World Meteorological Organization
Weather • Climate • Water

Bulletin

Vol. 54 (2)
April 2005

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The World Meteorological Organization (WMO)

Weather • Climate • Water

WMO Headquarters building

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 at least 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.

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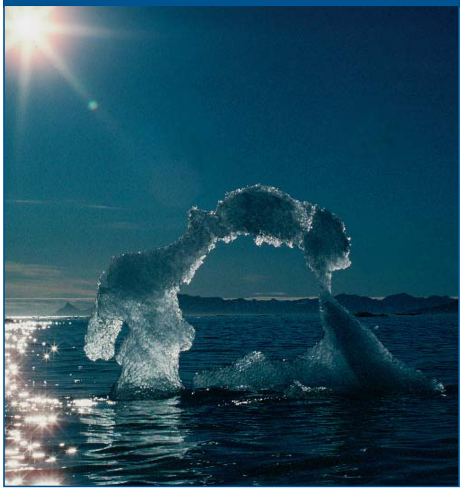

WMO celebrates 25 years of climate research for the benefit of society and looks forward to addressing the challenges of the future. A main focus of activities is the cryosphere.

This issue of the *Bulletin* celebrates 25 years of climate research by WMO and the World Climate Research Programme (WCRP), sponsored by WMO, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO. The main objectives set for the WCRP at its inception in 1980 remain valid today and for the foreseeable future: to determine the predictability of climate and the extent of human influence on climate.

The WCRP has made enormous advances in understanding specific components (ocean, land, atmosphere, cryosphere) of the climate system and created many new opportunities and challenges for research and its applications of the results for the benefit of society. The WCRP has been implemented mainly through a small number of "core projects" and related activities. Some have already been successfully concluded and left significant scientific, technical and practical legacies, in particular: the Tropical Ocean and Global Atmosphere project (TOGA, 1985-1994); the World Ocean Circulation Experiment (WOCE, 1982-2002); and the Arctic Climate System Study (ACSYS, 1994-2003). Today, the WCRP consists of four major core projects and various cross-cutting and co-sponsored activities. This issue contains articles on each of these core projects.

"Climate change and variability—what can we predict?" introduces and illustrates the wide and challenging remit of the Climate Variability and Predictability (CLIVAR) project, building on the legacies of its predecessors, TOGA and WOCE. CLIVAR research is aimed at developing more useful predictions of climate variability and change through the use of improved climate models and observations.

The Global Energy and Water Cycle Experiment (GEWEX) carries out investigations of the atmosphere, its global water cycle and energy budget, and how they might affect, and adjust to, climate change. "Water and energy cycles: investigating the links" recognizes GEWEX achievements to date and also highlights the ever-challenging objectives currently being addressed.

"From ozone hole to chemical climate prediction" is testimony to the strengths and value of international coordination, collaboration, and commitment in research as demonstrated by the achievements of the Stratospheric Processes and their Role in Climate (SPARC) project. Such collaboration resulted in an international team of SPARC scientists receiving WMO's Nobert Gerbier MUMM International Award in 2003.

"Frozen assets: the cryosphere's role in the climate system" traces WCRP's initiatives in promoting cryospheric research from the achievements of the regionally focused ACSYS to the development and introduction of WCRP's newest core project, Climate and Cryosphere (CliC), which recognizes the full global extent of the cryosphere's presence and influence. WCRP's main contributions to the International Polar Year 2007-2008 will be channelled through CliC.

These projects have benefited from WMO's major Programmes and the data provided by the observing networks operated by the National Meteorological and Hydrological Services.

Another feature article is one which describes the importance of regional workshops to produce indices of climate change for certain countries and regions where data have hitherto been lacking. They are also a good beginning for regional cooperation.

The North Atlantic hurricane season was a record-breaking one in terms of numbers, proximity and severity. *Ivan* caused death and destruction across the Caribbean. An article describing *Ivan*'s impact on the Cayman Islands shows the importance of international cooperation and of preparedness measures to reduce loss of life and property, promoted by WMO.

Other articles in this issue are "The global climate system in 2004" and "Weather and global crop production in 2004".

Climate change and variability—what can we predict?

By Antonio Busalacchi[1], David Legler[2], Howard Cattle[3], Tim Palmer[4] and John Gould[5]

Introduction

The impacts of climate variability and the threat of future climate change are now key issues that are brought to our attention on an almost daily basis. Obtaining a better understanding of climate variability, predictability and change lies at the heart of the mission of the Climate Variability and Predictability project, CLIVAR, of the World Climate Research Programme (WCRP). Ocean-atmosphere interactions form a particular focus for CLIVAR, reflecting the legacy from two previous WCRP projects, the Tropical Ocean-Global Atmosphere Project (TOGA) and the World Ocean Circulation Experiment (WOCE). Indeed, CLIVAR is now the WCRP spearhead for research on the global ocean, its interactions with the atmosphere and its key role in climate variability and change. The first part of this article briefly summarizes the overall legacy of TOGA and WOCE that CLIVAR now builds on. In the second part, we summarize some of the key contributions from CLIVAR since its inception, drawing on the outputs of the First International CLIVAR Science Conference held in 2004.

TOGA and WOCE—the legacy

The TOGA decade (1985-1994) provided, for the first time, a concerted international effort in observing and predicting a major component of the variability of the coupled climate system—the El Niño-Southern Oscillation (ENSO)—and its impact on the global atmosphere. During TOGA, 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 (Figure 1) and, under the sponsorship of CLIVAR, extended to the Atlantic and now to the Indian Ocean.

Other enhancements to the atmosphere and ocean observing systems critical to ENSO prediction were also made, whilst, at the same time,

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coupled ocean-atmosphere prediction models were established and implemented at many of the world's major prediction centres. Ocean data assimilation proved to be a key element in the initialization of seasonal-to-interannual climate forecast systems. 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 breed of climate scientist who was dedicated to exploring modes of variability that occur in the coupled ocean-atmosphere system and that do not exist in the uncoupled ocean or atmosphere.

In a similar manner, WOCE (1982-2002) left a significant imprint on our knowledge of, and ability to model, the global oceans. It introduced innovative technology, and made changes to our scientific method. WOCE provided a global perspective on the temporal variability and mean state of the world's oceans, from top to bottom. It established a baseline against which to assess past and future changes and evaluate anthropogenic effects on the global ocean circulation, a key activity being carried forward within CLIVAR. In partnership with the Joint Global Ocean Flux Study (JGOFS) of the International Geosphere-Biosphere

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5 Commonwealth Scientific and Industrial Research Organisation, Hobart, Australia

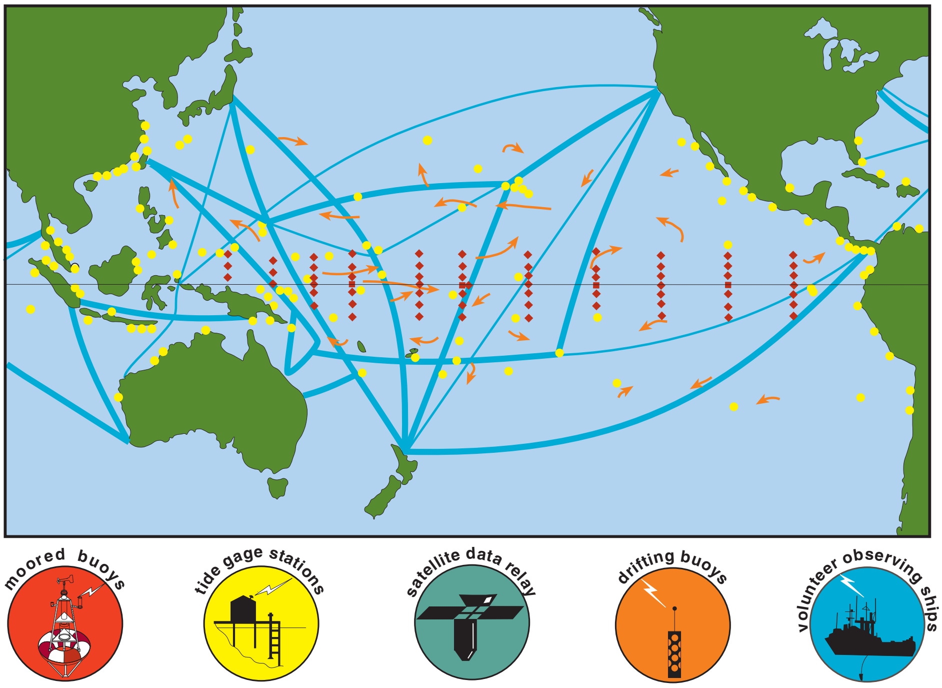


Figure 1 — In situ components of the El Niño-Southern Oscillation observing system

Programme (IGBP), a carbon dioxide (CO_2) and tracer chemistry survey was completed providing the first comprehensive inventory of CO_2 in the oceans. Regional process studies and focused observational campaigns improved our knowledge of the Southern Ocean and, deepwater formation in sub-polar seas and refined our understanding of ocean mixing, the global thermohaline circulation and the meridional transport of heat from Equator to Pole.

Advances in ocean technology played a major role in permitting this truly global perspective. For example, continuous observations of global sea surface height were provided by the TOPEX/Poseidon and ERS radar altimeters—a legacy on which we continue to build. Within the ocean, developments in float technology driven by WOCE led to the deployment of profiling floats that could monitor the temperature and salinity of the upper ocean and give subsurface current fields on global scales. These floats were the forerunners of the global Argo programme, the specification for which was drawn up by an Argo Science Team in late 1998 and publicised at the CLIVAR co-sponsored OceanObs'99 conference (St Raphael, France, 18-22 October 1999). An Argo array of 3 000 floats, co-sponsored by CLIVAR and the Global Ocean Data Assimilation Experiment (GODAE), was planned that would use observations and models to estimate the state of the global oceans.

The first Argo floats were deployed in 2001. By early 2005, 1 650 floats contributed by 18 countries were delivering data from the top 2 km of the global ocean (see Figure 2 and http://www.argo.net). The data are already used routinely by operational climate analysis and prediction centres and contribute substantially to the high-quality ocean datasets needed for climate research.

Initiated by the WOCE community modelling effort and enabled by advances in computer power, global ocean models can now resolve energetic boundary currents, associated instability processes, and flow between ocean basins and also provide a dynamically consistent description of many observed aspects of the ocean circulation. The ability to represent such ocean processes is an essential step towards increased realism in coupled climate models.

WOCE also contributed to the concept of GODAE and the prospect of ocean reanalysis efforts, parallelling the concept of atmospheric reanalysis now undertaken at a number of operational centres. WOCE changed the way we look at the ocean and the way we work as an oceanographic community. An ocean synthesis in which in situ and/or remotely-sensed observations are brought together with inverse methods or data assimilation methodologies is now possible. Finally, WOCE left the legacy of its unprecedented collection of ocean observations published on DVD in time for the final WOCE Conference in San Antonio, Texas, USA (18-22 November 2002). Atlases of the four major ocean basins based on these data will be published this year.

CLIVAR—scope and perspectives

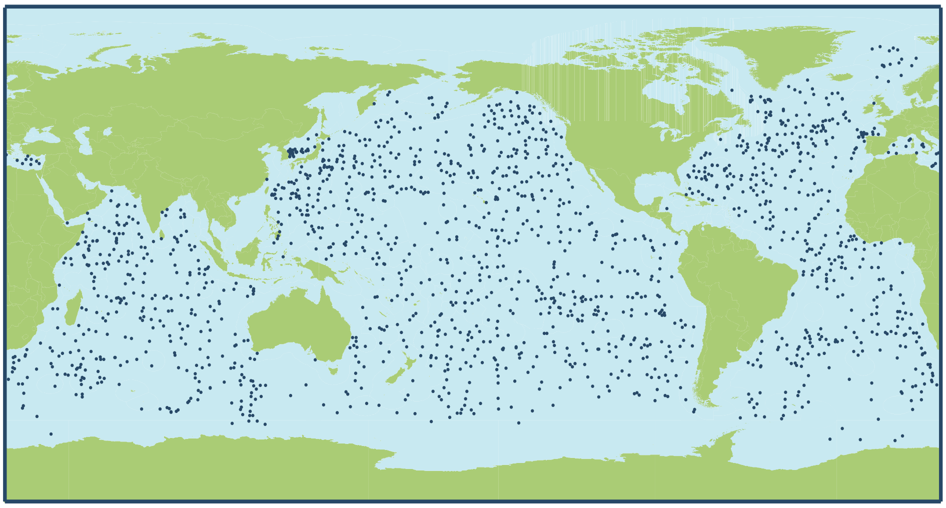
Nearly five years ago, in November 1998, representatives of 63 countries gathered in Paris and made commitments to enhance our understanding of, and ability to predict, climate variations on timescales of seasons and longer through CLIVAR. In order to highlight the many advances in CLIVAR science since then and identify the future research challenges, the first International CLIVAR Science Conference was held in 2004 (http://www.clivar2004.org). Over 640 scientists from 56 different countries attended—the largest WCRP conference to date. The conference specifically addressed a number of themes central to CLIVAR efforts: short-term climate prediction; monsoons; the challenge of decadal prediction; understanding long-term climate variations; the role of oceans in climate; human influence on climate; applications of CLIVAR science; and future challenges for CLIVAR.

Short-term climate prediction remains a key focus for CLIVAR, as it was for TOGA. There are several mechanisms which, through responses to anomalies in, and/or interactions with, sea-surface temperature (SST), sea ice, soil moisture, vegetation and perhaps even troposphere-lower stratosphere interactions, can result in climate variability on seasonal-to-inter-annual time-scales. While we have learned much about these mechanisms, a more complete understanding is critical for estimating predictability and improving our predictions. Through the advances brought about by TOGA and now CLIVAR, the current set of seasonal-to-interannual forecast models have demonstrated broad skills in predicting global temperatures and precipitation. The use of multi-model ensembles (Figure 3) has greatly enhanced overall capabilities, but predicting climate variability more than a few months in advance remains a fundamental challenge. The reasons for this include model error and error growth and the role of initial conditions and stochastic forcing. A sustained observing system is critical and there are continuing challenges for the research community to exploit these observations, guide their implementation, identify new and more cost-effective technologies, and maintain an active role as parts of the system transition to operations.

The monsoon systems in Asia, Africa, and the Americas have much in common, including a strong seasonality, land-sea temperature contrasts and even the connection of monsoons and mountains. The contrast between predictability based on statistical/empirical systems and the relatively low predictability realized from dynamical systems suggests that the coupled ocean-atmosphere-land system must be further understood and that model systematic biases should be reduced to improve monsoon forecasts. With WCRP's Global Energy and Water Cycle Experiment (GEWEX), CLIVAR is leading multinational investigations of the land-ocean-atmosphere coupling as manifested in the diurnal cycle and the low-level jet of the American monsoon systems (Figure 4) and in studies of the Asian-Australian monsoon system. Additionally, a new effort, the African Monsoon Multidisciplinary Analysis experiment, will provide critical contributions that could further our understanding of the African monsoon and its impact on life in western Africa.

Predicting decadal variability requires a more global perspective. The limited historical observational data (especially in the ocean) mean that models play an even more critical role in understanding decadal variability and identifying potential predictability. Models can suggest mechanisms, test diagnostic schemes, do experiments, and simulate predictions. Identifying the underlying mechanisms that are central to the climate system "memory" is a critical first step to characterizing the limits of predictability. In the Pacific, for example, at least three mechanisms (intrinsic atmospheric variations, ENSO variations, SST variations, and Kuroshio meanders) contribute to decadal variability, but there are competing theories on how each is involved. Hence, the level of predictability is still unclear. Observations are helpful in monitoring important mechanisms. For example, in the Atlantic, there is a multinational

Figure 2 — Argo float deployment (below); and the Argo float array in January 2005 (right). Some 1 600 floats provide a sparse array over the ice-free oceans in the upper 2 000 m. The array is building towards a target of 3 000 floats.



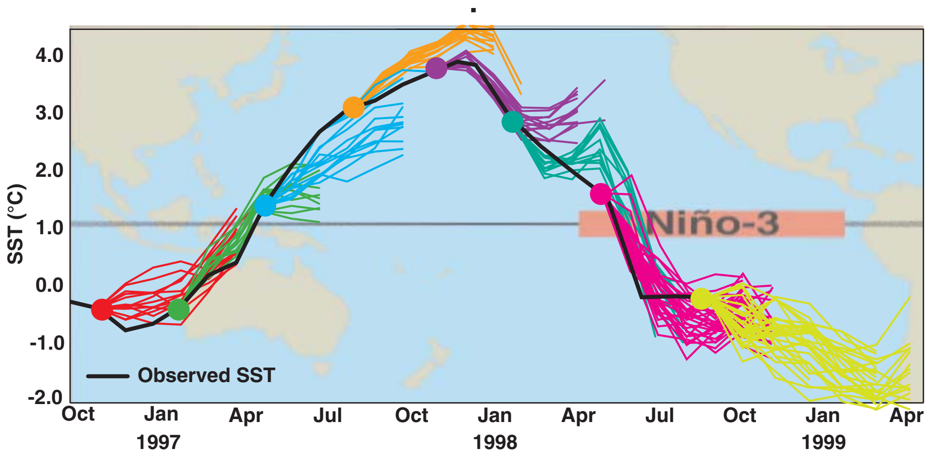


Figure 3 — ENSO forecasts, such as displayed here for the 1997/1998 event, have become possible through intensive research efforts in the field of seasonal predictions. The various colours represent multiple model runs (forecasts) initiated at different times of the year. (Courtesy ECMWF)

anomalies at a later time and often at a different place.

On longer time-scales, the connections between the tropical and extra-tropical oceans become more important (for example decadal variability of ENSO). The multidecadal freshening of the North Atlantic may be indicative of a change in global overturning circulation or of an accelerating global water cycle. Modelling evidence suggests some connection to polar atmospheric forcing, but these models resolve only coarsely important ocean processes, thus making it difficult to determine an answer. In addition to the hydrographic change of effort to monitor parts of the meridional overturning circulation. Much could be gained through more complete diagnostics leading to nowcasts of the current state of decadal variations and extending current efforts to predict the North Atlantic and Pacific Decadal Oscillations.

The ocean impacts most directly on the climate through changes in SST and the partial pressure of CO_2 (and other gases). Future changes in sea-level are a key question from a climate-change perspective. These are influenced not only by factors such as thermal expansion and glacier and ice cap melt but also by ocean transport and mixing processes, some of which are regionally intense and often poorly simulated and observed. We are still challenged as to how to represent eddies correctly in our models; how to consider coupling of the atmosphere to the ocean on fine scales; and how to better predict anomalous SST. The tropical oceans are central to climate because they redistribute large quantities of heat and freshwater, which are often manifested as SST and salinity

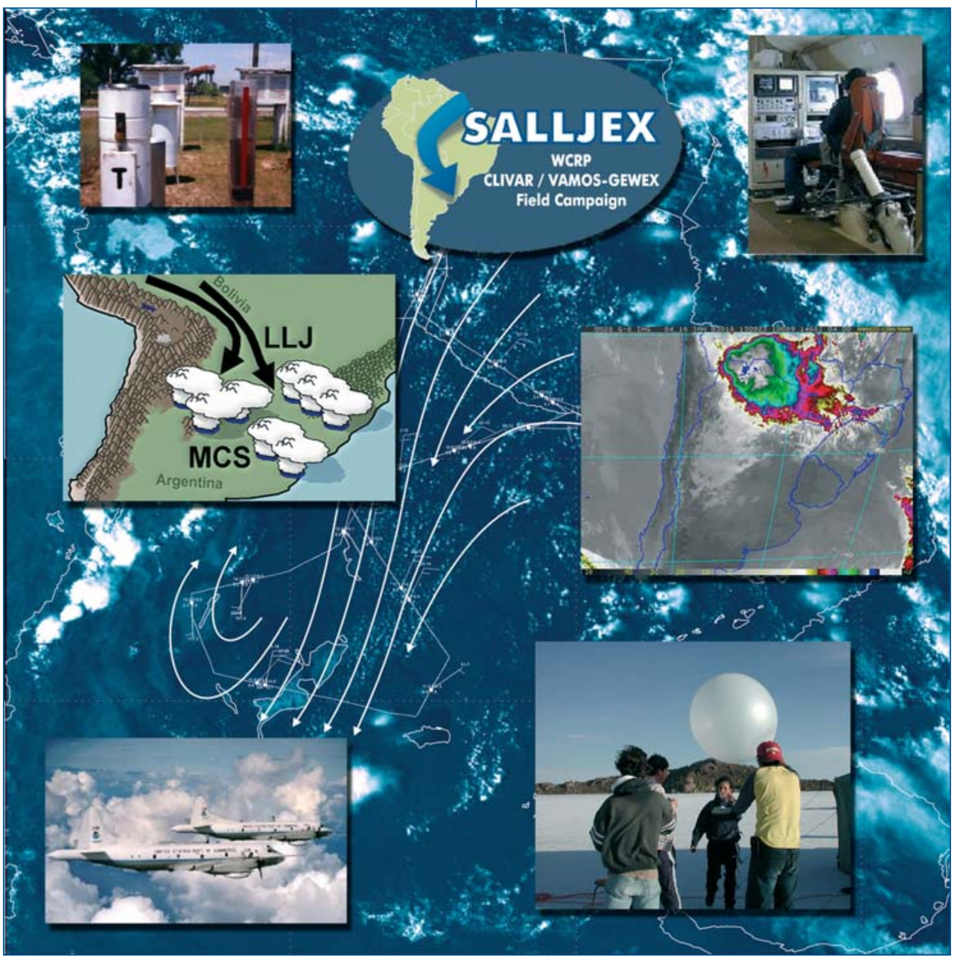


Figure 4 — The South American Low Level Jet Experiment, the first CLIVAR international campaign in South America

water properties, ocean circulations may be changing (as suggested by altimetric and *in situ* observations), which could enhance sea-level rise regionally.

These changes could have global impacts on ocean temperature, mixing rates, and CO_2 uptake rates. Characterizing the distribution and time variations of salinity is critical for both extra-topical and tropical oceans. Improved diagnostics of the global thermohaline circulation are needed. The Southern Ocean is also important in the global climate context. It connects the upper and lower limbs of the global overturning circulation, stores 60 per cent of the total anthropogenic carbon, may have an annular mode, has been linked to ENSO, and is likely to be sensitive to global climate variations.

Palaeoclimate records are critical for exploring longer time-scale climate variations, i.e. on time-scales of centuries and longer. When comparing multiple reconstructions based on palaeo-proxy data, proper scaling and calibration are critical. Many of the differences between reconstructions can be attributed to the calibrations that are often based on data in different seasons and regions. Nonetheless, the observed late 20th century warming is anomalous when compared to proxy reconstructions and models (over the past 2 000 years).

The recent increased melting of the Greenland Ice Sheet is not (according to palaeo-records) unprecedented but, if projected temperature changes under increased greenhouse-gas concentrations are realized, sea-level rise could be faster than anticipated. Finally, palaeoclimate models have improved and can provide some additional insight to climate variations (e.g. ENSO) and how their forcings and their evolution may have changed.

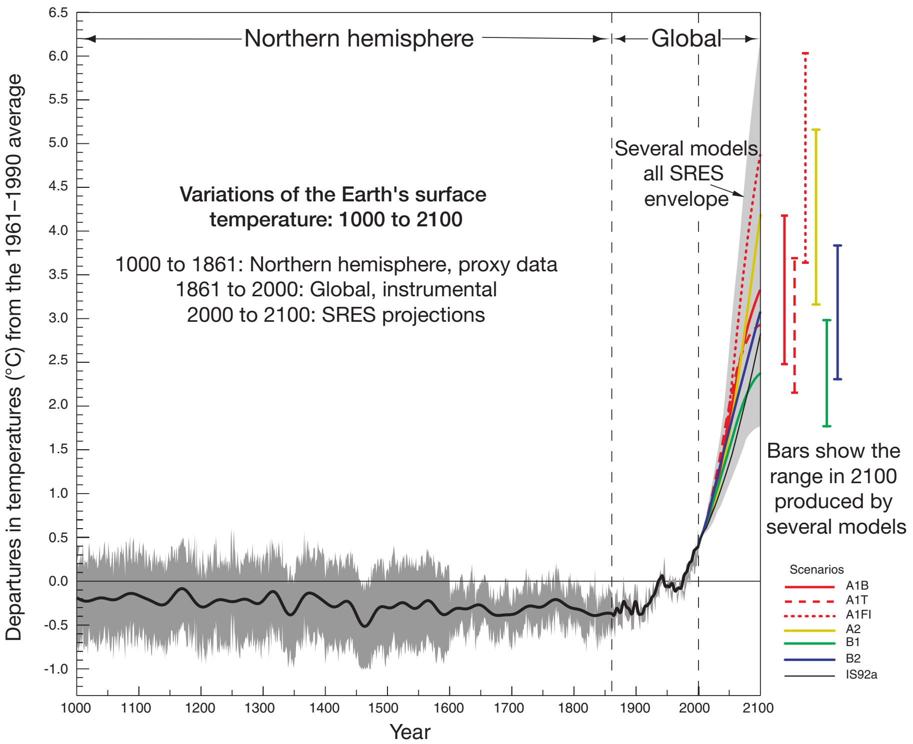


Figure 5 — Past 1 000 years and future projections of surface air temperature (after IPCC, 2001)

There are many scientific challenges regarding human influence on climate, including the linkages between natural climate variations and anthropogenically-induced changes. CLIVAR provides input into the Intergovernmental Panel on Climate Change (IPCC) by helping to meet these challenges through stimulating efforts on climate change prediction and detection. Thus, US CLIVAR Climate Process Teams, which are attracting international participation, are targeting major areas of uncertainties in IPCC-class models, whilst CLIVAR helped to lead efforts in the assessment of the model integrations for the Fourth IPCC Assessment Report (AR4), with a major workshop in March 2005.

The detection of anthropogenic change relies on a rigorous evaluation of observed and simulated data to provide estimates of changes in key climate parameters (Figure 5), including extreme values. To fully qualify any detected change, we must still account for all uncertainties, as well as be mindful of missing/uncertain forcings. Despite the increasing similarity of model sensitivities, predicted climate changes are often vastly different from model to model. Predicted future changes are also sensitive (often larger than the envelope of natural variability) to parametrizations, demonstrating the need to continue to refine them through the use of more discriminating diagnostics and analyses of the differences between the models and observations.

CLIVAR science is used for a variety of applications. For Africa, seasonal climate forecasts are being used to develop an early warning system for malaria and meningitis. Advance predictions of a range of variables such as precipitation (including totals, onset and ending dates) and environmental conditions (e.g. dust, humidity) are a necessary first step, but prediction systems have difficulty producing forecasts of these variables and the validation and monitoring observations are often inadequate. Lengthy histories of hindcasts are useful in demonstrating the value of seasonal forecasts and have led to their further operational use. CLIVAR and GEWEX are working together to improve the simulation and predictions of monsoons and intraseasonal-to-inter-annual forecasts that are valuable for water-resource managers. Seasonal forecasts have proved useful for hydroelectric power management. Some of the most notable applications of CLIVAR science have been in agriculture.

