is the main global multi-stakeholder forum on disaster risk reduction. At its second session in Geneva, 16-19 June 2009, it brought together 1 500 representatives of governments, UN agencies, regional bodies, international financial institutions, civil society, the private sector and the scientific and academic communities with the following aims: to raise awareness of disaster risk, to share experience, and to provide guidance to the ISDR system on how to better support countries to implement the Hyogo Framework for Action. The session reviewed a number of key issues, including the status of disaster risk, progress on its reduction, the reduction of disaster risk in a changing climate, achieving safer schools and hospitals, improving early warning systems, building community resilience, and the financing of disaster risk reduction.

The outcomes of the session provide important stepping stones to the deliberations at World Climate Conference-3 (WCC-3), Geneva, 31 August–4 September 2009. Together, these two events offer a valuable opportunity to develop concrete plans to address today's pressing needs for climate change adaptation and disaster risk reduction. There is clearly a need for a new thrust to build a coordinated global mechanism that can reliably provide accessible and usable climate information for risk assessment, risk management and risk reduction at all levels of society.

Priorities for action and practical examples

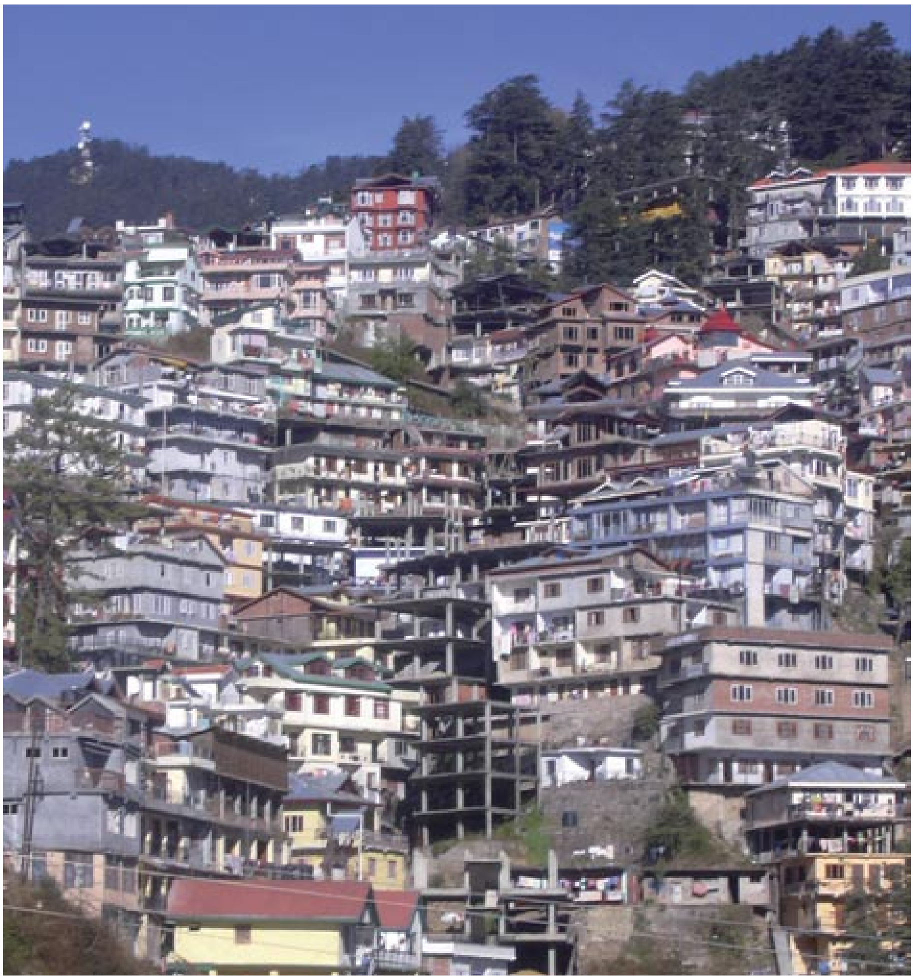
Based on a review of past successes and failures in reducing disaster risks, the Hyogo Framework sets out five priorities for action, as follows, each elaborated into a number of specific areas of attention where concrete risk-reducing adaptation measures are required. Each one requires the engagement and inputs of the meteorological and hydrological communities.

Priority for action 1: Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation

This priority is important for both adaptation and risk reduction. Suggested actions toward achieving it include: encouraging a core ministry with a broad mandate including finance, economics or planning, to be responsible for mainstreaming climate change adaptation policies and activities; organizing a national high-level policy dialogue to prepare a national adaptation strategy that links with disaster risk reduction strategies; formalizing collaboration and the coordination of climate-related risk reduction activities through a multi-sector mechanism such as a national platform for disaster risk reduction; and developing mechanisms to actively engage and empower women, communities and local governments in the assessment of vulnerability and impacts and the formulation of local adaptation activities.

Priority for action 2: Identify, assess and monitor disaster risks and enhance early warning

Important steps under this priority include developing and disseminating high-quality information about climate hazards and their likely future changes; conducting assessments of vulnerability and specially vulnerable groups; preparing briefings for policy-makers and sector leaders; reviewing the effectiveness of early warning systems; implementing procedures to ensure warnings reach vulnerable groups; and undertaking public information programmes to help people understand the risks they face and how to respond to warnings.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Priority for action 3: Use knowledge, innovation and education to build a culture of safety and resilience at all levels

This principle applies equally to adaptation and disaster risk reduction. Specific steps should include collating and disseminating good practices; undertaking public information programmes on local and personal actions that contribute to safety and resilience; publicizing community successes; training the media in climate-related issues; developing education curricula on climate adaptation and risk reduction; supporting research programmes on resilience; and improving mechanisms for knowledge transfer from science to application for risk management in climate-sensitive sectors.

Priority for action 4: Reduce the underlying risk factors

This covers the many environmental and societal factors that create or exacerbate the risks from natural hazards. Measures can include incorporating climate risk-related considerations in the development planning processes, macro-economic projections and sector plans; requiring the use of climate risk-related information in city planning, land-use planning, water management and environmental and natural resource management; strengthening and maintaining protective works such as coastal wave barriers, river levees, flood ways and flood ponds; requiring routine assessment and reporting of climate risks in infrastructure projects, building designs and other engineering practices; developing risk transfer mechanisms and social safety nets; supporting programmes for diversification of livelihoods; and instituting adaptation activities in plans for recovery from specific disasters.

Priority for action 5: Strengthen disaster preparedness for effective response at all levels

Actions include revising preparedness plans and contingency plans to account for the projected changes in existing hazards and new hazards not experienced before; building evacuation mechanisms and shelter facilities; developing specific preparedness plans for areas where settlements and livelihoods are under threat of permanent change; and supporting community-based preparedness initiatives. Resilience building and early warning systems also contribute to this priority.

Examples of adaptation and disaster risk reduction by sector

In most sectors that are relevant or sensitive to climate change, the role of National Meteorological and Hydrological Services is crucial, both for provision of data and expertise and for collaboration on design and implementation of policies and programmes. Some examples of cost effective actions are given below [10].

Agriculture and food security:

Well-known measures include altering crop strains to enhance their resistance to drought and pest, changing planting times and cropping patterns and altering land topography to improve water uptake and reduce wind erosion. Diversification is an option, for example, by combining food crops, livestock and agro-forestry. The introduction of insurance schemes can help people cope with crop losses. The options would be fewer, of course, without dependable climate information provided by National Meteorological and Hydrological Services.

Water sector

Adaptation measures include actions on both water supply and water risks, such as protecting water supply infrastructure and traditional water supply sources, developing flood ponds, water harvesting, improved irrigation, desalination, non-water-based sanitation and improved watershed and transboundary water resource management. Integrated water resource management provides the accepted framework for such actions. It has been reported that China spent US$ 3.15 billion on flood control between 1960 and 2000, which is estimated to have averted losses of about US$ 12 billion, and that the Rio de Janeiro flood reconstruction and prevention project in Brazil yielded an internal rate of return exceeding 50. Needless to say, the roles of national hydrological institutes are critical for water management.

Health sector

Measures include early warning systems and air-conditioning to address extreme weather events; systematic action on water- and vector-borne diseases to raise public awareness of watershed protection, vector control and safe water- and food-handling regulations; the enforcement of relevant regulations; and support for education, research and development on climate-related health risks. As one example, Philadelphia (USA) developed an excessive heat event notification and response programme to reduce the number of fatalities caused by future heatwaves in response to the heat-related deaths during the summer of 2003. This could be only done with the meteorological information generated by the National Weather Service.

Awareness raising and education

Measures include curriculum development for schools, supply of information to community groups and women's networks, radio and television programmes, public poster campaigns and leadership by national figures and celebrities. Awareness-raising for strategic intermediaries such as teachers, journalists and politicians and support to technical experts and groups are also important. Among other things, National Meteorological and Hydrological Services can provide sound scientific and technical knowledge to support these activities, including by providing clear understanding of basic concepts and terms, such as weather, climate, climate change, disaster risk, etc.

Environmental management

Healthy ecosystems provide risk reduction services with significant benefits for resilience, livelihoods and adaptive capacity. Measures can include strengthening of environmental management in areas at greatest risk from weather hazards; protecting ecosystems, such as coral reefs or mangrove forests, that shield communities from coastal hazards; supporting transitions of livelihoods away from those that degrade environments and aggravate risk; and enforcing regulations concerning these practices. As one example, a mangrove-planting project in Viet Nam aimed at protecting coastal populations from typhoons and storms was reported to yield an estimated benefit/cost ratio of 52 over the period 1994-2001.

Early warning systems

National Meteorological and Hydrological Services play an obvious key role here. New emphasis can be put on measures to improve existing systems to cover the changed hazard circumstances, to ensure dissemination of warnings to all affected people in a timely, useful and understandable way, with advice on appropriate actions to take upon receiving warnings. A comprehensive UN survey of early warning systems identified major gaps in coverage for some hazards and some countries: much more action is needed to address these shortcomings, especially given the important role of early warning as an adaptation policy. [11]

Development planning and practices

Adaptation and disaster risk reduction measures need to be made a formal part of development processes and budgets and programmed into relevant sector projects, for example in the design of settlements, infrastructure, coastal zone development, forest use, etc., in order to avoid hazardous areas, ensure the security of critical infrastructure such as hospitals, schools and communications facilities and to achieve sustainable land management. Again, National Meteorological and Hydrological Services and associated research institutes need to be active partners in these policy and planning processes.

Water and disaster: new recommendations for actions

The United Nations Secretary-General's Advisory Board on Water and Sanitation (UNSGAB) is tasked with raising awareness and building common understanding of global water issues, promoting cooperation, and encouraging responsible and sustainable water management practices. In order to develop concrete follow-up actions for disaster risk reduction following the Hashimoto Action Plan, UNSGAB established the High-Level Expert Panel on Water and Disaster in September 2007, led by the Founding Chair Han Seung-soo, Prime Minister of the Republic of Korea. The Panel subsequently produced its report with 40 concrete actions under six urgent imperatives [12]. These included the following three cross-cutting initiatives that are particularly relevant to National Meteorological and Hydrological Services, where the Panel decided to:

- Call on national governments to declare hydro-climatic data as public goods to be shared at all levels (regional, national and local) in order to assist in disaster risk reduction, and seek United Nations General Assembly endorsement;

- Call on the delta States to establish a Large Delta States Network to jointly tackle the negative impacts of sea-level rise associated with ongoing climate change;

- National and international hydrological institutes must take the initiative to identify underlying analytical and data requirements to meet climate changes that are likely to be highly uncertain and so as to support structural and non-structural measures for disaster risk reduction.

The Panel's recommendations offer specific concrete actions on water risks and disasters that deserve close support and follow-up. The Panel has proposed specific responsibilities for monitoring progress on the implementation of the actions, including for UNISDR and WMO.

Conclusions

The linkages between climate change, disaster risk reduction, national development and sectoral management are plain to see. Significant relevant knowledge and technical capacities exist, along with necessary international strategies and frameworks for action. Yet these assets have not been brought together in a coherent and effective way, with the sustained participation of all fields of expertise and responsibility, to achieve systematic global reduction in risks. Many problems remain, as is clear from the continued growth of vulnerabilities and disaster impacts. Developing countries are the most at risk, but all countries are exposed and none can ignore this whirlpool of issues.

National Meteorological and Hydrological Services need to be fully engaged in these processes. They are well placed through their specialist expertise and years of experience in dealing with weather impacts, climate variability and sector partners, and can provide key capacities to help integrate across the range of time-scales from short-term hazards and daily risk management to longer-term variation and change of the climate.

Suggested areas for attention include: applying best practice for tropical storm predictions and public response; implementing monitoring and response systems for high rainfall, flash floods and landslides, especially in urban and other populated areas; drawing lessons from, and improving the management of, El Niño/La Niña and other seasonal impacts; monitoring and managing regional-scale drought and multi-year anomalies; and contributing data and associated spatial and temporal modelling for national risk assessments. Achieving more globally systematic data collection and dissemination for climate research and sector management is an important priority. National Meteorological and Hydrological Services can also play a leading role in actively supporting the development of institutional mechanisms to link disaster risk reduction and adaptation policy-making at national level.

International mechanisms, such as the WMO system, the IPCC, the ISDR and the World Bank's Global Facility for Disaster Risk Reduction and

Recovery, together with their various frameworks and forums, in particular the Hyogo Framework, the Global Platform for Disaster Risk reduction and World Climate Conference-3, are important crucibles for the new ideas, commitments and coordination that are needed. These are not ends in themselves, of course, but are essential means to devise and guide accelerated concrete action where it counts, namely, supporting the permanent reduction of vulnerability and risk for all countries and all people.

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Addressing climate information needs at the regional level: the CORDEX framework

by Filippo Giorgi[1], Colin Jones[2] and Ghassem R. Asrar[3]

Introduction

The need for climate change information at the regional-to-local scale is one of the central issues within the global change debate. Such information is necessary in order to assess the impacts of climate change on human and natural systems and to develop suitable adaptation and mitigation strategies at the national level. The end-user and policy-making communities have long sought reliable regional- and local-scale projections to provide a solid basis for guiding response options.

To date, most regional climate-change information has been based on the use of Coupled Atmosphere-Ocean General Circulation models (AOGCMs) enabled by the World Climate Research Programme (WCRP) during the past 30 years (Busalacchi and Asrar, this issue of *WMO Bulletin*). AOGCMs have proved to be the most valuable tools in understanding the processes that determine the response of the climate system to anthropogenic forcings, such as increases in greenhouse-gas (GHG) concentrations and changes in land use and atmospheric aerosol loadings. They have also provided valuable information on climate change at the global to sub-continental scale (IPCC, 2007). Although we have seen significant improvements in these models, especially in the past decade, due to better representation of atmospheric and Earth surface processes and enhanced computational capabilities, the horizontal resolution of most present-day AOGCMs is still of the order of a few hundred kilometres (Meehl et al., 2007). This prevents them from capturing the effects of local forcings (e.g. complex topography and land-surface characteristics) which modulate the climate signal at fine scales.

Coarse resolution also precludes global models from providing an accurate description of extreme events, which are of fundamental importance to users of climate information with respect to the regional and local impacts of climate variability and change. In other words, a fundamental spatial scale gap still exists between the climate information provided by AOGCMs and the input needed for impact assessment work.

In order to circumvent this problem, various "regionalization" or "downscaling" techniques have been developed to spatially refine the AOGCM climate information and bridge this spatial scale gap (Giorgi et al., 2001). They have been traditionally divided into "dynamical" and "statistical" downscaling techniques. Dynamical downscaling (DD) makes use of physically based models, such as high-resolution and variable-resolution global atmospheric models (AGCMs and VARGCMs, respectively) run in "time-slice" mode (e.g. Cubasch et al., 1995; Deque and Piedelievre, 1995) and limited-area "regional climate models" or RCMs (Giorgi and Mearns, 1999).

In statistical downscaling (SD), statistical relationships are first developed between large-scale predictors and regional-to-local-scale predictands and are then applied to the output from climate-model simulations (Hewitson and Crane, 1996). Although many different SD models and techniques exist (e.g. Wilby et al., 2004; Giorgi et al., 2001; Wigley and Wilby, 2000; Hewitson and Crane, 1996), they all share this basic conceptual framework. A number of papers are available in the literature to review downscaling work and discuss the relative merits and limitations of the different techniques (Laprise et al., 2008; Schmidli et al., 2007; Giorgi, 2006; Wang et al., 2004; Leung et al., 2003; Mearns et al., 2003; Murphy, 1999; Giorgi and Mearns, 1999, 1991; McGregor, 1997), and the reader is referred to these papers for such discussions.

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Both dynamical and statistical downscaling tools, which we refer to as regional climate downscaling (or RCD) have been increasingly used to address a variety of climate-change issues and have by now become an important method in climate-change research (Huntingford and Gash, 2005). Particularly in the last decade, the development and use of RCD models have increased tremendously, as proved by an almost exponential increase in the number of peer-reviewed publications on this topic. (For example, searching for the string "regional climate model" in the information system interfaces (ISI) results in fewer than five entries/year up to 1994 to more than 150 in 2008.)

A reasonable question to ask is whether this tremendous development has resulted in an increased use of RCD-based products for climate change impact assessments. With a few exceptions, this is not the case. For example, most regional climate-change material presented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and further utilized in impact assessment work, is still based on relatively coarse resolution AOGCM simulations (e.g. Christensen et al., 2007).

What is the reason for the under-utilization of RCD-based products? We believe that a primary reason is the lack of a coordinated framework to evaluate RCD-based techniques and produce ensemble projections of sufficient quality to characterize the uncertainties underlying regional climate change projections. Such frameworks are available for global models, such as the Atmospheric Model Intercomparison Project (AMIP) or the Coupled Model Intercomparison Projects 1-3 (CMIP1-3). The global modelling community has benefited tremendously from such coordination activities in terms of process understanding, model evaluation and generation of climate change projections. Conversely, most RCD studies have been isolated and tied to specific targeted interests, so that a comprehensive picture of regional climate-change projections based on RCD experiments is currently not available.

Recognizing this limitation, WCRP recently formed the Task Force on Regional Climate Downscaling (TFRCD) whose mandate is to:

- Develop a framework to evaluate and possibly improve RCD techniques for use in downscaling global climate projections;
- Foster an international coordinated effort to produce improved multi-model RCD-based high-resolution climate-change information over regions worldwide for input to impact/adaptation work and to the IPCC Fifth Assessment Report (AR5);
- Promote greater interaction and communication between global climate modellers, the downscaling community and end-users to better support impact/adaptation activities.

As a result of the first activities of the TFRCD, and in consultation with the broader scientific community, a framework was initiated called the Coordinated Regional climate Downscaling Experiment (CORDEX). In this article, we describe the status and plans for CORDEX, which mostly resulted from a workshop held in Toulouse, France, 11-13 February 2009 (http://wcrp.ipsl.jussieu.fr/Workshops/Downscaling/DirectionVenue.html) and subsequent discussions.

Producing regional climate projections and associated uncertainties

In this article, we use the term "regional" in a broad sense to indicate the entire range of spatial scales of less than ~10 000 km². With this definition, the task of producing reliable regional climate projections is extremely difficult, since the regional climate change signal is affected by processes that occur at a wide range of spatial scales from the planetary to the synoptic and mesoscale. For example, the effect of increased greenhouse-gas concentrations will affect the general circulation of the atmosphere and the structure of planetary-scale dynamical systems. This large scale climate signature is then modulated at the regional to local level by a multiplicity of forcings, including complex topography, coastlines and aerosol distribution.

While current AOGCMs have proved quite successful in reproducing the main features of the general circulation (IPCC, 2007), they do not represent adequately the effects of regional-to-local-scale forcings. Their performance also generally deteriorates when going from lower- to higher-order climate statistics, such as variability, extremes and weather regimes. In addition, natural climate variability tends to increase as we move from large to fine scales, and this makes the identification of the climate-change signal from the underlying noise more difficult.

While RCD techniques can improve the AOGCM information at fine scales by accounting for the effects of regional forcings, they are still affected by systematic errors in the coarse-scale input data from AOGCMs. For example, the positioning of the storm track in an AOGCM will propagate into the interior domain of a nested RCM. Our imperfect knowledge and model description of physical processes represent a critical source of uncertainty when performing climate projections, which tends to increase as the scale of interest becomes increasingly finer. By virtue of this uncertainty, different models will generally produce different responses to the same climatic forcing (e.g. greenhouse-gas concentration). This uncertainty, which is referred to as "model configuration", is one of the greatest sources of uncertainty in climate projections and propagates directly from global model simulations to all RCD techniques. It compounds with other sources of uncertainty, such as those due to greenhouse-gas emission and concentration scenarios, internal variability and non-linearities in the climate system and, for the downscaling problem, choice of RCD method (Giorgi, 2005). Studies have indicated that the GCM configuration and scenario uncertainties represent the leading sources of uncertainty in climate-change projections, particularly on longer, centennial, timescales. The choice of RCD technique can also be important, whereas the uncertainty related to internal climate variability is mostly important on shorter timescales (e.g. for simulating the climate of 2020-2030) and for higher-order statistics.