CLIVAR science is used in a range of applications in various economic sectors, such as fishing. (Photo: FAO/I. De Borhegyi)

Studies on adaptation and utilization of climate forecasts by, for example, the Climate Prediction and Agriculture (CLIMAG) project of the Global Change SysTem for Analysis, Research and Training (START) and by others have been very valuable. It is important to develop region-specific advice; involve farmers early and have them test recommended strategies; and finally communicate risk factors to avoid calamitous losses.

The impacts of climate variability can be identified on a variety of fish species and on many different time-scales (from seasonal to multi-decadal). Factors influencing the changes in fish stocks include temperature, circulation changes, and trophic interactions. Recent models can provide planetary-scale simulations of some important biological components of the ecosystems. Thus, we should now test hypotheses and mechanisms linking the physical forcing and biological processes by embedding simple biological mechanisms into existing models that simulate critical ocean-atmosphere interactions.

Future challenges

There are clearly many future challenges for CLIVAR. The need for more exhaustive and coordinated efforts to identify and address model deficiencies remains. The observing systems we utilize for climate purposes continue to develop (some parts more slowly than others) but several components (especially for the ocean) remain the responsibility of the research community. As such, CLIVAR must ensure they evolve to serve its needs, and that mature components are transferred carefully to operational status. The melding of observations and models in an assimilative framework has led to more complete depictions of the climate system. We need more capabilities in this area and an increase in activities to refine details such as model and observation error characteristics in order to be able to use such tools for the design of better observing and forecast systems.

Prediction capabilities must continue to focus on validation (drawing even more strongly on the evolving observing system) and utilization of new science results. In particular, the diagnostic analysis of global datasets at regional level presents an opportunity to develop more strongly the links between CLIVAR science on the global scale and at the regional level—a strategy that CLIVAR is pursuing.

In the case of climate change, such analyses will get to the heart of what has often been seen as the essence of the unique CLIVAR perspective on climate change: analysis of how anthropogenic forcing can influence the natural patterns of climate variability. For example, to what extent can anthropogenic climate-change forcing on the Asian monsoon be understood in terms of the frequency of occurrence of the main patterns of intraseasonal and interannual variability of monsoon activity? Similarly,

how is the decadal mode associated with the Sahel drought influenced by anthropogenic forcing? To what extent do the models to be used in IPCC AR4 describe satisfactorily the coupled dynamics of ENSO and how will the frequency of ENSO be influenced by anthropogenic forcing?

In addition, for prediction of longer time-scale (e.g. decadal) variability, more systematic numerical diagnostics and experimentation are required while we also develop nowcasts and explore experimental predictions of important indices. The ocean continues to be an important focus of CLIVAR. We must exploit fully the developing observation system and push forward with improved models and coupled systems to characterize more fully the changes in ocean circulation, climate-critical processes, ocean intransitivity, changes in carbon uptake, and sea level. Differences in model feedbacks in climate-change integrations are a significant limiting factor in developing improved coupled climate models. The fidelity of key processes leading to these differences needs to be addressed. Finally, while it is gratifying to note the many applications of CLIVAR research, it is apparent that integrating climate predictions into decision-making systems is a key to more success in this area.

Water and energy cycles: investigating the links

By S. Sorooshian[1], R. Lawford[2], P. Try[2], W. Rossow[3], J. Roads[4], J. Polcher[5], G. Sommeria[6], R. Schiffer[2]

Introduction

The Earth's climate fluctuates and changes both regionally and globally. Inevitably, this is reflected in the variability and change of Earth's water budget and its complex and dynamic energy balance with the Sun. Processes controlling the transports, transformations and exchanges of heat and water in the climate system are inextricably intertwined over a large range of space- and time-scales from boundary-layer turbulence to global climate change. Recognizing the pressing requirement to better understand and predict these complex processes and their interactions, the World Climate Research Programme (WCRP) launched the Global Energy and Water Cycle Experiment (GEWEX) in 1990. GEWEX leads WCRP's 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. By virtue of this central role, GEWEX connects with other WCRP projects, including the Climate Variability and Predictability (CLIVAR) project, the Stratospheric Processes and their Role in Climate project, and the Climate and Cryosphere (CliC) project. Furthermore, WCRP's co-sponsors, WMO, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO, provide GEWEX access to researchers in both the academic and governmental sectors.

GEWEX: Phases I and II

The first phase of GEWEX (1990-2002) focused on the development of analysis tools and models, using operational and research satellites, regional analyses of continental scale basins, and process studies to support the development of parameterizations of feedback processes (relating to clouds and land) for global climate models. During Phase I, more than 1 500 scientists from over 35 countries participated in GEWEX activities and more than 20 special issues of refereed papers were produced.

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Understanding the role of water in the climate system is a priority for WCRP and GEWEX. As vapour, water is the Earth's strongest and most plentiful greenhouse gas. Clouds also have an important feedback role in the climate system and, depending on their composition, spatial distribution and altitude, may enhance or diminish climate-change effects. Feedback influences also come from land-surface states determined by soil moisture and vegetation, which controls the partitioning of incoming solar radiation into radiative, sensible, latent (evaporation) and ground-heat fluxes and precipitation into runoff and infiltration. The cycle is closed by evapotranspiration from the land and evaporation from the ocean. Understanding, characterizing and closing both the global water and energy

GEWEX Phases I and II

GEWEX Phase II (2003-2013) emphasizes the full exploitation of the understanding and tools from Phase I (1990-2002), along with increased reliance on upgraded models and assimilation systems and new environmental satellite systems to produce even greater contributions to climate science.

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3 NASA Goddard Institute for Space Studies, New York, USA
4 University of California, San Diego, USA
5 Laboratoire de météorologie dynamique du Centre national de la recherche scientifique (CNRS), Paris, France
6 WMO/WCRP

budgets have been a major focus for GEWEX research.

This agenda has placed GEWEX on the leading edge of science, which is directed at bringing the hydrology, land-surface, and atmospheric science communities together through process studies in order to show the importance of understanding soil moisture/ atmosphere and cloud/radiation interactions and their parameterization within prediction models. Also, by producing or fostering the production of global datasets to validate predictive models, GEWEX is ready to assess whether the global water cycle has been undergoing significant changes in the past two decades. GEWEX has also actively engaged and benefited the water resource community. As shown in Figure 1, GEWEX plays a critical role in relating WCRP prediction activities to hydrology programmes, such as those of the International Association of Hydrological Sciences (IAHS).

During Phase I, GEWEX activities included: (*a*) global dataset development; (*b*) process studies; and (*c*) model development support and modelling studies. In order to focus activities and to provide for better coordination, a programmatic structure was adopted in 1995 that set goals for GEWEX activities in three separate areas, namely radiation, hydrometeorology, and modelling and prediction. The hydrometeorology activities, coordinated through the GEWEX Hydrometeorology Panel, focused on the coupling of the land and the atmosphere and hydrological processes at the continental and mesoscales. Modelling and related process studies coordinated through the GEWEX Modelling and Prediction Panel addressed clouds, land-atmosphere interactions, and, more recently, boundary-layer processes. The radiation projects, coordinated by the GEWEX Radiation Panel (GRP), developed global data products and scientific understanding related to the global distribution and variability of clouds, water vapour, aerosols, surface radiation and precipitation.

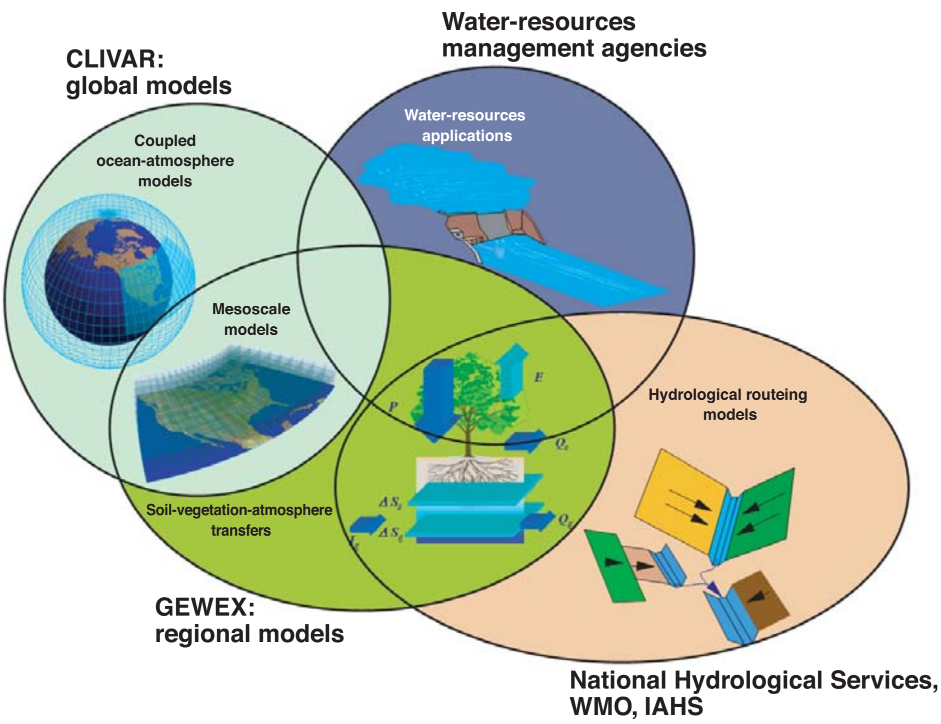

Figure 1 — Role of different international and national programmes and agencies in addressing climate prediction and water-resources management issues (Figure: S. Sorooshian)

GEWEX Hydrometeorology Panel (GHP)

GHP efforts are directed at demonstrating skill in predicting changes in water resources and soil moisture on time-scales up to seasonal and annual as an integral part of the climate system. It also focuses on building upon distributed process studies in the GEWEX Continental Scale Experiments (CSEs) as well as the Coordinated Enhanced Observing Period (CEOP) effort initiated by the GHP in order to coordinate globally the CSE observations and modelling efforts (Lawford *et al.*, 2004). Coupling of the land-atmosphere has been a central strategy for the GEWEX CSEs and five major continental-scale field campaigns have been underway for more than a decade to provide new process understanding and improved model representation in the Amazon, Baltic Sea, Mississippi and MacKenzie River Basins, and four areas in eastern Asia (Thailand, Tibet, Siberia and eastern China). New CSE initiatives have subsequently been developed for basins in Australia, the La Plata Basin of South America and, most recently, western Africa. The locations of the CSEs are shown in Figure 2.

Through new hydrometeorological data, models, and analyses, the GHP has demonstrated the critical importance of land-surface interactions, soil-moisture measurements and the

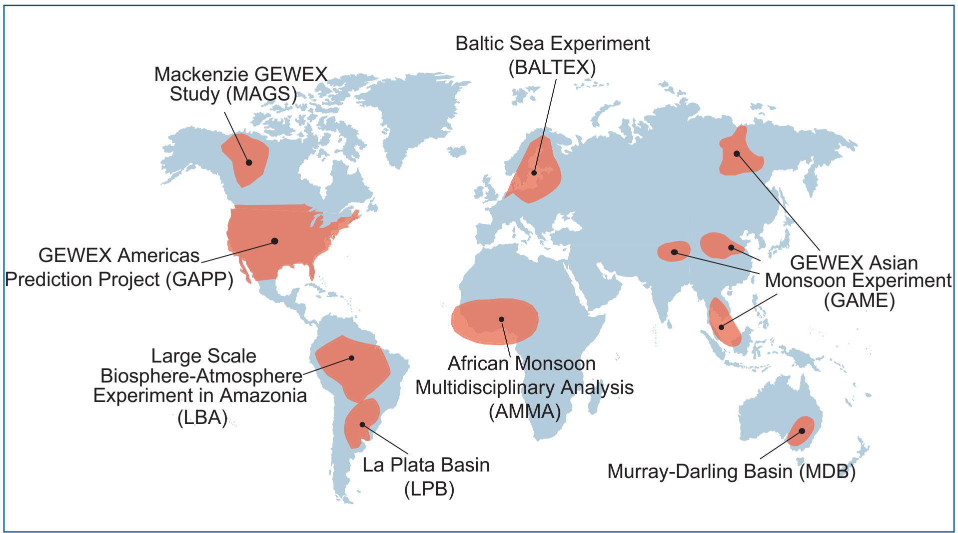

Figure 2 — Continental scale areas included in the GEWEX Hydrometeorology Programme

application of regional and global high-resolution precipitation data. Furthermore, major new land-surface scheme upgrades have resulted in improved regional to global prediction capability. The development of this new interdisciplinary relationship of the hydrological and atmospheric sciences with a focus on coupled land-surface-atmosphere interactions led to a large number of new research papers and helped to initiate the American Meteorological Society's *Journal of Hydrometeorology*. In brief, regional data and modelling have proved to be very effective in improving the understanding of local processes and led to suggested approaches to improve current regional and global models, which have difficulties simulating diurnal and surface-subsurface hydrological processes.

GEWEX Continental-scale International Project (GCIP)

The GCIP in the Mississippi River Basin was the first international project of its size to bring together the hydrological and meteorological science communities for a common research goal. The GCIP was launched in 1995 to take advantage of the extensive meteorological and hydrological networks that existed and were being upgraded there. The motivation for the GCIP came from the recognition of the need to close regional water and energy budgets and to improve parameterization of land-atmosphere interactions and land-surface hydrology in climate models. Other basins were soon established as CSEs after the adoption of the GCIP in order to study coupled hydrometeorology over diverse climatic and political regions. The success of the GCIP subsequently resulted in an expansion of activities as part of the GEWEX Americas Prediction Project (GAPP). Studies of the North American Monsoon System in GAPP have promoted closer linkages between GEWEX and CLIVAR in monsoon research.

GEWEX Asian Monsoon Experiment (GAME)

GAME research has been directed at understanding the role of the Asian monsoon in the Earth's climate system and to improve the simulation and seasonal prediction of Asian monsoon patterns and regional water resources. The scientific strategy of GAME includes monitoring by satellites and *in situ* surface observations, process studies based on the four regional experiments located in distinctive climate regions (tropics, sub-tropics, Tibetan Plateau and Siberia) and modelling of hydrometeorological processes in the climate system.

Baltic Sea Experiment (BALTEX)

BALTEX, which covers the Baltic Sea and its drainage basin, has explored and modelled the mechanisms determining the space and time variability of energy and water budgets over the BALTEX region, which covers roughly 20 per cent of the European continent. The experiment has analysed large seasonal, interannual and regional variations in climate and episodic hydrometeorological events in the basin that have produced flooding in densely populated areas and have led to important ecological changes in the Baltic Sea.

Mackenzie GEWEX Study (MAGS)

MAGS is a multidisciplinary project that is undertaking research to understand and model the response of the energy and water cycle in northern Canada to climate variability and change; to define the impacts of its atmospheric and hydrologic processes and feedbacks on the regional and global climatic systems; and to apply these predictive capabilities to climate, water resources, and environmental issues in the cold regions. MAGS identified sublimation in blowing snow as one of the main causes for the "missing surface water storage." Furthermore, MAGS scientists quantified evaporative losses from large northern lakes and improved understanding and model representation of runoff processes in the northern regions. Along with GAME-Siberia, MAGS has strengthened the links between GEWEX and CliC.

Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)

The hydrometeorological aspects of LBA have been directed at understanding the role of tropical forests and the consequences of deforestation for regional energy and water budgets. Phase I field experiments, modelling, and analyses showed a 44 per cent imbalance of the water cycle in the Amazon basin. Amongst the many important findings, LBA studies determined the transport of moisture from Amazonia to southern Brazil via the low-level jet east of the Andes and quantified the interannual variability of the Amazon Basin as a source/sink of carbon dioxide and moisture based on an assessment of carbon sequestration in tropical forest environments during ENSO events.

International Satellite Land Surface Climatology Project (ISLSCP)

ISLSCP initially focused on field experiments but more recently has undertaken the development of interdisciplinary datasets. These field experiments included the First ISLSCP Field Experiment (FIFE) and the Boreal Ecosystems-Atmosphere Study (BOREAS). Subsequently, ISLSCP launched two interdisciplinary data collections to develop co-registered interdisciplinary Earth science land datasets for variables needed by modellers for coupled land-atmosphere modelling. The first co-located 1 × 1° observational datasets covered a two-year period and have been used widely in research and education. The second data collection initiative (ISLSCP II) produced datasets at spatial resolution of 1° to 0.5° and 0.25° for the period 1986-1995.

GHP has mounted several global projects that integrate studies and activities in all the CSEs. These activities include the Water and Energy Budget Studies (WEBS) and the Water Resources Applications Project (WRAP). GHP also coordinates GEWEX-related research with global projects, including the Coordinated Enhanced Observing Period (CEOP) and the International Association of Hydrologic Sciences Project for Ungauged Basins, global data centres, including the Global Precipitation Climatology Centre and the Global Runoff Data Centre, and international agencies, including the International Atomic Energy Agency. Its activities help to coordinate and disseminate hydrological results to the international hydrological community.

GEWEX Modelling and Prediction Panel (GMPP)

GMPP contributes to the global modelling of the processes that control the global energy and water budget and demonstrates the value of predicting the variability of this cycle and its response to climate forcing with a particular emphasis on cloud and land-surface process representation. The goal of GMPP research is to demonstrate the capability to predict water storage and runoff over continental regions, as an element of seasonal-to-interannual climate predictability, and to demonstrate the capability to predict the radiation budget and fluxes as an element of decadal-to-centennial climate variability and response to changes in external forcing factors (Chahine, 1997).

Phase I components

The principal Phase I components of GMPP include the GEWEX Cloud Study System and Global Land-Atmosphere System Study with its primary subprojects: the Project for Intercomparison of Land-Surface Parameterization Schemes and the Global Soil Wetness Project. GMPP studies have reduced uncertainties in the understanding and simulation of key water-cycle variables through the application of Phase I observations and land-surface and cloud-process parameterizations derived through regional studies and model intercomparisons.

The GEWEX Atmospheric Boundary Layer Study was formed in 1999 to study how the interactions of the land surface and the boundary cloud layer are mediated through the atmospheric boundary layer.

GEWEX Cloud Study System (GCSS)

GCSS has carried out studies that support the development of new physically-based cloud parameterizations using cloud-resolving models of different cloud system types for numerical weather prediction and climate models: marine boundary-layer clouds, Cirrus, extra-tropical layer clouds, tropical deep convection and polar clouds. GCSS investigates these cloud types with a combined analysis of a wide range of models: from turbulent-eddy-resolving models to cloud-resolving and regional-scale models to single-column and general circulation models used for weather forecasting and climate in addition to a wide range of *in situ*, surface, and satellite remote-sensing observations.

Tools for conducting these studies have been gathered on a linked set of Websites, the main one being

the GCSS Data Integration for Model Evaluation. These activities are leading not only to improved cloud parameterizations but also to the implementation of new, more focused field experiments and advances in the use of combined sets of surface and satellite-based active sensors.

GCSS study results have supported improved understanding of the effects of the three-dimensional structure of clouds on radiative fluxes, the interaction of clouds with the marine surface and atmospheric boundary layer, the organization and distribution of precipitation in tropical convective complexes, and the character and evolution of Cirrus and polar clouds.

Global Land-Atmosphere System Study (GLASS)

GLASS seeks to improve our understanding of, and capability to simulate, surface processes from the plot scale to the global scale by multi-institutional experiments of both stand-alone land-surface models (LSMs) and coupled land-atmosphere models on both the local (point, plot and catchment) and large (continental to global) scales. Through multi-model experiments, GLASS confronts the hypothesis under which the LSMs have been developed and thus advance the community's knowledge of their capabilities. The goal of GLASS is to incorporate improved understanding of the physical processes at the land surface into global models and to identify and understand the important components of land-atmosphere interaction.

Project for Land-Surface Parameterization Schemes and Global Soil Wetness Project

Initially through the Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS) and now through GLASS, the development of improved land-surface models has been coordinated at the process level. Subsequently, the Global Soil Wetness Project (GSWP) carried out intercomparisons of land-surface models on the global scale. More generally, GLASS initiated within the community the transition for land-surface parameterizations bound to an atmospheric model to land-surface models. PILPS and GLASS have led to the accelerated development of LSMs by model and data intercomparisons for different climate regimes.

The evaluation of simulated soil wetness and precipitation predictions in ensembles of models within GSWP and the Global Land Atmosphere Coupling Experiment has raised the awareness of the community to the intrinsic limitation of LSMs to produce observable quantities. For example, coupled LSMs and global climate models have been assessed in terms of their sensitivity to soil moisture and ocean sea-surface temperatures, which can greatly affect their ability to simulate climate predictability. GLASS also developed a critical set of standards for the exchange of forcing data to facilitate modelling studies using land-surface models.

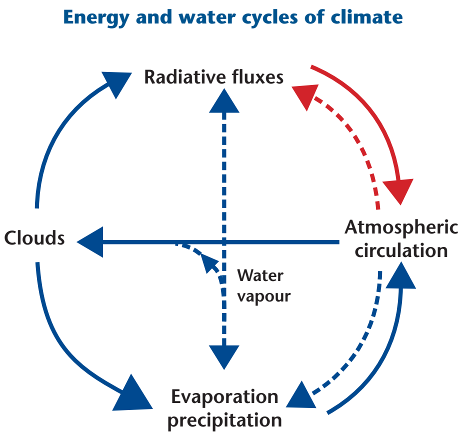

Figure 3 — Dominant atmospheric linkages in the global energy and water budgets

The GMPP facilitates the transfer of knowledge about models and modelling techniques to operations through an annual joint meeting with the WMO Commission for Atmospheric Science/Joint Scientific Committee Working Group on Numerical Experimentation.

GEWEX Radiation Panel (GRP)

Efforts of the GRP are directed towards determining the diabatic heating of the atmosphere and surface by radiative, sensible and latent energy exchanges with accuracy sufficient to diagnose the processes influencing variations of the surface and atmosphere from weather to decadal climate scales. GRP projects analyse long-term, global satellite observations that are supported by key, high-quality, long-term, *in situ* measurements that are used to diagnose the causes of forced and unforced climate variations (Rossow *et al.*, 2005). The GRP studies foster improvements in radiative transfer models used in weather and climate models and in the analysis of satellite- and surface-based remote-sensing observations.

The GRP projects have developed 15-25 year global data products quantifying the variability of radiative fluxes, clouds, water vapour, aerosols, precipitation and turbulent fluxes at the ocean's surface and are working to develop more advanced products. All these data products are available and are being used to study recent climate variations associated with volcanic eruptions and El Niño-Southern Oscillation cycles by quantifying all the interactions illustrated in Figure 3. A reconstruction by the Surface Radiation Budget project of the global radiation budget using GRP and other global data products has achieved a more accurate quantification of the role of clouds in partitioning

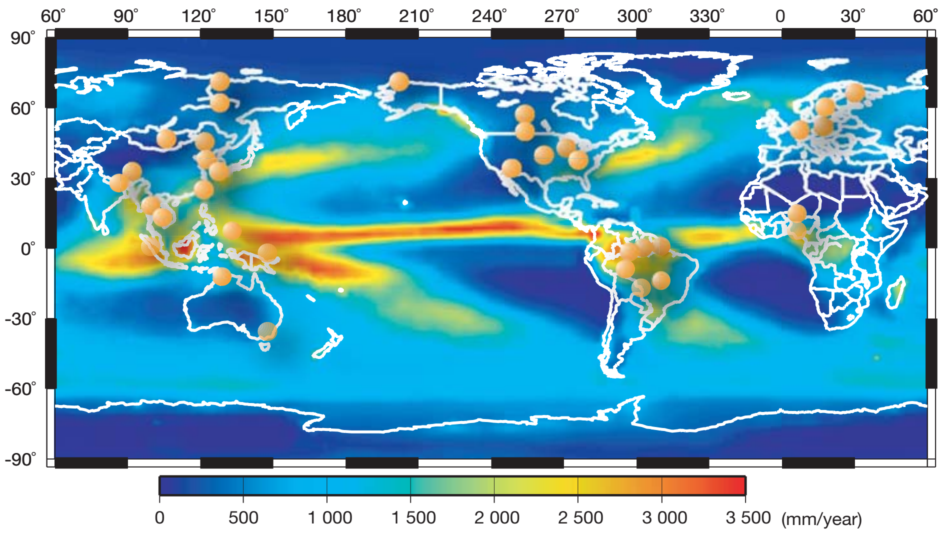

Figure 4 — Annual average precipitation 1988-1997: the Coordinated Enhanced Observing Period (CEOP) aims at developing a global network of pilot joint meteorological-hydrological stations and makes use of the huge amounts of Earth observing satellite data available today. (Source: GEWEX Continental-Scale International Project)

the planetary radiation budget among the atmosphere, ocean, land and cryosphere.

The International Satellite Cloud Climatology Project has pioneered the cross-calibration, analysis and merger of measurements from the international constellation of weather satellites to produce the first global quantitative description of the physical properties of clouds resolving diurnal-to-decadal variations.

The Global Precipitation Climatology Project has produced the first globally complete determination of precipitation resolving five-day-to-decadal variations by the analysis and merger of measurements from the international constellation of weather satellites and in situ measurements.

The Global Water Vapour Project conducted a pilot study that pioneered the merger of water-vapour measurements from the international constellation of weather satellites and *in situ* atmospheric soundings to produce a detailed description of the global distribution of atmospheric water-vapour profiles resolving daily-to-decadal variations.

The Global Aerosol Climatology Project recently completed a systematic analysis of year-to-year variations of aerosols that is now being merged with an analysis of the associated variations of cloud microphysical properties. In addition, the first comprehensive compilation of *in situ* ocean surface flux measurements was produced by the SeaFlux project.

These efforts have fostered improvements in global satellite-based products, providing turbulent fluxes of heat, water, and momentum resolving daily-to-decadal variations. The global satellite observation analysis projects are supported by reference networks established by GRP and data centres. For example, the development of the Baseline Surface Radiation Network has led to reductions in measurement uncertainties of more than a factor of two. The Global Precipitation Climatology Centre, a data centre that is linked with GRP precipitation studies, has compiled an extensive collection of surface precipitation gauge data and analyses. Both these initiatives are key elements of the Global Climate Observing System.

In preparation for Phase II of GEWEX, the GRP has an ongoing project, known as the Intercomparison of Radiation Codes in Climate Models, to foster significant development of radiative transfer codes in all atmospheric general circulation models and a working group to develop a coordinated approach for the reduction and analysis of combinations of atmospheric profiling instruments (radars, lidars and sodars) from a worldwide network of long-term monitoring sites. In addition, the GRP is working with other GEWEX activities to develop an advanced, comprehensive analysis of the fluxes of energy and water between the land and atmosphere.

Challenges

To achieve its objectives in Phase II (see box overleaf), GEWEX will develop and apply a wide range of modelling tools ranging from global climate models to regional and mesoscale models, and will evaluate downscaling methods suitable for the smaller spatial and temporal scales generally associated with hydrological models used in local water-resource management.

Another primary element of Phase II is the Coordinated Enhanced Observing Period (CEOP). The first phase of this experiment (CEOP I) is described in Koike (2004). CEOP II will focus on the development of a two-year dataset of *in situ*, satellite and model data for the period of 2003-2004 to support research objectives in the climate prediction and monsoon system studies. GEWEX also takes the lead on

GEWEX Phase II objectives

- Produce consistent research quality data sets complete with error descriptions of the Earth's energy budget and water cycle and their variability and trends on interannual to decadal time scales, and for use in climate system analysis and model development and validation

- Enhance the understanding of how energy and water cycle processes function and quantify their contribution to climate feedbacks

- Determine the geographical and seasonal characteristics of the predictability of key water and energy cycle variables over land areas and through collaborations with the wider WCRP community determine the predictabiity of energy and water cycles on a global basis

- Develop better seasonal predictions of water and energy cycle variability through improved parameterizations encapsulating hydrometeorological processes and feedbacks for atmospheric circulation models

- Undertake joint activities with operational hydrometeorological services and hydrological research programmes to demonstrate the value of new GEWEX prediction capabilities, datasets and tools for assessing the consequences of global change

behalf of WCRP in the Integrated Global Water Cycle Observations theme of the Integrated Global Observing Strategy Partnership. In that regard, CEOP has been endorsed as the first element of the new Integrated Global Water Cycle Observation theme. GEWEX also will contribute to the Global Water System Project within the Earth System Science Partnership framework. In addition, research projects in GEWEX Phase II will be supportive of WCRP's new strategy, the Coordinated Observation and Prediction of the Earth System. Readers wishing to follow the progress of GEWEX or to access the wide range of data and data products available are invited to visit the GEWEX home page (www.gewex.org).

Acknowledgements

The successes and progress reported here would not have been possible without the major contributions and data services of the US National Aeronautics and Space Administration, the US National Oceanic and Atmospheric Administration, the Japan Aerospace Exploration Agency, the German Association of Natural Resources, the European Space Agency, the European Organisation for the Exploitation of Meteorological Satellites, the European Commission, the Meteorological Service of Canada, and the Natural Sciences and Engineering Research Council of Canada. A number of other national and international agencies and programmes have also contributed data and infrastructure to the project. Also, the authors would like to thank Dr Bisher Imam, Ms Dawn Erlich and Ms Carolyn Serey for their help in preparing the figures and finalizing the text for this article.

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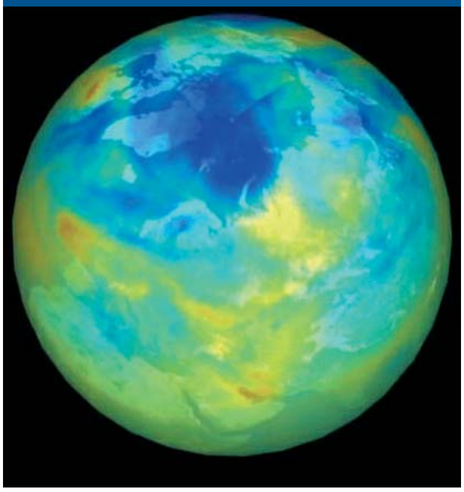
From ozone hole to chemical climate prediction



By N. McFarlane (SPARC International Project Office), A. Ravishankara (NOAA Aeronomy Laboratory, Boulder, USA) and A O'Neill (University of Reading, UK)

Stratospheric Processes and their Role in Climate (SPARC) Project—a short history

The SPARC project came about over a period of years through the efforts of a community of scientists, first to formulate its central goals and then to have it accepted by the main international scientific organizations. A number of scientists were involved in the long process which led to the recognition of SPARC as a project of the World Climate Research Programme (WCRP). The major efforts of M. Geller and M.-L. Chanin, the first Co-Chairs of the SPARC Project, were critical to final success.

Although depletion of ozone in the stratosphere had been an issue of interest in research for more than a decade, discovery of the Antarctic ozone hole in 1985 added enormous impetus to this field of investigation. Understanding the chemistry and dynamics of the ozone hole, and of stratospheric ozone more generally, was recognized as a scientifically challenging issue, as well as one of great concern for human health. In his Banquet response for the Nobel Prize in Chemistry (see SPARC Newsletter No.6. on the SPARC Website (http://www.atmosp.physics.utoronto.ca/SPARC), Prof. F Sherwood Rowland drew attention to the signing of the Montreal Protocol in 1989 as recognition of the great importance to be attached to monitoring and control of gaseous emissions to the atmosphere. Many important national programmes were set up in response to this.

Although depletion of stratospheric ozone was, at first, considered as being somewhat distinct from climate-change issues, it had become increasingly clear that the future evolution of the ozone layer and its eventual recovery were part of the broader story of climate change associated with increasing concentrations of radiatively and chemically active substances in the atmosphere as a result of human activities. The critical role of such substances in the chemistry of ozone in the Antarctic stratospheric winter polar vortex, remote from their source regions, is in itself indicative of the importance of transport and exchange between the troposphere and stratosphere on time- scales ranging from weeks to years. It was becoming evident, however, that this dynamical coupling could influence the troposphere as well. In addition, recognition that the signal of climate change was sensitive to the composition and structure of the upper-troposphere/lower-stratosphere region underlined the need for a programme of research directed toward understanding the role of the stratosphere in the climate system. It was also clear that, to be successful, this programme would have to combine a wide range of disciplines and expertise and fully recognize the key role of atmospheric

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We now know that ozone is subject to transformation by long-lived chemicals, both natural and man-made, released at the Earth's surface, and substantial reductions in its concentration could have a strongly deleterious effect upon mankind and upon the rest of the biosphere.
(F. Sherwood Rowland, Nobel Prizewinner for Chemistry, 1995)

Major foci of the early SPARC Programme

Stratospheric indicators of climate change

Goal: to detect trends in stratospheric constituents, physical properties and processes, and included particular emphasis on the following topics:

- Detection of stratospheric temperature trends
- Detection of trends in the vertical distribution of ozone
- Compilation of a water-vapour climatology and detection of long-term changes
- Stratospheric aerosol climatology and trend

Stratospheric processes and their relation to climate

This initiative dealt with key physical, chemical, and dynamical processes of importance for understanding and modelling the role of the stratosphere in the climate system. These were dealt with under the following topics:

- Stratosphere-troposphere exchange and dynamics and transport in the lower stratosphere and upper troposphere
- The Quasi-biennial Oscillation and its possible role in coupling the stratosphere and troposphere
- Gravity-wave processes and their parametrization
- Chemistry and microphysics in the lower stratosphere and upper troposphere

Modelling stratospheric processes and trends and their effects on climate

This initiative emphasizes large-scale modelling and comparison of models with observations. Two components of this initiative which have produced key achievements and ongoing activities are GRIPS (GCM-Reality Intercomparison Project for SPARC) project and Compilation of a Stratospheric Reference Climatology.

chemistry in climate change. By the early 1990s, this had already received full recognition within the International Global Atmospheric Chemistry (IGAC) Project of the International Geosphere-Biosphere Programme (IGBP). The issues covered by IGAC, however, dealt exclusively with the troposphere and did not include the complex interactions of chemistry, radiation and dynamics, which characterize the tropopause region and the stratosphere.

Two main organizations prepared the way for the recognition of the role of the stratosphere in the climate. The Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) included in its programme a topic entitled "Middle atmosphere response from above and below". The relevant Working Panel led by M. Geller and M.-L. Chanin had a large influence on the scientific content of SPARC. It included the issue of "Solar variability effects on the environment" under the leadership of K. Labitzke. This issue was picked up later by SPARC and has remained a theme of joint interest between SCOSTEP and SPARC.

During the same period, the role of the International Union of Geodesy and Geophysics (IUGG) in the IGBP was being discussed. As a member of the first SSC of IGBP, M.-L. Chanin undertook the task of finding a way to include the stratosphere in the IGBP Programme. Although these efforts did not succeed as planned, they were eventually rewarded with the acceptance of the SPARC project as part of the WCRP in March 1992.

The first main meeting of the SPARC Project took place in September 1992 in Carqueiranne, France, as a NATO Advanced Study Institute. It was organised by M.-L. Chanin and included a group of lecturers who played a major role in the definition of SPARC priorities (Initial Review of Objectives and Scientific Issues, 1993).

Achievements

The SPARC project has played a major role in highlighting the importance of stratospheric processes in the climate system. This has been achieved by an approach which has been: firstly, to be responsive to the need for scientific input to international scientific assessments; secondly, to identify manageable projects where coordination at international level can make a difference; and thirdly, to have clear deliverables for each project, such as scientific reviews which summarize the state of knowledge and facilitate and stimulate new directions for research.

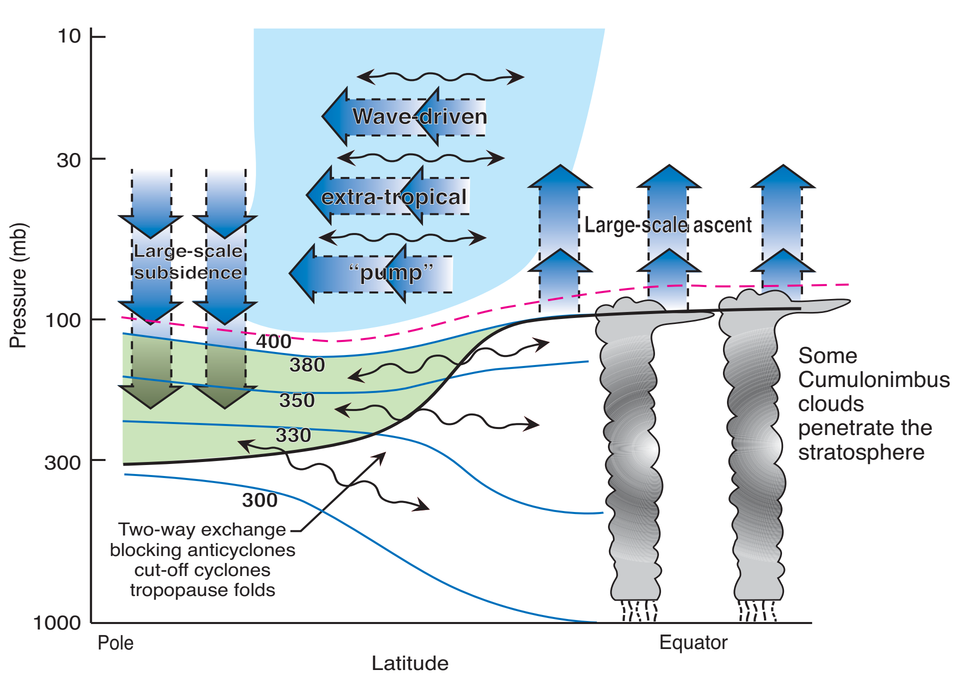


Figure 1 — The "Holton diagram" depicting the processes involved in stratosphere-troposphere exchange

Figure 1, taken from the widely cited paper of Holton et al. (1995), is an elaboration of an earlier one in the report by P. Haynes on the NATO Advanced Research Workshop on Stratosphere-Troposphere exchange (Cambridge, 6-9 September 1993) published in SPARC Newsletter No. 2. In this figure, the tropopause is shown by the thick line. Thin lines are isentropic or constant potential temperature surfaces (labelled in degrees Kelvin). The heavily shaded region is the "lowermost stratosphere" where isentropic surfaces span the tropopause and isentropic exchange by tropopause folding occurs. The region above the 380 K surface is the "overworld", in which isentropes lie entirely in the stratosphere. Light shading in the overworld denotes wave-induced forcing (the extra-tropical "pump"). The wiggly double-headed arrows denote meridional transport by eddy motions, which include tropical upper-tropospheric troughs and their cut-off cyclones as well as their mid-latitude counterparts including folds. Not all eddy transports are shown and the wiggly arrows are not meant to imply any two-way symmetry. The broad arrows show transport by the global-scale circulation, which is driven by the extra-tropical pump. This global-scale circulation is the primary contribution to exchange across isentropic surfaces (e.g. the ~380 K surface) that are entirely in the overworld.

The early SPARC programme

The early SPARC programme was organized around three major foci: stratospheric indicators of climate change; stratospheric processes and their relation to climate; and the modelling of stratospheric processes and trends and their effects on climate (see box).

Space does not permit a detailed discussion, but there have been many notable achievements within each of these foci and it is worthwhile drawing attention to some that have broadly influenced thinking and research in regard to stratospheric processes and, potentially, also public awareness and policy in important ways.

The now famous Holton diagram (Figure 1) encapsulates many of the ideas that have inspired SPARC activities and related research for the past decade. It illustrates schematically how upward propagation and dissipation of a broad spectrum of waves play a significant role in the dynamical coupling of the stratosphere and the troposphere. The Quasi-Biennial Oscillation and key features of the mean meridional circulation, transport and exchange processes in the stratosphere and upper troposphere are closely linked to upward propagation and dissipation of waves. Internal gravity waves, typically unresolved by large-scale numerical models, are an important component of the wave field. Parametrization of the effects of gravity-wave dissipation is now recognized as a key ingredient in successful modelling of the large-scale circulation of the stratosphere.

This challenging task motivated the SPARC initiative on Gravity Wave Processes and Parametrization (GWPP). A number of important activities have been organized under the

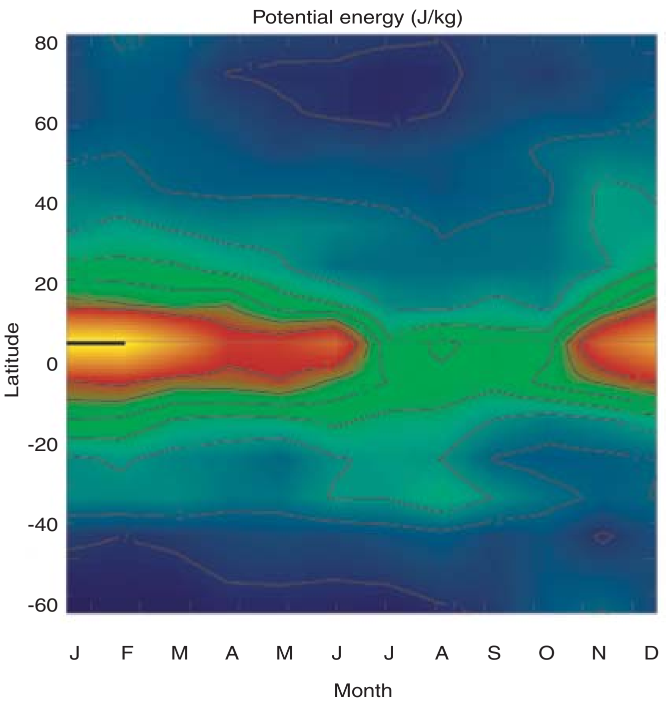


Figure 2 — Features of the gravity-wave climatology of the lower stratosphere

auspices of this initiative. These include field campaigns (e.g. the DAWEX campaign; Hamilton, 2003), workshops (e.g. the Chapman Conference on Gravity Wave Processes and Parameterization, Hamilton, 2004) and the accumulation and analysis of high-resolution radiosonde data from the Meteorological Services of several countries, under the aegis of WMO. Analysis of these data has enabled characterization of key features of the gravity-wave climatology in the lower stratosphere. Figure 2 depicts the meridional and seasonal dependence of the potential energy associated with gravity waves in the lower stratosphere, determined from the high-resolution data acquired and analysed by the scientists in the SPARC GWPP initiative. The contour labels are in J/kg.

Key findings with regard to temperature trends are illustrated in Figure 3. The first panel (Figure 3(*a*)) depicts zonal mean decadal temperature changes at three levels in the lower stratosphere, while Figure 3(*b*) illustrates the vertical profile and uncertainty (dashed lines enclose the two standard deviation range) at middle latitudes in the northern hemisphere. This figure is taken from the paper "Stratospheric temperature trends: observations and model simulations" (Ramaswamy *et al.*, 2001). A result of a SPARC collaboration, this paper was awarded WMO's Norbert Gerbier-MUMM International Award in 2003.

The increased cooling with height shown in the figure is consistent with model simulations, suggesting that changes in radiatively active trace-gas concentrations are major contributors to the observed cooling.

In addition to documented changes in the generally well-mixed gases (CO_2, CH_4, N_2O and chlorofluorocarbons), depletion of stratospheric ozone and increases in water vapour are also contributing factors. The globally averaged temperature changes observed in the lower stratosphere during the past two decades are a robust feature present in various observational datasets as is the corresponding change in the column ozone.

The vertical distribution of the trend in ozone is illustrated in Figure 4, taken from the SPARC-IOC Assessment of Trends in the Vertical Distribution of

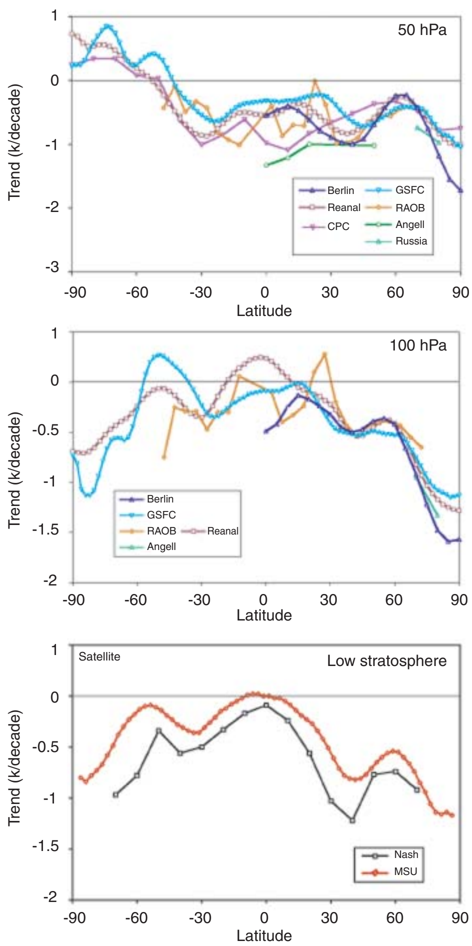


Figure 3(a) — Annual and zonal mean decadal temperature trends, 1974-1994

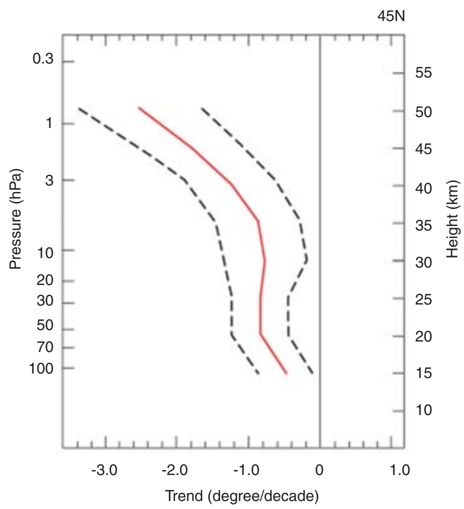


Figure 3(b) — Mean vertical profile and uncertainty of the temperature trend, 1979-1994

Ozone (SPARC Report No.1). The trends depicted in this figure were calculated using those derived from SAGE I-II, ozonesondes, SBUV and Umkehr measurements. Combined uncertainties are shown as 1σ (light solid lines) and 2σ (dashed lines). The combined trends and uncertainties are extended down to 10 km as shown by the light dotted lines but the results below 15 km should be viewed with caution.

The increasing water-vapour trend is illustrated in Figure 5 (SPARC Report No. 2) in terms of the water vapour mixing ratio linear change coefficient. Instruments, latitudes and valid time periods used are noted on the figure (error bars indicate the one standard deviation uncertainties on the coefficients from the linear regression analysis). Panel (*a*) and Panel (*b*) are identical with the exception of the HALOE time period used. Panel (*a*) shows the HALOE linear change term computed for 1993-1999, while Panel (*b*) shows the HALOE linear change term computed for 1993-1997. This water vapour trend has important radiative implications and could be contributing to warming in the troposphere and at the surface.

The Brewer-Dobson dehydration mechanism, condensation and freezing

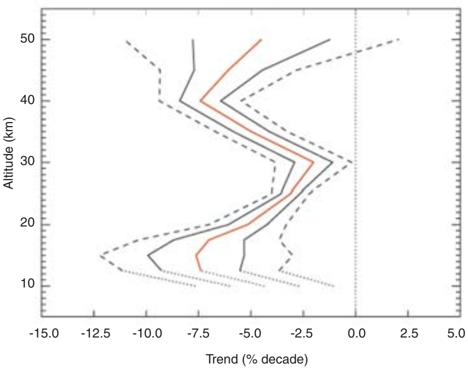


Figure 4 —Mean trends and uncertainties in the vertical distribution of ozone, northern mid-latitudes, 1980-1996

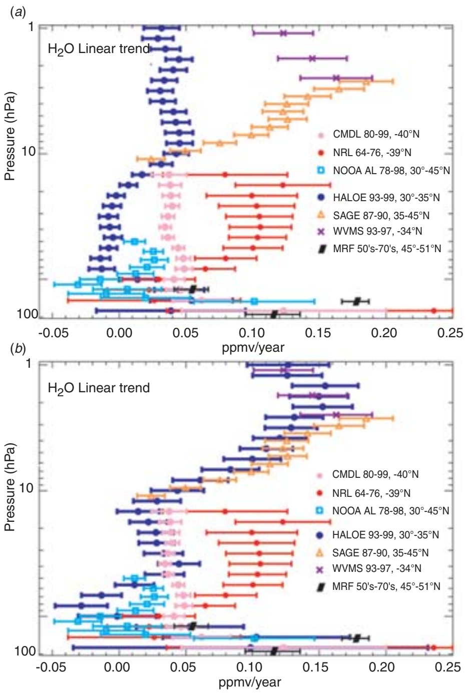


Figure 5 — Water vapour mixing ratio linear change coefficient

associated with low temperatures in the tropical upper troposphere and lower stratosphere (UT/LS), is considered to be the most important in controlling the water-vapour concentration in the lower stratosphere. This mechanism is clearly evident in the seasonal variation of water vapour in the tropical lower stratosphere derived from seasonal cycle fits of HALOE measurements (Figure 6), characterized by an elevated hygropause which ascends with time and is now widely known as the "tropical tape recorder" (Mote *et al*., 1996).

In view of the downward temperature trend in the lower stratosphere, the increasing water-vapour trend appears to be paradoxical. However, uncertainties in measurements of water vapour are substantial, particularly in regions of low amounts, and make the trend rather uncertain. Oxidation of methane, produced at the surface and transported into the stratosphere, is one of the main sources of water vapour in the stratosphere. The observed increase in tropospheric methane over the past several decades may have contributed to the stratospheric water vapour trend but is insufficient to explain it.

SPARC has taken keen interest in the coupling processes associated with stratosphere-troposphere interactions. One of its key successes has been to bring together dynamicists, specialists in atmospheric radiative transfer, chemists and microphysicists to address key research issues. The uncertainty concerning the water-vapour trend and mechanisms determining it is one of a number of important questions that relate to our understanding of key processes in the UT/LS region. This region is where coupling between chemical, microphysical and dynamical processes is of great importance. Because of the long radiative and chemical time-scales, this region is critical for climate sensitivity and understanding.

Modelling chemical and microphysical processes is critical to success in climate prediction. This is the transition between the high ozone and low water vapour regime of the middle stratosphere and the low ozone and high water-vapour regime in the troposphere. Transport processes play a particularly strong role in determining the structure of this region and a key role in determining abundances of ozone in the troposphere. These processes are also key to cloud formation and persistence and heterogeneous and multi-phase chemical reactions. Because of the complexity and variety of chemical, physical and dynamical processes within it, the UT/LS region is of interest to both SPARC and IGAC.

In the late 1990s, therefore, as a first step, SPARC and IGAC began a joint

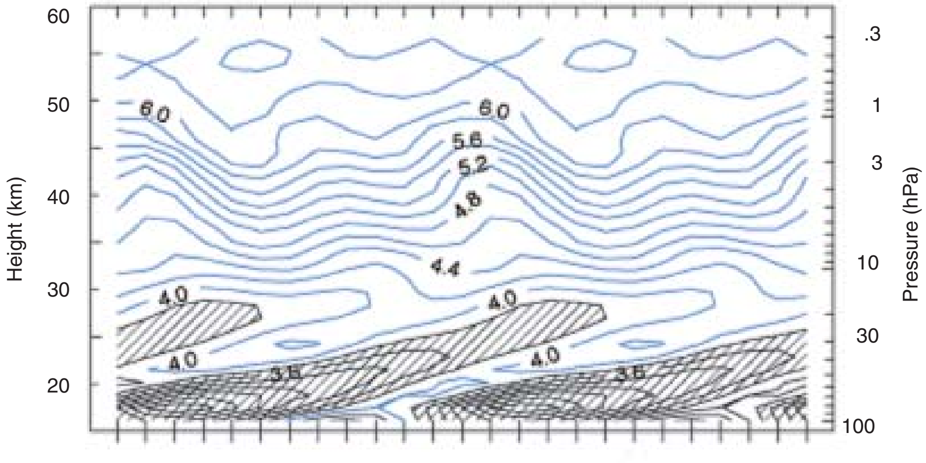


Figure 6 — Seasonal variation of the water vapour mixing ratio over the Equator

task on laboratory data of fundamental chemical processes which interested the two projects. This task produced many successful workshops that brought laboratory chemists together with the field measurement and modelling communities, and led to two successful review papers, one on the quantum yield of O(1D) in ozone photolysis (Matsumi *et al.*, 2002) and one on atmospheric chemistry of small peroxy radicals (Tyndal *et al.*, 2001). This initial collaborative task was the forerunner of the SPARC-IGAC collaborations on the Chemistry-Climate Interactions theme of SPARC (see "Future directions").

Comprehensive global climate models (GCMs) are among the most important tools for understanding the role of the stratosphere in the climate system and predicting climate change. Over the past two decades, rapid advances in computing technology and modelling expertise have resulted in the development of a number of such models, several of which include a realistic middle atmosphere.

The GRIPS project has become a focus for collaboration among major modelling groups on model development and evaluation. It has evolved through successive phases, from undertaking basic comparisons of models to studies of mechanisms. Annual workshops have served as the focus for presenting progress in the formal projects, as well as for presenting new results, as models have been developed. Key results from GRIPS collaborations have been published in journal articles. These include comparisons of simulations of key observable atmospheric variables from most of the major modelling centres (Pawson *et al.*, 2000) and documentation of other important features of model simulations such as the kinetic energy spectrum (Koshyk *et al.*, 1999) and the variability of precipitation and tropical wave activity (Horinouchi *et al.*, 2003).