In order to provide useful information for impact assessment studies, the uncertainties in regional climate change projections need to be fully characterized and, where possible, reduced. This requires the generation of ensembles of simulations exploring all the relevant uncertainty dimensions. The final goal of this process is the production of probabilistic climate-change information for climatic variables of interest in the form of probability density functions (PDFs). The width of the PDF gives a measure of the uncertainty. The larger the ensemble, the better the uncertainty space can be sampled and explored. A full exploration of the uncertainty space is, however, a daunting task, since it requires the completion of a multi-dimensional matrix of experiments whose number can quickly become extremely large (Giorgi et al., 2008). Figure 1 summarizes the set of areas of uncertainty that need to be covered when producing regional climate- change projections based on RCD products:

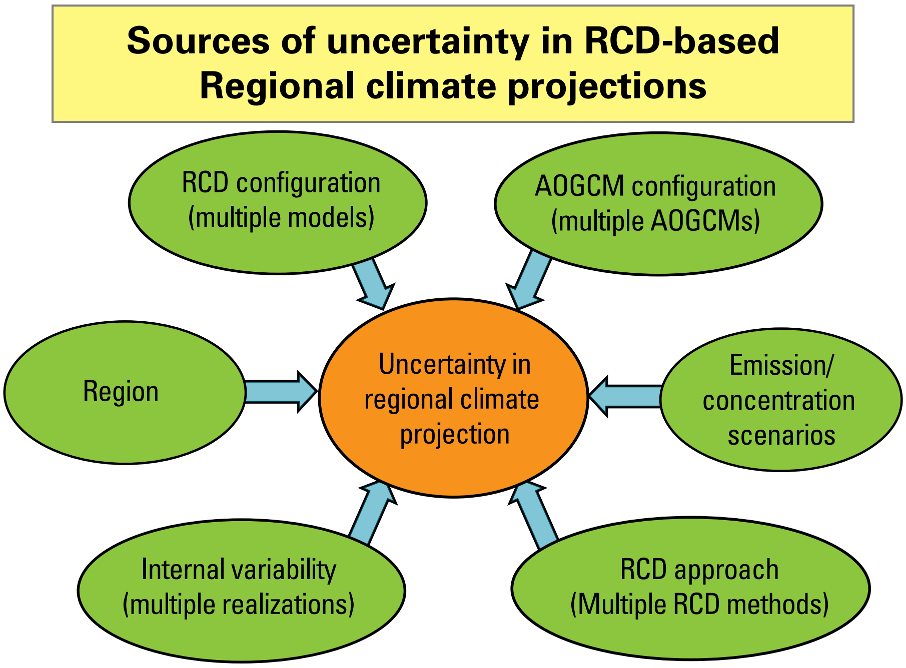

Figure 1 — Schematic depiction of the primary uncertainties in regional climate change projection

1 GHG emission scenarios
2 AOGCM configuration
3 AOGCM internal variability
4 RCD configuration
5 RCD internal variability
6 RCD method
7 Region of interest

Source 1 can be explored by simulating different greenhouse-gas emission scenarios; Sources 2 and 4 by using different AOGCMs and RCD models or, within the same modelling system, different model configurations (e.g. physics parameters); Sources 3 and 5 by performing different realizations of the same scenario each using different initial conditions (most importantly for the slow components of the climate system, such as oceans and vegetation conditions); Source 6 by using different RCD methods (e.g. RCMs and SD models); and Source 7 by applying the RCD models to different regions.

In addition, the reliability of climate-change projections needs to be assessed in view of the credibility of the models. This, in turn, can be measured by the model performance in reproducing observed climate conditions or different climate states observed in the past. Therefore, the process of producing climate-change projections cannot be disentangled from the process of evaluating the performance of the models. What is thus required is an overarching framework that, on the one hand, provides a benchmark for evaluating and possibly improving models and, on the other, a set of experiments that allow us to explore to the maximum extent possible the contribution of the different sources of uncertainty. The CORDEX programme aims to provide such a framework.

The CORDEX framework

CORDEX essentially has the two-fold purpose to provide a framework to evaluate and benchmark model performance (model evaluation framework); and design a set of experiments to produce climate projections for use in impact and adaptation studies (climate projection framework). It is schematically depicted in Figure 2 and described in the following sections.

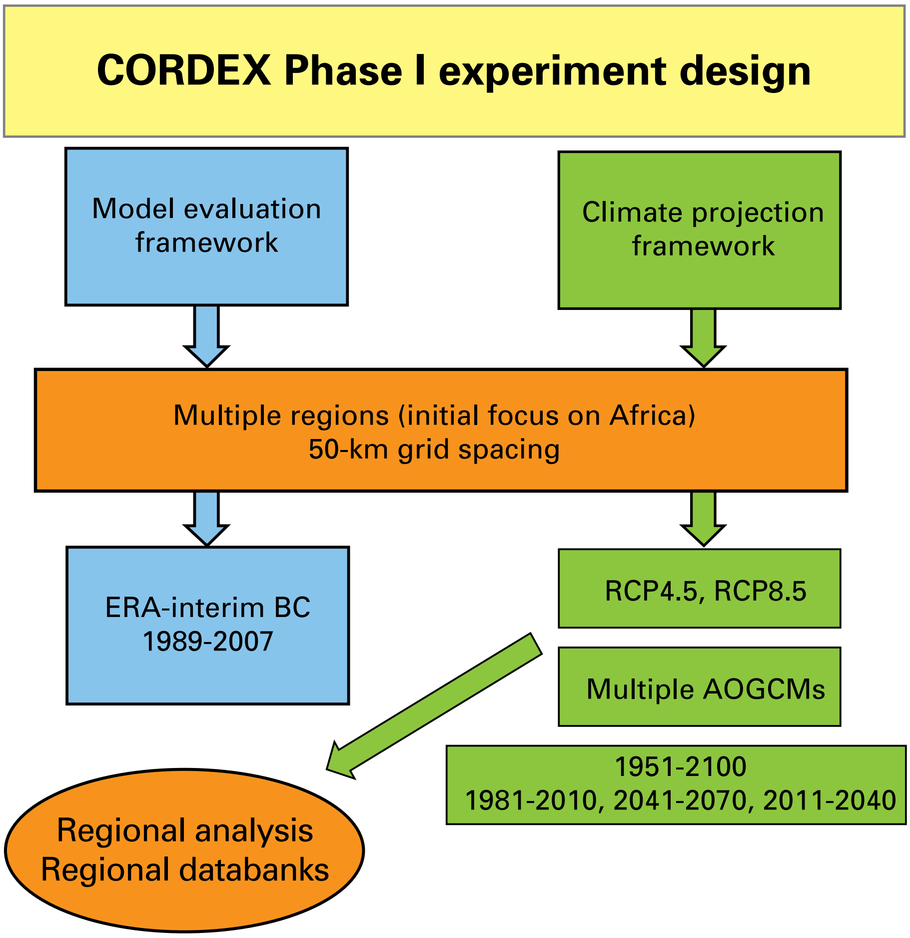

Figure 2 — Schematic depiction of the first phase CORDEX experiment set-up

Model domains and resolution

The choice of common RCD domains is a prerequisite for the development of the model evaluation and climate projection frameworks. The goal of CORDEX is to provide a framework accessible to a broad scientific community with maximum use of results. CORDEX domains therefore encompass the majority of land areas of the world. Figure 3 shows a first selection of common domains (currently still under discussion), where these should be interpreted as interior analysis domains, e.g. not including the lateral relaxation zone in RCMs. This selection is based partly on physical considerations (i.e. inclusion of processes important for different regions), partly on considerations of resources needed for the simulations and partly on the availability of ongoing programmes.

Figure 3 shows five domains covering the entire African, Australian, South American, North American and European continents. The latter three are essentially the same domains used in the projects CLARIS (www.claris-eu.org), NARCCAP (www.narccap.ucar.edu) and ENSEMBLES (ensembles-eu.metoffice.com) and respectively. A domain also includes Central America, together with the equatorial western Atlantic and Eastern Pacific regions, where current projections indicate large changes and possible effects on tropical cyclones. The Asian continent is divided into three domains, one centred on the Indian monsoon, a second on East Asia and a third targeting central Asia. Pan-Arctic and Antarctic domains will also be included, based on experience derived from the respective polar modelling communities (not shown in the figure).

In order to allow wide participation, TFRDC, in consultation with the broader community, decided to make

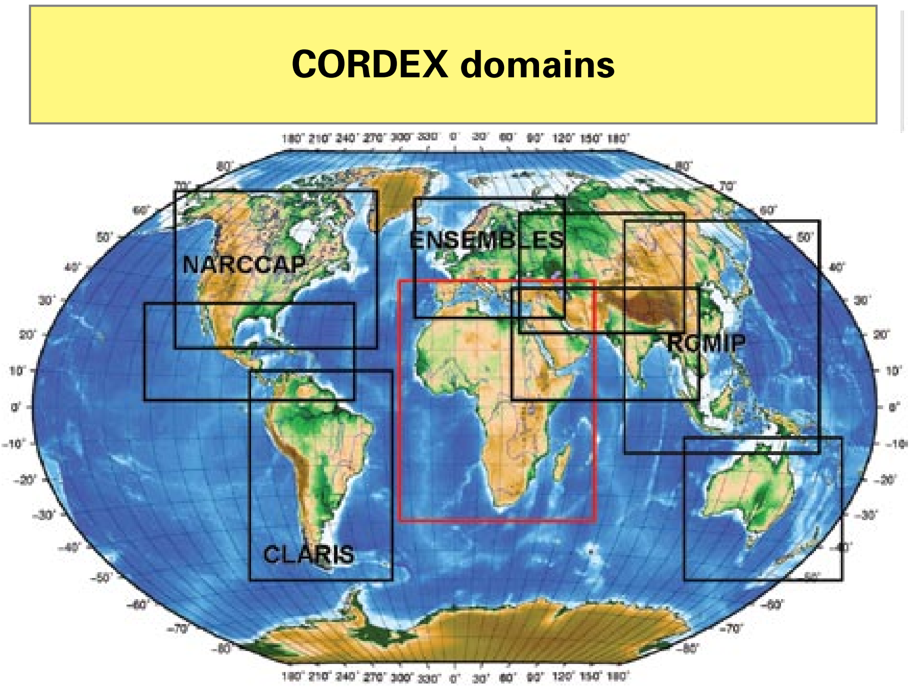

Figure 3— Regional domains planned for the CORDEX experiments (some still under discussion); also indicated are existing projects that make use of the corresponding domain.

the standard horizontal resolution for the first phase CORDEX simulations to be ~50 km (or 0.5 degrees). Today, many groups are running RCMs with considerably higher grid spacing than this (up to ~10 km) and they are encouraged to explore the benefits of increased RCM resolution within the CORDEX framework. Nevertheless, it was felt that a standard resolution, allowing contribution by many groups, would increase the sense of community ownership of the CORDEX project, while also increasing the size of any ensuing RCM scenario set for analysis and comparison purposes.

Model evaluation framework

In order to evaluate the performance of both DD and SD models, a set of so-called "perfect boundary conditions" experiments will be performed for the selected domains. Such experiments utilize analyses of observations to produce fields to drive the RCD models, for example as lateral and surface boundary conditions. Although still derived from (imperfect) models, analyses of observations include information from a varied set of observing systems (surface, atmosphere and remotely sensed) and thus provide the best available conditions to drive RCD models.

The CORDEX framework will initially utilize the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim re-analysis (Uppala et al., 2008), which covers the period 1989-2007 and improves a number of problems found in previous reanalysis products, particularly related to the hydrological cycle in tropical regions. Various efforts are currently underway to update reanalysis products in different centres and these will be used when available.

For model evaluation, a set of diagnostic teams will be formed for each simulated region, whose task will be to design a set of benchmark regional metrics for model evaluation. Observational datasets will need to be obtained/assembled for each region for use in the model evaluation process. This is a particularly delicate task as the evaluation process needs to be carried out at fine spatial scales for which suitable datasets are not always available. It will thus be important to tap into local resources and expertise to enhance current observational datasets to the extent possible.

Climate projection framework

The climate projection framework within CORDEX is based on the set of new global model simulations planned in support of the IPCC Fifth Assessment Report (referred to as CMIP5). This set of simulations includes a large number of experiments, ranging from new greenhouse-gas scenario simulations for the 21st century, decadal prediction experiments, experiments including the carbon cycle and experiments aimed at investigating individual feedback mechanisms (Taylor et al., 2009).

For its initial activities, CORDEX will focus on the scenario simulations. Different from the scenario runs employed in the fourth IPCC assessment cycle, which were based on the SRES GHG emission scenarios (IPCC, 2000), this next generation of scenario simulations is based on so-called reference concentration pathways (RCPs), i.e. prescribed greenhouse-gas concentration pathways throughout the 21st century, corresponding to different radiative forcing stabilization levels by the year 2100. Four RCPs have been selected, with stabilization levels at 2.9, 4.5, 8.5 and 11.2 W/m^2 (referred to as RCP2.9, RCP4.5, RCP8.5 and RCP11.2, respectively). Within CMIP5, the highest-priority global model simulations have been selected to be the RCP4.5 and RCP8.5, roughly corresponding to the IPCC SRES emission scenarios B1 and A1B, respectively. The same scenarios are therefore also planned to be the highest priority CORDEX simulations (Figure 3).

Ideally, all regional model simulations should span the period 1951-2100 in order to include a recent historical period, plus the entire 21st century. For many groups, however, it may prove computationally too demanding to run CORDEX simulations for this entire time span. The 1951-2100 period has thus been divided into five 30-year time slices and participating groups are requested to simulate time slices in the following order of priority 1981-2010, 2041-2070, 2011-2040, 2071-2100, 1951-1980. The first of these (1981-2010) represents the reference period for model evaluation and for the calculation of climate changes. The second priority time slice, covering a future time period, was selected as a compromise between the needs of the impact community in terms of future time horizon and the requirement to obtain a robust change signal. It is requested that all participating groups at a minimum perform these two time slices to have a reasonable set of simulations for analysis and intercomparison.

In the initial phase of CORDEX, it is planned to simulate one realization for each RCP scenario selected, using driving data from multiple global models. In this way, CORDEX will explore the model configuration uncertainty but not the internal variability one. As mentioned above, this should not represent a major drawback, since previous experience has shown that the former is a much more important source of uncertainty when looking at long temporal scales. The sampling of internal variability through multiple realizations is left for the next phases of CORDEX.

Initial focus on Africa

The purpose of CORDEX is to produce a framework valid for multiple domains across the world. Completing a large set of multi-decadal simulations for the entire set of regions shown in

Figure 3 is, however, a formidable task that will require considerable time and resources. In addition, it is useful to test the framework for one region in order to assess its strengths and weaknesses before applying it worldwide. It was therefore decided to select an initial priority region, which we hope will allow a useful matrix of RCD-based scenarios to be generated within the time frame of the IPCC AR5.

Africa was selected as the first target region for several reasons. First, Africa is especially vulnerable to climate change, both because of the dependence of many vital sectors on climate variability (e.g agriculture, water management, health) and because of the relatively low adaptive capacity of its economies. Second, climate change may have significant impacts on temperature and precipitation patterns over Africa, which, in turn, can interact with other environmental stressors such as land-use change, desertification and aerosol emissions. Finally, to date, only very few simulations based on RCD tools are available for Africa, so this region will benefit particularly from the CORDEX framework, from both the research and application points of view. The domain shown in a red frame in Figure 3 will therefore be the initial focus of the CORDEX experiments.

It is fully appreciated that many downscaling groups will favour simulating their "home" domain first and these regional projections are also welcomed in the CORDEX framework. The focus on Africa is mainly to encourage groups that can perform multiple regional climate projections, initially to prioritize Africa and obtain a relatively large ensemble for this region in order to enhance analysis and intercomparison of model results.

Data management

A key aspect of the CORDEX programme will be the management of large amounts of model inputs that it needs and the model outputs and intercomparisons that it will generate. There are two components. First, fine temporal resolution (six-hourly) AOGCM meteorological fields are required as boundary conditions for the RCMs. These need to be stored in a central databank for easy access to the CORDEX modelling community and also in a format standardized across AOGCMs (almost certainly following the official CMIP5 format guidelines). In addition, a fast-track procedure will need to be established in order to transfer data from the AOGCM to the RCD groups.

Second, the output from the RCD simulations will need to be stored in a way that allows easy access to the end-user community, likely also requiring standardization of formats (possibly adhering to the CMIP5 format guidelines). This can prove to be a formidable task in view of the large amounts of data produced by fine-scale climate models. A proposal is being evaluated for creating a distributed network of regional databanks all adhering to the same format and standards for archival and distribution of RCD output, that may be located in various regions/continents. This discussion is still ongoing.

Meeting the challenge:

Given the complex and multi-faceted nature of the CORDEX effort, it is legitimate to ask whether it can actually be successful in delivering the regional climate analysis and information for adaptation, mitigation and vulnerability assessments. Past experience with similar projects (albeit more limited in scope) can provide some guidance in this regard.

One good example is the European project PRUDENCE (Prediction of Regional Scenarios and Uncertainties for defining European Climate Change Risks and Effects (http://prudence.dmi.dk/)). PRUDENCE was an end-to-end project in which multiple global models were used to drive multiple RCMs over a European domain based on forcing from two greenhouse-gas emission scenarios. The results

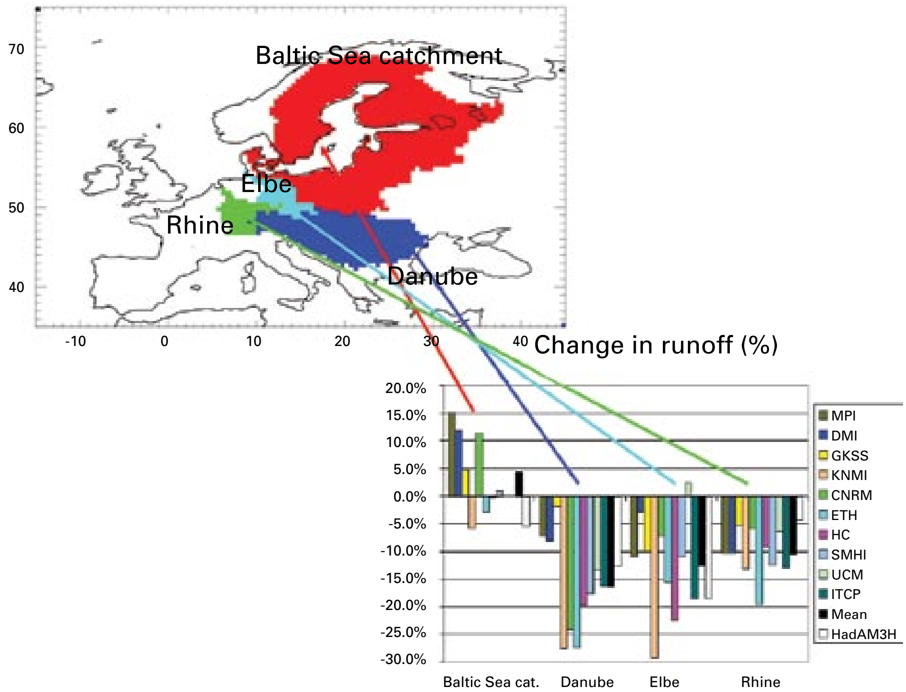

Figure 4 — Change in runoff (%, 2071-2100 minus 1961-2990, A2 scenario) calculated for four European drainage basins by the PRUDENCE multi-model RCM ensemble (from Hagemann and Jacob, 2007)

from the RCM simulations were then used in a range of impact assessment studies ranging from hydrology and agriculture, to health and economy. In the development of the PRUDENCE strategy, communication between the climate modelling and impact communities was essential. In addition, the complementary project STARDEX (Statistical and Regional dynamical Downscaling of Extremes for European regions (http://www.cru.uea.ac.uk/projects/stardex/) conducted similar experiments with different SD tools for intercomparison with the PRUDENCE RCM results.

The main PRUDENCE findings were presented in a special issue of *Climatic Change* in May 2007. Figure 4 (adapted from Hagemann and Jacob, 2007) shows an example of such results, where the output from an ensemble of RCM simulations was used in hydrological impact assessment. Surface runoff, an indicator of excess available water, was calculated for four European drainage basins (Baltic Sea, Danube, Elbe and Rhine rivers) in a set of reference (1961-1990) and future (2070-2100, A2 scenario) simulations with 10 RCMs driven by a single global model (HadAM3H).

The 10 RCMs exhibit a consistent signal of reduced water availability over the Danube, Elbe and Rhine basins, but a mixed signal over the Baltic Sea catchment. These results are attributed to the projected warming throughout Europe and corresponding decreased (increased) precipitation over central-south (north) Europe. This type of signal remains fairly consistent when different GCMs are used to drive the same set of regional models. The type of information in Figure 4 is an important input to guiding future management and planning of water resources at the European, national and even regional scales.

The PRUDENCE strategy can be extended to CORDEX and the Africa focus application will provide an important initial test-bed. Some groups have already started experimenting

June-July-August precipitation

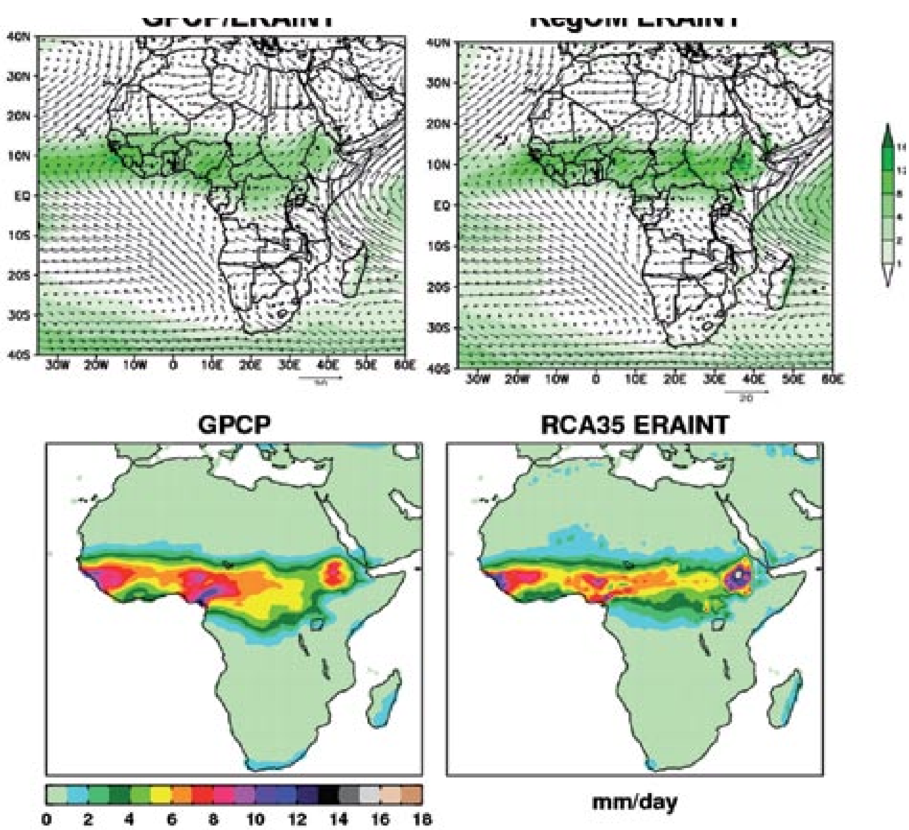

Figure 5 — Mean (1989-2005) June-July-August precipitation (mm/day) over Africa as simulated by RegCM3 (Pal et al., 2007, top right panel) and RCA (Jones et al., 2004, bottom right panel) RCMs driven by ERA-Interim lateral boundary conditions: the simulated precipitation is compared with the GPCP observed precipitation climatology (left panels). The top panels also compare RegCM3 low level (850 hPa) average winds (right panel) with ERA-Interim winds (left panel).

with the Africa domain within the ERA-Interim driven model evaluation framework. Figure 5 shows examples of such experiments. More specifically, June-July-August precipitation from two models, RegCM3 from ICTP (Pal et al., 2007) and RCA from the Rossby Centre (Jones et al., 2004), is compared with GPCP observations (Gruber and Levizzani, 2008). In addition, the top panels also compare simulated and observed (ERA-Interim) low-level winds from RegCM3. Both models show a generally good agreement with observations for the selected large domain.