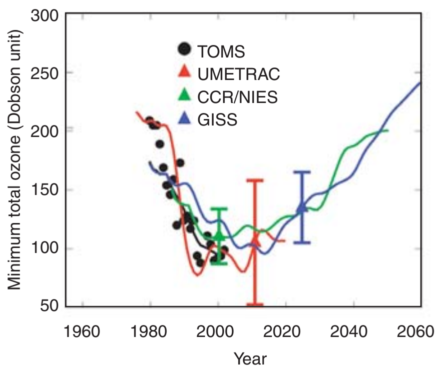


Figure 7 — Observed, simulated and predicted Antarctic total ozone

Figure 7 shows an example of chemistry-climate model predictions of Antarctic ozone changes to 2060 (from Austin *et al.*, 2003). Although the models are driven by the same imposed forcing changes, there are substantial differences in both time evolution and interannual variability among the models, and the reasons for these differences are poorly understood. Evaluating the reasons for such model sensitivities (in particular for coupled chemistry-climate models) is a crucial step forward for predicting future stratospheric change. This is but an example of intercomparisons of simulations of the current climate and of climate change that are of great value in understanding and improving the ability of models to predict future climate.

Meaningful comparison of model simulations with observations is greatly facilitated by the availability of a reference climatology which documents the observed means and variability of basic atmospheric variables that are predicted by models. The SPARC Reference Climatology Group was established to update and evaluate existing middle atmosphere (stratosphere and mesosphere) climatologies for GRIPS and other SPARC projects and activities. This led to publication of SPARC Report No. 3 (December 2002), which provides a comprehensive comparison of middle atmosphere climatologies.

Timely exchange of data between participating scientists is critical for successful collaboration. The SPARC Data Center (http://www.sparc.sunysb.edu/) was established in 1999 to facilitate collaboration and related research. Since its establishment, the number and variety of datasets in its archives and available on line have increased rapidly. These include key reference data used in SPARC assessments such as the Water Vapour

Assessment (WAVAS), as well as other data such as high-resolution temperature and wind data from radiosondes for selected years.

One of the hallmarks of SPARC has been the anticipation of the needs of international assessments such as the WMO ozone assessment and the assessments of the Intergovernmental Panel on Climate Change (IPCC). This has been done through timely workshops, development of key issues before the assessments (review articles and collaborative projects) and providing the expertise (participation of SPARC scientists as co-authors, lead-authors, contributing authors and reviewers). This service is expected to continue in the future.

Future directions

The progress of research and knowledge regarding stratospheric processes in the past decade, to a significant degree under the auspices of SPARC collaborations, has drawn attention to a number of issues that need to be addressed by collaborative research activities in the near future. In view of this, new themes and perspectives for the SPARC project have been developed and have received the support of the WCRP. Collaboration with other international projects is essential for promoting SPARC science within these themes. To this end, the Joint Scientific Committee of the WCRP has recognized that SPARC must play a leading role in achieving a number of specific objectives: (*a*) to lead a collaboration on chemistry-climate interactions with the IGAC project; (*b*) to focus on issues raised by recent studies of the Arctic Oscillation (AO); (*c*) to liaise with SCOSTEP on solar radiative forcing and temperature trends; (*d*) to work with WMO's Global Atmosphere Watch (GAW) project on the penetration of ultraviolet radiation; and (*e*) to contribute to international planning and mission planning. The above list is merely a subset of possible areas of collaboration. For instance, much stronger links with the WCRP's CLIVAR project are essential on long-term climate variability and predictability.

Recently, SPARC has organized its activities under three interlinked themes to consolidate its contributions to climate prediction and to make effective points of contact with other WCRP projects. The associated questions posed within each theme, though certainly not exhaustive, aim to identify primary foci for SPARC activities, at least in the immediate future.

Detection, attribution and prediction of stratospheric changes

- What are the past changes and variations in the stratosphere?
- How well can we explain past changes in terms of natural and anthropogenic effects?
- How do we expect the stratosphere to evolve in the future, and what confidence do we have in those predictions?

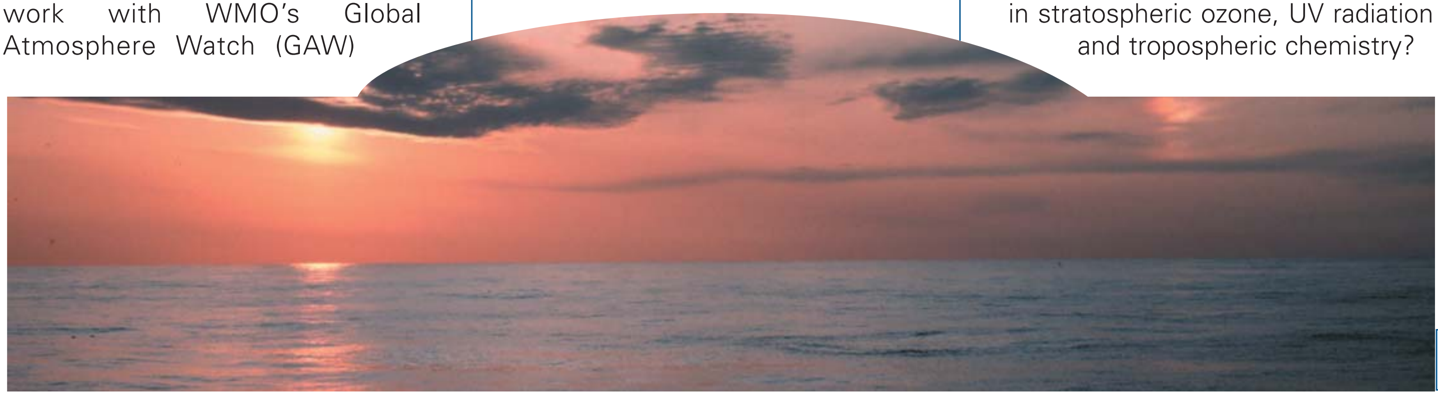
This theme is a continuation, synthesis and extension of earlier SPARC themes on long-term variability and trends in the stratosphere. Future work will emphasize attribution and prediction. This will require a concerted, collaborative research programme involving, in many instances, coupled chemistry-climate models.

Determining the magnitude of natural variability of key variables in key regions is critical to detection and attribution of long-term change. In many instances, the available observational record is not sufficiently long to evaluate the range of natural variability. For example, the major wintertime warming that occurred in the Antarctic stratosphere in 2002 (WMO, 2002) was the first recorded and abruptly reversed the trend toward a colder longer-lasting polar vortex, clearly evident in the previous 20 years of observations (Baldwin *et al.*, 2003). In contrast, wintertime warmings in the Arctic stratosphere are observed relatively frequently. The observing of this rare event in the Antarctic for the first time underlines the difficulty of evaluating the full range of natural variability from the observational record alone.

Evaluating the probability of such rare events with the aid of ensembles of long simulations using global climate models is a possibility (Taguchi and Yoden, 2002). Confidence in prediction and attribution will demand statistically significant results based on large ensembles of integrations with numerical models (or approaches that can be shown to be statistically equivalent). The experience gained within the GRIPS project is a basis for a future role of SPARC in coordinating experiments by different groups to facilitate meaningful comparison of results.

Stratospheric chemistry and climate

- How will stratospheric ozone and other constituents evolve?
- How will changes in stratospheric composition affect climate?
- What are the links between changes in stratospheric ozone, UV radiation and tropospheric chemistry?



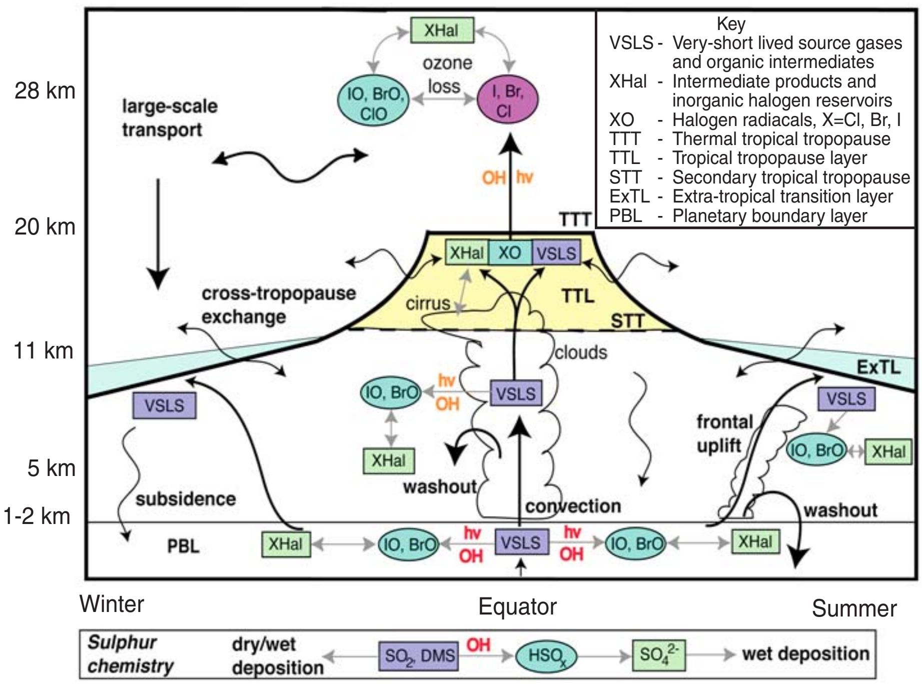


Figure 8 — Chemical and transport processes affecting very short-lived source gases and organic intermediates

The latest assessment report of the IPCC identifies insufficient knowledge of the coupling and feedbacks between atmospheric chemistry, the biosphere and the climate—and the consequent failure to represent the relevant processes adequately in climate prediction models—as serious scientific limitations. An interdisciplinary approach must be adopted, involving laboratory measurements, field campaigns and numerical modelling. Work under this theme will involve strong collaboration between the SPARC and IGAC projects. As noted above, the UT/LS region is where some of the scientific challenges are most demanding.

Clear understanding of the processes that connect emissions (source, precursors) to abundances, and the processes that connect the abundances to climate forcings are essential for an accurate prediction of the future climate and an assessment of the impact of climate change and variations on the Earth system. Studying processes involved in the chemistry and dynamics of the tropical tropopause layer (TTL) is an example of the kind of activities being undertaken in this theme. Some of these are depicted schematically in Figure 8 (Cox and Haynes, 2003; from Scientific Assessment of Ozone Depletion: 2002, WMO Global Ozone Research and Monitoring Report No. 47).

Stratosphere-troposphere coupling

- What is the role of dynamical and radiative coupling with the stratosphere in extended-range tropospheric weather forecasting and determining long-term trends in tropospheric climate?
- By what mechanisms do the stratosphere and troposphere act as a coupled system?

A strong motivation for this theme is that several recent observational studies have suggested that a so-called Arctic Oscillation (or Northern Annular Mode (NAM), with an equivalent Southern Annular Mode) is a dominant component of large-scale variability in the atmosphere. The finding that anomalies in an AO index can sometimes span the stratosphere-troposphere system has revivified the long-standing issue of stratosphere-troposphere coupling. In particular, the occasional downward propagation of anomalies from the stratosphere into the troposphere implies, with support from statistical analysis of the data, that knowledge of the state of the stratosphere can enhance our ability to predict aspects of the large-scale evolution of the troposphere, which would be of practical value for weather forecasting and climate prediction.

This is depicted in Figure 9, which shows that alterations of the tropospheric circulation down to the surface may be associated with a weakening (red) or strengthening (blue) of the stratospheric vortex. The diagrams show composites of the NAM index: (*a*) composite of 18 weak vortex events and (*b*) 30 strong vortex events (Baldwin and Dunkerton, 2001). Whether the state of the stratosphere influences the evolution of the troposphere in a causal sense (and if so, by what mechanisms and on what timescales?) are key issues demanding numerical experimentation.

As has been the case hitherto to for SPARC foci, addressing the scientific questions of the new SPARC themes will require underpinning activities within such general areas as model development, process studies and supporting data analysis and archiving. In many cases, facilitating these activities will require the setting-up (on a possibly temporary basis) of targeted working groups, some of which will numerical modelling. The Third SPARC General Assembly (Victoria, Canada, August 2004) highlighted the new themes and brought forward new results in a numbers of key areas that will continue to receive concerted attention from the SPARC community. (A report on the 3rd General Assembly is included in SPARC Newsletter No. 24 and expanded summary articles based on key presentations within it will appear in future newsletters). The General Assembly emphasized that, while our knowledge of the role of the stratosphere in the climate system has advanced enormously, major uncertainties remain, especially in the interaction of atmospheric chemistry and climate. Resolving these uncertainties will demand collaborative research that cuts across current WCRP projects.

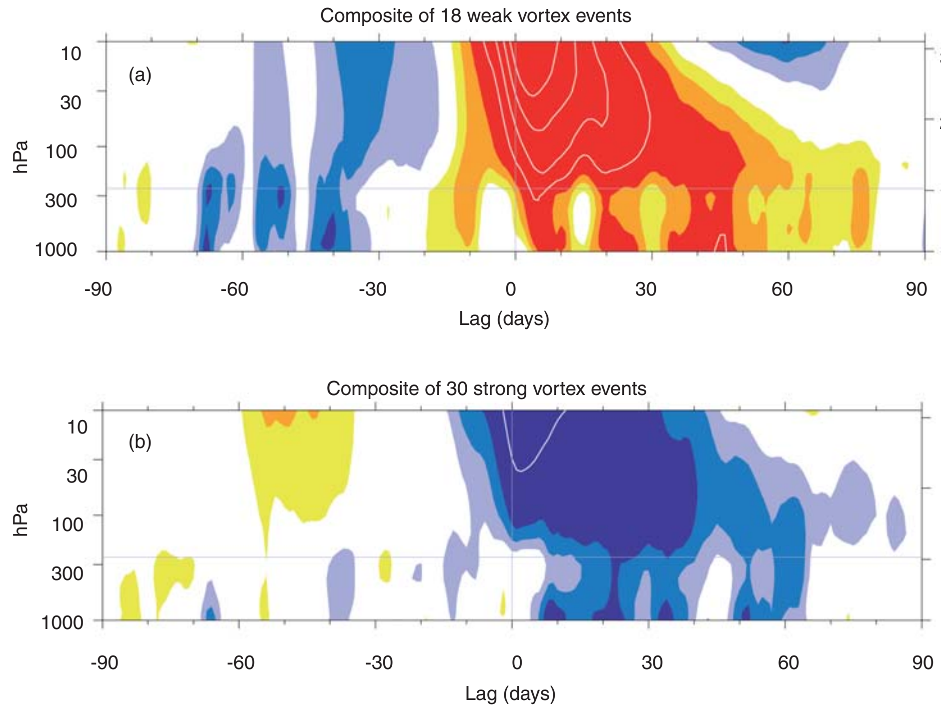


Figure 9 — Downward propagation of anomalies from the stratosphere into the troposphere

have evolved from current SPARC activities.

An example of such a new underpinning activity is the comparison of chemistry-climate models through process-oriented analysis and validation. An important component of several of the GRIPS workshops has been discussion of progress in coupled chemistry-climate models, even though no formal assessment had been organized. Climate models increasingly include chemical components and it is now well recognized that intercomparison and assessment of the performance of these components is important for improved understanding of both the chemical components and their underlying global climate models and, ultimately, for improved representations of these processes in global climate models.

Achievement of this goal as well as that of providing more scientifically useful information for upcoming assessments was the motor to include this activity as one of the supporting pillars of the SPARC programme themes. Concepts for this new activity were developed at a workshop in Grainau, Germany, in November 2003.

Targeted working groups will also be needed to resolve a variety of issues concerned with additional atmospheric processes within the context of the main scientific themes. One of many possible examples is the current uncertainty and lack of understanding of processes affecting the transport of water vapour from the troposphere to the stratosphere, which is needed to account for apparent long-term variability in water-vapour concentrations. SPARC will contribute to resolving these uncertainties through scientific assessments aimed at producing scientific review papers, and by promoting and participating in observational campaigns and associated

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Frozen assets: the cryosphere's role in the climate system

Cryospheric research camp at 6 100 m, 29°N on the south-eastern Tibetan Plateau (Photo: V. Aizen)

By Chad Dick, Director, CliC International Project Office

Introduction

Everyone knows we can't live without water, at least in its liquid form. But what about when it is frozen? For people living in or near the world's cold regions, snow and ice can be important for sustaining a way of life. In contrast, for many in temperate latitudes, they may seem merely an inconvenience or occasionally a danger; while for those in the tropics they may seem remote, uninviting and unimportant. But frozen water exists on the Earth's surface at all latitudes (Figure 1) and is vital to us all. Without it, and the freezing and thawing processes that affect its characteristics, the Earth's climate would be very different and perhaps far less hospitable for human life.

The "cryosphere" is defined as those regions of the Earth's surface where water exists in a frozen form. It includes snow cover, sea, lake and river ice, glaciers, ice caps and ice sheets and frozen ground, including permafrost. Wherever these cryospheric components exist, they have a profound effect on water, energy and chemical cycles. Snow and ice have relatively high albedo, reflecting incoming solar radiation away from the Earth's surface much more efficiently than the underlying land or water. Snowfall in cold regions can lock up freshwater for many months of the year, releasing it rapidly during the spring melt. Glaciers, ice caps and ice sheets can store water for hundreds or thousands of years and, if all this land ice were to melt, it is estimated that sea-level would rise by about 70 m. Sea-ice formation and melting redistribute freshwater and salt in the ocean and drive important water mass transformations that help to maintain global thermohaline circulation and to ventilate the deep ocean. Permafrost and frozen ground alter the fluxes of water, energy and gases between the land surface and the atmosphere and strongly influence land forms, hydrology and vegetation.

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Figure 1 — Ice coring at 4 115 m, 49°N, in the Altai Mountains (in the Southern part of Siberia). The cryosphere exists at all latitudes and there is an urgent need to collect ice cores from high-altitude, low-latitude glaciers before warming destroys the climate signals held in cold (polythermal) ice. (Photo: V. Aizen)

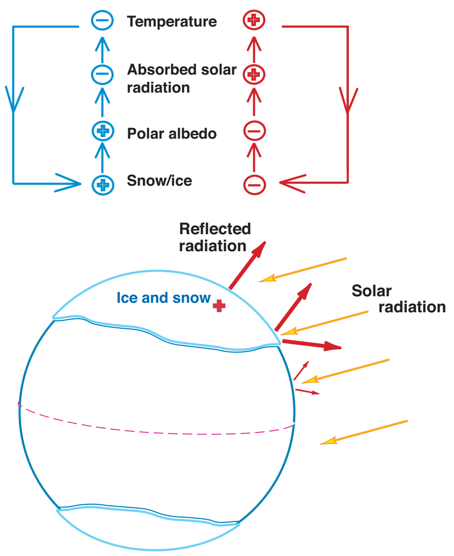

Figure 2 — Warming and cooling cycles in the snow and ice albedo feedback

In a changing climate, feedbacks and amplification of climate signals will play a crucial role in the future of the Earth system through their interaction with the cryosphere. For example, the snow-ice/albedo feedback (Figure 2) and the permafrost/greenhouse-gas amplification would both enhance any initial warming. Indeed, many global climate models predict that the Arctic region will show the greatest anthropogenic "greenhouse" warming, largely because of the albedo feedback.

Despite these connections to the rest of the global climate system, the cryosphere is still relatively poorly understood. Much of it is remote from major population centres, and its study can be difficult, dangerous and expensive. But without understanding the cryosphere and the climate interactions taking place in cold regions, we cannot fully understand the global climate system, and therefore cannot predict climate changes as atmospheric greenhouse-gas concentrations increase. With this in mind, the World Climate Research Programme (WCRP) has been responsible for setting up two major projects: the Arctic Climate System Study ((ACSYS), 1994-2003) and the ongoing (since 2000) project Climate and Cryosphere (CliC), to examine the interactions of global climate and the Earth's cryospheric regions.

The Arctic Climate System Study (ACSYS)

The Arctic climate system consists of four major elements: the ocean, the atmosphere, sea ice, and the land-based hydrological system. At the beginning of 1994 the Arctic Climate System Study (ACSYS) set out to study these four elements, their interactions and the interactions of this Arctic system with the rest of global climate. Of particular interest were the questions as to whether the Arctic was really as sensitive to increased greenhouse gases as many climate models suggested, and what the consequences of Arctic climate change would be for the rest of the globe. The decade-long project revealed many insights and a number of surprising and perhaps worrying results. Many of these were presented at a final ACSYS conference in St Petersburg, Russian Federation, in November 2003.

Disappearing sea ice

A record low Arctic sea-ice extent, at least for the 25-year period of satellite observation, occurred in September 2002, and was virtually matched in both 2003 and 2004. Since satellite monitoring began in 1979, sea-ice extent has reduced by approximately 2.3 per cent per decade. Over the same period, multi-year ice, that fraction which survives over the summer period to grow again the following winter, has reduced by a dramatic 8.9 per cent per decade. This multi-year ice is generally thicker than first-year ice, which is the result of only one winter's freezing, so some reduction in ice thickness would be expected as multi-year ice disappears. Studies by Rothrock *et al.* (1999) and Wadhams and Davis (2000), however, found a thinning of more than 40 per cent between submarine measurements (ACSYS/CliC, 2002) made between the 1950s and 1970s and modern measurements from the 1990s. Not only was the magnitude of thinning greater than expected but, remarkably for such a dynamic system, no region was found where the ice had increased in thickness.

Put together, this retreat and thinning indicate a major decrease in sea-ice volume, and would seem to be a clear indication of important climate change. Not all scientists were convinced, however. In a coupled atmosphere/ocean/ice modelling study of freshwater and energy balances in the Arctic Ocean, Holloway and Sou (2001; 2002) showed a similar pattern of thinning in the central Arctic, where the submarine measurements had been made, but a thickening of ice against the Canadian coast and north of Greenland (Figure 3).

With a much smaller net change shown by the model, this study suggested that the ice had moved due to changing patterns of atmospheric pressure and wind, rather than having melted away. The ACSYS Observation Products Panel carried out a review of all results and concluded that thinning had occurred, particularly in summer, but that it was likely to be less than the 40 per cent decrease suggested by the submarine measurements. The review also highlighted, however, the paucity of data, that so often plagues cryos-

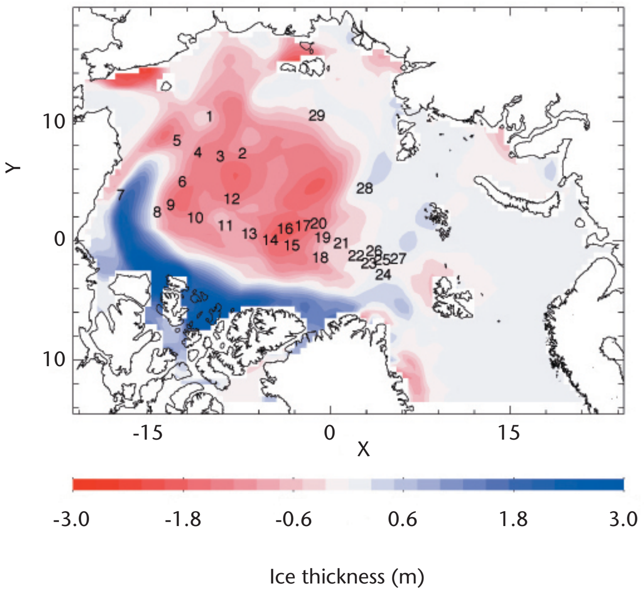

Figure 3 — Changing Arctic sea-ice thickness. Numbers show where observations found an average decrease of 40 per cent in ice thickness from the 1950s and 1970s to the 1990s, but models show that this may have been because the ice moved rather than melted.

pheric studies. Continuing measurements using both *in situ* and remote-sensing techniques will be necessary over the next few years to determine whether the thinning is part of a trend or a cycle.

Given the difficulty of collecting climate data in the Arctic Ocean, a remarkable success story has been the International Arctic Buoy Programme (IABP). Combining the efforts of currently 10 nations and 22 groups, this programme has successfully deployed drifters on the Arctic pack ice for more than 25 years. The drifters are tracked by satellite, revealing a detailed picture of the sea-ice motion in otherwise inaccessible areas of the central Arctic. In addition, pressure and temperature sensors have provided meteorological data in a region with few conventional measurements. Results have revealed changes of the major pattern of ice motion between the 1980s and the 1990s (Figure 4).

In the 1990s, there was an increase in ice advection away from the Siberian coast, a decrease of ice advection from the western to the eastern Arctic, and a slight increase in transport out of the Arctic Ocean through the Fram Strait (Rigor *et al.*, 2002). These patterns of ice motion have been found to be related to the Arctic Oscillation, which is essentially a statistical measure of the strength of the polar vortex. Between the 1980s and the 1990s, this oscillation switched to a generally positive phase, meaning that more warm air was brought to the Arctic with a consequent rise in mean temperature. It seems likely, therefore, that both the warming and the changes in ice motion are contributors to the reduction of sea ice observed during the ACSYS decade.

Warming of the Arctic Ocean and atmosphere

The Arctic atmosphere has become warmer during the past 20 years, with two of the fastest warming regions of the Earth being northwestern Canada/Alaska and eastern Siberia. This relatively abrupt warming is of similar magnitude to that observed during the 1930s. Comparison of these two warming "events" is crucial to understanding whether the current Arctic warming is of anthropogenic origin or part of natural climate variability. Whilst the magnitude of warming observed in the 1930s was similar, a major difference is that the current Arctic warming reflects a hemispheric warming trend (Figure 5). That of the 1930s occurred only at high latitudes and a different mechanism was responsible: greater exchange of air with lower latitudes, which in turn were cooled (Overland *et al.,* 2004) The hemispheric warming now occurring suggests an anthropogenic role is more likely over recent decades.

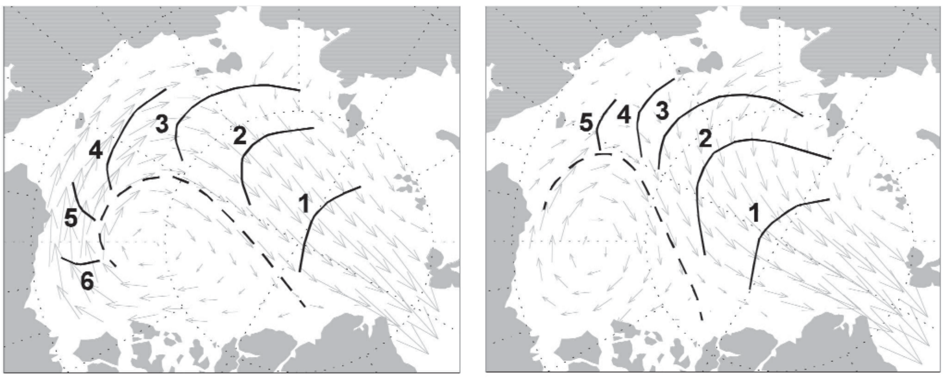

Figure 4 — The International Arctic Buoy Programme has demonstrated different modes of Arctic sea-ice motion corresponding to low and high Arctic Oscillation indices. The numbered lines show how many years it would take to drift across the Arctic Ocean and exit through the Fram Strait; the boundary between ice that will exit Fram Strait or recirculate in the Beaufort Gyre (dashed black line) is also shown. (Figure: I. Rigor)

Along with this recent atmospheric warming, the Arctic Ocean has also changed. In particular, there has been a weakening of the cold halocline, the near surface layer of cold, relatively freshwater that normally keeps warm, salty, Atlantic water well clear of the ocean surface—and hence clear of the sea ice. The abrupt density change observed in the past has become more smooth in recent years and has come closer to the surface. The area occupied by Atlantic water has also increased, particularly along the coast of Siberia, and the core of this water is now found 150 m nearer the surface. Of concern is the fact that, should it reach the surface, the heat contained in the Atlantic water layer is certainly enough to melt all the sea ice—an occurrence that would have widespread impacts, not only on Arctic ecosystems, but also on Arctic and global climate systems.

Faster flowing Arctic rivers

Of all the world's oceans, the Arctic is the most influenced by river runoff. It contains only 1 per cent of the ocean volume and covers only 5 per cent of the world's ocean area, yet receives 10 per cent of global river runoff and holds 20 per cent of the ocean shelf area. To add to this unusual situation, the freshwater input is highly seasonal. Flows are low in winter when rivers are frozen and precipitation in the Arctic Basin falls as snow, but spring melt brings a rapid increase in runoff. This input has a major effect on ocean buoyancy fluxes and its influence on the next season's sea-ice formation is still being investigated.

A major finding during the decade of ACSYS research, however, was that river runoff to the Arctic from the Eurasian continent had increased by 7 per cent between 1936 and 1999 (Peterson *et al.*, 2002). Much of this increase occurred in winter, reflecting warmer winter temperatures over much of Siberia. What is more surprising is that, whilst the increase in western Siberia matches an increase in precipitation, in eastern Siberia, precipitation has decreased but runoff has increased. Thawing of permafrost and consequent release of water is one suggested cause, which, if true, indicates that changes to landscape and vegetation will take place, as well as possible release of CO_2 and methane: all changes that could amplify initial climate warming.

Ongoing monitoring of river runoff and other land-based hydrological parameters is essential. To aid this, ACSYS set up two major databases. With the assistance of the WMO Global Runoff Data Centre at the Federal Institute of Hydrology in Koblenz, Germany, the Arctic Runoff DataBase (ARDB) was created to collect, process, store and distribute, runoff data from all the major rivers flowing into the Arctic. In addition, the WMO/WCRP Global Precipitation Climatology Centre at the Deutscher Wetterdienst, in Offenbach, Germany, has set up the Arctic Precipitation Data Archive (APDA) to collect precipitation data from the entire Arctic drainage basin. The data from these two centres provide an extremely useful resource for ongoing climate and hydrological research.

A major concern for Arctic hydrological studies has been the decaying observation networks in the region. ACSYS, along with partners in the Hydrology and Water Resources

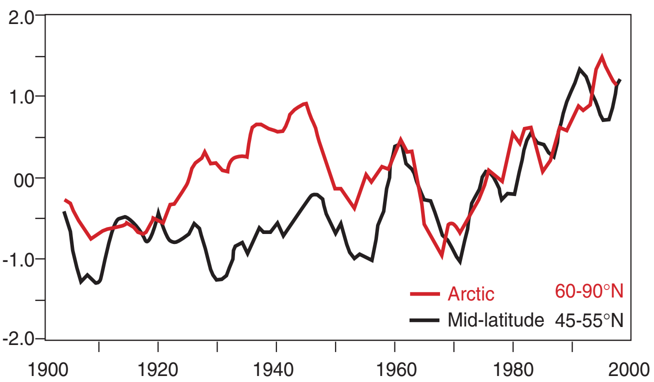

Figure 5 — 20th century zonal mean surface air temperature anomalies (November–March): recent increases in Arctic air temperature are part of a hemispheric trend, whilst increases in the 1920s and 1930s were largely an Arctic phenomenon. (Figure: after J. Overland)

CliC—the goals

The two-way interaction of the cryosphere and the rest of the climate system is recognized as extremely important: not only do changes in climate affect the cryosphere, but changes to the cryosphere can have a dramatic effect on local, regional and global climate. Reflecting this two-way interaction, the principal goal of CliC is:

- To assess and quantify the impacts of climatic variability and change on components of the cryosphere, and the consequences of these changes for the climate system.

Supporting objectives seek to enhance and coordinate our ability to observe and monitor the cryosphere, to carry out intensive climate-related process studies, to improve models of the cryosphere's role in the climate system, and to use cryospheric changes as indicators of climate change.

Department of WMO and the Arctic Monitoring and Assessment Programme has supported the development of an Arctic component of the World Hydrological Cycle Observing System (WHYCOS)—the Arctic HYCOS—which, it is hoped, will lead to an increase in the collection of vital *in situ* hydrological data in the Arctic Basin.

A variable Arctic climate system

One principal result of the ACSYS project was the identification of Arctic climate variability. Measurements made during ACSYS show that the overall Arctic climate system, and all the system's major elements, are much more variable than was imagined at the start of the project. Sea-ice distribution changes from one year to the next; the paths and strengths of major ocean currents change; freshwater export from the Arctic can vary by a factor of 2 from year to year; some years are warmer than others with melt seasons several days longer; and location, timing and amount of river input to the Arctic Ocean vary dramatically.

These unexpected variations have made it more difficult to understand the interplay between the various elements of the climate system, harder to identify trends, and more difficult to predict future changes. Useful clues to the future often come from understanding the past but, in this data-sparse region, even the data collected have not always received the best stewardship. Early leaders of the ACSYS project set up a number of data-recovery efforts to improve the situation, resulting in a number of records of Arctic climate parameters stretching back for decades or even centuries. The "BarKode" project, which recovered ocean temperature and salinity data from the Barents and Kara Seas region going back to 1898 (ACSYS, 1999) was recently overtaken for length of record by the ACSYS Historical Ice Chart Archive (ACSYS, 2003). This effort to record historical changes in the extent of Arctic sea ice was started by Torgny Vinje of the Norwegian Polar Institute, and drew on sailing ship logbooks, historical diaries, sealing and whaling records and a number of other historical sources, and used modern aircraft- and satellite-assisted charts to continue the series to the present day (Figure 6).

The result is one of the longest observational records of any climate parameter, with the first charts dating back to a doomed British expedition to the Barents Sea in 1553. Modern analysis of these charts is revealing even more variability. It appears that not only was past interannual variability similar to that of the present day, but also that the Arctic is profoundly influenced by decadal and multi-decadal climatic cycles (Divine and Dick, 2005; Polvakov *et al.*, 2003). The recovered data have confirmed again the complexity of the system and its interactions with the rest of the global climate system. This complexity emphasizes the importance of continued study of Arctic climate as a fully-interactive element within the global climate system.

Future studies: the Climate and Cryosphere (CliC) Project

As ACSYS progressed and the importance of the Arctic to global climate became ever clearer, attention was drawn to the Earth's other cold regions. It seemed likely that, like the Arctic, these other cold regions could have a greater influence on the global system than had previously been allowed for. A review of relevant scientific efforts identified the need for a greater understanding of the cryosphere and all its elements and interactions, in order for WCRP to fully cover the Earth's climate system. Many cryospheric elements were touched on within other WCRP projects. But, with the relatively small global cryospheric research community, the remoteness of much of the cryosphere and the complexity of adding the solid phase of water into conceptual and numerical models, the cryosphere often received a lower priority within these projects than perhaps was warranted by its importance within the climate system. With this in mind, in the late

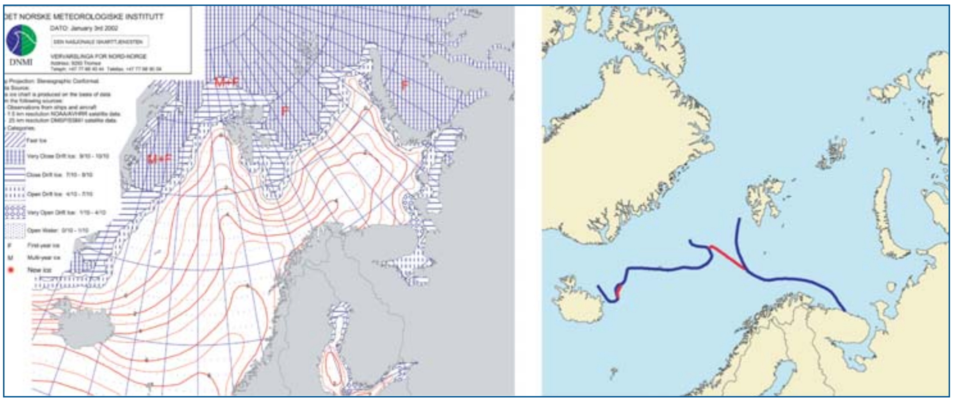

Figure 6 — The ACSYS Historical Ice Chart Archive used old log books from sailing vessels to reconstruct ice-edge positions going back to 1553. Modern charts (chart from 2002, left) now supplement historical data (chart from 1866, right).

1990s, the WCRP developed the Climate and Cryosphere (CliC) project (CliC, 2001) as a core project covering both polar regions and all cryospheric regions (continental and marine) in between.

Studying the cryosphere/climate system

The list of cryospheric elements is a clear indication of the breadth of the interaction of the cryosphere and climate. Each element responds to, and affects, climate in different ways, interacting on time-scales from short-term to seasonal effects of snow or frozen ground, to the millennial-scale responses of ice sheets and permafrost. It was therefore considered an essential simplification to tackle the CliC project as a series of related themes—CliC Project Areas (CPAs)—guided by key scientific questions. These CPAs cover broadly the terrestrial cryosphere, the contribution of land ice to sea-level rise, the marine cryosphere, and the links between the cryosphere and global circulation. Cryospheric indicators of climate change form an issue that cuts across all four CPAs.

The terrestrial cryosphere and hydrometeorology of cold regions (CPA 1)

Many of the processes involving snow cover on land, lake and river ice, glaciers and ice caps, permafrost, seasonally frozen ground and solid precipitation are poorly understood and poorly represented in current climate models (Figure 7). Key questions for this CPA are:

- What will be the magnitudes, patterns and rates of change in terrestrial cryosphere regimes on seasonal-to-century time-scales? What will be the associated changes in the water, energy and carbon cycles?

Major outputs are expected to be better understanding of water, energy and carbon fluxes in the Earth's cold regions, historical datasets on past cryosphere/climate variability and change, improved and validated satellite remote-sensing algorithms and improved schemes for assimilation of cryospheric data in both numerical weather prediction and coupled climate models.

Glaciers, ice caps and ice sheets, and their relation to sea-level (CPA 2)

If greenhouse-gas concentrations were stabilized at today's levels, sea-level rise would nonetheless continue for hundreds of years, with loss of land ice contributing significantly. Key questions are:

- What is the contribution of glaciers, ice caps and ice sheets to sea-level rise on decadal to century time-scales? How can we reduce the uncertainty of these estimates?

Major outputs will include new measurements, models and explanations of the current state of balance of glaciers, ice caps and ice sheets and a quantification of the indirect role of ice shelves through their influence on the flow of land-based ice sheets and glaciers. A comparison of ice-sheet models is already underway, seeking to improve our understanding of the past and future changes of the Greenland and Antarctic ice sheets.

The marine cryosphere and its interactions with high-latitude oceans and atmosphere (CPA 3)

Sea ice and its snow cover form an insulating layer that interacts with both the ocean and the atmosphere, while icebergs and ice shelves modify ocean water mass properties, and respond strongly to atmospheric warming (Figure 8). Key questions are:

- What are the mean state, variability and trends in sea-ice characteristics in both hemispheres, and what physical processes determine these characteristics? How will sea ice respond to, and affect, a changing climate in the future? How stable are ice shelves and how do they affect the surrounding ocean?

Major outputs will be systems for tracking key sea-ice variables (including thickness, extent and snow cover), understanding of key sea-ice processes, and observations and models of ice-affected ocean circulation and water

Figure 7 — Snow and lake ice in northern Norway. How fast will the terrestrial cryosphere change with changing climate? (Photo: H. Goldman)

Figure 8 — Sea-ice research will be vital for understanding and predicting future climate. (Photo: S. Gerland)

mass transformation. CliC will seek to build on the International Programme for Antarctic Buoys and the International Arctic Buoy Programme to maintain key climatic observational time-series, encourage new technologies for observing under-ice ocean properties (e.g. autonomous underwater vehicles and acoustic data transmission for profiling floats) and evaluate and improve remote sensing algorithms.

Links between the cryosphere and global climate (CPA 4)

Understanding the major influence of the cryosphere on the Earth's climate through its complex radiative, thermal, hydrological, and chemical interactions with the atmosphere and the injection of freshwater into the ocean and subsequent modification of water masses and circulation, remains a challenge.

Key questions are:

- What will be the impact of cryospheric changes on atmospheric and oceanic circulation? What is the likelihood of abrupt or critical Earth- system change resulting from processes in the cryosphere?

Major outputs of this highly cross-disciplinary CPA cover broad issues dealing with global climate interactions and millennial time-scales. Of specific interest are the teleconnections that link the cryosphere with the rest of the climate system, the mechanisms by which such major interactions occur, and the major feedbacks and amplifications of climate change that occur through the cryosphere. The project area will assess cryospheric predictions and predictability, with particular reference to abrupt climate change and effects on global biogeochemical cycles.

As the First CliC International Science Conference takes place in April 2005 in Beijing, China, the global science community looks forward to the International Polar Year (IPY), which starts in March 2007. This period of intensive effort will focus climatologists attention on the cold polar regions, and the CliC project will play a major role in coordinating studies of polar climate and the cryosphere. In addition, CliC will continue to promote efforts to study the cryosphere at all latitudes. Without such studies, our understanding of global climate, and our ability to make climate projections for the future will remain incomplete.

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Climate change indices

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Introduction

For decades, most analyses of long-term global climate change using observational data have focused on changes in mean values. Several well-respected datasets of monthly station temperature and precipitation data provide quite good coverage across the globe. Analysing changes in extremes (e.g. the number of days exceeding the 90th percentile of minimum temperature observations), however, requires long-term digital daily data. Unfortunately, such data are not readily available internationally for large portions of the world. In the 2002 "global" analysis by Frich *et al.* (2002), almost no analysis of extremes was possible for most of Central and South America, Africa and southern Asia. However, a concerted series of efforts to remedy that situation is underway.

Role of an international expert team (ET)

Two complementary efforts to enable global analysis of extremes are being coordinated by the joint WMO Commission for Climatology (CCl)/ World Climate Research Programme (WCRP) Climate Variability and Predictability (CLIVAR) project's Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI). Detailed information on the ET is available at http://www.clivar.org/organization/etccd. Members of the Expert Team come from all continents and encompass a wide range of expertise in the field of climate change. The author is not a member of the ET but works closely with it as chair of the CCl Open Programme Area Group (OPAG) on the Monitoring and Analysis of Climate Variability and Change to which the ET belongs. As all ET members are volunteers with full-time jobs, the focus of their work must be on what they can coordinate, recommend or inspire, rather than do themselves.

One of the ET's activities is international coordination of a suite of climate-change indices derived from daily data which focus primarily on extremes. The development of the indices involves not only ET members but also numerous other scientists working with daily climate data. By setting an exact formula for each index, analyses done in different countries or different regions can fit together seamlessly.

A total of 27 indices are considered to be core indices. They are based on daily temperature values or daily precipitation amount. Some are based on fixed thresholds that are of relevance to particular applications. In these cases, thresholds are the same for all stations.

Other indices are based on thresholds that vary from location to location. In these cases, thresholds are typically defined as a percentile of the relevant data series. The definitions of the 27 indices and the formulas for calculating them are available from http://cccma.seos.uvic.ca/ETCCDMI. This Website also provides the FORTRAN code for calculating the indices from daily data and a user-friendly software package to calculate the indices. This software package, called RClimDex, uses the free software R (see http://www.r-project.org for more information), which is a language and an environment for statistical computing and graphics.

Analysis software does not, however, perform without data. In many parts of the world, enough daily data have been digitized to contribute to an analysis but institutions are reluctant to share them. This is a difficult problem to address. The solution proposed by the ETCCDMI's predecessor was to hold regional climate-change workshops modelled after the Asia Pacific Network workshops (Manton *et al.*, 2000; Peterson *et al.*, 2001). Two were held in 2001 and, in view of the experience gained, the ETCCDMI decided to hold a series of other such workshops to cover all areas of the globe.

Regional workshop concept

The workshops bring together participants from as many countries as possible across an area for a combination of seminars and hands-on analyses of the daily data they bring with them. Through this process, a workshop "recipe" has been created. The workshops start with overview seminars, describing the reasons for holding the workshops and how the climate of the region is projected to change. The participants then describe the climate of their countries and the station data they bring with them.

The hands-on analysis starts with quality control (QC). RClimDex has several QC checks. Some identify specific data points as outliers. For these tests, each data point that is potentially a problem is examined. Based on data before and after, as well as the understanding of the climate of the region, the data are edited if the problem is obvious (e.g. 182° changed to 18.2°); set to missing if it is clearly a problem with unknown solution; or kept if deemed probably valid. With each change or acceptance of an outlier, a record of the decision and the reasons behind it is made in the QC log file. The second stage of QC involves evaluating numerous detailed graphs of daily data to detect evidence of possible quality issues with the data. An example of this would be an impossibly long period of time with zero precipitation. This problem can arise because many countries do not record zero precipitation, so missing values must initially be assumed to be zero.

The next stage of analysis is to conduct homogeneity assessments. Homogeneity adjustments of daily data are complex and difficult to make well (Aguilar, 2003). The focus on homogeneity is therefore to identify significant problems. When the homogeneity-testing software identifies a likely problem, the participant consults station history metadata, if available, to understand why. Non-climatic jumps in the time series have resulted in some stations not being used in the indices analyses or used only for the period after the discontinuity.

The work described in this article is the result of the collaborative effort of many individuals, who have been supported in this endeavour by their home institutions. Unfortunately, they are too numerous to be mentioned here by name. WMO, through its Expert Teams, provides the structure and coordination so that these volunteers may make these accomplishments.

Once QC and homogeneity testing have been accomplished, the calculation of the indices is quite simple. One of the benefits of doing this at a regional workshop is the synergy of immediately being able to see how results compare across borders. The participants create a short presentation of what the analysis is indicating about changes in extremes for each country. Similar results that span country borders verify the robustness of the analysis. Participants have found this workshop product quite useful when they return home.

The last part of the workshop looks to the future. This includes user feedback and advice for future workshop organizers. Discussing how to improve the available Global Climate Observing System (GCOS) Surface Network (GSN) data, now that the participants clearly understand the value of being able to compare analyses across country borders, is also relevant. Lastly, the participants discuss how to make the results of the analyses started at the workshop useful for climate-change assessments. This includes deciding who will lead the writing of multi-authored peer-reviewed journal articles, making the time-series of the indices available to other researchers, and the data themselves available to other researchers (the author list includes all participants who bring data contributing to the analysis).

So far, none of these workshops has been able to release time-series of daily data. There has been great success, however, in reaching agreement to release the indices and some success in encouraging the release of data from GSN stations to the GSN

Regional Climate Change Workshop in Brazil, August 2004

Archive Centre. For each of these series of workshops, peer-reviewed journal articles on changes in extremes in the regions are either in preparation or have already been submitted and the indices prepared to contribute to the global indices paper.

The workshops

The previous incarnation of the ETCCDMI, a CCI/CLIVAR Working Group, also addressed indices and regional climate change and held two workshops in 2001. The first was in the Caribbean, where 18 of the 21 National Meteorological Services participated. This workshop resulted in the release of daily data, indices, a meeting report, and a 17-author peer-reviewed journal article on how the climate in the region is changing (Peterson *et al.*, 2002). The second workshop was held in Casablanca, Morocco, for various African countries (Easterling, 2003).

The ETCCDMI sought to improve and extend those workshops to cover more of the world. Financial support was a limiting factor but adequate resources have become available to hold five workshops.

Summary

This series of regional climate-change workshops is achieving several important objectives. In regions where data are not readily accessible, a suite of climate-change indices that focus primarily on extremes has been produced and made available. The analyses would gain increased credibility by being reproducible with the release of the data. The strong focus on quality control and homogeneity testing (the results of which are being released), however, make it possible to evaluate the analysis independently, even without the digital data.

Regional workshops on climate change indices are "a very good beginning for regional cooperation".

The workshops

Southern Africa

Cape Town, South Africa,
31 May-4 June 2004

Southern South America

Maceio, Brazil, 9-14 August 2004

Middle East

Alanya, Turkey, 4-9 October 2004

Central America and northern South America

Guatemala City, Guatemala,
8-12 November 2004

South-Central Asia

Pune, India, 14-19 February 2005

Training scientists in these countries may not have been the driving goal, but the workshops have definitely had a major capacity-building aspect, as outside experts worked closely with regional participants on data analyses, provided them with user-friendly software, and introduced them to a free statistical package. The capacity building has, in turn, helped foster a greater appreciation of the importance of long-term *in situ* data and this has resulted in renewed efforts at digitizing historical records, as well as fulfilling GSN data-exchange goals.

These workshops are making a clear contribution to our understanding of how climate extremes are changing around the world. In addition to the in-depth peer-reviewed regional papers, the indices analysed at each of the workshops are contributing to two global extremes papers. Thanks largely to these workshops, these papers will indeed be global. Together, they will make a significant contribution to the upcoming Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Lastly, as one participant wrote after the Middle East workshop, they are "a very good beginning for regional co-operation".

Acknowledgements

These workshops were made possible by the generous financial support from the US State Department, the SysTem for Analysis, Research and Training, the World Climate Research Programme (co-sponsored by WMO, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO) and the Inter-American Institute for Global Change Research.

Thanks are also due to the institutions which hosted the workshops: the University of Cape

Regional Climate Change Workshop in Turkey, October 2004

Regional Climate Change Workshop in Guatemala, November 2004

Town, South Africa; the Federal University of Alagoa, Brazil; the Turkish State Meteorological Service; the National Institute of Seismology, Vulcanology, Meteorology and Hydrology, Guatemala, and the Regional Committee for Water Resources of the Central American Isthmus (Costa Rica); and the Indian Institute of Tropical Meteorology (Pune)

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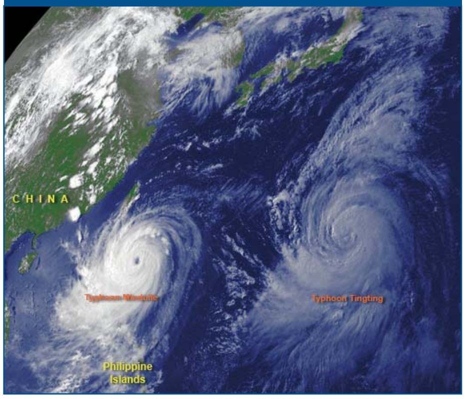
The global climate system in 2004



Typhoons Mindulle and Tingting on 29 June 2004 (Image: NOAA)

Since 1993, WMO has issued annual statements on the status of the global climate to provide credible scientific information on climate and its variability. These statements complement the periodic assessments of the WMO/United Nations Environment Programme Intergovernmental Panel on Climate Change. This article is drawn from the statement describing the climatic conditions, including extreme weather events, for the year 2004. (WMO-No. 983)

Global temperatures

The global mean surface temperature in 2004 was 0.44°C above the 1961–1990 annual average (14°C). This value places 2004 as the fourth warmest year in the temperature record since 1861 just behind 2003 (+0.49°C). The last 10 years (1995–2004), with the exception of 1996, are among the warmest on record. The five warmest years in decreasing order are: 1998, 2002, 2003, 2004 and 2001.

Over the 20th century, the increase in global surface temperature was between 0.6°C and 0.7°C. The rate of change since 1976 is roughly three times that for the past 100 years as a whole. In the northern hemisphere, the 1990s was the warmest decade with an average of 0.38°C. The surface temperatures averaged over the past five years (2000–2004) were, however, much higher (0.58°C). Surface air temperatures measured by a worldwide network of land stations have shown that trends of night-time minimum temperature on still nights were the same as on windy nights.

Calculated separately for both hemispheres, surface temperatures in 2004 for the northern hemisphere were the fourth warmest (+0.62°C) and, for the southern hemisphere, the sixth warmest in the instrumental record from 1861 to the present (+0.25°C). Globally, the land-surface air temperature anomalies for October and November 2004 were the warmest on record for these months. The blended land and sea-surface temperature (SST) value for the Arctic (north of 70°N) in July and the land-surface air temperature values for Africa south of the Equator in July and November were also the warmest on record for these months. Significant positive annual regional temperature anomalies, notably across much of the land masses of central Asia, China, western parts of the USA and Alaska, as well as across major portions of the North Atlantic Ocean, contributed to the high global mean surface temperature ranking.

Regional temperature anomalies

Large portions of the northern hemisphere had warm conditions in 2004 that exceeded 90 per cent of the annual temperatures recorded in the 1961-1990 period (the 90th percentile). Northern China, parts of central Asia and the eastern North Atlantic had warm temperatures exceeding the 98th percentile. Only a few small areas experienced temperatures below the 10th percentile.

During June and July, heatwaves with near-record temperatures affected Portugal, Romania and southern Spain, with maximum temperatures reaching 40°C. In the second week of August, an unusual heatwave affected parts of Iceland, making the month of August the second warmest there on record.

An exceptional heatwave affected much of eastern Australia during February, as maximum temperatures soared to 45°C in many areas with temperature anomalies exceeding 8°C. The spatial and temporal extent of the heatwave was greater than that of any other February heatwave on record and ranked among the top five Australian heatwaves in any month.

A prolonged severe heatwave across northern parts of India during the last week of March and the beginning of April caused more than 100 deaths. During this period, maximum temperatures generally exceeded the long-term averages by 5-7°C. In Japan, extremely hot conditions persisted during the summer with record-breaking maximum temperatures. Tokyo experienced a maximum temperature of 39.5°C on 20 July, which broke the previous record set in 1923.

During the northern hemisphere winter, very cold weather episodes were observed in the northern parts of India and Bangladesh, which were blamed for as many as 600 deaths. Maximum and minimum temperatures were 6-10°C below normal. During the austral winter, abnormally cold conditions in the high-altitude areas of the Andes in southern Peru reportedly killed 92 people and more than 100 000 farm animals.