Some results based on SD studies for Africa are also available in the literature such as Hewitson and Crane (2006), who use SD models to downscale results from multiple AOGCMs showing how this approach can in fact narrow the uncertainty emanating from global model simulations. These examples indicate that a RCD-based framework can indeed provide valuable climate-change information to guide future impact, adaptation and vulnerability assessments towards defining choices for coping with climate variability and change across Africa.

Summary and conclusions

In this article, we present a new framework for regional climate modelling and downscaling, called CORDEX, with the two-fold aim of developing a coordinated framework for evaluating and improving RCD techniques and producing a new generation of RCD-based fine-scale climate projections for identified regions worldwide. We envision that CORDEX will provide a framework for better coordination of RCD-related research and modelling activities within the regional climate modelling and downscaling communities. Past experience has shown that projects such as AMIP and CMIP are invaluable for the global modelling community and CORDEX is essentially structured to play a similar role for the RCD community.

A complementary role of CORDEX is to bridge the existing gap between the climate modelling community and the end-users of climate information. This can be achieved by increasing communication across these two communities and by targeting the structure of the CORDEX experimental and data-management activities to facilitate the use of common standards and formats that will enhance more effective and greater use of the resulting climate information by the end-users.

Here we have described the first design and implementation phase of CORDEX, with an emphasis on the next two-four years (i.e. on the timescale of IPCC AR5). It is envisaged, however, that CORDEX will provide a longer-term framework for continued use and support by the RCD community. While the initial focus is on Africa, as stated earlier, simulations over other domains are welcomed. Similarly, while the initial grid spacing is 50 km, to foster wide participation, groups are encouraged to explore the benefits of increased model resolution as their resources permit, but also in a coordinated fashion with other interested participants. While the initial focus of CORDEX is on 21st century scenario simulations, we plan to extend the CORDEX framework in the future to address the decadal prediction problem also, as research in this area matures sufficiently within the global climate modelling community.

Finally, we stress that it is important that the common interior domains and experiment plans are adopted as much as possible by participating groups so as to facilitate the intercomparison and analysis of models and techniques and the assessment of uncertainties in regional climate-change projections. Coordination of RCD activities is essential for a better understanding of RCD techniques and a more fruitful use of RCD-based products for societal needs.

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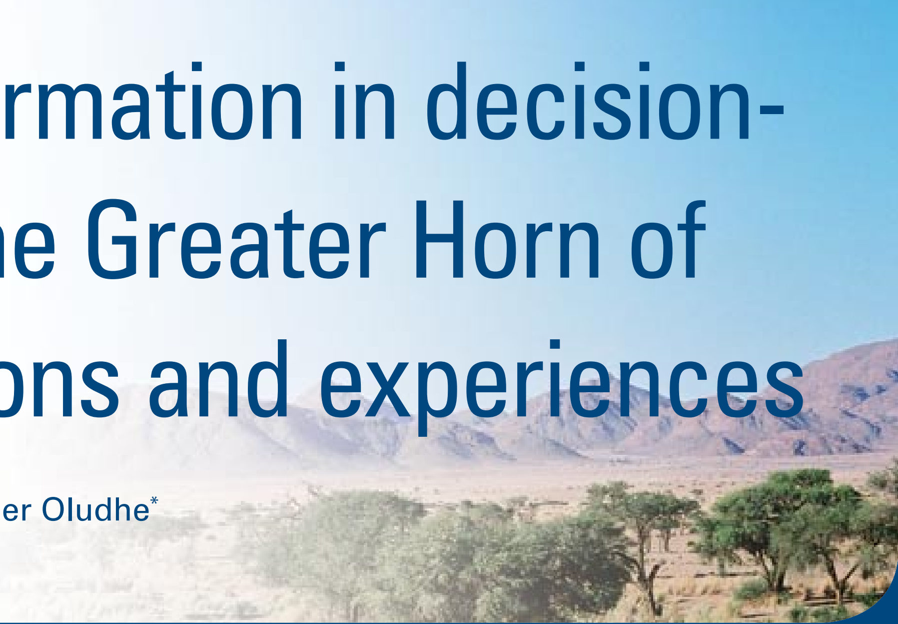
Acknowledgements

The authors thank Stefan Hagemann for providing the material for Figure 4.

Climate information in decision-making in the Greater Horn of Africa: lessons and experiences



by Laban Ogallo* and Christopher Oludhe*

Introduction

The Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC) is a specialized regional centre charged with the responsibility of climate monitoring, prediction, early warning and applications for the reduction of climate-related risks, including those associated with climate variability and change in support of national/regional poverty alleviation and sustainable development strategies.

This is achieved through capacity-building of both meteorologists and the users' specific sectors; mapping of climate hazards; climate monitoring, prediction and early warning; downscaling of climate products; development and application of the climate tools required by various climate-sensitive sectors, among others, in order to reduce sector-specific climate risks. This article presents some of the lessons learned and experiences gathered from ICPAC since 1989 in the successful use of climate Information in the decision-making process.

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Applications of products from Regional Climate Outlook Forums (RCOFs)

ICPAC disseminates a seasonal climate outlook at the beginning of each season through an innovative process known as the Regional Climate Outlook Forum (RCOF) that was pioneered in Africa. The RCOF process was initiated by WMO's Climate Information and Prediction Services (CLIPS) project, in collaboration with National Meteorological and Hydrological Services (NMHSs) and regional/international climate centres, among many other partners.

The RCOF process brings together national, regional and international climate experts, on an operational basis, to produce regional climate outlooks based on input from NMHSs, regional institutions, Regional Climate Centres (RCCs) and international climate institutions. This is done to catalyse linkages among meteorologists, users' specific sectors, governments, non-governmental organizations and universities, among others. In so doing, the forums ensure consistency in the access to, and interpretation of, climate information.

Through interaction with sectoral users, extension agencies and policy-makers, RCOFs assess the likely implications of the outlooks on the most pertinent socio-economic sectors in the given region and explore the ways of making use of the outlooks. The RCOF process also includes a pre-RCOF capacity-building component for climate scientists to improve understanding of the regional climate processes; improvement of models and prediction of regional climate; verification and assessment of prediction skills; addressing the benefits of RCOF products, etc. RCOF sessions are followed by the regular production and dissemination of 10-day and monthly climate updates. It is expected that RCOFs will be integral components of the programmes of the various institutions and relevant partners.

ICPAC and partners have also undertaken a number of pilot application projects aimed at assessing and communicating examples of the successful use of, and impediments to, seasonal climate prediction products; the development of new methodologies for better production, dissemination, interpretation, use and evaluation of climate information and seasonal prediction products in the reduction of climate-related risks; and the development of new applications tools that enable decision-makers to take advantage of seasonal forecast information.

These have made an enormous contribution to the improvement of the quality of the seasonal rainfall outlook; interaction of users from various sectors; and overall awareness, education and improved dissemination of climate information and prediction products for early warning and disaster management. Some successful examples are highlighted in the following sections.

Agriculture and food security outlooks

Seasonal regional agriculture and food security outlooks are now released regularly with Famine Early Warning Systems Network (FEWSNET) and other partners (Figure 1), based on ROF products. These are developed through pre-RCOF capacity-building workshops by climate and agriculture/food-security experts. Most areas where climate outlooks indicated drought risks had received below-normal rainfall for two successive seasons, exposing livelihoods to high levels of vulnerability and indicating high risks of food-insecurity levels. Some of the regional governments responded to the projected food deficits through advisories for mixed cropping, shifting of planting locations, changes in crop types (e.g. from maize to millet) and early food imports, among many other interventions.

Human health outlooks

Vector-borne diseases are sensitive to changes in meteorological parameters such as rainfall, temperature and humidity. Climate extremes such as floods and droughts are common in the Greater Horn of Africa (GHA). This makes GHA very vulnerable to outbreaks of malaria, cholera, Rift Valley Fever and many other vector-borne diseases. Other factors that contribute to the high vulnerability of the region to outbreaks of vector-borne diseases include poverty; poor health facilities; a high population rate beyond the coping capacity of available health facilities; deteriorating and poor economies that cannot

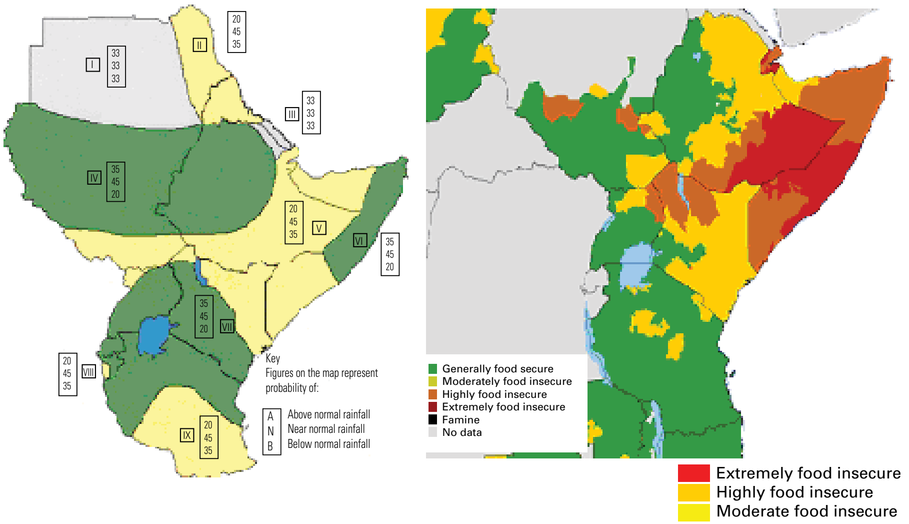


Figure 1 — September – December 2008: climate (ICPAC) and food security (FEWS/NET) risks outlooks

adequately support the basic health care needs, including health insurance of all members of the society; non-preparedness and/or lack of integrated policies that adequately take the available climate information into consideration.

Recent IPCC assessments have shown that Africa is the most vulnerable continent to climate change. Other studies have also shown that some diseases such as malaria are spreading to areas that were in the past malaria-free, such as the relatively cool highlands.

ICPAC, NMHSs, the World Health Organization and other regional partners now release regular regional malaria outlook information based on RCOF products. Verifications of the released products are undertaken during the following RCOF. As part of the verification assessment, Alfred Langat, Chief Public Health Officer of the Ministry of Health in Kenya, had the following to say about the successes of RCOF products:

> Since 2001, when the health sector started participating actively in Climate Outlook Forums (COFs), the Ministry of Health in Kenya has optimally utilized periodical climate information released by ICPAC and the Kenya Meteorological Department (KMD).
>
> Over the last four years, Kenya has not experienced a malaria outbreak. Previously, malaria epidemics occurred annually in the Kenyan highlands after the long rain seasons. With climate information from ICPAC and KMD, the Ministry has been able to prepare adequately to counter the epidemics. Adequate larvicides, insecticides and antimalarials are procured and distributed in time before the predicted climate extremes occur. The health sector in Kenya has therefore benefited immensely from COF products.

Water availability outlooks

Most of GHA may be classified as arid and semi-arid with an uneven distribution of surface-water resources. The quality and quantity of the available water resources have been linked to regional climatic factors. Climate factors also have significant impacts on hydroelectric power, one of the major sources of energy for most GHA countries. Hydroelectric power is highly vulnerable to fluctuations in

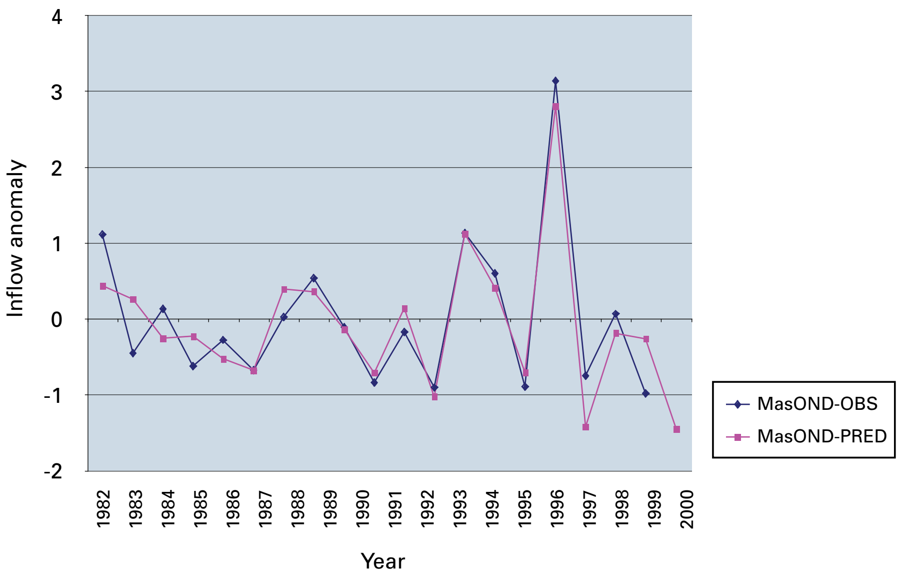


Figure 2 — Masinga Dam and the comparison between observed and predicted October-November-December (OND) inflow anomaly (source: ICPAC)

rainfall. Droughts lead to low water levels in the dams for electrical power generation, resulting in huge economic losses, loss of jobs and negative economic development. On the other hand, too much rainfall can lead to floods that pose threats of dam breakages and siltation, etc.

Some efforts have been made in the region to reduce climate risks associated with the negative impacts of extreme climate events on water and hydroelectric power resources through good understanding of the climate patterns of the previous events and their linkages with the regional hydrological cycle; enhanced monitoring; early warning; and effective and timely disseminated early warnings. Pre-COF sessions regularly include capacity-building workshops on streamflow forecasting that also address expected risks to regional hydroelectric power generation. Figure 3 gives an example of a simple model that is being used by ICPAC, KMD and the Kenya Electricity Generation Company to provide the company with regular seasonal climate risk information, based on RCOF products.

Enhanced dissemination of climate early warning information

Timely availability of climate information in user-friendly language is critical to the effective application of climate products and information. Most of the users of climate information in GHA are illiterate and living in rural areas where tribal/clan languages are the only mode of communication. Women and children often constitute the sections of the society most affected by climate hazards and need to be appropriately targeted for disseminating early warning information on climate risks.

ICPAC, NMHSs and the media have developed partnerships to ensure that climate information is suitably downscaled, translated into local languages and disseminated in a timely fashion to enable the communities to develop community-specific disaster risk reduction strategies, including integration of indigenous knowledge (see Figure 3).

Challenges

Several challenges remain to achieving the successful use of climate information in the decision-making process in Africa. These include:

- Poor observation networks and databases that limit not only the accuracy but also the availability of data and products that are critical for the community-level decision-making process;
- Limited understanding of climate variability and change, including extremes, at regional and local levels;

Figure 4 — Dissemination of seasonal climate outlook through local students and women's groups

- Many climate risks have direct impacts on poverty alleviation and sustainable development challenges in the region, yet little research has been done in these areas. Integrated and sector-specific monitoring, prediction and early warning systems are constrained by lack of capacity;

- Lack of education and awareness regarding linkages among climate variability/change challenges, environmental resources availability/renewability; and socio-economic well-being;

- Lack of and/or non-implementation of relevant policies;

- Difficulty in the understanding and use of available climate products, particularly on the probabilistic nature of most climate advisories;

- Non-consideration of cost-benefit assessments in the use of available climate information and prediction products;

- Weak monitoring, modelling, prediction and early warning systems;

- Lack of effective institutional partnerships of NMHSs with national, regional and international users for integrated decision-making;

- Most users in the region are illiterate and still unable to interpret/understand the terminology commonly presented by climate scientists;

- Limited interdisciplinary research that includes hazards, impacts, vulnerability mapping, prediction and early warning;

- Limited human, as well as infrastructure, resources.

Climate risk management in western South America: implementing a successful information system

by Rodney Martínez Güingla[*] and Affonso Mascarenhas[*]

Introduction

Six years after opening, in January 2003, the International Centre on "El Niño" Research (CIIFEN) has succeeded in consolidating its presence in Central and South America by providing climate information services designed principally for users and decision-makers.

One of CIIFEN's most significant challenges in its short life, however, has been to demonstrate through practical experience how to improve the management of climate information as a central pillar of genuinely people-centred early-warning systems. CIIFEN's mission focuses on promoting and implementing fundamental and applied research projects to improve understanding of El Niño/La Niña and climate variability and change in order to help improve early warning on a regional scale and reduce the social and economic of climate impacts.

This article offers a brief summary of CIIFEN's contributions to the management of climate risk in western South America and how its activities have developed in line with its mandate and future plans for the region.

Conceptual elements of a regional early warning system

The United Nations International Strategy for Disaster Risk Reduction (ISDR) gave a clear definition of early warning systems in 2009. The backbone of the concept of CIIFEN's operation is what we regard as a slightly modified early-warning scheme based on four main themes:

- Development of climate prediction;
- Construction of climate-risk maps applied to development sectors;
- Building information systems;
- Establishing mechanisms to ensure that governments respond to early climate warnings and take action (Figure 1).

Based on our vision, we explain the complex path from early climate warning to risk management. When this climate information actually provokes a response from governments, it takes

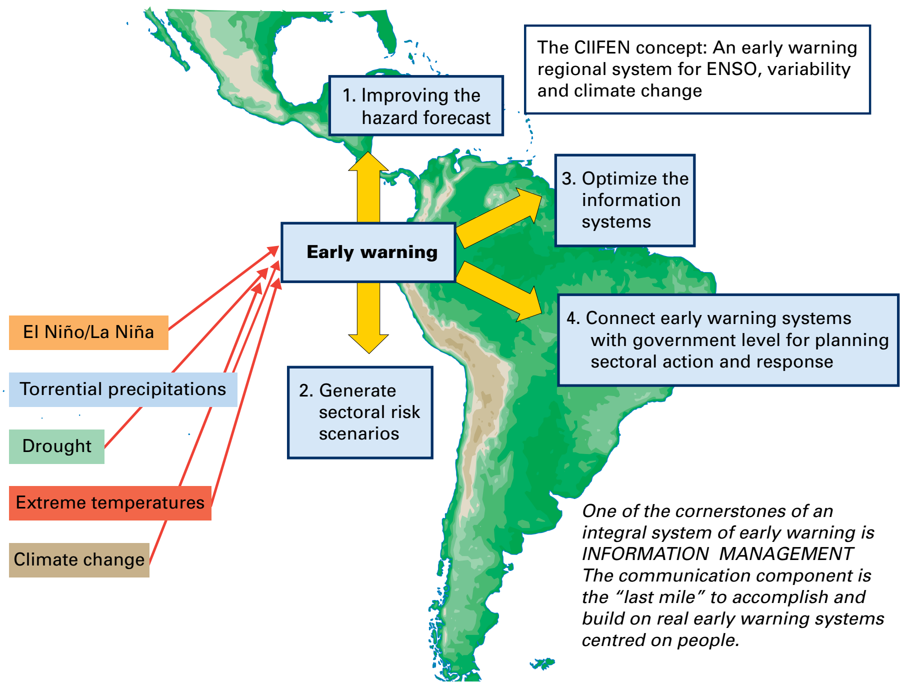


Figure 1 — Conceptual elements of CIIFEN operations, Martínez (2004)

1 International Centre on Research "El Niño" (CIIFEN)

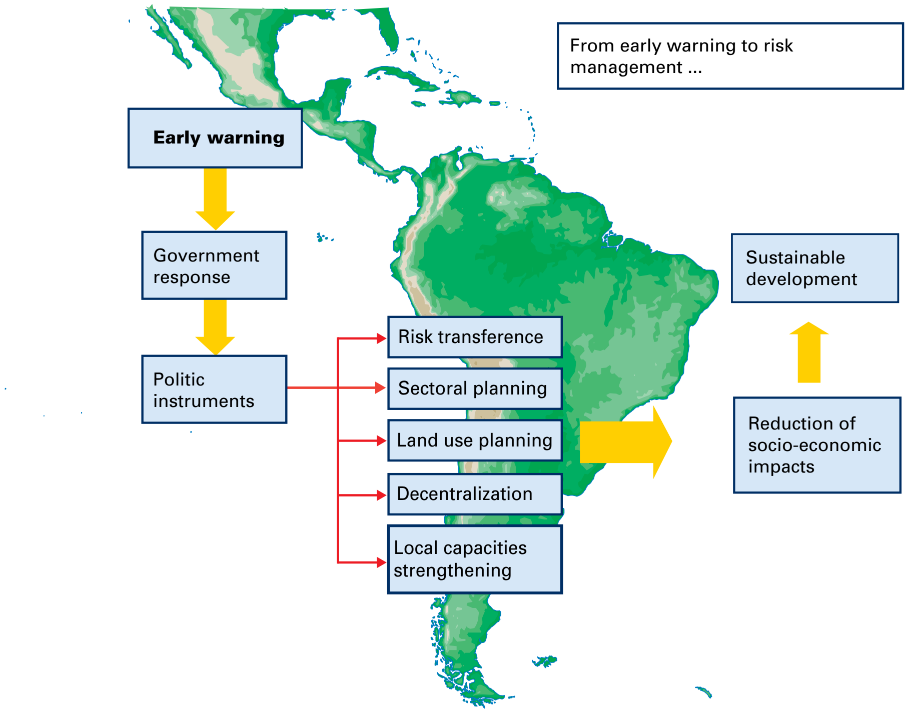


Figure 2 — Conceptual elements of early warning to risk management systems, Martínez (2004)

the form of policy instruments which may be implemented as a variety of mechanisms of differing complexities: regional planning, decentralization, risk transfer and environmental management, among others. National governments can also strengthen the capacities of National Meteorological and Hydrological Services (NMHSs) and research centres, constantly improving the computing resources and building personnel capacities so that they can at last lead their countries along a path of truly sustainable development (Figure 2).