Prolonged drought in some regions

In early 2004, drought conditions continued to affect parts of eastern South Africa, Mozambique, Lesotho and Swaziland. However, enhanced precipitation in the last half of the rainy season (November to March) provided some benefit to crops in southern Africa. Rainfall during both the long (March to June) and short (October to November) rainy seasons of 2004 was well below normal across parts of the Greater Horn of Africa, resulting in a continuation of multi-season drought. Isolated regions in the southern sector and portions of Uganda experienced driest conditions on record since 1961. In Kenya, a premature end to the 2004 long rains exacerbated the drought conditions resulting from several years of poor rainfall in many areas. Food production in Kenya was projected at approximately 40 per cent below normal. In spite of abundant rainfall in 2004, multi-year drought conditions also continued in Somalia, threatening agriculture and food security in the region. In Eritrea, struggling from nearly four years of drought, poor rains during the March-May rains exacerbated drinking-water shortages.

In India, the 2004 seasonal rainfall during the south-west monsoon season (June-September) over the country as a whole was 13 per cent below normal with 18 per cent of the country experiencing moderate drought conditions. Rainfall deficiency was the highest over north-west India, where only 78 per cent of normal rain-

A disastrous cyclone season

The 2004 tropical cyclone season over the North Atlantic and the north-west Pacific saw some of the most deadly hurricanes and typhoons responsible for more than 6 000 deaths and heavy damage to infrastructure. The 2004 cyclone season was the second costliest cyclone season after 1992 and the number of deaths due to tropical cyclones was the highest since 2000.

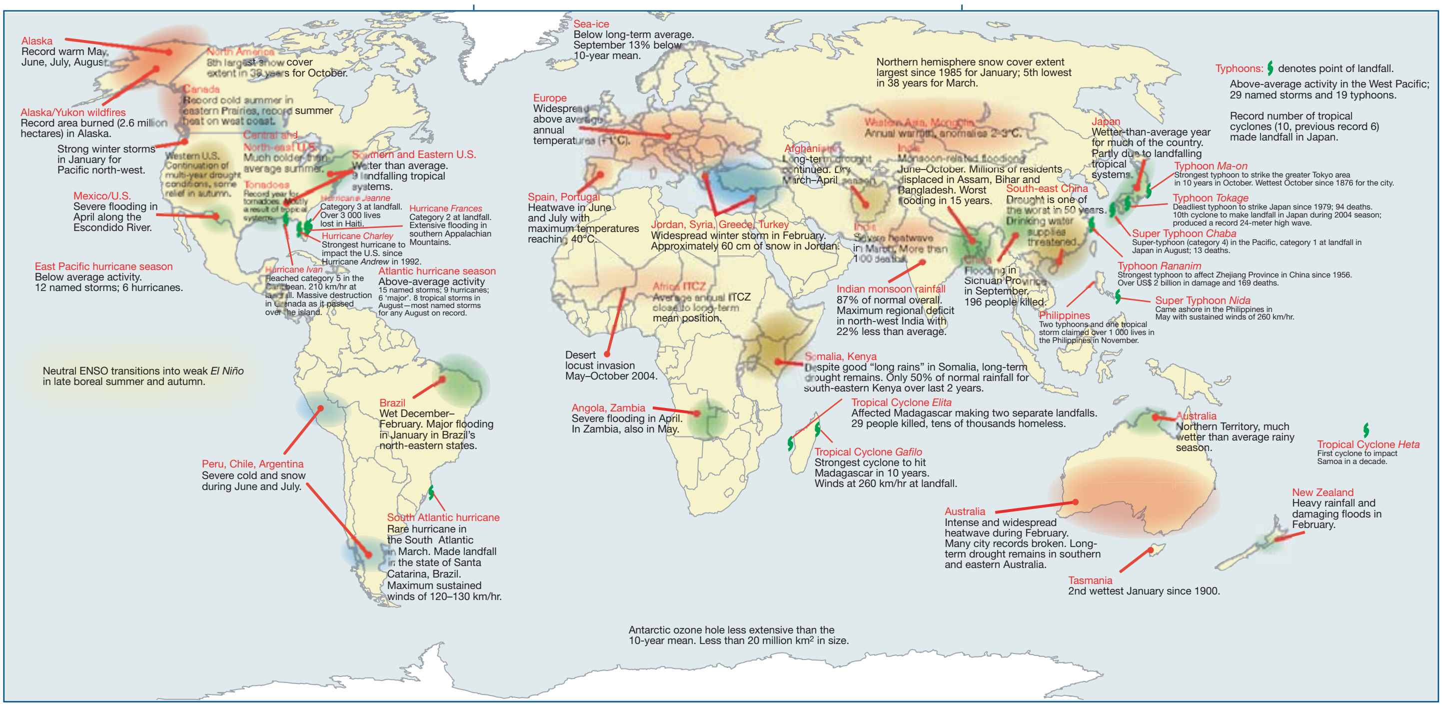
During the Atlantic hurricane season, 15 named tropical storms developed; the average is around 10. During August, eight tropical storms formed, which is a record for the most named storms for any month of August. Since 1995, there has been a marked increase in the annual number of tropical storms in the Atlantic Basin, which is coincident with the active phase of the Atlantic multi-decadal signal. Nine of the named storms were classified as hurricanes. Six of those were “major” hurricanes (category three or higher on the Saffir-Simpson scale). Hurricane *Ivan* was the most powerful storm to affect the Caribbean in 10 years. Hurricane *Charley* was the strongest and most destructive hurricane to strike the USA since *Andrew* in 1992. In all, nine named storms impacted the USA, causing extensive damage estimated at more than US$ 43 billion and making 2004 the costliest hurricane season in the USA on record. Atlantic tropical cyclones were directly responsible for more than 3 000 deaths in 2004; the vast majority were in Haiti due to floods from Hurricane *Jeanne*.

Conversely, in the eastern North Pacific, tropical cyclone activity was below average. Only 12 named storms developed during the year, compared to an average of 16. Out of those 12 storms, six reached hurricane strength and three reached “major” status. None of the cyclones made landfall as a tropical storm or hurricane.

In the South Atlantic Ocean, sea-surface and atmospheric conditions do not favour the formation of hurricanes. During March 2004, however, the first documented hurricane since geostationary satellite records began in 1966 developed. Unofficially named *Catarina*, it made landfall along the southern coast of Brazil (in the state of Santa Catarina) on 28 March 2004, causing great damage to property and some loss of life.

In the north-west Pacific, 29 named storms developed; the average is around 27. Nineteen of them reached typhoon intensity, which was slightly more than the long-term average. On an average, three tropical cyclones make landfall in Japan. However, in 2004, 10 tropical cyclones made landfall, breaking the previous record of six, established in 1990. Typhoon *Tokage* was the deadliest typhoon to affect Japan since 1979. Two hundred and nine people were killed in Japan by floods, landslides, strong wind and storm surge caused by the tropical cyclones. They also caused damage to infrastructure worth around US$ 10 billion. Typhoon *Rananim*, which was the most severe typhoon affecting Zhejiang, China, since 1956, claimed 169 fatalities and caused damage worth over US$ 2 billion.

The South-West Indian Ocean cyclone season was also active with an above normal number of tropical storms. Tropical cyclone *Gafilo*, which was responsible for 237 deaths, was the strongest to affect Madagascar in 10 years. Tropical storm 02B made landfall on the coast of Myanmar on 19 May, causing 200 fatalities. However, tropical cyclone activity over the South Pacific/Australian region was suppressed.



Significant climatic anomalies and events in 2004. The average global temperature was the fourth warmest on record, with a rise in global temperature greater than 0.6°C since 1900. (Source: US NOAA National Climatic Data Center)

fall was received. In neighbouring Pakistan, poor rains in July and August aggravated the long-term drought conditions, which had prevailed since the boreal spring. The rainfall deficiency was the largest over Balochistan and Sindh provinces, causing a water crisis. In Sri Lanka, drought conditions prevailing since the end of 2003 were aggravated by deficient rainfall during the 2004 summer monsoon season. In Afghanistan, drought conditions that had plagued the country for the past four years continued in 2004 due to below-normal precipitation in March-April. In the spring season, parts of north-eastern China experienced the worst drought conditions since 1951, owing to deficient spring rainfall and above-normal temperatures. Later in the autumn, the southern provinces of China received the lowest rainfall since 1951, resulting in a drought which affected agriculture and drinking water.

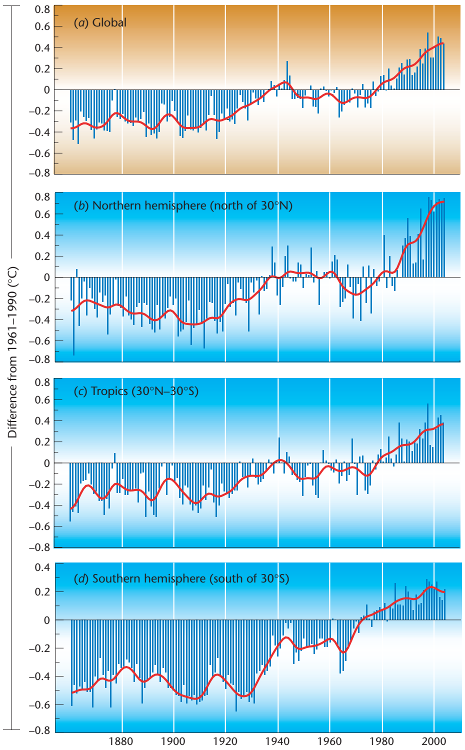
Long-term hydrological drought continued to affect much of southern and eastern Australia as a result of rainfall deficits since the major drought event of 2002/2003. The weak El Niño conditions in the Pacific hindered any significant recovery from long-term rainfall deficiencies. This resulted in significant crop losses in many areas of eastern Australia.

Moderate-to-severe drought conditions continued in some areas of the western USA for the fifth year in a row. At the beginning of 2004, moderate-to-extreme drought conditions covered about one-third of the contiguous USA. Some rain in September and October caused a decrease in the national drought area to about 5 per cent by the end of October. In 2004, due to deficient annual rainfall, the eastern provinces of Cuba experienced a drought which eroded 40 per cent of farmlands. A prolonged drought also affected and severely threatened food security and health in the south-eastern El Chaco region of Bolivia.

Rainfall and flooding

Precipitation in 2004 was above average for the globe and 2004 was the wettest year since 2000. Wetter-than-average conditions prevailed in the southern and eastern USA, Russia, parts of western Asia, Bangladesh, Japan, coastal Brazil, Argentina and north-west Australia.

The Asian summer monsoon during June-September brought heavy rain and flooding to parts of northern India,



Combined annual land (near surface) and sea-surface temperature anomalies from 1861-2004 (departures in °C from the average in the 1961-1990 base period). The solid red curves have had subdecadal time-scale variations smoothed with a binomial filter. Anomalies (in °C) for 2004 are: +0.44 (a); +0.75 (b); +0.38 (c); and +0.22 (d). (Sources: Hadley Centre, Met Office, UK, and the Climatic Research Unit, University of East Anglia, UK)

Nepal and Bangladesh, leaving millions stranded. Throughout India, Nepal and Bangladesh, some 1 800 people died from flooding brought by heavy monsoon rains. Flooding in north-east India (Assam and Bihar, in particular) and Bangladesh was the worst in over a decade. In eastern and southern China, heavy rains during the summer produced severe flooding and landslides that affected more than 100 million people and caused more than 1 000 deaths nationwide. Heavy monsoon rainfall during July and August produced flooding along several rivers in north-eastern and central Thailand. A significant low-pressure system brought record-breaking snowfalls in the Republic of Korea on 5 March, resulting in damage to agriculture worth more than US$ 500 million.

In October, two typhoons and active frontal systems brought record-breaking heavy rainfall to Japan. Tokyo received a total amount of 780 mm precipitation in October, which is the largest monthly amount on record since 1876. In the second half of November and the beginning of December, two typhoons and one tropical storm passed over southern and central parts of the Philippines, drenching the islands with several days of torrential rainfall and triggering catastrophic flash floods and landslides, which killed, according to reports, more than 1 800 people.

Mudslides and floods due to heavy rains across areas of Brazil during January and early February left tens of thousands of people homeless and resulted in 161 deaths. The rainy season in the Peruvian and Bolivian highlands brought heavy seasonal rainfall, hailstorms and landslides, which caused heavy damage to agricultural crops and lands and killed at least 50 people. In Haiti, torrential rainfall due to the passage of Hurricane *Jeanne* produced disastrous flooding that claimed some 3 000 lives.

This disaster came in the wake of flooding and landslides that affected Haiti and the Dominican Republic in late May 2004, in which more than 2000 people were killed and several thousand others were affected. A series of winter storms in late June and early July 2004 brought heavy rains and produced mudslides over the Patagonia region of Chile and Argentina.

In April, a storm brought heavy rain and flash floods to the south-western USA and adjoining Mexico. In February, a winter storm brought record-breaking snowfalls and blizzard conditions in Canada. The city of Halifax recorded 88.5 cm of snow on 19 February, which doubled the previous record for a single day. In July, torrential rain and a hailstorm resulted in horrendous flash floods in Edmonton and Peterborough, which were estimated to be the worst in 200 years.

Severe winter weather also affected much of western and northern Europe during the last week of January with heavy accumulations of snow reported in parts of the United Kingdom, France, Germany and Denmark. In April, heavy long rains caused flooding in some parts of western Siberia. In the northern Caucasus, hundreds of buildings, bridges and motorways were heavily damaged and crop production was affected. In November, an early season winter storm brought record-breaking heavy snowfall and strong winds across much of the Scandinavian region and central Europe, causing extensive damage.

Heavy rains from mid-January to March in areas of Angola produced flooding along the river system which flows into neighbouring Zambia, Botswana and Namibia. Extensive flooding along the Zambezi River, the worst flooding since 1958, threatened more than 20 000 people in north-eastern Namibia and caused extensive damage to crops.

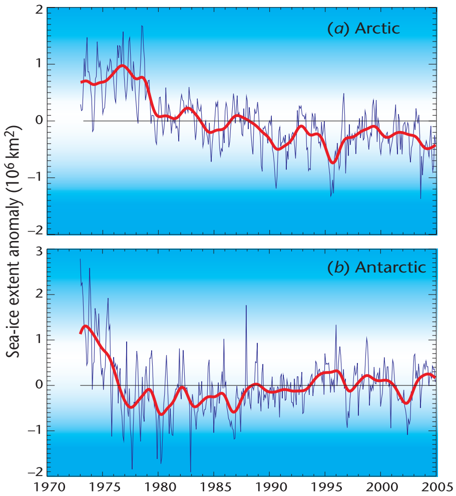
Rainfall was above normal over most of the western and central Australian tropics during the 2003–2004 tropical wet season (October–April). In some parts of the Northern Territory, it was the wettest rainy season on record. A series of strong storms in February produced heavy rainfall and damaging floods in southern parts of New Zealand's North Island.

Weak El Niño conditions

Sea-surface temperature and sea-level atmospheric pressure patterns in the tropical Pacific at the beginning of 2004 reflected near-neutral El Niño conditions. However, the increase and eastward expansion of anomalous warmth in the central and east-central equatorial Pacific during July-December indicated weak El Niño conditions. Since the last week of July, sea-surface temperatures over the equatorial central Pacific region were approximately 0.8°C above average. However, the pattern of above-average SST anomalies was focused only near the dateline. The eastern Pacific, which is usually instrumental in the development of an El Niño event, remained largely neutral throughout 2004. The Tahiti-Darwin Southern Oscillation Index was negative since June 2004, but fluctuated considerably. The large-scale atmospheric changes expected during an El Niño event were, however, conspicuously absent during this episode.

Antarctic ozone hole

Extensive ozone depletion was observed over the Antarctic during the southern hemisphere winter/spring of 2004. This year, the Antarctic ozone hole area (defined as the area covered by extremely low ozone values of less than 220 Dobson Units) reached a maximum size of 19.6 million km^2 in mid-September. Except for the year 2002, when the ozone hole split into two, the October ozone hole in 2004 was the smallest observed in more



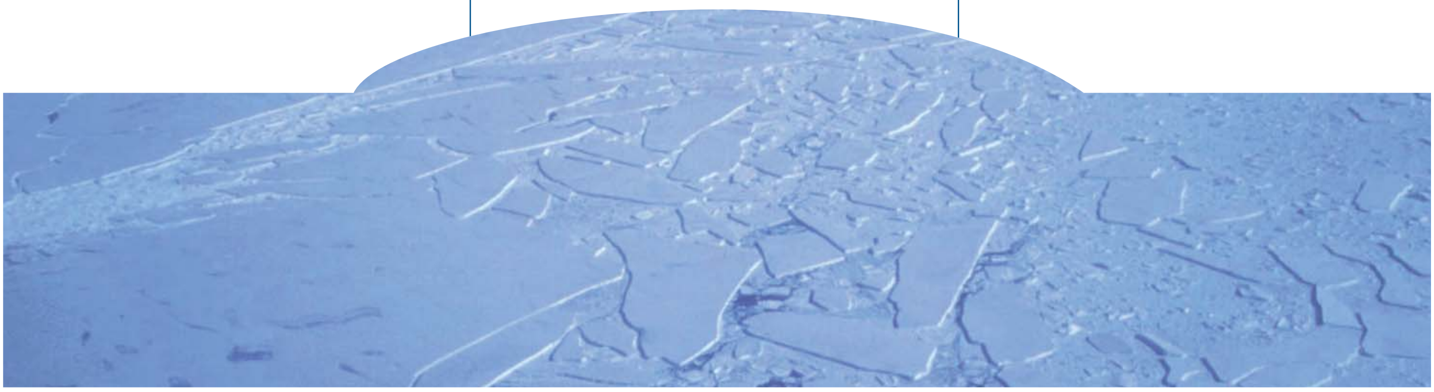
Monthly sea-ice extent anomalies for 1973–2004 (departures in millions of km^2 from the average in the 1973-2004 base period) for the Arctic and the Antarctic. The values are derived from satellite passive microwave sounder data. (Source: Hadley Centre, Met Office, UK)

than a decade and dissipated earlier than usual, in mid-November.

Variations in size, depth and persistence of the ozone hole are due to year-to-year changes in the meteorological conditions in the lower stratosphere, rather than to changes in the amount of ozone-depleting substances present in the ozone layer. Measurements show that most of these substances are decreasing in the lower atmosphere. However, chemicals already in the atmosphere are expected to continue to impact the ozone concentration for many decades to come. Continued monitoring and measurements are essential to achieve the understanding needed to identify ozone recovery.

Arctic sea ice

In 2004, sea-ice extent in the Arctic remained well below the long-term average. In September 2004, it was about 13 per cent less than the 1973–2003 average. Satellite information suggested a general decline in Arctic sea-ice extent of about 8 per cent over the last two-and-a-half a decades. This is the third year in a row with extreme sea-ice losses. The September sea-ice deficit was especially evident in extreme northern Alaska and eastern Siberia. Sea-ice extent responds to a variety of climatic factors. While natural variability is responsible for year-to-year variations in sea-ice extent, three extreme minimum extent years, together with the evidence of thinning of the ice pack, suggest that the sea-ice system is experiencing changes not solely related to natural variability.



Weather and global crop production in 2004

The objective of WMO's Agricultural Meteorology Programme is to foster a better understanding by farmers and other users in the agriculture, forestry and related sectors of the use and value of weather and climate information in planning and operational activities. This article, based on information provided by the United States Department of Agriculture's Joint Agricultural Weather Facility, illustrates how weather and climate information can be used to assist agricultural decision-makers.

The following is an annual review of regional crop production, comparing 2004 with the previous year. For both the northern and southern hemispheres, these summaries reflect growing-season weather for crops that were harvested in the calendar year of 2004. For most countries, changes in production for 2004 are based on crop estimates released by the United States Department of Agriculture in February 2005.

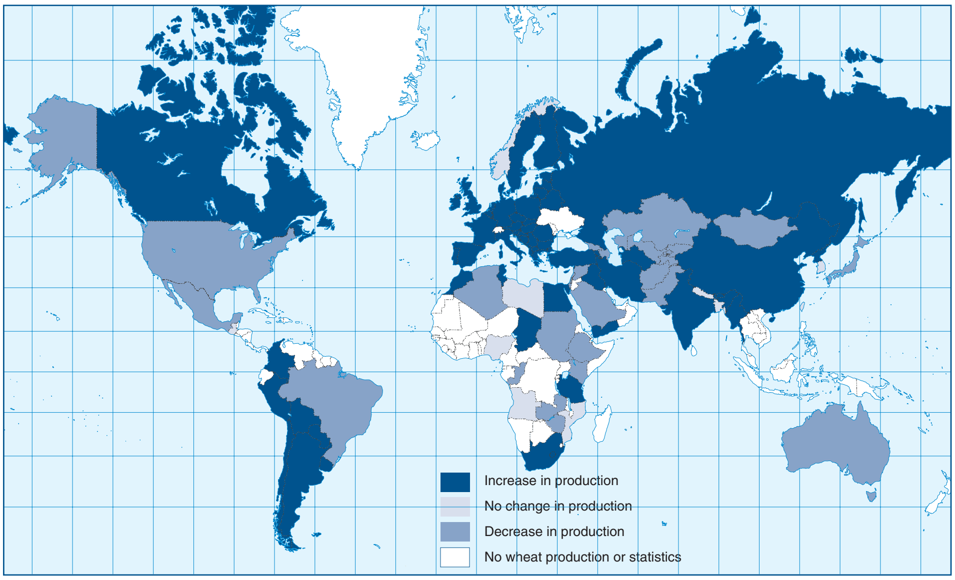
Wheat and coarse grain

World wheat production increased by 13 per cent over 2003. Wheat production increased in Argentina, Canada, China, countries of the European Union, India, the Islamic Republic of Iran, Morocco, Tunisia, Turkey, the Russian Federation, South Africa and Ukraine and declined in Algeria, Australia, Brazil, Kazakhstan, Mexico, Pakistan and the USA. World coarse grain production increased by 9 per cent. Production increased in Canada, China, the European Union, the Islamic Republic of Iran, Morocco, Turkey, Ukraine and the USA and declined in Argentina, Australia, Brazil, India, Kazakhstan, Mexico, the Russian Federation and South Africa.

In Canada, wheat and barley production rose 10 and 7 per cent, respectively, due to a generally mild, wet weather pattern that dominated the Prairies for much of the spring and summer. This was a welcome change from recent years of drought and untimely dryness, while long-term moisture conditions improved in many previously dry growing areas. As a result of late plantings and below-normal summer temperatures, however, crops lagged behind the normal pace of development throughout the region for most of the growing season. An earlier-than-normal autumn freeze resulted in some damage and quality reductions, with reports of unusually large amounts of small grains registering as feed grade. In Ontario, corn production fell about 8 per cent as smaller area more than offset excellent yields.

In China, wheat production increased 4 per cent due to favourable weather and timely rain throughout the growing season on much of the North China Plain. Corn production rose nearly 9 per cent, from a combination of increased area and higher yields. Despite spring dryness in parts of northern Manchuria, timely summer rainfall throughout Manchuria and the North China Plain boosted yields.

In the European Union, France, Germany, Italy, Poland, Spain and the United Kingdom account for about 80 per cent of total wheat production. In 2004, growing-season weather returned to normal after the harsh winter, drought and summer heatwave of 2003. There were some lingering problems with dryness from the 2003 drought for winter grain planting in the United Kingdom but, for the most part, seasonable autumn rainfall provided adequate soil moisture for its



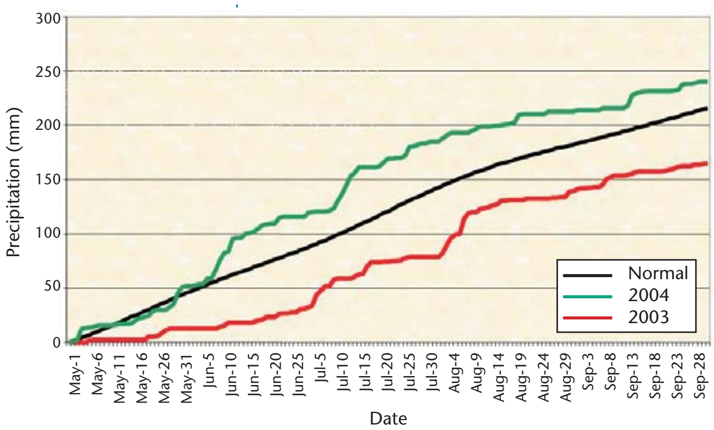
Change in wheat production by country in 2004, compared with 2003 establishment. During the winter of 2003/2004, near-normal temperatures and seasonable precipitation were a marked contrast to the wide temperature swings and winterkill events of the 2002/2003 winter. There were only isolated winterkill events during 2004, occurring in south-east Poland and Slovakia. Near-normal spring rainfall benefited reproductive winter grains.

There were no major problems with harvesting, except for excessive August rain in the United Kingdom, which reduced production and quality. For the major producing countries, wheat production increased 30, 10, 31, and 25 per cent from 2003 in France, the United Kingdom, Germany and Poland, respectively.

A return to favourable weather conditions also caused European Union coarse grain production to increase 22 per cent, with corn and barley production increasing 32 and 13 per cent, respectively. Near-normal summer rainfall and temperatures provided excellent growing conditions after the drought and heatwave of 2003. Corn production increased 20-30 per cent across most of the European Union. Hungary reported a 74 per cent increase. Likewise, in most European Union countries, barley production increased 7-20 per cent from the 2003 drought-stricken crop. Only the United Kingdom and Lithuania reported barley production decreases of 7 and 13 per cent, respectively. Production declines in the United Kingdom were related to the loss in area due to excessive rainfall during harvest.

Favourable weather also returned to south-eastern Europe, greatly increasing wheat and coarse grain production. In Bulgaria and Romania, wheat production increased 105 and 225 per cent, respectively. In Romania, Serbia and Montenegro and Bulgaria, corn

Cumulative precipitation in north central Kazakhstan, 1 May-30 September 2004. Some 75 per cent of Kazakhstan's spring wheat and barley crops are grown in this region.



production increased 85, 65, and 50 per cent, respectively. Barley production increased 159, 50, and 111 per cent, respectively.

In Kazakhstan, most of the wheat grown in the country is of a spring variety. Wheat production declined sharply (14 per cent). In May, unseasonably warm, dry weather prevailed throughout most of the country, helping fieldwork for spring grain planting. However, periodic heat prevailed throughout most spring grain areas during the month, causing rapid drying of topsoils. The dryness persisted throughout most of the major spring grain-producing areas of north-central Kazakhstan in June and July, reducing yield prospects for crops as they progressed through the reproductive phase of development. While above-normal precipitation fell in some areas in early August, crops were not able to recover fully from the earlier heat and dryness.As a result, wheat production declined by 14 per cent and coarse grain production dropped 19 per cent. Spring barley typically accounts for about 80 per cent of Kazakhstan's coarse grain production.

In north-western Africa, the 2004 growing season rainfall was above average, although lower than in 2003. In both Morocco and Tunisia, wheat production increased by 7 per cent. In Algeria, a 27 per cent reduction in wheat area more than offset increased yields. Wheat production decreased nearly 13 per cent. In Algeria and Morocco, barley production increased by 7 and 5 per cent, respectively. In Tunisia, lower yields reduced production by 14 per cent.

In the Russian Federation, winter wheat is mostly grown in southern Russia and in the southern areas of the central and Volga regions. Most of the spring wheat crop is grown from the Volga region eastwards to the Siberia region. In 2004, growing conditions for the winter wheat crop were considerably better than in 2003, resulting in an 80 per cent increase in production. In southern Russia, wet weather in early September was followed by a drier weather pattern that prevailed during the remainder of the month, aiding fieldwork for winter wheat planting, but lowering topsoil moisture for crop establishment. Nevertheless, mild weather and adequate moisture in October and November favoured crop establishment, and crops entered dormancy in better condition than the previous year.

Unseasonably mild winter weather prevailed over most winter grain areas, providing favourable overwintering conditions. A few brief episodes of bitter cold spread over winter grain areas. In most cases, the extreme cold was of short duration and occurred in areas protected by adequate snow cover, minimizing the threat for significant winterkill. In March, unusually mild weather caused winter wheat in major producing areas to break dormancy one to two weeks earlier than usual. Near- to above-normal precipitation favoured winter wheat development in April and May. Major winter wheat-producing areas in the southern region experienced the second wettest June weather in at least the past 25 years, benefiting filling wheat, but hampering the start of large-scale winter wheat harvesting. Below-normal rainfall and unseasonably mild weather in May helped fieldwork for spring wheat grain planting. Near- to above-normal June precipitation favoured crop emergence and establishment.

These weather conditions continued for spring wheat in Siberia, while hot, dry weather developed in the Urals in early July and persisted throughout key growth stages of the crop, reducing yield prospects. The declines in crop prospects were not made up in other areas that experienced more favourable weather, resulting in a 4 per cent decline in spring wheat production over the previous year. Coarse grain production in Russia declined by 3 per cent, due mainly to unusually high winterkill in key rye-producing areas and a 7 per cent decline in spring barley production. Spring barley is grown throughout most of Russia. In contrast, ideal corn growing-season weather in key areas helped raise production 64 per cent.

In southern Asia, an increase in both area and yield resulted in an 11 per cent jump in winter wheat. Indian coarse grain production fell about 20 per cent, as sporadic monsoon showers led to a drop in planted area and a 10 per cent reduction in overall yields. Production fell slightly in

Pakistan, as declining yields offset an increase in area.

In the southern hemisphere, following record production in 2003, Australian wheat production dipped approximately 18 per cent. As in the 2003 growing season, generally favourable weather helped autumn wheat development. In western Australia, however, winter and spring rainfall was less abundant than in 2003, causing slight declines in production. More significantly, in eastern Australia, untimely heat and dryness stressed wheat during the heading and filling stages of development, causing more substantial declines in production. In South Africa, wheat production rose 17 per cent, mostly from increased area. Yield increases were marginal, as growing-season weather disappointed farmers for the second consecutive season.

In contrast, timely summer rains led to higher South African corn yields, although production was only slightly higher because of lower acreage. Argentine corn production fell 10 per cent as a lingering spring drought in major production areas fuelled reductions in both area and yield. Winter wheat production rose about 19 per cent due to an increase in yield and area, although rainy harvest weather reportedly impacted grain quality. Similarly, Brazilian corn production fell about 6 per cent due to summer drought in the southern corn belt, but an excellent winter corn crop in the more northerly growing areas prevented larger declines. Winter wheat production remained virtually unchanged as increased area nearly offset lower yields.

In Turkey, winter wheat and barley production increased 5 and nearly 3 per cent, respectively. In the Islamic Republic of Iran, favourable growing-season weather and a continued expansion in area boosted wheat production 9 per cent and made another record year.

In Ukraine, most of the wheat grown is of winter varieties. Dry weather in September delayed planting in some southern and eastern areas. September's dryness was followed by above-normal precipitation in October, which provided much-needed moisture for winter grain emergence and establishment. In November, mild weather and adequate moisture continued to favour crop establishment and winter grains entered dormancy during the second half of the month in much better condition than the previous year. Unseasonably mild weather prevailed over winter grain areas, providing favourable overwintering conditions.

Winterkill for winter grains was reportedly below average at 5 per cent, well below the 65 per cent of the previous winter. Unusually mild weather in March prompted winter grains to break dormancy one to two weeks earlier than usual. Dryness returned to southern and eastern winter grain areas in March and April, but was followed by timely rain in May, benefiting winter grains in the high-moisture and temperature-sensitive

reproductive phase of development. Although wet weather in early July hampered early harvest activities, mostly dry weather during the second half of the month allowed activities to accelerate. Overall, winter wheat production rose by more than 450 per cent above the previous year, when severe winter weather and spring drought damaged most of the crop. Coarse grain production increased by 47 per cent, with barley and corn production increasing by 62 per cent and 29 per cent, respectively. The sharp increase in production for these crops was a result of ideal growing conditions.

In the USA, wheat production (winter, spring and durum) fell 8 per cent. Despite timely spring rains in many wheat-producing areas, long-term drought and subsoil moisture shortages reduced wheat-yield potential across parts of the High Plains. US corn production was up 17 per cent from the record established in 2003. Mid-western growing-season weather was nearly ideal, with abundant rainfall and minimal heat stress.

Oilseed

World oilseed production rose 16 per cent in 2004. Oilseed production increased in Brazil, Canada, China, the European Union, India, Indonesia and the USA and declined in Argentina, the Russian Federation and Ukraine.

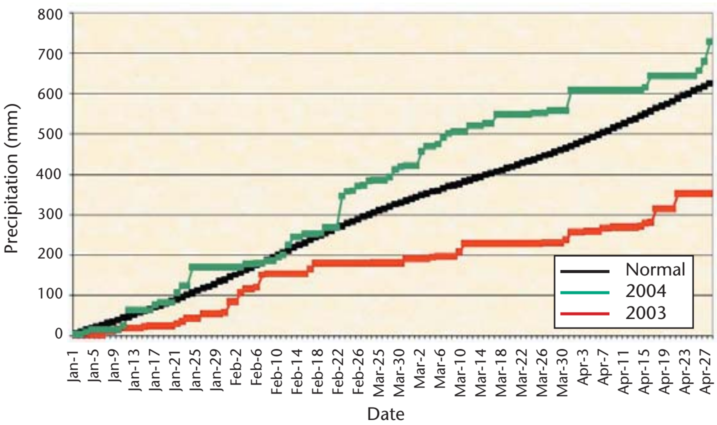
At the start of the growing season in Argentina, lingering drought in Cordoba disrupted corn planting, and soybeans went into most of the late planted farmland. However, the impact of late-season dryness in eastern growing areas, exacerbated by the overall lateness of the crop, lowered soybean production by about 4 per cent, despite record acreage. Similarly, sunflower production dropped 14 per cent, despite higher yields, as harvested area fell over 20 per cent. Brazilian farmers also experienced a disappointing season, with production levels similar to 2003, in spite of the fifth consecutive year of record planted area. The lowest yields since 1998 were the result of untimely dryness in major production areas and the spread of Asian Rust in the more northerly growing areas.

In China, consistent spring rainfall and increased area boosted winter rapeseed production by 5 per cent. Additionally, soybean production was up nearly 17 per cent due in part to favourable weather throughout the growing season in Manchuria and the North China Plain.

In the European Union, total oilseed production increased 22 per cent due to improved weather. A 32 per cent increase in rapeseed production greatly offset a nearly 6 per cent decline in sunflowerseed production. Rapeseed production increased 43 per cent in Germany and 14 per cent in France, following a return to seasonable weather after the severe drought and heatwave of 2003. Only the United Kingdom reported an almost 10 per cent decline in rapeseed production, partly due to excessive rainfall during harvest. Sunflowerseed production declined in many countries due to

reduced area, despite favourable weather that increased yields.

In India, total oilseed production remained virtually unchanged in 2004. Winter rapeseed production dropped 6 per cent from last year's record levels, despite a slightly larger area. Summer oilseed production was mixed, as many major production areas were affected by periods of untimely dryness, including some during the height of the planting season. Soybean production, which is concentrated in parts of central India, most affected by the erratic start to the 2004 monsoon season, declined 4 per cent, as higher acreage offset a projected 20 per cent drop from the



Cumulative precipitation for Rio Grande Do Sul, Brazil, 1 January-30 April 2004

2003 record yields. Peanut (groundnut) production suffered only slight declines in yield and production, mainly due to above-normal monsoon rainfall in Gujarat and timely, late-season rains in important growing areas of India's southern interior.

In North America, US soybean production was the highest on record, up 28 per cent from 2003. Generally favourable growing-season conditions in major mid-western and southern soybean-producing areas led to this sharp increase. In Canada, rapeseed (canola) rose 13 per cent as both area and yield continued to rebound from the past several seasons of prairie drought. Similarly, soybean production jumped 35 per cent to record levels due to record acreage and near-optimal growing conditions in Ontario.

In the Russian Federation, although growing-season weather conditions were mostly favourable for the sunflower crop, yields declined slightly from the previous year. In Ukraine, less favourable weather together with lower harvested area resulted in a 28 per cent decline in sunflower production.

Rice

World rice production rose 3 per cent. Rice production increased throughout most of South-East Asia, but overall production fell in South Asia.

In India, production was down slightly by 1 per cent, despite an increase in yield. Planted acreage fell an estimated 1.5 million hectares because of the poor start to the monsoon. Production dropped about 3 per cent in Bangladesh, which was plagued by flooding for much of the season. Pakistan recorded an increase of about 2 per cent due to slightly higher yields. In Thailand, production dipped by over 3 per cent, due in part to an early end to the wet season while rice was still in the filling stage of development. In Viet Nam, rice production remained virtually unchanged from the previous year. In China, rice production rose over 12 per cent, due to increases in area and yield.

Cotton

World cotton production increased about 23 per cent. Cotton production increased in Argentina, Brazil, China, India, Turkey, the USA and Uzbekistan.

In the northern hemisphere, production in China increased by 30 per cent. Despite wet weather in Shandong at the end of the season, yields increased 18 per cent. In India, production rose 16 per cent, due to increased area and yield. Production in Pakistan rose 48 per cent with significant increases in both yield and area. Turkish production increased by nearly 4 per cent due to favourable weather. US cotton production was up 26 per cent from 2003 and reached a record high. Most of the US cotton belt experienced favourable growing and harvest conditions, although excessive wetness caused local concerns across the southern plains and the western Gulf Coast region. In Uzbekistan, favourable weather conditions during the growing season and harvest resulted in a 22 per cent increase in cotton production.

In the southern hemisphere, Australian cotton production increased 1 per cent. Similar to the 2003 growing season, well-below normal rainfall was measured across much of eastern Australia. As a result, recovery from the devastating drought of 2002 remained slow, limiting soil moisture and irrigation supplies. In Argentina, production jumped 79 per cent, due to a huge increase in area. Brazilian cotton production rose 50 per cent from a combination of larger area and record yields. Both Argentina and Brazil recorded their largest cotton acreage since the 1990s.

Hurricane *Ivan*'s impact on the Cayman Islands

Hurricane Ivan moves towards the Cayman Islands on 11 September 2004 (image: NOAA).

By Fred Sambula, Director, Meteorological Services, Cayman Islands

The hurricane

Ivan developed from a fast moving depression that formed in the eastern Atlantic near the Cape Verde Islands on 2 September 2004. The system became the 2004 season's ninth named storm on 3 September (centred south-west of the Cape Verde Islands) and was upgraded to the fifth named hurricane (centred some 1 950 km east-southeast of the Lesser Antilles, at 09h00 on 5 September). At 03h00 on 8 September, the Government of the Cayman Islands issued a hurricane watch. By 03h00 on 10 September, the eye of Category 5 hurricane *Ivan* was located near latitude 17.5°N, longitude 76.9°W, i.e. some 56 km south of Kingston, Jamaica. It was forecast to affect the Cayman Islands the following day. A hurricane warning was issued at this time. Another undesired development was the considerable reduction in forward speed of the system from 29-32 km/h to 13-16 km/h.

Hurricane *Ivan* affected the Cayman Islands from the afternoon of Friday, 11 September until the evening of Monday, 13 September. Although hurricane-force winds began affecting Grand Cayman from around 01h00 on Sunday, the centre of this slow moving and very large hurricane—diameter about 645 km—crossed within 34 km of the island of Grand Cayman as a strong Category 4/borderline Category 5 storm, around 10h00 on Sunday, 12 September, with maximum sustained winds of 250 km/h (measured and reported by hurricane hunter aircraft).

Effectiveness of warning system

Before *Ivan*

With excellent cooperation from the media, the National Hurricane Committee of the Cayman Islands (NHCCI) began issuing information to the public 72 hours prior to *Ivan*'s arrival. The effectiveness of this collaboration enabled the voluntary evacuation of some 5 000 people from the islands and nearly all hurricane shelters were filled to capacity by the evening of Saturday, 11 September.

The NHCCI, through the Government Information Service, issued regular bulletins from the National Meteorological Service (NMS) on the functioning of the system, as well as advice on what actions residents were required to take to protect life and property. The fact that all media outlets carried these bulletins from a single official source is believed to have played a major role in the effective public response that followed.

Ivan's progress over Grand Cayman

- Storm surge, estimated at 2.5-3 m breached far inland in many areas and covered some parts of the island for several hours between late 11 September and the morning of 12 September
- Winds of 120 km/h and higher blew for about 15 hours with sustained winds of over 160 km/h for seven hours on Sunday. For two of these hours, the winds were at their highest speeds of 225–250 km/h. (An automatic weather observing station (AWOS) on the western end of the island recorded sustained wind speeds of 241 km/h with a peak gust of 274 km/h around 10h00; another AWOS over central Grand Cayman reported sustained wind speeds of 234-250 km/h with a peak gust of 306 km/h). This led to widespread damage and destruction
- Widespread saltwater flooding caused damage in many single-storey buildings and up to the first floor of many higher buildings.

During *Ivan*

The NMS continued to issue the latest information, to the public, through the NHCCI and the Government Information Service. By midnight, electrical power was lost throughout the island and telecommunications were lost at around 05h00 on Sunday, 12 September, after the first storm surge from the North Sound breached the main telecommunications station and the Government Radio Station went down.

The emergency power units at the telecommunications headquarters, the Government Radio Station and the Emergency Operations Centre enabled continued Internet access that allowed for reception and broadcast of the latest information on *Ivan* from the National Hurricane Center (NHC) in Miami through the night. However, after the telecommunications went down, no further information could be issued to the public about the system's progress. The only way information on the system was obtained was via intermittent satellite phone calls to NHC Miami.

After *Ivan*

Damage assessment on Monday, 13 September, after the passage of the hurricane, revealed a total infrastructure failure of telecommunications and other utilities. A cellular telephone service was quickly restored, however, by one provider, enabling an occasional call outside the Cayman Islands.

The Meteorological Office was breached by 60-90 cm of saltwater and most equipment was non-functional. Via a telephone conversation with the Director of the Jamaica Meteorological Service, it was agreed to operate in accordance with the regional hurricane plan and that Jamaica would take over forecasting and responsibilities for the Cayman Islands. The lack of telecommunications into the Cayman Islands, however, meant that no information could be received from Jamaica.

The recovery effort required airline flights into the Island during daytime hours and these flights needed weather observations. To accomplish this, the meteorological observer was temporarily stationed at the control tower. This situation lasted nearly three weeks before the Meteorological Office could gradually resume forecasting and other operations from its permanent premises.

Damage and recovery

The table below gives a summary of meteorological data on *Ivan's* passage through the Cayman Islands.

	Grand Cayman	*Little Cayman*	*Cayman Brac*
Wind (sustained)	241 km/h (AWOS WB) 10h00, 12 September	119 km/h	82 km/h
Wind (peak)	274 km/h (AWOS WB) 10h00, 12 September	N/A	108 km/h
Rainfall	305 mm: 19h00, 11 September-07h00, 13 September	N/A	125 mm: 19h00, 12 September-07h00, 13 September
Minimum pressure	Below 970 hpa	N/A	997 hpa
Storm surge	Estimated approx. 2.5-3 m	–	–
Wave heights (breaking) (observed estimates)	6-9 m	–	–
Duration of winds >160 km/h	7 hours	N/A	N/A
First 160 km/h wind	06h00, 12 September	N/A	N/A
Last 160 km/h wind	13h00, 12 September	N/A	N/A
Duration of hurricane winds	13 hours	2 hrs	N/A
First hurricane winds	04h00, 12 September	04.00, 12 September	N/A
Last hurricane winds	17h00, 12 September	06h00,12 September	N/A
Duration of tropical storm winds	41 hours	31 hours	30 hours
First tropical storm winds	13h00, 11 September	08h00, 11 September	07h00, 11 September
Last tropical storm winds	06h00, 13 September	15h00, 12 September	13h00, 12 September

Nine people were trapped here from 08h00–18h00 on Sunday before rescue.

Total collapse of an apartment complex

Cars under water under portico at a school

Wave erosion on coastal road

A parking lot

One-metre surge struck this hydrogen generator room (elevation 1.8 m).

Some of the impacts of Ivan in Grand Cayman

Damage assessment indicated roof damage to most premises on Grand Cayman with total failure of a few older structures. A report by the UN Economic Commission for Latin America and the Caribbean reveals that the damage in the Caymans from *Ivan* was greater than the total hurricane season damage this year for the Bahamas, the Dominican Republic, Grenada and Jamaica combined. The total loss and damage are equivalent to two years of Cayman's GDP at US$ 94 625 per resident. The total impact of the hurricane on three major sectors—social, productive and infrastructure—is around US$ 3.5 billion. Over 80 per cent of the impact was in damage to, and destruction of, property, with housing suffering most. The remaining 20 per cent represents future financial losses as a result of the damage inflicted (e.g. restoration of accommodation).

Fortunately, only two fatalities associated with this hurricane were reported. A sum of US$ 2.8 billion for damage reconstruction, has been quoted by the national Government. As of early November 2004, piped water was restored to 100 per cent of the Island and approximately 85 per cent of electrical power. By mid-December 2004, this figure was 100 per cent.

At the time of writing (April 2005), the meteorological infrastructure is still without an AWOS located at the airport but the high-resolution satellite receiving system, which was also lost during the storm, has now been replaced and is in operation. With the exception of the upper-air system, other meteorological operations have either been fully restored or are nearing total restoration.

Conclusions and recommendations

The WMO RA IV (North America, Central America and the Caribbean) Hurricane Operational Plan (Tropical Cyclone Programme Report No. 30/WMO-TD No. 494), proved quite effective for our national preparedness and mitigation efforts for hurricane *Ivan*. The excellent cooperation and coordination between the RSMC, Miami and the National Weather Service of the Cayman Islands resulted in the timely issue of information for guiding decision-makers. The WMO Regional Plan emphasizes regional cooperation and this was highlighted when Jamaica expeditiously assumed responsibility for forecasts and warnings for the Cayman Island, when telecommunications within the Islands failed completely.

Some conclusions and recommendations from the *Ivan* experience are:

- The NMS provided proper and timely information to enable an effective warning and preparation system from one official source, i.e. the National Hurricane Committee of the

Cayman Islands (NHCCI). Coupled with excellent media collaboration, the message reached the public, who prepared accordingly and only two lives were lost.

- There is a need for a purpose-built meteorological facility and to reinforce the supporting infrastructure, such that failure of this function is kept to an extreme minimum.

- Two of the most effective and reliable tools in hurricane tracking and forecasting, i.e. a weather radar and a storm-surge model, were noticeably absent from our preparedness and mitigation arsenal. Every effort must be made to obtain these as they will significantly improve the quality of warning information provided by the NMS for decision-making for preparedness and mitigation.

- This event proved that the NMS is capable of offering effective early warnings on severe weather to the nation.

- There is a need to have a robust telecommunications and information communication and technology network capable of affording reliable operations before, during and after storm events.

- The Government should be encouraged to take a more active role in ensuring the health and sustainability of weather services for the nation. In hurricane-prone countries, such as the Cayman Islands, there is a need to ensure that early warnings of natural disasters become an integral part of government policy and that they form an effective instrument for preventive strategies.

Visits of the Secretary-General

The Secretary-General, Mr 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.

Brussels, 16 February 2005 — The third Earth Observation Summit

France

At the invitation of HE Mr Jacques Chirac, President of France, Mr M. Jarraud visited France on 15 February 2005. He participated in a roundtable discussion on climate-related issues with the President, high-level scientists and decision-makers.

The Secretary-General highlighted WMO's contributions and the role of National Meteorological and Hydrological Services (NMHSs) in climate monitoring and research activities, support to the World Climate Research Programme, the Intergovernmental Panel on Climate Change and the Global Climate Observing System, as well as partnerships with international organizations in addressing climate change issues. The need to support regional and global initiatives on climate monitoring and research was also raised.

Group on Earth Observations (sixth session) and third Earth Observation Summit

The Secretary-General visited Brussels (Belgium) on the occasion of the sixth session of the Group on Earth Observations and the third Earth Observation Summit (EOS-III), which were held from 14-15 February and on 16 February 2005, respectively. He took the opportunity to have wide-ranging discussions with the Co-chairs and delegates to the Summit on WMO's potential support to the implementation of a Global Earth Observing System of Systems (GEOSS). Among the major outcomes of EOS-III was the decision that the GEO Secretariat would be located at WMO Headquarters.

St Petersburg, Russian Federation — Participants in the 13th session of the Commission for Basic Systems (23 February-3 March 2005)

De Bilt, The Netherlands, 10 April 2005 — Presentation of the 19th Dr Vilho Vaisala Award (from left to right): Dr Frits J.J. Brouwer, Permanent Representative of The Netherlands with WMO; Dr Iwan Holleman and Mr Hans Beekius (the two prizewinners); Mr Kenneth Forss, Director of the Instruments Division of Vaisala Oyj; and Mr Michel Jarraud

Commission for Basic Systems—13th session

Mr Jarraud addressed the 13th session of the Commission for Basic Systems (CBS-XIII), which was held in St Petersburg (Russian Federation) from 23 February to 3 March 2005. HE Mme Valentina Matvienko, Governor of St Petersburg, and Dr Alexander Bedritsky, Head of the Russian Federal Service for Hydrometeorology and Environmental Monitoring, Permanent Representative of the Russian Federation with WMO, and President of the Organization, were present at the opening ceremony.

Mr Jarraud presented the WMO/CBS Certificate award to Mr Hubert Allard (Canada) and Mr Stefan Mildner (Germany) for their long and lasting contributions to the work of the Commission.

The Secretary-General exchanged views with delegates on the increasing role of CBS in support of various WMO Programmes and the strengthening of national capacities. He also took the opportunity to discuss a number of issues concerning WMO with Dr Bedritsky.

Nineteenth Dr Vilho Vaisala Award

The Secretary-General visited De Bilt (The Netherlands) for the presentation of the 19th Dr Vilho Vaisala Award to Dr Iwan Holleman and Mr Hans Beekius.

The award ceremony took place on 10 April 2005 at the Royal Netherlands Meteorological Institute. Mr Jarraud and Mr Kenneth Forss, Director of the Instruments Division of Vaisala Oyj, made the presentation. The Secretary-General thanked the Permanent Representative of The Netherlands with WMO, Dr Frits Brouwer, for hosting this ceremony and for the support of his Government to the Programmes and activities of WMO.

Arab Permanent Meteorological Committee of the League of Arab States—21st session

The Secretary-General visited Doha, Qatar, on the occasion of the 21st session of the Arab Permanent Meteorological Committee of the League of Arab States. Mr Jarraud addressed the opening session on 15 March 2005, in the presence of Mr Abdul Aziz Mohamad Al-Noaimi, Chairman and Managing Director of the Civil Aviation Authority; Mr Mourad Shawki Saadallah, Chairman of the Arab Permanent Meteorological Committee of the League of Arab States; Mr Ashraf Noor Eldean Ali, Representative of the League of Arab States Secretariat; and Mr Ahmed Abdulla Mohammed, Acting Director of the Meteorological Department and Permanent Representative of Qatar with WMO.

Mr M. Jarraud took the opportunity to exchange views with the permanent representatives of WMO Members

Doha, Qatar, March 2005 — The Secretary-General with (from left to right): Dr Saeed Al-Sulaiman, Director of Academic Affairs and Registration; Mr Ali Ibrahim Al-Malki, Principal of Qatar Aeronautical College; and Mr Eisa Al-Majed, Director, WMO Regional Office for Asia and the South-West Pacific present at the session, on the strengthening of the NMHSs and their relationship with WMO.

The first Qatar International Exhibition on Meteorology Techniques, co-sponsored by WMO, was held in Doha on 20 and 21 March 2005. Mr Jarraud opened the Exhibition with Mr Abdul Aziz Mohamad Al-Noaimi.

Mr Jarraud met with the Director-General of Qatar Aeronautical College, Mr Ali Ibrahim Al-Malki, and discussed issues relating to education and training in aviation meteorology. The Secretary-General also visited the Qatar Foundation for Education, Science and Community Development, where he was briefed on the activities of the Foundation.

San José, Costa Rica, 5 April 2005 — Participants in the 14th session of Regional Association IV (North America, Central America and the Caribbean)

France

The Secretary-General visited France on 21 March 2005 and met with HE Mr Michel Barnier, Minister of Foreign Affairs. They exchanged views on a wide range of subjects of interest to France and WMO, including natural disaster prevention, water-resources management, climate change and marine meteorological services. The Secretary-General expressed his appreciation to France for its continuous support to WMO's Programmes and activities, in particular that provided through Météo-France.

Regional Association (RA) IV Hurricane Committee—27th session

The 27th session of the RA IV Hurricane Committee was held in San José (Costa Rica) from 31 March to 5 April 2005. The Secretary-General addressed the closing ceremony and discussed with delegates the events of 2004, which had seen one of the most severe tropical cyclone seasons ever in the Caribbean.

Regional Association IV—14th session

The Secretary-General addressed the opening ceremony of the 14th session of Regional Association IV (North America, Central America and the Caribbean), which was held in San José (Costa Rica) from 5 to 13 April 2005.

Mr Jarraud had the opportunity to meet with HE Mrs Lineth Saborío, Vice-President of Costa Rica; Dr Carlos Manuel Rodríguez Echeverría, Minister of the Environment and Energy; and Dr Roberto Tovar, Minister of Foreign Affairs. The Secretary-General discussed WMO's activities in the Region, in particular, those carried out in cooperation with the National Meteorological Institute of Costa Rica, and the strengthening of the excellent cooperation between Costa Rica and WMO.

The Secretary-General also met with the permanent representatives of WMO Members attending the meeting and discussed issues related to the strengthening of their NMHSs and their relationship with WMO.