It is not sufficient, however, to have a conceptual scheme and merely talk about it. CIIFEN had to validate this scheme in the field by means of a pilot project. CIIFEN had this great opportunity when the Inter-American Development Bank approved, in the category Regional Public Goods, the project "Climate information applied to agricultural risk management in the Andean countries", which involved the National Meteorological and Hydrological Services of Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela, coordinated by CIIFEN.

Early warning system

The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss. This definition encompasses the range of factors necessary to achieve effective responses to warnings.

A people-centred early warning system necessarily comprises four key elements:

- Knowledge of the risks;
- Monitoring, analysis and forecasting of the hazards;
- Communication or dissemination of alerts and warnings; and
- Local capabilities to respond to the warnings received.

The expression "end-to-end warning system" is also used to emphasize that warning systems need to span all steps from hazard detection through to community response (source: UNISDR Terminology on Disaster Risk Reduction).

Building a climate information system for agroclimatic risk management in the Andean countries

This project was launched in June 2007 and is, by its nature and structure, one of the main exercises of regional scope focused on climate risk management. Its objective was to help reduce the socio-economic impact of the action of the climate on farming activity in the countries of the Andean region by setting up a climate information system as a Regional Public Good, focusing on the needs of farmers, supporting decision-making and risk management in the agricultural sector.

The project had the following components:

- System for processing data and climate information;
- Information dissemination system;
- Institutional strengthening.

Regional climate database for western South America

Under the first component, in the National Meteorological and Hydrological Service of the six countries of western South America, the project undertook a complex process of recovery and conversion of data from meteorological stations for digitizing and quality-control processing. At the same time, it worked on the design of a regional climate database that culminated in the input of the 3 879 035 records of precipitation and maximum and minimum temperature from 169 meteorological stations in the region. A digital interface was built for displaying historical data (http://

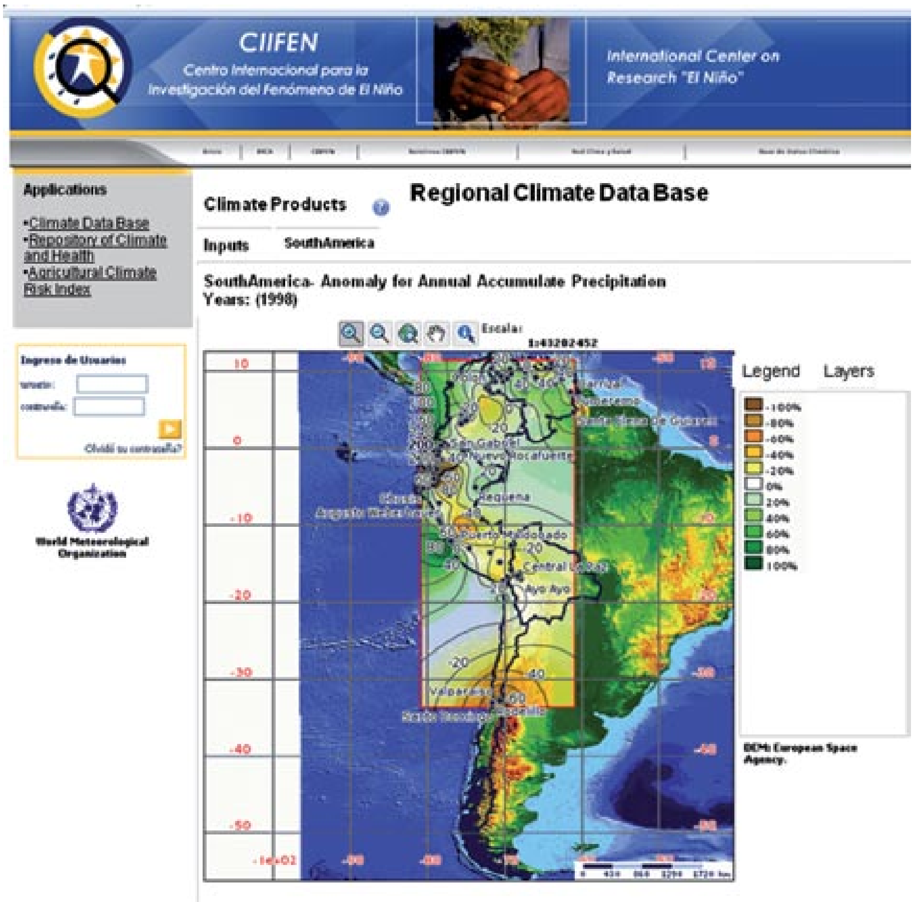


Figure 3 — Regional climate database for western South America: *http://vac.ciifen-int.org*

vac.ciifen-int.org) with daily data from 1960 to the present. This major step forward in regional interchange and integration of climate data is a first, and heralds a new chapter in cooperation between meteorological services in the region. The regional climate database is run and maintained by CIIFEN and an agreement for its operation was approved and signed by the NMHSs of the six countries and CIIFEN (Figure 3).

Statistical and dynamic modelling

The project made a considerable effort to improve climate forecasting capabilities (1-3 months) in the six countries. Since one of the pillars of a climate information system must be to base forecasts on reliable information to reduce subjectivity and increase robustness, it was based on statistical tools and numerical models designed, as far as possible, to match the conditions in each country. This particular activity was a major challenge for CIIFEN and the project team on account of the major imbalances between the countries taking part in the project in this area.

Despite the various considerable constraints on implementation, we were able to provide workstations for the countries and work was carried out on two fronts at the same time. For statistical modelling, we used the Climate Predictability Tool. This is a world-renowned tool for statistical downscaling developed by the International Research Institute for climate and society (IRI). Regional workshops were combined with experts accompanying each country's teams. The valuable experience of the forecasting teams was organized in terms of selection and use of both atmospheric and oceanic prediction parameters. We worked to validate forecasts and, after a long process, the six NMHSs were fully capable of generating seasonal forecasts and, in some cases, monthly and bi-monthly ones. With some differences, over the lifetime of the project, these statistical forecasts reached the operational phase in all the countries, in most cases providing forecasts for a hitherto unavailable time horizon. For numeric modelling we used the climate mode of the MM5 and WRF models (see box below). On this component, too, we worked closely with the NMHSs and held two regional training workshops on numerical modelling. The numerical experiments are continuing and are now operational in at least three countries (Figure 4).

Decision-support systems

One of the most important pillars of CIIFEN initiatives is decision-support tools. For the agricultural sector in particular, we designed

The MM5 and WRF models

The MM5 is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation (http://www.mmm.ucar.edu/mm5/).

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs for a broad spectrum of applications across scales ranging from metres to thousands of kilometres (http://www.wrf-model.org/index.php).

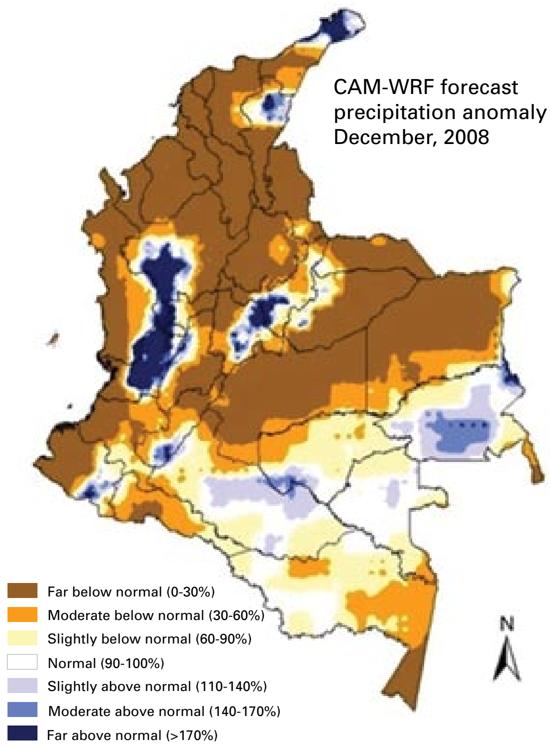


Figure 4 — Operational seasonal forecast produced by IDEAM, Colombia, for December 2008

a geographical information system representing spatially the vulnerability of a number of selected crops for each country in which the project was implemented, including multiple layers of information that can be used to define levels of exposure to climate and levels of resilience based especially on social, economic, political and institutional parameters. Among other factors, the territory is characterized in terms of land use, water-retention capacity, topography and texture.

In the case of crops, the phenological cycles and their various climate requirements were estimated on the basis of historical information and information obtained in the field. Likewise, for crops, we considered sensitivity to pests and diseases more related to the climate. The layers of information for estimating vulnerability were weighted according to the region and the crop and then crossed with dynamic layers derived from forecasts of seasonal rainfall, maximum and minimum temperatures, to produce dynamic maps of agroclimatic risk by crop. We validated the system in each country and worked closely with the experts in each NMHS. Finally, the system can generate maps that are updated with each new forecast to provide three-month risk scenarios, available every two months or monthly. Users can display the vulnerability layer, the forecast and also the associated risk for the coming season using a very simple colour scale on the map. The system was designed to be updated via the Website (http://ac.ciifen-int.org/sig-agroclimatico/ (Figure 5).

Community information systems

The project invested a major effort to work on the most critical phase of the process of disseminating the information, reaching end-users without further interference or intermediaries. To achieve this, once all the technological systems reached the operational phase, we worked intensively in the selected areas of each country to map players, forge alliances and contact and connect with the media. A special effort was made to involve the private sector, which was quite successful. We obtained support from mobile telephone companies to send climate warning messages free of charge in Ecuador to a large network of users. Similarly, we succeeded in including products generated by some of the NMHSs in magazines circulated widely in the farming sector at no cost to the producers. We made important alliances with community radio stations, even succeeding in broadcasting climate bulletins in native languages. Other important achievements included demonstrating the feasibility of setting up effective climate information systems that meet the needs of the most remote users (Figure 6).

We carried out an assessment of user perception of the climate information in the pilot areas in all six countries. Access to, understanding and use of, the information improved from 30-35 per cent of the target population at the start of the project to 60-65 per cent by the end. One of the main indicators of the success of this initiative was the response of the national or local authorities. During the final phase of the project, government funding was given to replicate the initiative in other areas and improve the installed capacity. The information system was provided for advanced or technical users and for decision-makers in business and government over the Internet, and the products are easy to use and understand. However, the system was also provided for end-users through alternative methods and more complex forms, such as radio, local communications systems, agricultural networks or community associations. Both communities provided their points of view on the information and the presentation format was altered several times to satisfy demand as far as possible.

The effectiveness system is now measured through demand. Users with access to e-mail can join the system and the number of users increased by no less than 80 per cent in two years. Meteorological services

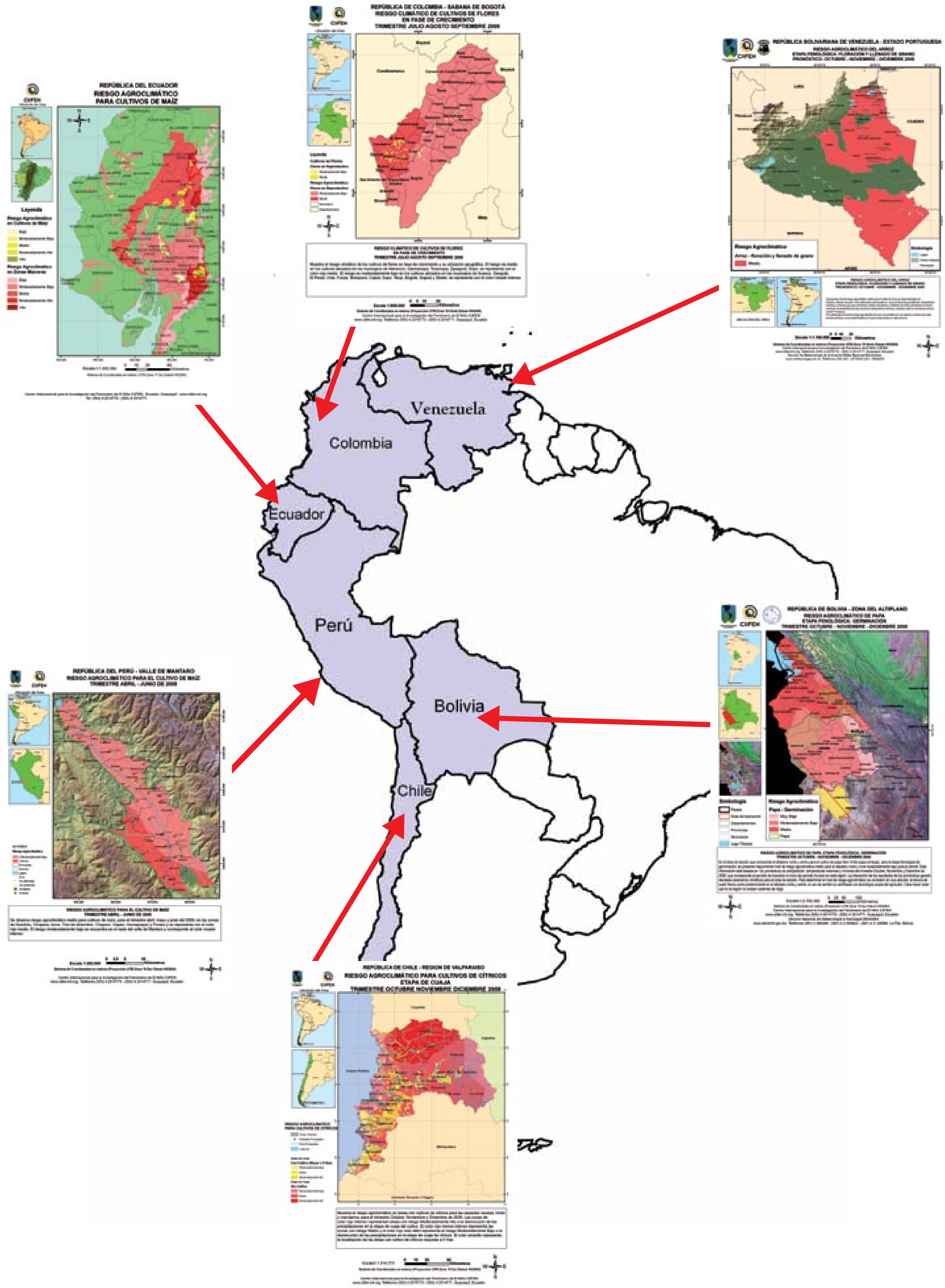


Figure 5 — Climate risk maps on western South America:
http://ac.ciifen-int.org/sig-agroclimatico/

Figure 6— (a) climate dissemination systems in western South America; (b) alliances with local media and private sector to disseminate climate information

have a long list of main users of the information that they disseminate regularly. The list is also constantly expanding to include users receiving the information by radio, the media and mobile phones (the mass media in the Andean region).

Leaders of communities in various countries have been trained to use climate information. Educational material has been prepared to train trainers in the use of climate information and to take advantage of NMHS information. This material was designed taking account of the specific social and cultural features of the communities in each country.

Another indicator of success related to alliances for cooperating with the private sector. Through formal agreements with the NMHSs, additional long-term support was guaranteed through the publication of seasonal climate forecasts and other data free of charge for training purposes in the communities linked to these industries, including specific support measures.

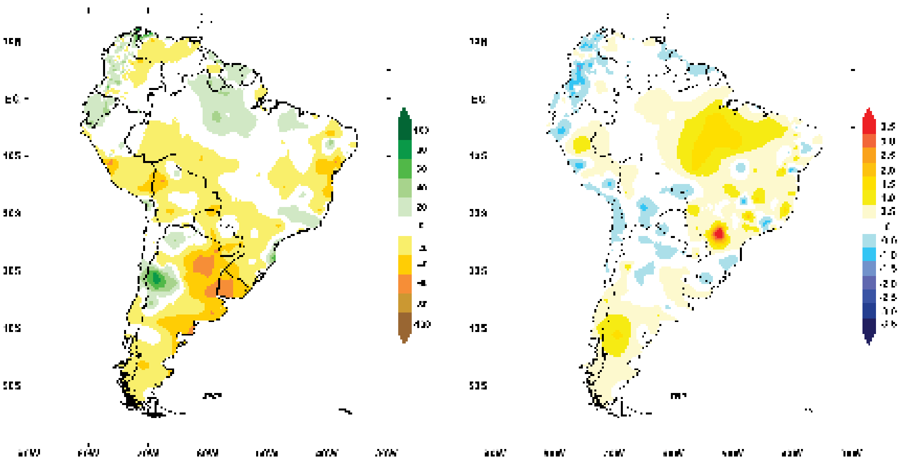
Principal results of the climate information system for western South America.

- The first regional climate database to be implemented in western South America;
- Capabilities enhanced by the application of statistical and dynamic downscaling in the region;
- Application of the operational dynamic of climate risk maps for agriculture in the region;
- Implementation of self-sustainable community climate information networks, with support from the authorities for the data networks, media and private sector;
- Intense capacity-building in the region, closely linked to the implementation system;
- Application of regional agreements between the region's NMHSs and the networks;
- Positive political response by the local and national authorities with the system that will serve to replicate the initiative in other areas and for other crops with national funding.

CIIFEN contributions to the Bulletin of the American Meteorological Society: *State of the Climate*

At the 14th session of the WMO Commission for Climatology (CCl-XIV), in Beijing in November 2005, Recommendation 5.5.3 was adopted, requesting WMO to ensure that editions of the *Bulletin of the American*

State of the climate in South America in 2007



Annual mean temperature anomaly (°C) 2007- South America.
Sources: National Meteorological Service from: Argentina, Bolivia, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, CPTEC (Brazil) and NCDC/GHCN (USA)
Reference period 1961-1990
Data compilation and processing: CIIFEN

Annual precipitation anomalies (% normal) South America.
Sources: National Meteorological Service from: Argentina, Bolivia, Chile, Colombia, Ecuador, Uruguay, Paraguay, Peru, Venezuela, CPTEC (Brazil) and NCDC/GHCN (USA)
Reference period 1961-1990
Data compilation and processing: CIIFEN

Figure 7 — Regional anomalies maps published in South America chapter from BAMS State of the Climate 2005

Meteorological Society (BAMS) would strive for a regional balance in terms of coverage and greater involvement of the National Meteorological and Hydrological Services. CIIFEN took on this responsibility and, from that year, coordinated an exercise that was both unprecedented and fruitful for generating the contribution of WMO Regional Association III (South America) to the annual BAMS State of the Climate publication.

Since 2006, with the active participation of the Region's NMHSs and coordination by CIIFEN, we succeeded not only in incorporating a large number of the Region's stations in the analysis (up from 516 in 2005 to more than 900 in 2009) but also increased participation in this important publication by authors from various South American countries. To date, our ever-increasing contributions have been published in the BAMS State of the Climate 2005, 2006, 2007 and 2008 (Figure 7). Assembling and sharing climate information are other useful functions of information services as they allows the conversion of basic historical assessment and analysis data that is highly relevant for forecasting and estimating indices.

Western Coast of South America Climate Outlook Forum (WCSA-COF)

Since 2003, CIIFEN, under the auspices of WMO, has coordinated the Western Coast of South America Climate Outlook Forum (WCSA-COF), with the participation of the National Meteorological and Hydrological Services of Bolivia, Chile, Colombia, Ecuador, Peru and Venezuela, So far, seven forums have been held in Guayaquil, Ecuador (2002, 2003, 2004); Santiago de Chile (2005); Armenia, Colombia (2006); La Paz, Bolivia (2007); and Caracas, Venezuela (2008). The next one will be held in Cuzco, Peru, in the last quarter of 2009. This event was originally intended to produce by consensus the seasonal climate outlook for the region, but it has now become a forum for intense dialogue and interaction between users in the member countries.

WCSA-COF has now become the platform for NMHSs to improve the dialogue with end-users in the various sectors and to analyse and improve the seasonal forecasting operations in the region. The interface mechanism between climate information providers and users in the communities also allows a better understanding between users and encourages better adoption by them, thereby reducing adverse results.

The seasonal forecast for the region is the outcome of a monthly debate and consensus between all the NMHSs. All members share a common methodology involving a number of parameters which have been agreed and are being improved year after year. Special efforts are now being made to apply a verification technique. Once a consensus is achieved, the forecast is sent out by e-mail to more than 15 000 users throughout Central and South America and a few other contacts in other continents. The COFs have provided the NMHSs and CIIFEN with a substantial legacy of experience and lessons learned regarding user profiles, expectations and concerns, that has helped to understand the climate information and the complex process of managing it at regional and national levels as the fundamental bases for early warning and risk-management systems.