United Nations Chief Executives Board for Coordination

The Secretary-General participated in the United Nations Chief Executives Board for Coordination (CEB), which met on 9 April 2005 at Mont Pèlerin, Switzerland. The meeting considered the follow-up to the Millennium Declaration, as well as preparations for the 2005 Summit to be held in September at UN Headquarters, New York. The Board also discussed UN system support for the New Partnership for Africa's Development (NEPAD); a system-wide strategy on conflict prevention; and preparations for the second phase of the World Summit on the Information Society, scheduled to be held in Tunis (Tunisia), from 16 to 18 November 2005. The Secretary-General took the opportunity to coordinate the UN system position with respect to the Group on Earth Observations with the Executive Heads of FAO, UNESCO and UNEP.

The CEB also exchanged views on a wide range of additional issues of interest to the UN system organizations, such as increased support to Members, such as coordinated support at the national level, enhanced synergy and greater transparency in operations.

Briefing for the UN Special Envoy for Tsunami Recovery

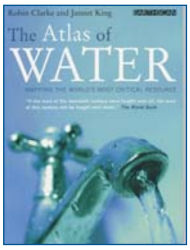
On 12 April 2005 in New York, the UN Special Envoy for Tsunami Recovery in Asia, President W. Clinton, was briefed, at his invitation, by the Secretary-General of WMO, Mr M. Jarraud, the Executive Secretary of the UNESCO Intergovernmental Oceanographic Commission, Dr P. Bernal, and the Director of the UN International Strategy for Disaster Reduction, Mr S. Briceño, on multi-hazard prevention and early warning systems, with particular reference to the tsunami early warning system to be implemented in the Indian Ocean.

Mr Jarraud provided President Clinton with background information on hydrometeorological hazards and the capabilities for early warning of National Meteorological and Hydrological Services of WMO Members, with special emphasis on the culture of prevention.

United Nations Headquarters, New York, 13 April 2005 — The Special Envoy for Tsunami Recovery, President W. Clinton, at a press conference with UN Secretary-General, Kofi Annan

Book reviews

The Atlas of Water—mapping the world's most critical resource



Robin Clarke and Jannet King. Earthscan, London (2004). 127 pp. numerous illustrations in colour. ISBN 1-84407-133-2. Price: £12.99.

This useful atlas should be on the desk of everyone concerned with the the provision, conservation and optimal use of freshwater resources. It gives a wealth of information in comparatively few pages. Statistics are presented in table form and in double-page maps. Although some of these maps have insets with parts of the world in greater detail, some of the information is difficult to read, particularly at the division between the two pages. This design, which seems to be more concerned with prettiness than legibility, does not facilitate the task of reading, particularly for those with reading difficulties or with colour-vision problems.

The intention of the publication, in addition to the presentation of the information on the global problems of access to adequate water, seems to be to draw attention to the possibilities of reducing water consumption and of increasing the efficiency of water use in a number of areas. This has already been done in some countries with regard to agricultural use, for example, by using drip irrigation, and particularly industrial use, where it has been possible to make savings of 50 per cent of water, while almost quadrupling output.

In the final section, attention is drawn to one of the messages of the United Nations World Water Development Report that, by the year 2025, the world could be faced with a severe water shortage that could lead to a reduction in food production; and that, by 2050, 4 billion people could be living in countries that are chronically short of water. It is suggested that much could be achieved by using water more productively as a result of radical changes in water management.

In looking to the future, however, neither the Atlas of Water nor the UN World Water Development Report has given much consideration to the fact that approximately half the present global population now between the ages of one day and 16 years, will mature and can be expected to seek better standards of living and to have rather different patterns of resource use from their parents. Increased access to imagery of how people live in the industrialized world can have major impacts on desires for different, if not necessarily better, nutrition, transport and way of life generally.

For nutrition, the amount of water required to produce 1 kg of cereal is about 1.5 m^3, of poultry 6 m^3 and of beef 15 m^3. Changes from tortilla and beans to a beefburger, for example, will have significant effects on water use. For transport, to take but one example, China at present has about eight cars per 1 000 residents (compared with 122 in Brazil and 940 in the USA) but, from 1 million in 1990, the estimate is that it will be 14 million before the end of 2005. If the same rate of growth continues until 2025, there will be more than 30 million, but a semi-official estimate is that there will be more than 140 million. In reflecting on this one has to take into consideration not only the prime resources that will be needed to produce the cars but also the energy to be used in them and the waste products produced.

A third factor is the possible desire to migrate to another country where the standard of living seems, and may be, better. What will be the effects of increases in migrations on water resources? A fourth factor is the increasing amount of man-made chemicals that are discharged into rivers, estuaries and the sea. The effects on wildlife although still imprecisely known, are likely to be negative, especially for aquatic mammals.

The Atlas of Water makes no mention of the WMO or of the lead taken by the Organization in the collection of data on water, nor is any WMO publication given as a "useful source".

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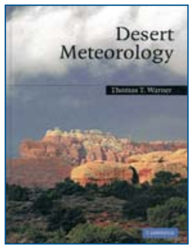
Desert Meteorology



Thomas T. Warner, Cambridge University Press (2004); xvi + 595 pp. ISBN 0-52181798-6. Price: £80/US$ 120.

This book is a welcome addition to the scientific works on dryland issues initiated in the 1950s by the UNESCO arid zone programme. Its title expands the concept of meteorology (physics of the lower troposphere) to encompass almost all elements of ecology: the 20 chapters of the book present a rich range of material. Because of this admirably broad range, chapters often contain a degree of repetition, requiring the reader to do some inter-chapter cross-referencing. The sequence of chapters may also be a distraction but not a serious one.

The three principal areas covered are:

- The physics of atmospheric dynamics that relate to microscale (interface between air and surface and subsurface features of the ground), meso- and macroscale continental or ecogeographical units

- Ecological interactions of biota, including human beings, with the elements of the desert system

- Impacts of desert processes on global climate and the worldwide geography of deserts.

The geography of climatic aridity (causes) is explained and forces that may drive climate change are reviewed, as are likely impacts of desert environment, particularly dust, on atmospheric processes. This is a comprehensive coverage.

The global dimension of impacts of deserts and processes of dryland degradation (desertification) caused primarily by human overexploitation, has relevance to issues of international governance of global environmental issues. When the World Bank/UNDP/UNEP envisaged the establishment of a Global Environment Facility (GEF) in 1991 as a financial mechanism in support of schemes for managing global environment issues, desertification was not considered to be a global environment issue to be included with protecting the ozone layer; limiting emission of greenhouse gases; protection of biodiversity; and protection of international waters. The position of GEF towards desertification has mellowed since 2002. Some chapters of this book explain the scientific basis for this change in attitude.

Two chapters address issues of interactions of vegetation with, and impacts of humans on, dryland ecosystems. Advanced students of desert ecology will find here sources of ideas. One chapter addresses the question of human adaptation to a desert environment that is dry and austere.

Two chapters deal with desert rainfall: a climatic feature that controls the ecological features of deserts. Paucity and wide-scale variability make water resources poor and non-predictable. Excess may cause floods that can be destructive: this is the dilemma of desert inhabitants and desert biota. Recurrent drought is the most damaging environmental menace for inhabitants of the world's drylands.

The text is based on solid science and the author presents his diverse material in a commendable style of clear and well-illustrated text. Because climate studies depend on the science of physics, the presentation includes mathematical equations (and models) but the author handles this in a way that keeps the book accessible for a broad readership, which is an added merit.

A set of appendices adds to the utility of the text. The list of references, though rich, misses several useful and relevant publications, examples: *Interactions of Desertification and Climate*, by M.A.J. Williams and R.-C. Balling, 1996, WMO/UNEP; *Atlas of African Rainfall and its Interannual Variability*, by S.E. Nicholson, J. Kim and J. Hoopingarner, 1988, Florida State University.

This is a reference book that deserves acclaim. It does indeed present an "in-depth review of [desert] meteorology and climate … desert geomorphology, desert hydrologic systems, and desert thermal energy budget". It provides excellent text and teaching material: each chapter ends with "questions for review" and "problems and exercises", as well as hints to solving some of the problems and exercises.

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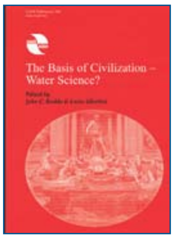
New books received

The basis of civilization—Water science?

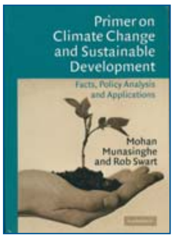


John C. Rodda and Lucio Ubertini (Eds.). International Association of Hydrological Sciences. IAHS Publication 286. ISBN 1-901502-57-0 x + 342 pp. Price: £58.50.

The introduction explores the linkages between hydrology and society throughout history and outlines the slow development of water technology and the even slower development of water science. Other authors provide specific examples of the rise of understanding of water science.

The impact of water resources development and management on society is discussed from political, economic and cultural viewpoints. The approaches to risk and conflict involving water are considered in detail: intellectual and philosophical inspiration and discursive politics in the changing role of risk awareness are central to any analysis of how future water policy-making will be made. Issues of governance, past and present are also reviewed.

Primer on climate change and sustainable development—facts, policy analysis and applications



Mohan Munasinghe and Rob Swart. Cambridge University Press (2005). ISBN 0-521-00888-3. xii + 445 pp. Price: £30.

This Primer on climate change and sustainable development gives an up-to-date, comprehensive and accessible overview of the links between climate change and sustainable development. Building on the main findings of the last series of Intergovernmental Panel on Climate Change (IPCC) assessment reports, in which both authors were involved, the book summarizes the latest research linking the two. Our current knowledge of the basic science of climate change is described, before moving on to the future scenarios of development within the context of climate change. The authors identify opportunities for synergies and resolving potential trade-offs. Discussing theory, policy analysis and applications, they analyse effective implementation of climate policy at scales ranging from global to the local.

Marine turbulence—theories, observations and models (Results of the CARTUM Project)

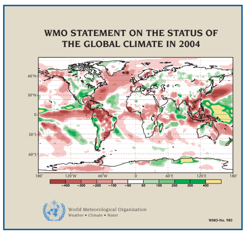
Helmut Z. Baumert, John H. Simpson and Jürgen Sündermann (Eds.). Cambridge University Press (2005). ISBN 0-521-83789-8. Price: £175/US$ 275.

This books gives a comprehensive overview of measurement techniques and theories for marine turbulence and mixing of greenhouse gases, nutrients, trace elements, and hazardous substances in our oceans and shelf seas—from local to planetary scales. These processes buffer climate changes and are centrally important for regional to global ecosystem dynamics.

The book is divided into eight parts, covering turbulence in relation to stratification, waves and intermittence; observational techniques for field studies; selected computural means for the study of turbulence, boundary layers; practical case-studies in estuaries, fjords, lakes and shelf seas, and at the shelf edge; small scale three-dimensional turbulence and quasi-two-dimensional turbulence occurring on the planetary scale, and an overview of comprehensive data sets and models codes.

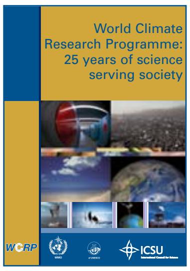
Recently issued

For the full WMO catalogue of publications and how to order these and other publications, see:
http://www.wmo.ch/web/catalogue/



WMO Statement on the Status of the Global Climate in 2004 (WMO-No. 983)
[E] - [F] – [R] - [S]
12 pp.
Price: CHF 15.

This year's statement (WMO-No. 983) describes the climatic conditions, including extreme weather events, for the year 2004 and provides a historical perspective of some of the variability and trends that have occurred since the 19th century. The statement places 2004 as the fourth warmest year in the temperature record since 1861 and indicates that there has been a rise in global temperature greater than 0.6°C since 1900.



World Climate Research Programme: 25 years of science serving society
[E]
24 pp.

This brochure was issued to mark the 25th anniversary of the World Climate Research Programme. It can also be viewed in pdf form and downloaded from the WCRP Website: http://www.wmo.ch/web/wcrp/news.htm

WMO Integrated Global Observing System (WMO-IOS)
[E]
8 pp.

The WMO-IOS takes Earth observations, processes them to build products and tools which help decision-makers respond to the needs of users. It is a core component of the Global Earth Observation System of Systems (GEOSS). This brochure explains what the Integrated Global Observing System is and how it can contribute effectively to activities in almost all sectors of human endeavour. The brochure is useful for decision-makers, the media and the public.

See
http://www.wmo.ch/news/news.html
and click on the icon for the pdf version. Hard copies are available upon request from the WMO Secretariat.

Regional Association II (Asia), Thirteenth session—Abridged final report with resolutions (2004) (WMO-No. 981)
116 pp.
[A] - [C] - [E] - [F] - [R]
Price: CHF 25.

Applications of Climate Forecasts for Agriculture. Proceedings of an Expert Group Meeting for Regional Association I (Africa) (WMO/TD-1223, AGM-7)
198 pp.
[E]
Price: CHF 30,

Servicios de Información y Predicción del Clima (SIPC) y Aplicaciones Agrometeorológicas para los Países Andinos: Actas de la Reunión Técnica (Proceedings of the Third Regional Technical meeting on CLIPS and Agrometeorological Applications for the Andean Countries) (WMO/TD No. 1234, AGM-6)
iii + 221pp.
[S]
Price: CHF 30.

Staff news

Appointments

Philippe Dupraz: Assistant Printing Operator/Handyman in the Printing and Electronic Publications Section of the Conferences, Printing and Distribution Department on 1 January 2005

Christian Giroud: Offset Operator in the Printing and Electronic Publications Section of the Conferences, Printing and Distribution Department on 1 January 2005

Yvon Staub: Stock Clerk in the Publications Sales and Distribution Unit of the Printing and Electronic Publications Section of the Conferences, Printing and Distribution Department on 1 January 2005

Datius G. Rutashobya: Scientific Officer in the Hydrology Division of the Hydrology and Water Resources Department on 10 January 2005

Robert J. Stefanski: Scientific Officer in the Agricultural Meteorology Division of the World Climate Programme Department on 17 January 2005

Xiaoxia (Anny) Zhang: Head of the Payroll and Pension Unit in the Human Resources Division of the Resource Management Department on 24 January 2005

Edgard E. Cabrera: Chief of the Ocean Affairs Division in the Applications Programme Department on 31 January 2005

Herbert Lanz: Assistant Webmaster, Information Systems Division, Resource Management Department on 1 February 2005

Stuart J. Baldwin: Treasurer in the Finance Division, Resource Management Department on 1 February 2005

Isabelle Rüedi: Programme Coordination Officer, World Weather Watch Department, on 1 February 2005

Nina Maslina: Editor (Russian language) in the Linguistic Services and Publications Department on 17 February 2005

Robert Maire: Maintenance Assistant in the Common Services Division of the Resource Management Department on 1 April 2005

Slobodan Nickovic Scientific Officer in the Environment Division of the Atmospheric Research and Environment Department on 17 April 2005

Transfers

Nelly Conforty-Ferreux, Interpreter/Translator in the Linguistic Services and Publications Department, was transferred to the Conferences Services of the Conferences, Printing and Distribution Department on 1 February 2005.

Marc Peeters, formerly Human Resources Officer, Resource Management Department, was transferred to the Conferences Services of the Conferences, Printing and Distribution Department on 1 February 2005.

Michel Jardon was appointed to the post of Human Resources Assistant in the Entitlements and Administration Unit of the Human Resources Division, Resource Management Department, by transfer from the post of Human Resources Clerk in the Recruitment and Training Unit of the same Division on 1 March 2005.

Joanna Drake-Stewart was transferred from the post of Library Clerk in the Technical Library of the Atmospheric Research and Environment Programme Department to the post of Process Control Clerk in the Printing and Electronic Publications Section of the Conferences, Printing and Distribution Department on 1 March 2005.

Departure

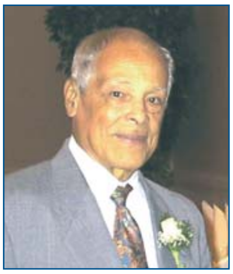
Maria Kheir retired from her post of Senior Secretary in the Cabinet and External Relations Office of the Secretary-General's Office on 31 January 2005.

Anniversary

Lucia Bertizzolo, Procurement Assistant in the Procurement and Travel Office of the Resource Management Department: 30 years on 4 March 2005

Obituaries

Cyril Egbert Berridge



Cyril Egbert Berridge, former First Vice-President of WMO, died at his home in Port of Spain, Trinidad and Tobago, on 28 February 2005 at the age of 75. "Bert", as he was commonly known, served the Caribbean and international meteorological and hydrological communities with distinction for 52 years.

Bert started his career in meteorology as a weather observer with the British Caribbean Meteorological Service in 1947, rising through the ranks to become a weather forecaster in 1958. He graduated with a B.Sc from Florida State University, USA, then served as Director of his Meteorological Service between 1970-1972 and as the Permanent Representative of Trinidad and Tobago with WMO.

In 1972, the Caribbean Governments decided to establish the Caribbean Meteorological Organization (CMO) as a specialized agency of the Caribbean Community (CARICOM) to replace the Caribbean Meteorological Service. The CMO, comprising a ministerial-level Caribbean Meteorological Council, the CMO Headquarters, the Caribbean Institute for Meteorology and Hydrology (CIMH) and the Caribbean Meteorological Foundation, coordinates the joint scientific and technical activities in meteorology, operational hydrology and related fields of its 16 Member States. Bert Berridge was appointed as the first Coordinating Director of the CMO. It was in this capacity that he truly made his regional and international mark. He was instrumental in the development of the various new NMHSs and in the establishment of a well-operated regional early warning system for tropical storms, hurricanes and other severe weather events.

In the global arena, he attended his first World Meteorological Congress in 1971, representing Trinidad and Tobago. When he joined the CMO, he became the Permanent Representative of the British Caribbean Territories with WMO, and later for the island State of Dominica. He attended every session of Congress since that time and, in 1983, was elected to the WMO Executive Council (EC). He served two terms as president of WMO Regional Association IV (North America, Central America and the Caribbean) between 1985 and 1993 and, at Twelfth Meteorological Congress (1995), he was elected First Vice-President of WMO to serve from 1995 to 1999.

In these various capacities, Bert was particularly active as a member of several WMO committees, including the RA IV Hurricane Committee (from its inception); the Financial Advisory Committee (from its inception); the WMO Building Committee and the Committee on follow-up to the UN Conference on Environment and Development. He served as Chairman of the EC Advisory Group of Experts on Technical Cooperation and, for 10 years, was either an invitee or a member of the WMO Bureau.

Bert Berridge was a tireless supporter of WMO and was held in high regard in international circles as an avid defender of developing country interests. He was achievement-oriented, apolitical and unafraid to express contrary views. He earned the respect of his colleagues for being witty, outspoken and honest. Some of his international colleagues have written that he has left us all a grand legacy, including a model for international collaboration and practical solutions.

His 52 years of dedicated service ended in 1999 with his retirement as Coordinating Director of the CMO. In recognition of his outstanding contribution to the Caribbean in general, the British Caribbean Territories in particular, and the entire global meteorological and hydrological communities, HM Queen Elizabeth II conferred on him the Order of the British Empire, which was presented to him in Port of Spain by HRH Prince Charles on 22 February 2000.

He is survived by his wife, Sylvia, four sons and an adopted daughter. They have lost a loved one, the Caribbean has lost a meteorological icon and the WMO community has lost a true friend.

Tyrone W. Sutherland

Dr William James Gibbs

Dr William James (Bill) Gibbs OBE, Director of the Australian Bureau of Meteorology from 1962 to 1978, First Vice-President of WMO from 1967 to 1975 and winner of the 27th IMO prize (1982), died in Melbourne on 17 March 2005, aged 88 years.

Dr Gibbs was born in Sydney on 17 October 1916. With the support of a fund for children whose fathers had been killed in action in World War I, he obtained his Bachelor's degree from

Sydney University where he first encountered meteorology and resolved to make it his career.

He joined the Bureau of Meteorology in Sydney in 1939, went for training in Melbourne in March 1940, married Audrey Taylor in Sydney en route to a two year posting in Port Moresby in September 1940 and returned to the role of staff meteorologist in General MacArthur's Allied Headquarters in Brisbane in July 1942. After the War, he became heavily involved in tropical and Southern Ocean research and soon had his first taste of international meteorology when he accompanied his then Director, Mr H.N. Warren, to the 1947 Washington DC Conference of Directors, which finalized the WMO Convention. A few years later, as a Harkness Fellow, he had the opportunity for two years' study for his Masters degree in the US, at the Massachusetts Institute of Technology.

Back in Australia, Bill rose quickly through the ranks to be appointed Assistant Director of Research in the Bureau of Meteorology in 1958 and Director of Meteorology in 1962. His 16 years as Director were the "golden years" of the Australian Bureau, with a dramatic expansion of its operations and services, a doubling of its staff and major enhancement of its scientific standing and influence at the national level. Much of this was the product of Bill's personal leadership, especially the establishment of World Meteorological Centre Melbourne, the introduction of powerful computers into Bureau operations, the pioneering application of satellite imagery for analysis over the Southern Ocean and important national initiatives in water resources assessment, drought monitoring, tropical cyclone warning and numerical weather prediction.

As Permanent Representative of Australia and member of the WMO Executive Council from 1963 to 1978, Bill played a leading role, along with close colleagues Dr Alf Nyberg, Dr Bob White, Dr (now Sir) John Mason, Dr Eric Sussenberger, Academician Federov and, in later years, Dr Roman Kintanar, in the scientific and technical work of WMO, especially on climate change, for which he chaired the Executive Committee Panel whose report led to the convening of the (First) World Climate Conference in 1979. I was privileged to accompany him to his last WMO Congress in 1975 and to see, through his example, how international cooperation in meteorology can do great good in the world.

Following his retirement as Director on 13 July 1978, Bill threw himself into his role as Honorary Archivist for the Bureau of Meteorology and, for the next 20 years, led the collection and writing of the detailed history of the Bureau in preparation for the centenary of its commencement of operation as a national organization on 1 January 1908.

At the function for the celebration of his life on 22 March 2005, former colleagues spoke of his leadership, vision and commitment to national and international meteorology and his love for the "very special family" that was the Bureau. He is survived by his wife Audrey, their children Jennifer, Judie, Gregory and Amanda and their families and by a generation of Australian meteorologists who were inspired by Bill and by his life-long fascination with the atmosphere and its ways.

John Zillman

Calendar

Date	Title	Place
16-27 May	Regional Training Seminar for National Instructors of RA II and RA V	Kuala Lumpur, Malaysia
23-27 May	Sixth Southern Hemisphere Workshop on Public Weather Services	Melbourne, Australia
23-27 May	ICAM/MAP 2005—28th International Conference on Alpine Meteorology and Annual Scientific Meeting of th Mesoscale Alpine Programme (*co-sponsored by WMO*)	Zadar, Croatia
25-31 May	Fourteenth International TOVS Study Conference (ITSC-XIV) (*co-sponsored by WMO*)	Beijing, China
1-3 June	Thirteenth session of the GCOS Steering Committee	St. Petersburg, Russian Federation
14-16 June	Workshop on Climatic Analysis and Mapping for Agriculture	Bologna, Italy
20-24 June	Fifth International GEWEX Conference	Orange County, CA, USA
20-24 June	The Aviation Seminar (*co-sponsored by WMO*)	Exeter, UK
20 June	Fifty-fourth session of the WMO Bureau	Geneva
20 June	Financial Advisory Committee (FINAC)—twenty-fourth session	Geneva
21 June-1 July	Executive Council—fifty-seventh session	Geneva
13-16 July	Regional Technical Meeting on CLIPS and Agrometeorological Applications for the Mercosur Countries	Sao Paulo, Brazil
25-29 July	Third Regional Workshop on Storm Surge and Wave Forecasting A Hands-on Forecast Training Laboratory	Beijing, China
8-19 August	CLIPS Focal Point Training Workshop for RA III	Lima, Peru
20 Aug.-9 Sept.	Thirteenth Brazilian Meteorological Congress	Fortaleza (Ceara), Brazil
5-6 September	Technical Conference on International Cooperation in Meteorology and Hydrology in RA VI	Heidelberg, Germany
5-9 September	WWRP International Symposium on Nowcasting and Very Short-Range Forecasting	Toulouse, France
7-15 September	Regional Association VI (Europe)—fourteenth session	Heidelberg, Germany
19-23 September	International Workshop on Flash Flood Forecasting (*co-sponsored by WMO*)	San José, Costa Rica
19-28 September	Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology—second session	Halifax (Nova Scotia), Canada
26-29 September	SPARC Scientific Steering Group—thirteenth session	Oxford, United Kingdom
24-28 October	CliC Scientific Steering Group—second session	Boulder, CO, USA

Members of the World Meteorological Organization

At 31 March 2005

STATES (181)

Afghanistan
Albania
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei Darussalam
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Cape Verde
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo
Cook Islands
Costa Rica
Côte d'Ivoire
Croatia
Cuba
Cyprus
Czech Republic
Democratic People's Republic of Korea
Democratic Republic of the Congo
Denmark
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
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Finland
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Gabon
Gambia
Georgia
Germany
Ghana
Greece
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
Iceland
India
Indonesia
Iran, Islamic Republic of
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kiribati
Kuwait
Kyrgyzstan
Lao People's Democratic Republic
Latvia
Lebanon
Lesotho
Liberia
Libyan Arab Jamahiriya
Lithuania
Luxembourg
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Mauritania
Mauritius
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Mongolia
Morocco
Mozambique
Myanmar
Namibia
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Niue
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Oman
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Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Republic of Korea
Republic of Moldova
Romania
Russian Federation
Rwanda
Saint Lucia
Samoa
Sao Tome and Principe
Saudi Arabia
Senegal
Serbia and Montenegro
Seychelles
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
Spain
Sri Lanka
Sudan
Suriname
Swaziland
Sweden
Switzerland
Syrian Arab Republic
Tajikistan
Thailand
The former Yugoslav Republic of Macedonia
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Uganda
Ukraine
United Arab Emirates
United Kingdom of Great Britain and Northern Ireland
United Republic of Tanzania
United States of America
Uruguay
Uzbekistan
Vanuatu
Venezuela
Viet Nam
Yemen
Zambia
Zimbabwe

TERRITORIES (6)

British Caribbean Territories
French Polynesia
Hong Kong, China
Macao, China
Netherlands Antilles and Aruba
New Caledonia

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Meteorological Balloons

- Meteorological Balloons
- Parachute Inside Balloons
- AB Balloons
- Parachutes for Radiosonde Balloons
- Meteorological Instruments

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CD-ROM

The CD-Rom contains (in pdf format in both high and low resolution):

- WMO Bulletin 54 (2) – April 2005
- MeteoWorld – April 2005
- Weather, climate, water and sustainable development (WMO-No. 974) (Brochure for World Meteorological Day 2005)
- Saving paradise, ensuring sustainable development (WMO-No. 973)

The CD-Rom also contains (in pdf format in low resolution) :

- World Climate Research Programme: 25 years of science serving society (Brochure)
- Global Energy and Water Cycle Experiment—Phase I (Brochure)
- Nine WCRP flyers

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