CIIFEN information products

CIIFEN maintains an operational information system serving a large number of users (more than 15 000) registered by means of a subscription system in Central and South America, Europe and Asia. Of visits to the CIIFEN products section, 77 per cent come from Central and South America, 19.4 per cent from Europe, the USA and Canada, and the remaining 3.6 per cent from Asia, Africa and other regions.

Capacity-building courses

- Regional workshop for South America on managing and rescuing climate data, 2003 (15 countries)
- Regional workshop for South America on climate applications in agriculture, 2003 (16 countries)
- Regional workshop for South America on climate applications in the health sector, 2004 (14 countries)
- Regional workshop on regional ocean and climate modelling, 2004 (8 countries).
- Alexander Von Humboldt international conference: The El Niño phenomenon and its global impact, 2005 (75 countries, 350 participants).
- International workshop: El Niño and its impact on the Pacific basin, 2005 (23 countries)
- Ibero-American workshop on climate change and risk management, 2006 (21 countries)
- Regional workshop: ENSO and its social and economic impacts, 2006 (14 countries).
- Regional workshop on climate-change indices and indicators, 2006 (6 countries)
- Regional workshop on statistical modelling, 2007 (6 countries)
- Regional workshop on dynamic modelling, 2007 (6 countries)
- Regional workshop on agricultural climate risk mapping, 2008 (6 countries)
- Regional workshop on advanced numerical modelling, 2008 (6 countries)
- Ibero-American workshop on seasonal forecasting, 2008 (20 countries)
- Regional workshop on processing climate data, 2008 (6 countries)
- Regional Climate Outlook Forums III, IV, V, VI, VII and VIII, 2003, 2004, 2005, 2006, 2007, 2008 (6 countries)
- More than 35 local workshops conducted at community level throughout Bolivia, Chile Colombia, Ecuador, Peru and Venezuela
- Regional course on statistical modelling, Maracay, Venezuela, 2007
- Regional course on dynamic modelling I, Lima, Peru, 2007
- Regional course on mapping agroclimatic risk, Guayaquil, Ecuador, 2008
- Regional course on dynamic modelling II, Guayaquil, Ecuador, 2008
- Course on climate data analysis and processing, Maracay, Venezuela, 2008
- Training courses for experts in the region at IRI, 2007, 2008

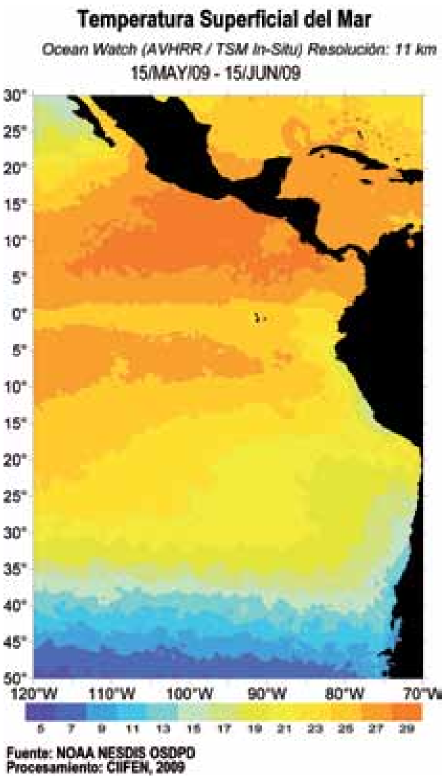
CIIFEN's operational products (Figure 8) are:

- Sea-surface temperature images for the eastern Pacific (weekly);
- CIIFEN bulletin on the state of El Niño/Southern Oscillation (ENSO), focusing on impacts in Central and South America (monthly);
- Seasonal forecast for western South America (monthly);
- Oceanographic analysis of the eastern Pacific (monthly)

Climate change, risk management and adaptation

Climate change is a regular item on the CIIFEN agenda. From the conceptual point of view, the agendas of climate change, risk management and environmental management are not necessarily parallel or independent. The common ground is where the population interacts with the ecosystems and goes about its business. Climate variability is a constant factor that is being affected by climate change. But, in practice, people alter the land, degrading the ecosystems and creating the risk of increased social, economic and environmental vulnerability.

CIIFEN's work focuses on risk management for the local climate as the main tool for devising strategies to adapt at local level because this is the best stage to understand and tackle environmental, social and cultural aspects. Working at local level requires close contact with the authorities and the community, and this does not require scenarios for 80 or 100 years. CIIFEN is promoting the use of RClimDex (a software package for indices calculation, see http://cccma.seos.uvic.ca/ETCCDMI/software.shtml) to establish trends of indicators and indices of climate change on much shorter timescales with a better local approximation.



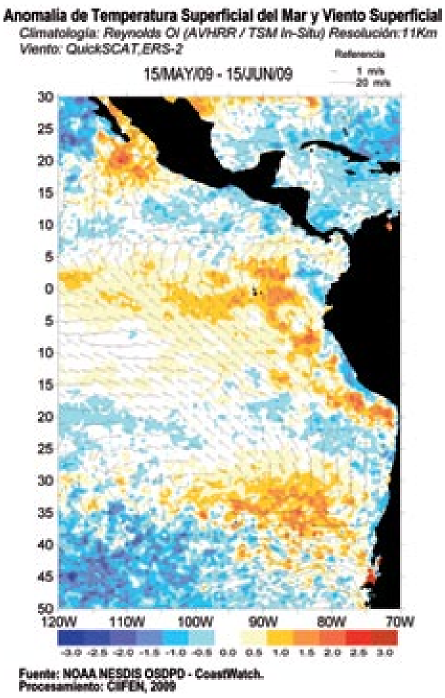


Figure 8 — CIIFEN´s operational products

There is also a need to understand the relationships between climate, territory and humans that can partly explain future climate vulnerability. CIIFEN considers that climate risk management can be adapted in the present and resilience achieved gradually.

CIIFEN has taken part in two projects related to climate change, the first on the determination of indices of climate change indicators for the coast of Ecuador and an initial report of these results with possible trends in land use in the area from previously determined climate-risk zones; the work took place in close coordination with the National Meteorological and Hydrological Institute of Ecuador.

A second experience for CIIFEN was its participation in the analysis of the vulnerability to climate change of the biodiversity and population of the Galapagos Islands. This project was supported by Conservation International and the World Wildlife Fund and allowed the conceptual framework described above to be applied to a specific case.

Strengthening capabilities

In all its projects, CIIFEN has worked hard to strengthen capabilities and set up regional working groups. In recent years, as part of our projects, we have devised many training courses in line with a whole strategy for strengthening capabilities for the provision of climate services (see box on previous page).

As a result, more than 150 experts in the region have been trained, and three active networks or working groups have been consolidated:

- Regional numerical modelling group;
- Regional seasonal forecasting group;
- Regional climate-change indicators group.

Worthy of a special mention is the recent Ibero-American workshop on seasonal forecasting attended by 52 participants from 19 countries and, which is to be held again in the second half of 2009, in Guayaquil, Ecuador.

Final comments

After a difficult path towards consolidation, CIIFEN is celebrating its sixth anniversary in a phase of positive development and a strong position in western South America. There is a growing number of ongoing projects and interaction with the region's institutions, as well as the number of members. Many challenges in prospect that motivate us in our work and enable us to believe that our work on climate applications, user interface, climate risk management and feasible adaptation have been positive and well received by all institutions, organizations and donors. Over CIIFEN's short life we have much to share and much more to offer to benefit the region, so the future looks increasingly promising.

Acknowledgements

To Alexandra Rivadeneira, Abigail Alvarado and Juan José Nieto from CIIFEN Information Systems Unit for their contribution to this article.

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Water and climate: issues, examples and potential in the context of hydrological prediction

by Ann Calver*

Introduction

The interplay between hydrological and climatological information and analyses offers a maturing capability to assess expected terrestrial water regimes. This article is concerned with hydrological aspects of this water-climate linkage. It considers the major areas of information exchange between the two domains that enhance the capabilities of both. It then discusses capabilities of hydrological analyses in assessing impacts of climate conditions, describing some specific examples in flood and water resource contexts to illustrate both potentials and difficulties associated with such analyses. The final section of the article deals with future challenges to be met in this area of prediction in the terrestrial phase of the water cycle.

The use of hydrological analyses and modelling to explore climate impacts is by no means a new field of investigation, nor is the need for data exchange between atmospheric and Earth sciences a new requirement. It is, however, the case that there is currently a compelling impetus in these activities because of perceived improvement in technical developments in predictive tools and, in many regions of the world, increased awareness and concern of possible climate-induced changes in water regimes and availability. The considerations addressed in the article are important not only in the light of any man-induced changes to the climate system but to the management of terrestrial water under the ubiquitous conditions of natural variability of the climate system.

The question of climatic impact on the hydrological domain is an area of widespread concern, investigation and publication, both of global scale and overview information and of many academic articles addressing specific points of research. Useful examples of wide scale work, but by no means the only sources, include Bates et al. (2008); Dialogue on Water and Climate (2003); European Commission (2005); and WMO (2009).

In this article, the time base in the consideration of climate (as opposed to meteorology) is taken to be greater than seasonal, with the emphasis on periods of years and decades: it is of course the case that linkages between the atmospheric and terrestrial water domains also enhance shorter-term predictions, albeit used in a somewhat different manner. The term hydrology is used in the sense of covering the land phase of the water cycle (natural and managed): the interaction of the marine environment with the climate system is beyond the scope of this article, as are issues of water quality, as opposed to water quantity. The aim of the article is to discuss the nature and direction of some technical developments, together with their potential and drawbacks, and to look at some example applications addressing major strands, accompanying this with

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comment on key research aspects required to tackle the provision of appropriate information.

Information flows between climate and water domains

This section gives a succinct overview of the main aspects of information which the hydrological practitioner and researcher benefit from receiving from the climatological community, together with the information which hydrologists can usefully provide to enhance climatological science. It is interesting to note that hydrology-to-climatology data exchanges are used primarily to enhance climate modelling capability, whilst climatology-to-hydrology information flow, as well as enhancing predictive hydrology, also plays a more direct part in policy and management decision-making, reflecting the scope in the land phase of the hydrological cycle to effect hazard-reducing action.

The key aspects of water-related information which benefit climate scientists are the topographic configuration of the region of concern, including that of major water bodies, the character of soil and aquifer classes and their distributions, and land uses and management, both urban and rural. The more highly dynamic aspects are river and water body levels and soil and aquifer water contents, together with surface temperatures and state of vegetation growth. The scale of information provision needs to be made compatible with the operating resolution of global (or general atmospheric) circulation models (GCMs), commonly around 150-300 km, and with regional climate models (RCMs) at around 25-50 km. Data rescue and infilling are of importance, as well as scale transformations. Remotely sensed data are increasingly looked to in providing good spatial coverage, albeit sometimes of useful rather than ideal-choice variables.

Figure 1 shows the atmosphere/land surface interface of the United Kingdom Met Office Unified Model (MetUM) (see, for example, Cullen, 1993; Essery et al., 2003) where the linkages and feedbacks across the atmospheric/terrestrial boundary are highlighted. MetUM has been designed to allow configurations for use in weather forecasting and climate predictions: DePreSys, for example, deals with decadal predictions; PRECIS serves as a regional climate model; and HadGEM as a global climate model predicting up to a century ahead. MetUM formulations are used in a number of countries in addition to the United Kingdom, including Australia, India, the Republic of Korea, New Zealand, Norway and South Africa. It is important to note that, whilst some hydrological modelling is carried out within systems coupled to atmospheric models, arguably a greater amount is undertaken in uncoupled mode with atmospheric drivers.

The key outputs from climate models of benefit to hydrologists are precipitation and temperature fields at a range of time and space scales. With, often, further transformation to finer scales, this information, combined with other regional and/or catchment data, facilitates statistical and/or physically based analyses of the hydrological system. The availability of past hydrological records allows methods to be tested for performance before being used in predictive mode with future climate drivers. Whilst concern is sometimes raised that conditions of the future may be outside the range of those tested in the past, to do the latter testing is a wise step if at all feasible.

Good precipitation predictions over space and time are plainly an essential requirement, as also are temperature and wind fields for determining snow and ice conditions and evaporation. For some risks, notably flooding, there is a compelling need for reliable rainfall extremes, including those at

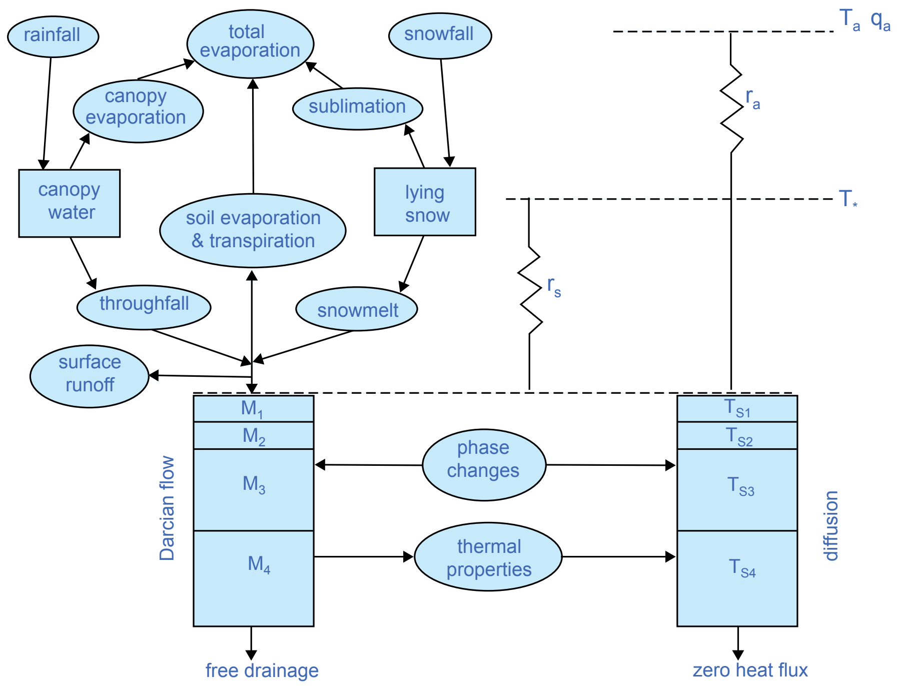

Figure 1 — Schematic diagram of the structure of the atmosphere/land surface interface of the UK Met Office Unified Model. M_1 … M_4 soil moisture in each of four soil layers; T_{s1} … T_{s4} soil temperature in these layers; r_s stomatal or surface resistance; r_a atmospheric resistance; T_* surface temperature; T_a atmospheric temperature; and q_a atmospheric specific humidity (diagram reproduced with the permission of the UK Met Office).

short durations: this is the case for long-term frequency quantification as well as for (near-) real-time in that short-term intensities can be of crucial hydrological importance. The rate and direction of any climatic trend are valuable indicators, even where specific numerical predictions are not possible: they are especially valuable if the cause of the trend is reliably identifiable. The scientific uncertainty around climate projections is being quantified: of value to the practitioner is an expression of the reliability of climate projections. To effect good hydrological projections, further data in addition to those of climate are plainly required, notably other environmental information and that from social and economic sciences, including adaptation possibilities. This, in turn, paves the way for exploration, not only of water quantity, considered here, but also of water quality, environmental quality and food and health issues.

Hydrological analyses of climate effects

Hydrological analysis encompasses many types of approaches, occasioned by a domain rich in processes and in spatial and temporal variability, by the range of levels of available data, and by the variety of requirements driving the analysis. The hydrological domain is a highly multivariate system in which it is difficult to unravel the separate effects of climate and other factors that affect the terrestrial water regime. While atmospheric and land surface processes are, to varying degrees, coupled in global and regional climate modelling, the detail of hydrological regimes is frequently as well, and in many cases better, served by essentially hydrological models, driven by time series of climatic inputs, particularly precipitation and temperature. The latter models have in many cases developed a maturity which can be capitalized on in terms, for example, of formulations for subregional structural detail of catchments, lateral water transfers and rapidly responding flood generation with accompanying representation of inundation levels. In short, to explore aspects of hydrological response to climate drivers, there are numerous methodologies which are not necessarily intimately coupled with climate model systems: a large array of generic models is available, some models encapsulated in software packages, and with a variety of code access levels. Methods range from simple parameter-sparse formulations to fully coupled surface and groundwater systems of partial differential equations solved by numerical schemes and offering three-dimensional spatial variability. Whilst the more detailed formulations plainly offer more hydrological variables and more spatial definition, it is to be noted that complex representations are not always the most appropriate, particularly when data are sparse. Statistical analyses of hydrological data complement these modelling approaches. Hydrological futures are frequently evaluated through the consideration of expected frequency distributions relating to particular periods as well as of transient time series.

With much work undertaken in exploring effects of climate variability and change on aspects of the hydrological environment, it is not a straightforward matter to choose which specific examples to discuss. Whilst recognizing opinions may differ on the most apposite, a selection of work is commented upon below, dealing with water deficit and water excess, which serves to demonstrate points of interest and relevance beyond the individual application in terms of generic capabilities and shortcomings.

Broad-scale flood risk

An investigation into flood risk in the United Kingdom was undertaken in 2002-2004 by a range of scientists working with the Government's (then) Department of Trade and Industry's "Foresight" team looking in particular at likely conditions under the climate predictions for the 2030-2100 period in order to inform policy-making. The cross-government socio-economic "futures scenarios" (Department of Trade and Industry, 2002), shown in Figure 2, were taken to represent an encapsulated range of development possibilities. These have a fair degree

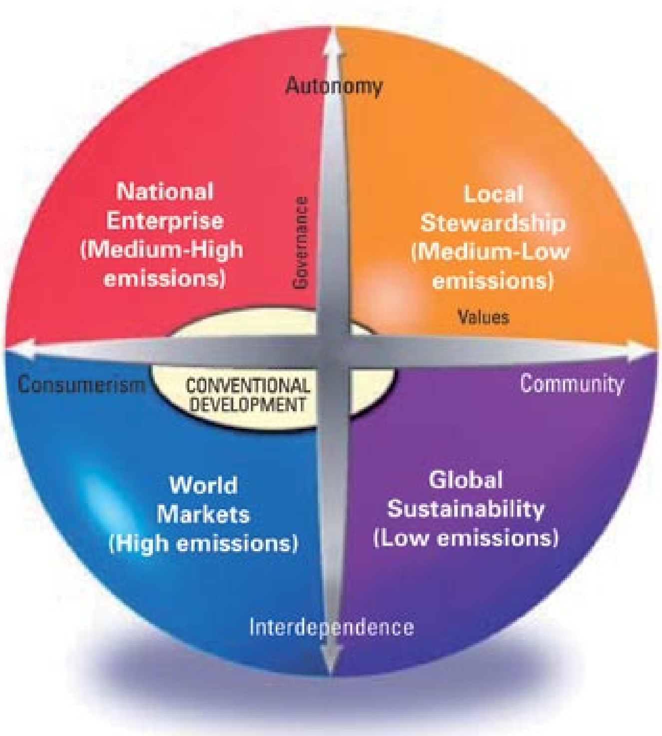

Figure 2 — Socio-economic futures scenarios, with system of governance represented on the vertical axis and social values indicated on the horizontal axis. (figure reproduced with permission, from UK Floods Foresight report (Evans et al., 2004)).

of generic applicability in wider regions (though the "conventional development" is arguably less transferable), covering level of governance and range of social aspirations/values.

Each of these socio-economic scenarios was linked with a likely climate scenario (Hulme et al., 2002) in terms of global greenhouse-gas emission scenarios considered compatible with the development characteristics. The estimated scale of effects of the climate drivers, together with the other influences on flood risk implicit in the development scenarios (such as environmental regulation, sea-level change, urbanization, infrastructure development, etc.) were assessed by groups of experts. The results were then factored in to a modified version (Hall et al., 2003) of an existing software system for determining, by quantitative but broad-brush hydrological and hydraulic procedures, the expected spatial extents of fluvial (1-in-100-year event) and coastal (1-in-200-year event) flooding, together with the associated cost implications in social and infrastructure terms. Extensive details of the methods are to be found in Evans et al. (2004). Figure 3 shows some results from this procedure in terms of average annual flood damage for the 2080s under the four combined climate-and-socioeconomic scenarios. Further numerical explorations introduced mitigating measures to gauge the effect of actions to reduce flood risk.

This Floods Foresight project was undoubtedly influential in the UK in raising the profile of the possible scale of climate impacts and has attracted interest in, for example, China, India, Japan, the Netherlands and the USA. It is plainly a 'broad-brush' approach with advantages and drawbacks inherent in such a procedure. The drawbacks centre on the inevitable need for approximation which should be recognized by the scientists but the degree to which it is apparent in outcome summaries is

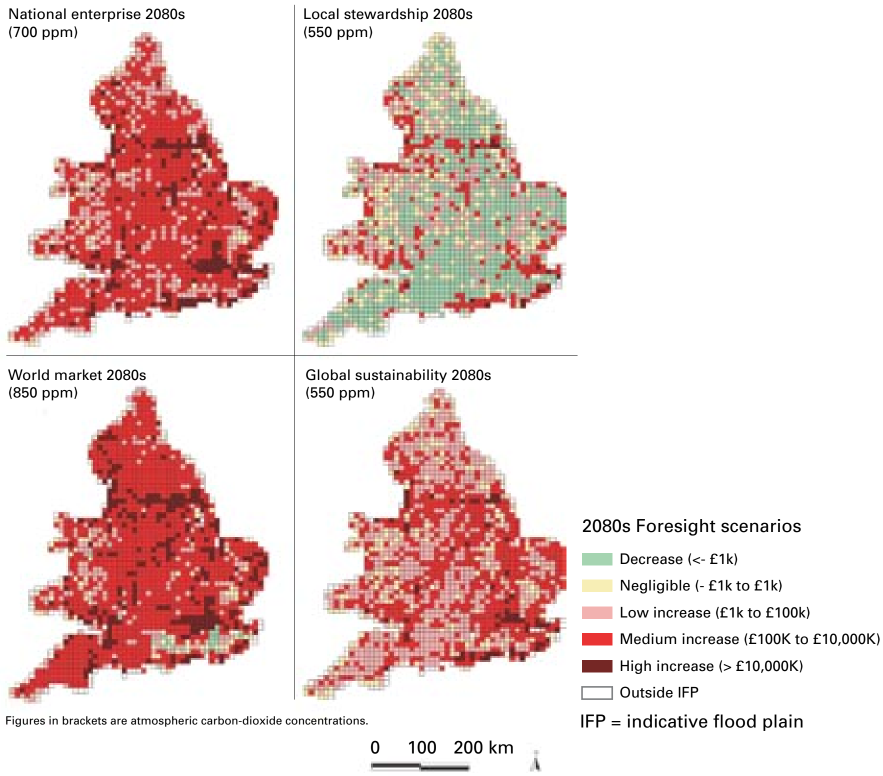

Figure 3 — Change in average annual flood damage costs (in pounds sterling per 10 km by 10 km grid square) in England and Wales by the 2080s as estimated by UK Floods Foresight project under the four scenarios of Figure 2 (figure reproduced, with permission, from UK Floods Foresight report (Evans et al., 2004)).

debatable. Some such points include the establishment of rankings and multipliers by expert groups (which, while probably the best approach one can take, may not give repeatable results); the use of global climate projections with local development scenarios; and in estimating the major rather than all sources of flooding. The advantages reside in developing good estimates across a wide spread of disciplines, including climatology and hydrology, to explore future flood risk and management options.

Modelling uncertainties in flood probabilities

As a contrast to the above type of broad-scale approach to flood risk under changed climate, the next example considered here is a detailed modelling approach to fluvial flood risk, attempting, in particular, to quantify the errors associated with the aspects of the assessment. When using climate model predicted precipitation as input to hydrological modelling systems to predict river discharge regimes, uncertainty enters results from a range of sources. These can include the structure of the GCM used, emission scenarios, RCM structure, downscaling of climate outputs to drive runoff models and the structure of the hydrological models. Figure 4 gives an example of the relative importance of these sources of uncertainty for an investigation reported by Kay et al. (2009). The underlying form of the figure is based on a flood frequency curve, here relating change in flood peak river flow magnitude to its mean return period. The change relates to 2071-2100 projected flows in comparison with the baseline (1985-2001) observed records caused by a range of factors.

Five GCMs were used (HadCM3, CSIRO-Mk2, CGCM2, ECHAM4 and CCSR), together with eight RCMs and two hydrological catchment models, a parameter-sparse conceptual model

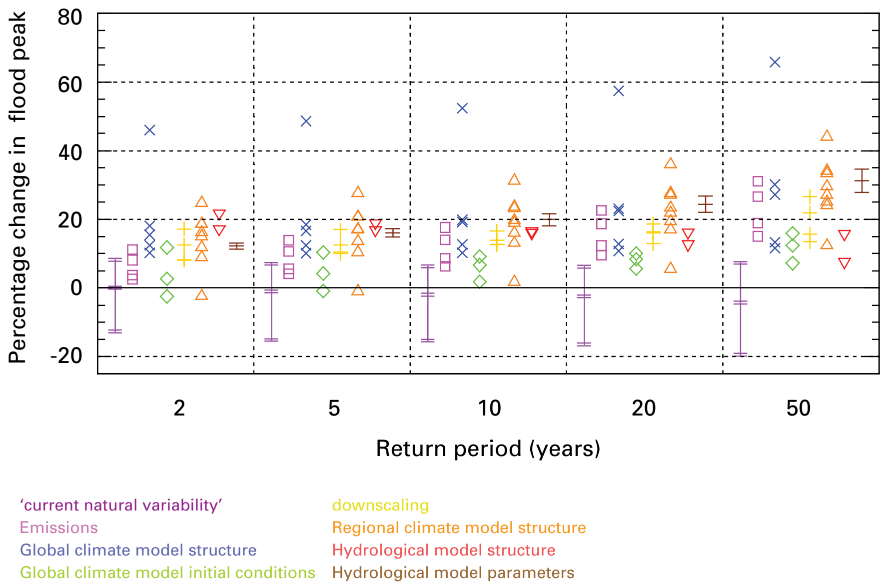

Figure 4 — Sources of uncertainty, denoted by different colours, in river flood magnitude/frequency relationships from a variety of sources. Change refers to the difference between the 1985-2001 baseline and 2071-2100; results are shown for the 86 km² River Duddon catchment in north-west England (median annual flood 120 m³/s). The "current natural variability" plots indicate the median and 90 per cent upper and lower bounds (obtained from resampling) (after Kay et al., 2009).

and a grid-based runoff and routing model, the precise combinations of models being detailed in Kay et al. (op. cit.). The figure is for one particular river catchment in the United Kingdom: results are similarly available for a number of other United Kingdom catchments, the pattern of outcomes differing between them. An important background metric to be aware of is how much variation in the flood frequency curve is to be expected from "natural" climate variability without any anthropogenic climate pressures considered. The "current" variability is approximated in this work by repeated monthly resampling of the baseline data: whether this is a true reflection of the extent of variability in climate other than as a result of emissions is open to question.

A conclusion suggested in the work is that uncertainty from GCMs is the largest of the sources of uncertainty tested. The outlier GCM result (see Figure 4) is the CCSR model which is relatively extreme in terms of the winter rainfall it predicts for the United Kingdom. Limitations of even a very detailed investigation are discussed in the work.

The approach of this example, of using downscaled RCM data to drive hydrological catchment models to derive flow time series from which future flood metrics can be established, is one which the United Kingdom government has taken as the basis for its guidance on appropriate allowances to make on flood management scheme design in the light of climate variability (Department for Environment, Food and Rural Affairs, 2006; Department of Communities and Local Government, 2006). Advice has been updated as climate scenarios evolve and as model systems develop.

The work of Figure 4 is part of a suite of research seeking to offer a measure of confidence around best estimates of flood impacts from climate drivers. In a manner somewhat similar to the presentation of GCM results in terms of convergence of sign of change between different model outcomes, Bell et al. (2009), for example, have investigated whether or not different flood magnitude-frequency outcomes under different climate projections for regions of the United Kingdom show convergence in terms of the sign of the direction of change of peak flood flow at a range of recurrence intervals. This represents a welcome move towards defining the robustness of hydrological projections and is a move towards indicating probabilistic outcomes from (partial) ensembles. In even a relatively small country like the United Kingdom, and one which is relatively data-rich, the pattern, even of direction of change in (say) the 50-year recurrence interval flood is seen to be complex and accompanied by considerable error margins. These approaches are at an interesting exploratory stage of research rather than one as yet mature in practical application. Assessment of relatively comprehensive approaches like this to climate-induced hydrological impact highlight the wide array of components that can be taken into account, the variability thereby produced and the informed judgement which needs to be brought to bear in using such information in flood risk policy-making and management.

Water demand and resource

The last example in this section moves from consideration of climate effects on flooding to an investigation of impacts on water resources, again discussing an example investigation in the light of more general lessons that can be drawn on advantages and disadvantages of particular techniques. Figure 5 shows an analysis of water availability under a scenario of climate and demand change in eastern and southern Africa, covering a region of some 12.8 million km² with a population of over 300 million. A consistent and realistic approach applied across 20 countries was sought to cover spatial and temporal variations in water availability and demands, with an impetus from the UN Environment Programme and Food and Agriculture Organization objectives.

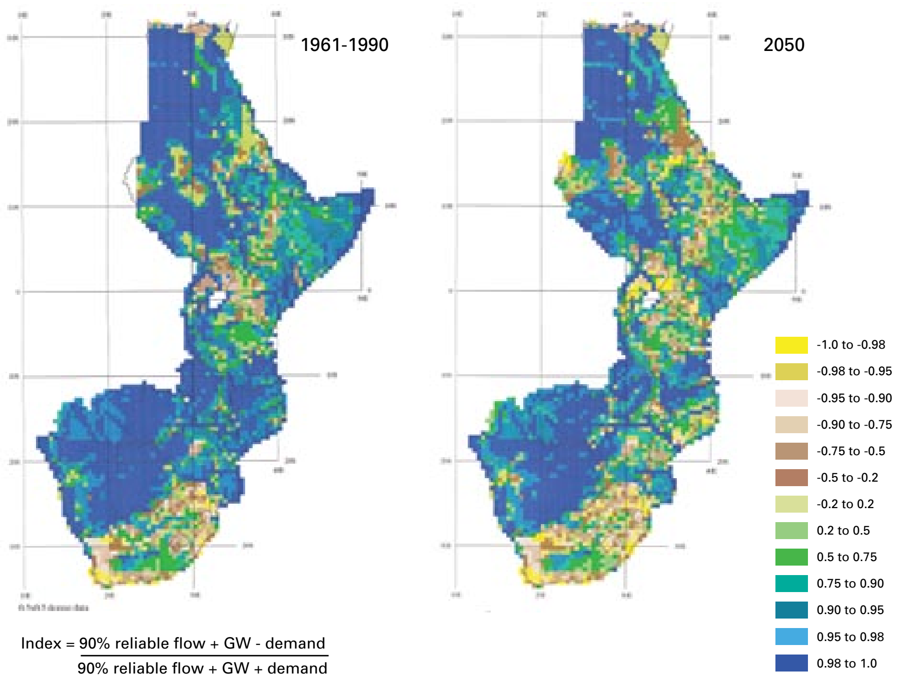

Figure 5 — Estimated differences in combined surface water and groundwater (GW) availability between 1961-1990 and 2050 under a climate change projection accompanied by high water demand: water stress is indicated by negative values (after Meigh et al., 1998).

The essence of the methodology (Meigh et al., 1999) is the estimation of surface water flows, groundwater yield and water demand on a 0.5 by 0.5 degree latitude and longitude gridded basis, using interlinked numerical estimates and conceptual models, whose parameters are derived from data with wide-scale availability such as land cover, soil type, aquifer type, population and livestock distributions. Some data infilling and some sub-model systems were incorporated: hydrological model components were tested against 1961-1990 data. Monthly climate projections to 2050 (Hulme, 1996) and water demand scenarios were considered for urban and rural populations and for agricultural and industrial developments. Details of results are given in Meigh et al. (op. cit.): in short, increased populations and the trend towards improved living standards suggested the likelihood of significant increases in the proportions of countries affected by water scarcity with, in this example, Sudan, Eritrea and Mozambique being particularly at risk from changes in water availability and parts of South Africa and regions round Lake Victoria predicted to see exacerbation of existing problems.

This semi-distributed water resource modelling system with subsequent enhancements has been used in West Africa, the Caspian Sea Basin, the Ganges-Brahmaputra Himalayan region and the South American continent. Merits of this type of approach lie in its design for spatially distributed application in the light of very data-sparse conditions and in the use of effective surrogate variables to address the issue. As such, methods like this may be considered to be more appropriately used for exploring trends and planning at regional scales rather than for estimating the specifics of local demands.

The concluding section of this article outlines challenges yet to be met beyond the undoubted insights and information that investigations like those examples described in this section have already afforded the hydrological and wider communities.

Challenges to be met

It was noted in the introduction to this article that effective planning and management of the hydrological domain is imperative whether climate is naturally and/or anthropogenically varying. Much recent research has focused on possible future changes in temperature and precipitation under anthropogenic modification of climate but, in many regions of the world, the current climate poses significant water-management problems in terms of deficit and/or excess water, particularly where natural variability is great. It has been argued that, in many regions, issues essentially of climatic variability may dominate over those of climate change for some considerable period. In terms of anthropogenic climate change, it is important to note that, in around one-third of the world (Bates et al., 2008) the expected direction of rainfall change 2090-2099 compared with that of 1980-1990 is, under the SRES A1B emission scenario (representing rapid economic growth, regional convergence and balanced energy sources), indeterminate from multi-GCM projections.

Against this background, the final part of this article looks briefly at research challenges for the way ahead. It would be advantageous to quantify natural variability in climate, the baseline against which human-induced effects operate. In general it would be good to know where greatest sensitivity in predictions arises. It is useful also to quantify, as much work increasingly does, uncertainties attributable to various sources in projections of climate and hydrological futures. Importantly, it would be good, though undoubtedly challenging, to distinguish, in the notably multivariate hydrological response, the separate effects on water regimes of factors beyond that of climate, especially of land use and surface water and groundwater management practices and regimes, not least because many adaptation measures are most readily achieved through these routes.

In order to effect some of the above aspirations, methods of transferring climate and hydrological information between temporal and spatial scales, whilst active subjects of research in terms of both statistical and physically based procedures (see, for example, Fowler et al., 2007), remain an area with scope for improvement to capture effects of physical processes, both atmospheric and terrestrial. The point has been made however that, for example, even good downscaling from a large-scale model that is itself imprecise and/or inaccurate will yield finer-discretization data which are of doubtful quality and relevance. There remains a compelling need, particularly for flood risk quantification, for more reliable estimation of extreme precipitation, particularly at fine time discretization.

Climate model outputs to hydrology, and indeed hydrology outputs to users, are increasingly supplied as ensembles and should be accompanied by some measure of reliability. Research can also be usefully directed to a greater degree towards spatial coherence in estimates of changes in the water regime, as opposed to arrays of (largely independent) point (or grid) estimates plotted in a spatial sense. This is of value in addressing adaptation measures and, as with other research aspects, should cover procedures for areas of low, as well as higher, data availability.

Reference was made above to the multivariate nature of the hydrological system: it would be of value to include in hydrological methods and models an appropriately dynamic representation of the domain in terms of features (beyond water contents and flows) that can respond to changes in climate including land use, water management practices and features of socio-economic and infrastructure development. This incorporation of degrees of feedback to changing climates paves the way for the more realistic assessment of adaptation options. Readily comprehensible expressions of risk should accompany these transient hydrological scenario explorations.

From a water policy and management perspective climatological and hydrological futures are best accompanied by reliability estimates and/or guidance for management in the light of uncertainties. It may also be profitable to approach the problem by considering what water policies and actions can, given economic and political conditions, most readily be introduced to address current requirements whilst future-proofing water management. Wilby (2008) for example promotes “low-regret” solutions keeping open future adaptation options. Climate and derived hydrological scenarios can serve as test cases for checking proposed interventions rather than featuring primarily in the derivation of responses.

These types of research and actions plainly benefit from collaborative effort and information-sharing across scientific and national communities. Elucidating the separate and varied influences on the behaviour of the water cycle, while challenging, offers much potential for assessing the relative risks in hydrological changes and their patterns over space and time, together with opportunity for exploration of adaptation options for safe water regimes under evolving climatic conditions.

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Food security under a changing climate

by Hideki Kanamaru*

Introduction

Human beings have learned to live with climate variability on various timescales, from daily to decadal. However, the climate variability we are accustomed to is changing quickly, accompanied by a rise in global mean temperature due to increasing greenhouse-gas concentrations in the atmosphere. The poor in developing countries who already have difficulties in coping with current climate variability will be even more vulnerable. They are the ones who contribute the least to emissions of greenhouse gases, yet need to learn to cope with changing climate with few financial or technical resources.

This article first discusses the multiple aspects of food security in the light of climate change. The next part looks at impacts on crop production at different spatial scales. Adaptation to climate variability is most urgent for food security of smallholders, while climate prediction and longer-term climate-change-impact assessments constitute the basis for adaptation measures. This is discussed with an example of a study in Morocco and a focus on use of climate prediction and information. The article concludes with a discussion on adaptation and mitigation measures that are often mutually supportive in the agriculture sector.

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Food security and climate change

Climate change affects livelihoods of poor and rich alike by impacting basic human needs, including food, clothing and shelter requirements. The four components of food security—food availability, food access, food utilization and food production system stability—are the heart of the mandate of the Food and Agriculture Organization of the United Nations (FAO). All four components are affected by climate (FAO, 2008(a)) but food availability is most intimately associated with climate and its changes, from crops to animal products, marine and aquaculture products and wood and non-wood products from forests. Even when production is sufficient, if a system of food allocation, whether it is through market or not, is negatively affected, food access is impaired and food security is compromised. Urbanization is rapidly taking place in many countries of the world, creating a category of urban poor who do not themselves farm and are very vulnerable to climate change.

Projections of increased pests and diseases due to climate change have an important implication for nutrition. New risks will affect crops, livestock, fish and humans. When human health is compromised, particularly that of women who prepare foods for household members, the capacity to utilize food effectively is dramatically lowered. Food safety may also be compromised with degraded hygiene in preparing food under limited fresh-water availability or food-storage ability due to warmer climate. Malnutrition may also increase, due to shrinking food biodiversity and excessive dependence on a few staple foods.

The changes in climate variability have a direct implication on food - production system stability. Increased frequency and intensity of extreme events such as drought and flood would be a great threat to stability, whether the impact is domestic or through the global food market. The frequency and magnitude of food emergencies might increase, resulting from complex interrelations between political conflicts and migration in a context of increased competition for limited resources.

Global impacts on potential agricultural production

Food availability and agricultural production under climate change are discussed in Chapter 5 "Food, fibre and forest products" of the second volume of the Fourth Assessment

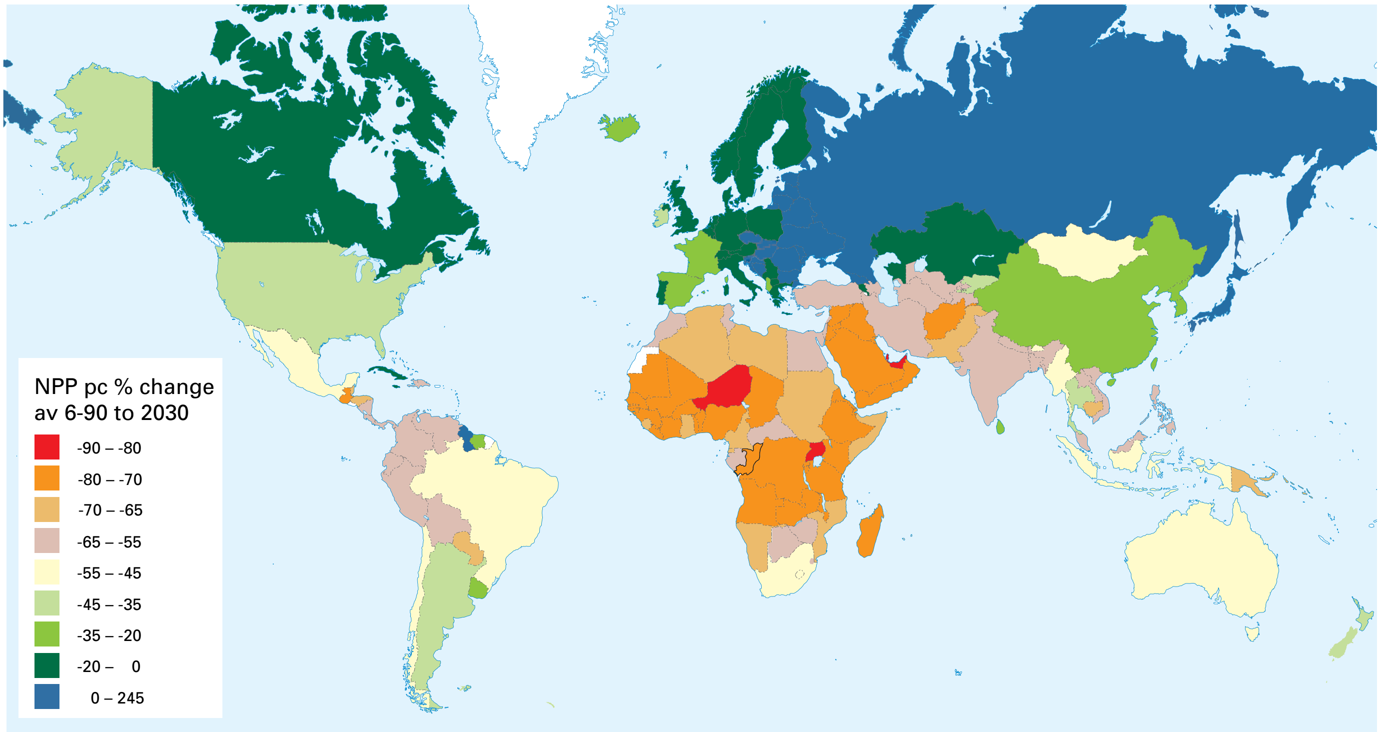

Figure 1 — Net primary production of biomass per capita percent change (from 1961–1990 mean to 2030): data compiled and adjusted by FAO Environment, Climate Change and Bioenergy Division, based on "World maps of climatological net primary production of biomass (NPP)" (2006) available at http://www.fao.org/NR/climpag/globgrids/NPP_en.asp

Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) and a number of other studies that have been published since then (e.g. Cline, 2007; Lobell et al., 2008).

In general, crop yields will increase in cold areas where low temperature currently limits crop growth. On the other hand, heat stress on crop and water availability will lead to a decrease in yields in warm environments. Globally, food production may increase but a net negative impact is expected if night temperatures increase and averages rise by more than a few degrees Celsius.

In addition to the potential negative impact on global food production, there is pressure from the projected increase in population in most developing countries. This is illustrated in a plot of net primary production of biomass, a biophysical indicator of potential agricultural production, from a recent FAO study which produced a typology of vulnerable countries to climate change (Figure 1). Net primary production per capita in 2030 was calculated from temperature, precipitation and population projections. From purely biophysical, geophysical and demographical factors, it appears that only parts of Europe, the Russian Federation and Japan may benefit from increased productivity due to warming in the next couple of decades.

Projections at the national scale have only limited relevance to food security of rural populations, however. While temperature increase is projected almost globally, the pattern of rainfall changes varies significantly from region to region and at sub-national level due to topography and proximity to water bodies. For the NPP projection shown in Figure 1, global climate model output on about 2.5° x 2.5° grid points were interpolated to each country's area. Small countries sometimes fall within a single cell of model output and the results for these countries need to be interpreted with caution. It is probably meaningless to compare relative magnitude of changes with other small neighbouring countries.

Subnational impacts on crop production

To assess food security in the light of climate change for smaller countries and different populations within a country, fine spatial scale climate information is essential and the need is higher than ever. Any planning of adaptation measures to climate change requires finer spatial climate information that feeds into impact-assessment models, such as crop simulation. Good historical climate data are required for calibrating impact models along with future projections of climate to calculate future crop yields.

FAO recently conducted a study of the impacts of climate change on Moroccan crop production up to the end of this century under the framework of a World Bank climate change project (Gommes et al., 2009). The study covered six agro-ecological zones, 50 crops and two climate-change scenarios.

In a number of experiments, elevated carbon dioxide was shown to have a positive impact on plant growth and yield. It was found, however, that carbon dioxide fertilization will bring only marginal benefit to future Moroccan yield due to the water stress to which rainfed crops are exposed. On the other hand, there is still room in Moroccan agriculture for technological advances such as more efficient irrigation systems, improved crop varieties and more efficient fertilizer use. Agriculture may adapt, at a cost, by overcoming some of the negative climate change impacts.

Use of climate information for impact assessments

The Morocco study used statistically downscaled climate projections. With increasing computing power and progress in scientific research, regional climate models (RCM) are being used as a tool to provide fine spatial scale climate information. A dynamical regional model can produce projections of all climate variables that are physically, dynamically and hydrologically consistent with each other. When global climate models can do multi-decadal simulations at 100-km grid spacing, regional climate models can simulate at down to 10 km grid spacing and below. In this connection, the initiative by WMO to establish Regional Climate Centres (RCCs) for provision of a wide suite of regional-scale climate information is a welcome development.

In the course of the Morocco study, the interpretation of a finding required on many occasions a correct understanding of climate data and its propagating uncertainty into the crop model. In order to encourage appropriate use of climate data, the interactions between the climate science community and the impact application (physical and social) science community should be more actively promoted. Climate modellers need to better understand end-user needs regarding required variables, data format, temporal frequency, spatial scale, length of data period, etc. Above all, climate scientists are responsible for providing guidance on correctly using the data in applications and interpreting the results from impact models. The impact-study community, on the other hand, needs to ensure that climate data are used for what they were intended for and to understand the assumptions and uncertainty associated with the data accurately.

Vulnerable populations are concentrated in arid and semi-arid areas and projections of freshwater availability under climate change is a crucial variable for the assessment of agricultural production. As it turns out, global climate models do not necessarily agree on the projected direction of changes in precipitation in low to mid-latitudes which coincide with the area of arid climate, distribution of vulnerable people and rainfed agriculture. The Mediterranean region, including Morocco, is one of the few places where most models agree that precipitation will decrease in the future. When assessing food security in the regions where models do not have good ability in precipitation projection, extra caution should be paid in choosing climate models and their output to work with. It is possible to arrive at totally different conclusions on future rainfed agriculture with data from different climate models.

A similar point can be made for emission scenarios. A wide range of future projections is possible, depending on socio-economic development. The uncertainty needs to be recognized in the results derived from climate-model outputs by a crop model. Climate models are not meant to predict the future precisely but are rather designed to indicate the response of climate system given changes in forcing. A 20 per cent decrease in barley yield at a given location by 2030 is accurate only if the assumptions made in the emission scenario and a number of assumptions in climate and crop models are correct. Placing too much confidence in impact models might prevent the formulation of sound adaptation measures.

The IPCC data distribution centre offers a variety of projection data from a range of climate models and emission scenarios. Impact studies often do not have the resources to make use of all the available data, however. The cost lies in downscaling data to suitable spatial resolution. Most downscaling models (statistical model or regional climate model) are designed for using outputs from a couple of global climate models only. Computing resources are limited. When impact studies do not have the luxury of using multiple emission scenarios and global climate model outputs, one needs to carefully interpret the results from impact models. If the target area does not have good skill in precipitation, sensitivity studies may be preferred in order to see the impact of different magnitude of precipitation changes (from decrease to increase).

One of the biggest assumptions in the Morocco example is that current agricultural practices will remain unchanged in the future. We have little confidence for this assumption to hold until the end of century. What we are more interested in is the near future, perhaps up to 2030, in order to devise adaptation measures that are appropriate for local conditions and climate projections and to start implementing them. Since the climate change signal may be hidden in large climate variability, in near forthcoming decades, it may be worthwhile to make projections for 2100 and pattern-scale them back to 2030. The end-of-century projection of crop production itself should not be interpreted literally, however, as is clear if we think back to what agriculture looked like 100 years ago.

While the time horizon we should focus on in terms of food security and climate adaptation is the next two decades, climate predictions on this timescale is both not well understood and limited. In this respect, the timing of this year's theme of the World Climate Conference-3 is perfect. The climate science community has started to address this big challenge. Improved skills in decadal climate prediction, together with down-scaling, will better inform impact assessments that constitute food security: crop simulation, watershed modelling, etc.

Adaptation in the agriculture sector

Regardless of international commitments to reduce greenhouse gases, a certain level of climate change cannot be avoided. Global mean temperature is expected to keep rising at least over the next few decades. Adapting to climate change is an urgent action needed particularly for developing countries. Joint activities by FAO and WMO in organizing international workshops in different regions such as the International Symposium on Climate Change and Food Security in South Asia (August 2008, Dhaka, Bangladesh) and the International Workshop on Adaptation to Climate Change in West African Agriculture (Ouagadougou, Burkina Faso, April 2009), are bringing together representatives of the National Meteorological and Hydrological Services (NMHSs), the agricultural ministries, and regional and international organizations to discuss strategies for regional climate change adaptation and develop appropriate recommendations for implementation in the vulnerable regions.

Impact studies discussed in previous sections inform decision-makers of vulnerable areas and sectors in order to plan adaptation measures. FAO assists subsistence farmers in building capacities to better adapt to climate change through the provision of technical help. To begin with, there is much to be done to reduce vulnerability to current climate variability. In this context, climate change adaptation has a strong linkage with disaster risk management.

An ongoing FAO project in Bangladesh takes a comprehensive approach to livelihood adaptation. At the local level in the field, measures introduced are: better agronomic management, income diversification, strengthening extension services and testing recommended adaptation techniques. Farmers could adapt by changing planting dates and crop variety that suit better warmer and drier/wetter climate. Improved fertilizer use would increase per unit area yield. Efficient irrigation and watershed management would alleviate water stress that may be exacerbated under climate change.

Operational use of climate data and forecasts, particularly seasonal forecasts, can effectively improve resilience of agricultural production systems. Extension workers assist farmers to put new agriculture technologies and approaches into practice. Targeting those workers who are closest to the farmers in the field, FAO is developing an e-learning tool on community-based climate change adaptation in the agriculture sector that can be used in the classroom or for self-learning. The course teaches the basics of climate change and helps learners to plan adaptation actions in a step-wise fashion.

Mitigation—carbon sequestration

Many adaptation options for agriculture provide mitigation benefit at the same time; they are readily available and can be adopted immediately. Agriculture and forestry sectors combined are responsible for one-third of total anthropogenic greenhouse-gas emissions and are the largest sources of methane and nitrous oxide emissions. Tapping great mitigation potential in these sectors is a key to achieving an ambitious greenhouse-gas-reduction target.

Soil-carbon sequestration has perhaps the biggest potential in terms of the amount of carbon dioxide. Global technical mitigation potential from agriculture is about 5.5 Gt C-eq per year by 2030. Soil-carbon sequestration can contribute about 89 per cent of this potential. We can expect a high return of reduced carbon for relatively low cost with managing land better across all climatic zones and a variety of land

use systems—cropping, grazing and forestry (FAO, 2008(b); FAO, 2009).

There are many management practices that can restore wastelands, soils and ecosystems to enhance soil organic carbon and improve soil quality and health. Such practices include organic agriculture, conservation tillage, mulching, cover crops, integrated nutrient management (including the use of manure and compost), agroforestry and improved management of pastures and rangelands. Improved nutrient management can also reduce nitrous oxide emissions, while contributing to soil carbon sequestration.

Sustainable land management practices that increase carbon in soil come with multiple benefits: improved soil fertility, enhanced above-ground biodiversity and increased soil water storage. Rural livelihoods will build resilience to climate change through enhanced/stabilized productivity, the provision of a range of ecosystem services, and reversing degradation and desertification.

Conclusion

Climate change affects smallholders in many ways but enhanced climate prediction and efficient use of climate information can guide all concerned with food security, from farmers to governments, to sound adaptation and mitigation measures. Agriculture has a significant potential to reduce greenhouse-gas emissions with multiple benefits for adaptation and rural development. Agriculture, however, has been insufficiently recognized as a major player in climate change negotiations so far.

FAO hosted a high-level conference on world food security in June 2008 to address the challenges of climate change and bioenergy. It was the first time that world leaders got together to discuss the specific issue of food and climate change. The countries present agreed that there was an urgent need to help developing countries to improve agricultural production, to increase investment in agriculture and to address the challenge through mitigation and adaptation measures.

The next two decades are the most crucial period to implement those measures, given ever increasing greenhouse-gas emissions and rapidly rising temperature. As the 15th session of the Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen, Denmark, nears, it is the right time for the international community to take action to tackle climate change while improving food security.

Acknowledgements

The author wishes to thank his FAO colleagues, René Gommes, Claudia Hiepe, Reuben Sessa and Selvaraju Ramasamy for comments on the manuscript.

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Obituary

Margaret Bushby (née Atkins)

Margaret Bushby (née Atkins) died on 27 December 2008. She married late in life and was well-known in international meteorological circles under both surnames.

Norfolk-born, she graduated with a BSc Hons in Mathematics from Nottingham University in 1966 and joined the United Kingdom Met Office. She found her niche in its team of workers on mathematical models for numerical weather prediction (NWP), headed by F.H. Bushby, and with J.S. Sawyer. She described the United Kingdom's first operational model (used in the Central Forecast Office from 2 November 1965) in an article in *Meteorological Magazine* in 1970.

By then, the Met Office was working towards its next supercomputer and a more detailed NWP model. In February 1971, for example, Bushby, Mavis Hinds and Margaret carried punched Hollerith cards on the weekly Royal Air Force flight to Washington en route to the IBM facility in Poughkeepsie, NY, to develop the model on their newest supercomputer. Later that year, the IBM 360/195 was installed in the newly built Richardson Wing at Bracknell, to be opened by Prime Minister Edward Heath.

In this way, first as a scientist in the Forecasting Research Branch and then, by the early 1980s, in the group adapting the operational model of the atmosphere to the needs of the Central Forecast Office at Bracknell, she helped the forecasters there meet not only national needs but also their obligations as a WMO Regional Meteorological Centre and as one of the two World Area Forecast Centres for aviation. She was an essential part of the team which continually improved the accuracy of NWP products from 1967 to the present day; the team which Sir John Mason and Colin Flood wrote "helped bring about a total transformation in the way weather forecasting is carried out".

In the mid-1980s Margaret joined the Met Office's international affairs branch and quickly made her distinctive mark. When she became its Director in 1990, she also became the first woman to reach that level in the Met Office. Sometimes supporting the Director-General, Sir John Houghton, and often alone, she contributed to many international meetings, including World Meteorological Congress, WMO constituent bodies and the Council and Finance Committee of the European Centre for Medium Range Weather Forecasts (EMCWF).

Colleagues from across the world have written, testifying to her strong support of projects, her understated sense of humour, how they appreciated her knowledge and agreeable help, how her interventions were always received with a deal of affectionate amusement, how she was a great personality; she was remembered for all sorts of reasons. In my later years in the Office, I enjoyed her company, both in Bracknell, at ECMWF and in Geneva: I found that, once she chose to work on a problem, her ability to analyse it and her proposals on how to implement the results of her thinking were superb.

A highlight of her international life was a visit to the National Meteorological Service of Ghana, where she represented the Met Office as a fellow Commonwealth Meteorological Service. The ladies there made a delightful fuss of her that she never forgot.

In 1990 she became the first woman to be elected a member of the Meteorological Club, a subset of some of the more distinguished Fellows of the Royal Meteorological Society.

Her de facto memorials are on the World-Wide Web: a random sample of the activities she was involved in during her later years includes reports on the Automated Shipboard Aerological Programme Panel and the tenth session of the Coordinating Group for the Composite Observing System for the North Atlantic.

All scientists leave behind them foundations and building bricks on which others construct the fabric of their particular speciality: in the online catalogue of the United Kingdom's National Meteorological Library (http://www.metoffice.gov.uk/corporate/library/catalogue.html) Margaret is shown as author or co-author of some 20 titles over the period 1970-1988.

She was close to retirement when she married her former boss Fred Bushby and they had five happy years together before he died in 2004. She was a devout Methodist and played the cello in a local orchestra.

Like many people involved with WMO, Margaret influenced decisions which affected, affect and will continue to affect, the lives of millions. She received no particular notice by the world at large but knew that she had been lucky to be able to contribute to the benefit of humankind and to have enjoyed the camaraderie of international meteorology. I hope she knew well-deserved feelings of a job well done and a life well lived.

Stan Cornford

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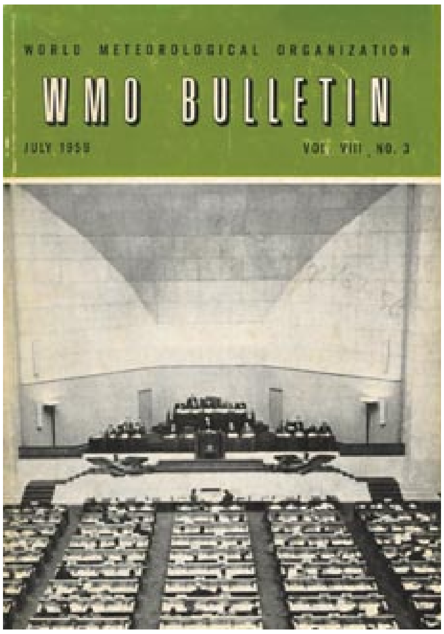
Fifty years ago ...

WMO Bulletin Vol. VIII, No. 3, July 1959



The Assembly Hall of the Palais des Nations in Geneva has been the scene of many important international sessions but rarely have representatives from so many different countries gathered there as for the Third World Meteorological Congress, the opening meeting of which is featured in the picture on the cover. ... The next four years, during which the programme decided by Congress will be implemented, will no doubt provide still further evidence of how WMO and the other specialized agencies can contribute to making the world happier and more united.

Third World Meteorological Congress

The session was opened in the Assembly Hall of the Palais des Nations on 1 April 1959 by the President of WMO, Mr Andre Viaut. ... [the] Deputy Director of the European Office of the United Nations, spoke of the long record held by WMO and its predecessor of international cooperation in the scientific and technical field, of the progress made by WMO since the holding of its Second Congress in 1955, and of the important part played by WMO in the organization of the International Geophysical Year. The membership of the Organization, now larger than that of any other specialized agency, was a proof of its vitality and of the increasing importance of meteorology in the world of today.

Mr Viaut referred to the accession of the I00th 100th Member of WMO, which had taken place just before the opening of Third Congress and exactly eight years after the adoption by First Congress of the resolution transferring to WMO the functions and obligations of the IMO. ...

WMO Convention

... . It was decided to amend Article 13 (c) to the effect that the number of elected members of the Executive Committee should be increased from six to nine.

Technical assistance

Congress decided not to adopt a regular technical assistance programme but to continue on an increased scale the Operational and Technical Development Fund created by Second Congress. An amount of 60 000 US dollars was included in the budget for this purpose.

WMO's responsibility in hydrology

... It was finally decided to establish a Technical Commission for Hydrological Meteorology ...

It was further agreed to create a small section for hydrological meteorology in the WMO Secretariat, the main functions of which would be to assist the work of the new commission and of the working groups on hydrology of the regional associations and also to continue the close collaboration of WMO in the water resource development programme of the United Nations and of the other specialized agencies.

International ozone work

The proposals for transferring to WMO responsibility for certain aspects of international ozone work which had hitherto been assumed by the International Ozone Commission

* A fuller account of the WMO Bulletin 50 years ago can be found in the Bulletin online: http://www.wmo.int/pages/publications/bulletin_en/index_en.html

were accepted with the exception that ozone data would not be collected on a permanent basis by the WMO Secretariat. A sum of 5 000 US dollars was included in the budget for the purpose of carrying out interregional comparisons of ozone instruments.

Public information

Congress noted that the publicity given to the work of WMO, especially during the IGY, had helped to draw attention to the value and necessity of meteorological activities in the economic life of the world. It was considered that efforts should be concentrated on the dissemination of information regarding the applications of meteorology to other activities (such as agriculture, aviation and shipping) and the unparalleled international collaboration through the daily worldwide exchange of meteorological information.

Discussions were held regarding the celebrations of the 10th anniversary of the coming into force of the WMO Convention (1960) and it was decided that these celebrations should take place jointly with the ceremonies on the occasion of the opening of the new permanent building of WMO in the same year.

Officers of the Organization

A. Viaut (France) was re-elected President of WMO for a second term of office; L. de Azcarraga (Spain) was elected first Vice-President and M.F. Taha (United Arab Republic), second Vice-President. D.A. Davies was reappointed Secretary-General.

Eleventh session of the Executive Committee

... This was an historic gathering in that it was the first session of the enlarged committee and in all probability the last session to be held in the Palais — it is planned that future sessions will take place in the new WMO headquarters.

General and financial questions

The budget approved for 1960 amounted to US$ 655 105. This includes provision for the recruitment of a small number of additional personnel in the Secretariat in accordance with decisions taken by Congress.

Membership of WMO

Guinea became a Member of WMO on 26 April 1959. Ruanda Urundi became a Member of WMO on 28 April 1959. WMO now has 102 Members: 78 States and 24 Territories.

Television in pre-flight briefing, at Dublin Airport

When Aer Lingus, the Irish airline company, recently decided to remove its flight operations office from the main terminal building at Dublin Airport to a site remote from the meteorological office, the personal attendance of crews for pre-flight meteorological briefing threatened to become a problem. On the one hand it was considered that much valuable time would be wasted by the crews journeying to and from the meteorological office; on the other hand it was felt that the personal briefing, always regarded as an integral part of the flight meteorological service, should not be dispensed with. The solution proposed was remote briefing by closed circuit television, supplemented by facsimile equipment for the transmission of flight documents.

... With a little practice, forecasters and crews grew accustomed to the new technique of briefing and, when removal finally took place, the system was already well established and accepted by all concerned. ...

The briefing procedure is simple. Flight forecast documents are transmitted by facsimile to the operations room and are in the hands of the flight crew as they follow the forecaster's discourse on the screen. As the TV transmission is in black and white, fronts have to be specified as warm, cold, etc., but, otherwise, briefing is similar to the normal personal briefing.

It is believed that this is the first occasion on which TV has been put into regular and routine use in preflight meteorological briefing. Aer Lingus and the Irish Meteorological Service deserve to be congratulated on their initiative and the undoubted success of the venture.

News from the Secretariat

Visits of the Secretary-General

The Secretary-General, Michel Jarraud, recently made official visits to a number of Member countries as briefly reported below. He wishes to place on record his gratitude to those Members for the kindness and hospitality extended to him.

Turkey

The World Water Council's 5th World Water Forum was held in Istanbul from 16 to 22 March 2009, under the theme "Bridging divides for water". The Secretary-General delivered WMO's statement and met with Turkey's Minister of Environment and Forestry, Mr Veysel Ero lu. Moreover, Mr Jarraud met with His Serene Highness Albert II, Prince of Monaco, for private discussions on climate change and development issues, including preparations for World Climate Conference-3.

At the same venue and in the context of the African Ministers' Council on Water initiative, Mr Jarraud and a number of other dignitaries participated in a side event chaired by Prince Willem-Alexander of Orange and organized by the African Development Bank and UN-Water/Africa. The Secretary-General highlighted WMO's role in the strengthening of Africa's integrated water resources management systems and informed the participants on the importance of the forthcoming World Climate Conference-3.

Istanbul, Turkey, March 2009 — Mr Jarraud with Mr Veysel Ero lu, Minister of Environment and Forestry of Turkey

Croatia

On the occasion of the 14th session of the WMO Commission for Basic Systems (CBS) (25 March-2 April 2009), the Secretary-General visited Dubrovnik and met with the Permanent Representative of Croatia with WMO, Mr Ivan Čačić. The CBS session was preceded (23 and 24 March) by the Technical Conference on the WMO Integrated Observing System.

Chile

The Secretary-General visited Santiago de Chile on 26 and 27 March 2009, when national ceremonies took place to mark the 125th anniversary of the historic legal act of 26 March 1884 which established coordinated meteorological observations in Chile and their telegraphic concentration at the Central Meteorological Office.

Dubrovnik, Croatia — Participants in the 14th session of the WMO Commission for Basic Systems (25 March-2 April 2009)

Santiago de Chile, March 2009 — (from left to right): José Huepe, Director of the Chilean Directorate of Meteorology (DMC); Myrna Araneda, Director of DMC; Alejandro Muñoz, Chief of the Forecasting Subdepartment of DMC; Michel Jarraud; and Patricio Aceituno, Vice-Dean of the Faculty of Physical and Mathematical Sciences of the University of Chile

Mr Jarraud met with Chile's Minister of Environment, HE Ms Ana Lya Uriarte, as well as Mr José Huepe Pérez, Director-General of Civil Aviation; Mr Fernando Danús, Director of Environment at the Ministry of Foreign Affairs; and Ms Myrna Araneda, Director of Meteorology and Permanent Representative of Chile with WMO.

France

The Secretary-General participated in the regular session of the UN System Chief Executives Board for Coordination (CEB) hosted by UNESCO in Paris on 4 and 5 April. CEB endorsed the decisions taken on its behalf by the High-level Committee on Programme (HLCP), the High-level Committee on Management and the United Nations Development Group. The session focused on UN System actions and deliverables to the 15th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in Copenhagen, December 2009. These will include WCC-3 outcomes, policy recommendations on the UN system security and safety of staff and latest political developments. CEB adopted a statement to Member States underscoring the UN System's commitment to a strengthened and enhanced system-wide security management system and highlighting the need for adequate financial resources.

CEB discussed the global financial and economic crisis and the outcome of the G-20 Leaders' meeting in London on 2 April. Following its deliberations, CEB adopted a communiqué which highlights the social effects of the crisis, including its impact on the achievement of the Millennium Development Goals. The communiqué also underscores the central role of the multilateral system in articulating and delivering a coherent global response to the crisis and calls for joint action of the United Nations, the International Monetary Fund and the World Bank in translating the multilateral response into action at the country level.

CEB reiterated the UN's "common commitment to assist countries and the global community to confront the crisis, accelerate recovery and build a fair and inclusive globalization, allowing for sustainable economic, social and environmental development for all, while facing the future in a spirit of conviction of the need for transformational change". The UN Chief Executives agreed upon nine joint initiatives to help address the multiple facets of the crisis, as suggested by HLCP. These include additional financing for the most vulnerable; food security; trade; a green economy initiative; a global jobs pact; a social protection floor; humanitarian, security and social stability; technology and innovation; and monitoring and analysis.

Portugal

At the kind invitation of ITU Secretary-General Mr Hamadoun Touré, the Secretary-General of WMO visited Lisbon on 21 April 2009 to participate in the Fourth World Telecommunication Policy Forum (21-24 April 2009). In his address, Mr Jarraud stressed the importance of telecommunication for the collection

UNESCO, Paris, April 2009 — Participants in the UN System Chief Executives Board for Coordination and exchange of meteorological, hydrological and climatological information. Mr Jarraud also remarked that a number of specific radiofrequency bands are today essential for the effective provision of weather services needed for the protection of lives and property in all WMO Member countries.

Ouagadougou, Burkina Faso, April 2009 — (from left to right) Goroza Guehi, Permanent Representative (PR) with WMO of Côte d'Ivoire; Arthur Gar-Glahn, PR of Liberia; Anthony Anuforom, PR of Nigeria; M. Jarraud; Mactar Ndiaye, PR of Senegal; Ali Jacques Garane, PR of Burkina Faso; and Awadi Abi Egbare, PR of Togo

Bahamas

On 24 April 2009 the Secretary-General visited Nassau to participate in the closure of the 31st session of the RA IV Hurricane Committee and the opening of the 15th session of Regional Association IV (24 April-1 May 2009). During his visit, he met with the Rt Hon. Hubert A. Ingraham, Prime Minister of the Bahamas, and HE the Hon. Earl D. Deveaux, Minister of the Environment.

Mr Jarraud had extensive discussions with the newly-elected president of RA IV, Mr Arthur W. Rolle, the vice-president, Ms Luz Graciela de Calzadilla, and with all permanent representatives present in Nassau on the occasion.

Burkina Faso

The Secretary-General visited Ouagadougou from 27 to 30 April 2009 to address the opening session of the International Workshop on Adaptation to Climate Change in West African Agriculture, which was organized by WMO, FAO, the State Agency for Meteorology of Spain, the African Development Bank, the Economic Community of West African States, the International Crops Research Institute for the Semi-Arid Tropics, the International Livestock Research Institute and the General Directorate of Civil Aviation and Meteorology of Burkina Faso.

Mr Jarraud met with Burkina Faso's Minister of Transport, HE Gilbert G. Noël Ouedraogo, and had discussions with Mr Moumouni Dieguimde, Director General of Civil Aviation and Mr A.J. Garane, Director, National Meteorological Service and Permanent Representative of Burkina Faso with WMO. Furthermore, the Secretary-General met with the permanent representatives who participated in the workshop.

Nassau, Bahamas — (from left to right) Rob Masters, Director, WMO Development and Regional Activities Department; Arthur Rolle, president of RA IV; Hubert Ingraham, Prime Minister of the Bahamas; and the Secretary-General of WMO.

Senegal

In order to further develop the existing close cooperation between the two organizations, the Secretary-General of WMO visited Dakar on 28 and 29 April 2009 and met with Mr Youssouf Mahamat, Director-General of the Agency for Air Safety in Africa and Madagascar.

France

In Paris, on 14 May 2009, the Secretary-General addressed on behalf of WMO a special session at France's Senate, at the kind invitation of Senator Christian Gaudin, Vice-President of the Parliamentary Evaluation Office for Scientific and Technological Options. The session was dedicated to the official closure in France of the International Polar Year 2007-2008 campaign.

Bahrain

On 17 and 18 May 2009 the Secretary-General visited Manama on the occasion of the launch of the UN International Strategy for Disaster Reduction 2009 Global Assessment Report. Mr Jarraud delivered a keynote speech and met with the Prime Minister of the Kingdom of Bahrain, HH Khalifa Bin Salman Al Khalifa; the Minister of Foreign Affairs of Bahrain, HE Sheikh Khalid Bin Ahmed Bin Mohamed Al Khalifa, and other high-level officials.

The UN Secretary-General, Ban Ki-moon, Mr Jarraud and the Assistant UN Secretary-General for Disaster Risk Reduction, Ms Margareta Wahlström, participated in a UN press conference, during which Mr Jarraud stressed the importance of investments in meteorological, hydrological and climate infrastructure and services to facilitate improved decision-making in disaster risk reduction and climate change adaptation.

Russian Federation

At the kind invitation of Alexander Bedritsky, President of WMO and Head of the Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), the Secretary-General visited Moscow on 27 May 2009 and participated in the celebrations commemorating Roshydromet's 175th anniversary. On the occasion, Mr Jarraud met with deputy Chairman of the Duma, Artur Chilingarov, and other governmental, scientific and academic authorities.

Moscow, Russian Federation, 27 May 2009 — (from right to left): Alexander Bedritsky, Head of Roshydromet and President of WMO; Mr Jarraud; and Artur Chilingarov

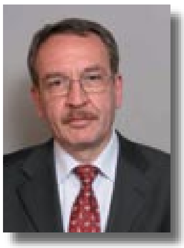
Staff matters

Appointments

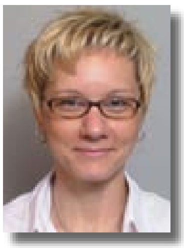
Carolin RICHTER: Director, Global Climate Observing System Secretariat, on 31 March 2009

Nhyan TRAN NGUYEN, Chief, Information Technology Division, Resource Management Department, on 1 April 2009

Christian BLONDIN: Senior External Relations Officer, Cabinet and External Relations Department, on 15 April 2009



Dimitar IVANOV: WMO Representative for Europe, Development and Regional Activities Department, on 17 May 2009.



Oksana TARASOVA: Scientific Officer Atmospheric Research and Environment Branch, Research Department, on 7 June 2009.

Elizabeth HEWITT: Translator/Editor, Linguistic Services and Publishing Branch, Programme Support Services Department on 7 May 2009

Roberta BOSCOLO, Scientific Communication Officer, World Climate Research Programme, Research Department, on 1 June 2009.

Celina IÑONES MULLER: Translator/Editor (Spanish), Linguistic Services and Publishing Department, on 1 June 2009

Mamy DOUNO: Internal Auditor, Internal Oversight Office, on 30 April 2009.

Departures

Virginia GUERRERO, Senior Human Resources Officer, retired on 31 March 2009.

Alexander KARPOV, acting Director, Global Climate Observing System Secretariat, retired on 31 March 2009.

Caifang WANG, Senior External Relations Officer, retired on 31 March 2009.

Françoise PLIVARD, Administrative Assistant, Documentation and Publications Management Unit, Linguistic Services and Publishing

Branch, Programme Support Services Department, took early retirement on 31 March 2009.

Dieter SCHIESSL, Director, Strategic Planning Office, Office of the Assistant Secretary-General, retired on 30 April 2009.

Jean-Michel RAINER, Acting Director, WMO Information System Branch, Observing and Information Systems Department, retired on 30 April 2009.

Abderrahmane QARBAL, Senior Stockroom Clerk, Common Services Division, Conferences, Contracts and Facilities Management Branch, Programme Support Services Department, took early retirement on 30 April 2009.

Lisbet RAINER, Information Management Assistant, Information Technology Division, Resource Management Department, left on 31 May 2009 for health reasons.

Transfers and re-assignments

José Arimatea de Sousa Brito was designated Acting Director, WMO Information System Branch, Observing and Information Systems Department, with effect from 1 May 2009.

Momado SAHO, formerly Chief, Education and Fellowships Division, Education and Training Office, Development and Regional Activities Department, was transferred to the post of Chief, Training Activities Division, in the same Office on 1 May 2009.

Yinka R. ADEBAYO, formerly Senior Strategic Planning Officer in the Strategic Planning Office, ASG's Office, was transferred to the post of Chief, Education and Fellowships Division, Education and Training Office, Development and Regional Activities Department on 1 May 2009.

Lisa-Anne JEPSEN, Administrative Officer, Intergovernmental Panel on Climate Change Secretariat, was transferred to the Linguistic Services and Publishing Branch, on 1 June 2009.

Magaly ROBBEZ, Secretary (half time), Staff Committee, was transferred (full time) to the Development and Regional Activities Department on 1 July 2009.

Anniversaries

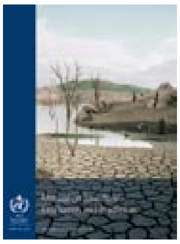
Nathalie TOURNIER, Senior Secretary, Atmospheric and Environment Branch, Research Department: 20 years on 1 February 2009

Faisal MIAH, Conference Technical Clerk, Conference Services Unit, Programme Support Services Department: 20 years on 21 February 2009

Dieter SCHIESSL, Director, Strategic Planning Office: 20 years on 1 March 2009

Recent WMO publications

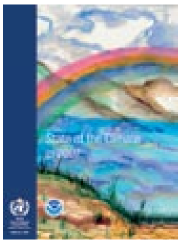
Manual on low-flow estimation and prediction (WMO-No. 1029)
[E]
2008; 136 pp.
Price: CHF 25



Regional Association II (Asia), 14th session — Abridged final report with resolutions (WMO-No. 1037)
[A - C- E - F - R - S]
2009; vi + 145 pp.
Price: CHF 16

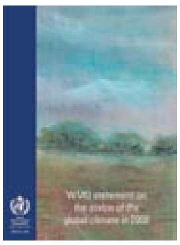
Secure and sustainable living (WMO-No. 1034)
[E - R] (F - S in preparation)
2008; 101 pp.
Price: CHF 42

State of the climate in 2007 (WMO-No. 1036)
[E]
2009; xii + 179 pp.
Price: CHF 78



Weather forecasting for soaring flight (WMO-No. 1038)
Technical Note No. 203
[E]
2009; iv + 65 pp.
Price: CHF 25

WMO statement on the status of the global climate in 2008 (WMO-No. 1039)
[E - F - S]
2009; 12 pp.
Price: CHF 15



Intercomparison of global UV index from multiband filter radiometers: harmonization of global UVI and spectral irradiance
(WMO/TD-No. 1454)
[E]
2008; ii + 61 pp.
Price: CHF 30

IGACO-ozone and UV radiation implementation plan
(WMO/TD-No. 1465)
[E]
2009; iii + 41 pp.
Price: CHF 30

Operations handbook—Ozone observations with a Dobson spectrophotometer
(WMO/TD-No. 1469)
[E]
2008; vii + 85 pp.
Price: CHF 30

Climate observations and climate data management guidelines
(WMO/TD-No. 1481)
[E]
2009; CD-ROM
Price: CHF 30

The potential role of WMO in space weather
(WMO/TD-No. 1482)
[E]
2008; iii + 25 pp.
Price: CHF 30

Status of the availability and use of satellite data and products by WMO Members for the period 2006–2007
(WMO/TD-No. 1483)
[E]
2008; ii + 42 pp.
Price: CHF 30

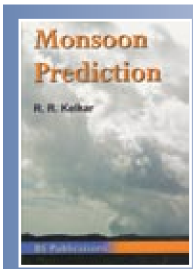
Recommendations for the verification and intercomparison of QPFs and PQPFs from operational NWP models
Revision 2, October 2008
(WMO/TD-No. 1485)
[E]
2008; iii + 25 pp.
Price: CHF 30

14th WMO/IAEA Meeting of Experts on Carbon Dioxide, Other Greenhouse Gases and Related Tracers Measurement Techniques
(WMO/TD-No. 1487)
[E]
2009; xi + 145 pp.
Price: CHF 30

World Climate Conference-3 Third Announcement
[A - C- E - F - R - S]
Free copy on request:
WCC-3@wmo.int

World Climate Conference-3 Better climate information for a better future No. 1—Benefits to society No. 2—Focus on Africa
[E/F/S multilingual]
Free copy on request:
WCC-3@wmo.int

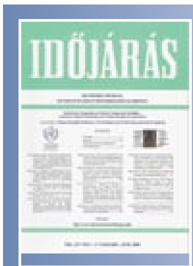
New books received



Monsoon Prediction

By R.R. Kelkar
BS Publications (2009)
ISBN 978-81-7800-185-2
xviii + 234 pp.
Price: Rs 995

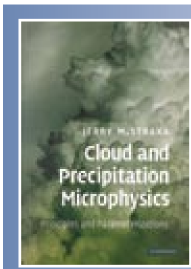
Life in India revolves around the Indian southwest monsoon which is the most intense among all global monsoons. It is India's prime source of water, and Indian agriculture, food grain production and the GDP growth rate are linked to the behaviour of the monsoon rains. This book deals with the particular challenge posed by the need for monsoon prediction, users' expectations, the current state-of-the-art in monsoon modelling, present scientific limitations and future prospects. It discusses the projections of monsoon behaviour in the 21st century, and the likely impact of global warming on the monsoon.



Idojaras—Quarterly Journal of the Hungarian Meteorological Service

Guest editors: S. Orlandini, M.V.K. Sivakumar, Tor Sivertsen and A.O. Skjelvåg
Co-sponsored by WMO and Cost Action 734

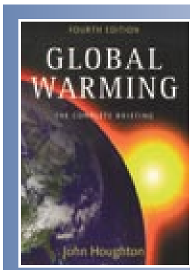
Special issue: Symposium on Climate Change and Variability—Agrometeorological Monitoring and Coping Strategies for Agriculture



Cloud and Precipitation Microphysics
Principles and Parameterizations

By Jerry M. Straka
Cambridge University Press (2009)
ISBN 978-0-521-88338-2
xiv + 392 pp.
Price: £ 70/US$ 130

This book focuses primarily on bin and bulk parameterizations for the prediction of cloud and precipitation at various scales. It provides a background to the fundamental principles of parameterization physics, including processes involved in the production of clouds, ice particles, rain, snow crystals, snow aggregates, frozen drops, graupels and hail. It presents complete derivations of the various processes, allowing readers to build parameterization packages, with varying levels of complexity based on information in this book. Architectures for a range of dynamical models are also given, in which parameterizations form a significant tool for investigating large non-linear numerical systems. Model codes are available online at www.cambridge.org/straka.



Global Warming: The complete briefing

By John Houghton
Cambridge University Press (2009)
ISBN 978-0-521-70916-3
xviii + 438 pp.
Price: £ 24.99/US$ 59

Global Warming is a topic that increasingly occupies the attention of the world. Is it really happening? If so, how much of it is due to human activities? How far will it be possible to adapt to changes of climate? What action to combat it can or should we take? How much will it cost? Or is it already too late for useful action? This book sets out to provide answers to all these questions.

Calendar

Date	Title	Place
13–15 July	YOTC (Year of Tropical Convection) Implementation Planning Meeting	Honolulu, USA
20–22 July	Task Team on Updating the GCOS Implementation Plan	Geneva
20–23 July	CBS Expert Team on Modelling of Atmospheric Transport for Non-nuclear Emergency Response Activities	Toulouse, France
21–24 July	Planning Meeting on Heat-Health Warning Systems	Shanghai, China
22-31 July	The 9th Typhoon Operational Forecasting Training (*co-sponsored*)	Tokyo, Japan
27 July–7 August	Targeted Training Activity: Predictability of Weather and Climate — "Theory and Applications to Intra-seasonal Variability" and South Asian Climate Outlook Forum (*co-sponsored*)	Trieste, Italy
24–26 August	The 24th Greater Horn of Africa Climate Outlook Forum (GHACOF-24) (*co-sponsored*)	Nairobi, Kenya
24–28 August	6th International Scientific Conference on GEWEX	Melbourne, Australia
31 August–4 September	World Climate Conference-3 (WCC-3)	Geneva
31 August–4 September	4th session of the Reduced Joint Meeting of the CIMO Expert Team on Upper-Air Systems Intercomparisons and 4th International Organizing Committee on Upper-Air Systems Intercomparisons	Yangjiang, China
31 August–4 September	RA III and RA IV Iberoamerican Countries Attendance to the WCC-3	Geneva
6–12 September	8th IAHS Scientific Assembly and 37th IAH Congress (*co-sponsored*)	Hyderabad, India
16–17 September	WMO Regional Seminar on the implementation of the RA VI Strategic Plan	Brussels, Belgium
17–18 September	40th session of IPCC Bureau	Geneva
18–24 September	15th session of Regional Association VI (Europe)	Brussels, Belgium
21–25 September	CAeM Management Group	Geneva
28 September–2 October	CBS Expert Team on Ensemble Prediction Systems (ET-EPS)	Exeter, United Kingdom
28 September–3 October	25th session of the Data Buoy Cooperation Panel and 29th session of the Argos Joint Tariff Agreement	Paris, France
5–9 October	5th WMO International Symposium on Data Assimilation	Melbourne, Australia
5–9 October	Training Workshop on GUAN Upper-Air Observations for RA II (Asia)	New Delhi, India
12–16 October	ECMWF Training Course for WMO Members (*co-sponsored*)	Reading, United Kingdom
15–16 October	2nd Meeting of Joint Steering Group for the IODE Ocean Data Portal and the WIGOS Pilot Project for JCOMM	Ostend, Belgium
4–11 November	JCOMM-III	Marrakech, Morocco
10–13 November	Regional Workshop on Climate Monitoring and Analysis of Climate Variability: Implementation of Climate Watch System in RA II with focus on monsoon affected areas	Beijing, China
16–17 November	Commission for Atmospheric Sciences Technical Conference	Incheon, Republic of Korea
18–25 November	Commission for Atmospheric Sciences - 15th session	Incheon, Republic of Korea
24–28 November	International Conference on Nurturing Arid Zones for People and the Environment: Issues and Agenda for the 21st Century (*co-sponsored*)	Jodhpur, India

The World Meteorological Organization

WMO is a specialized agency of the United Nations. Its purposes are:

- To facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations as well as hydrological and other geophysical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close cooperation between Meteorological and Hydrological Services;
- To encourage research and training in meteorology and, as appropriate, in related fields, and to assist in coordinating the international aspects of such research and training.

The World Meteorological Congress

is the supreme body of the Organization. It brings together delegates of all Members once every four years to determine general policies for the fulfilment of the purposes of the Organization.

The Executive Council

is composed of 37 directors of National Meteorological or Hydrometeorological Services serving in an individual capacity; it meets once a year to supervise the programmes approved by Congress.

The six regional associations

are each composed of Members whose task it is to coordinate meteorological, hydrological and related activities within their respective Regions.

The eight technical commissions

are composed of experts designated by Members and are responsible for studying meteorological and hydrological operational systems, applications and research.

Executive Council

President
A.I. Bedritsky (Russian Federation)
First Vice-President
A.M. Noorian (Islamic Republic of Iran)
Second Vice-President
T.W. Sutherland (British Caribbean Territories)
Third Vice-President
A.D. Moura (Brazil)

Ex officio members of the Executive Council (presidents of regional associations)

Africa (Region I)
M.L. Bah (Guinea)
Asia (Region II)
V. Chub (Uzbekistan)
South America (Region III)
R.J. Viñas García (Venezuela)
North America, Central America and the Caribbean (Region IV)
A.W. Rolle (Bahamas)
South-West Pacific (Region V)
A. Ngari (Cook Islands)
Europe (Region VI)
D.K. Keuerleber-Burk (Switzerland)

Elected members of the Executive Council

M.A. Abbas	(Egypt)
A.C. Anuforom	(Nigeria)*
G.P. Ayers	(Australia)*
O.M.L. Bechir	(Mauritania)
Y. Boodhoo	(Mauritius)
S.A. Bukhari	(Saudi Arabia)
F. Cadarso González	(Spain)
M. Capaldo	(Italy)
B.-S. Chun	(Republic of Korea)*
H.H. Ciappesoni	(Argentina)
W. Gamarra Molina	(Peru)
D. Grimes	(Canada)
S.W.B. Harijono (Ms)	(Indonesia)
J.L Hayes	(USA)*
J. Hirst	(United Kingdom)*
F. Jacq	(France)*
W. Kusch	(Germany)
L. Makuleni (Ms)	(South Africa)
J.R. Mukabana	(Kenya)
M. Ostojski	(Poland)
M.M. Rosengaus Moskinsky	(Mexico)
K. Sakurai	(Japan)*
P. Taalas	(Finland)*
A. Tyagi	(India)*
F. Uirab	(Namibia)
K.S. Yap	(Malaysia)
G. Zheng	(China)

** acting*

Presidents of technical commissions

Aeronautical Meteorology
C. McLeod
Agricultural Meteorology
J. Salinger
Atmospheric Sciences
M. Béland
Basic Systems
F.R. Branski
Climatology
P. Bessemoulin
Hydrology
B. Stewart
Instruments and Methods of Observation
J. Nash
Oceanography and Marine Meteorology
P. Dexter and J.-L. Fellous

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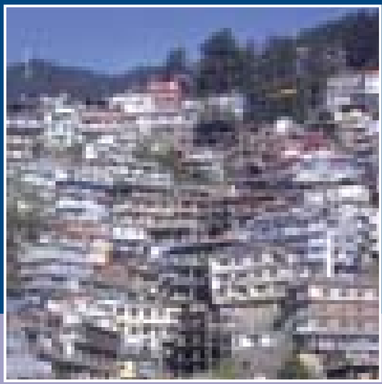

World Meteorological Organization

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ISSN 0042-9767