THE WORLD CLIMATE RESEARCH PROGRAMME ACHIEVEMENTS

Scientific Knowledge for Climate Adaptation, Mitigation and Risk Management

WCRP
World Climate Research Programme

The World Climate Research Programme
Achievements Report
Scientific Knowledge for Climate Adaptation, Mitigation and Risk Management

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WMO/TD-No. 1499

WCRP is sponsored by WMO, IOC of UNESCO and ICSU.

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WCRP
World Climate Research Programme

FOREWORD

Ghassem R. Asrar
Director

It gives me great pleasure to present this accomplishment report, which spotlights selected activities that were sponsored, coordinated and carried out by the World Climate Research Programme (WCRP) core projects and working groups during the past five years. The report demonstrates the progress and achievements of the WCRP team of volunteers and contributors who collaborate on this complex interdisciplinary research to collectively attain results that no single nation, let alone an organization, could achieve on its own. The strong support and sustained engagement by the international scientific community in WCRP, its core projects and its working groups are the best indicators of the value added role of WCRP in facilitating and coordinating international climate research during the past 30 years. The entire WCRP team is grateful for the strong support we receive from our sponsors: the World Meteorological Organization (WMO), the International Council for Science (ICSU), and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The sustained support of these sponsors has made it possible for WCRP to attain the results highlighted in this report.

WCRP is widely recognized for the success of its past activities, such as the Global Atmospheric Research Programme (GARP), a foundation for today's numerical weather forecasts, followed by the Tropical Ocean and Global Atmosphere Programme (TOGA) and the World Ocean and Circulation Experiment (WOCE), which established the basis for today's comprehensive ocean observing system(s) and oceans state estimation products. The Arctic Climate System Study (ACSYS) brought to light the critical role of the cryosphere in the climate system. These efforts have culminated in today's WCRP core projects, which are jointly contributing to building the foundation for the coupled-climate and Earth system models of the future.

This report illustrates the depth and breadth of observational research and analysis, modelling and synthesis, and climate projection and prediction activities that are being coordinated by WCRP. In addition it provides the highlights of the solid scientific foundation that WCRP has established for developing and disseminating the climate science knowledge that will be required in the ensuing decades to inform decision-makers on all aspects of mitigation, adaptation and risk management associated with climate variability and change. A companion document to this report, the WCRP Implementation Plan, identifies the major areas of research coordination and the expected deliverables by WCRP and its core projects to the benefit of the global society during the next five years.

The prime challenge I envision for the WCRP team, as well as the climate science community, is the development and training of the next generation of experts and leaders who will guide the future research activities of WCRP. For this reason, education and capacity-building constitute a high priority area of coordination that will require the support of WCRP and its partner programmes and organizations worldwide.

I do hope you will find this report useful. I welcome your feedback and suggestions regarding means by which we can further improve this report to make it an even more effective communication tool for WCRP sponsors, supporters and participants.

THE MISSION OF WCRP

DIGITAL VISION

The World Climate Research Programme (WCRP) was established in 1980. Its aim is to "facilitate analysis and prediction of Earth's climate system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society."

The major scientific objectives of WCRP are to:

(1) determine the extent to which climate can be predicted;

(2) determine the extent of human influence on the climate system.

Progress in understanding climate system variability and change makes it possible to address its predictability and to use this predictive knowledge in developing adaptation and mitigation strategies. Such strategies assist the global communities in responding to the impacts of climate variability and change on major social and economic sectors including food security, energy and transport, environment and health and water resources.

There has never been a greater demand for information on climate and WCRP plays a critical role in the development of climate information for many user communities. The foci of WCRP research are:

- observing changes in the components of the Earth system – atmosphere, oceans, land and cryosphere – and in the interfaces among these components;
- improving our knowledge and understanding of global and regional climate variability and change, and of the mechanisms responsible for this change;
- assessing and attributing significant trends in global and regional climates;
- developing and improving numerical models that are capable of simulating and assessing the climate system over a wide range of space- and timescales and that are suitable for operational predictions;
- investigating the sensitivity of the climate system to natural and human-induced forcings and estimating the changes resulting from specific disturbing influences.

In 2008, the main sponsors[1] of WCRP organized an independent review of the programme. The review recognized the many important achievements of WCRP and its role in helping society meet the challenges of global climate change. In response to this review, WCRP is devoting considerable resources to strengthening its relationship with key end-user groups of climate information and to developing an Implementation Plan for the next five years.

1 The World Meteorological Organization (WMO), the International Council for Science (ICSU), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

THE STRATEGY OF WCRP

ESA/AOES MEDIALAB

In 2005, WCRP developed a strategic framework for its research activities. The so-called Coordinated Observation and Prediction of the Earth System (COPES) provides a unifying context and agenda for the wide range of climate science relevant to society. WCRP is currently facilitating the development and implementation of comprehensive, reliable, end-to-end global climate observations, analyses and models for:

(1) describing the current and future state of the Earth's climate and its variability taking into account the complex interactions and feedback mechanisms among the Earth's oceans, atmosphere, land and human activities;

(2) making this scientific information and knowledge available to decision-makers for establishing policies and/or managing the risks and opportunities associated with climate variability and change in all sectors of the global economy.

The challenges identified in the COPES strategic framework include:

(1) the seamless prediction of climate from seasons to decades and centuries;

(2) the predictability of the Earth's climate system in light of its extreme complexity;

(3) the prediction of climate taking into account the whole Earth system, including the contribution of human activities;

(4) the analysis of climate system behaviour in order to understand, detect and attribute the causes of change, including those induced by human activities;

(5) the application of the resulting knowledge to socio-economic impacts of climate change that are confronting the nations around the world.

THE IMPLEMENTATION OF WCRP

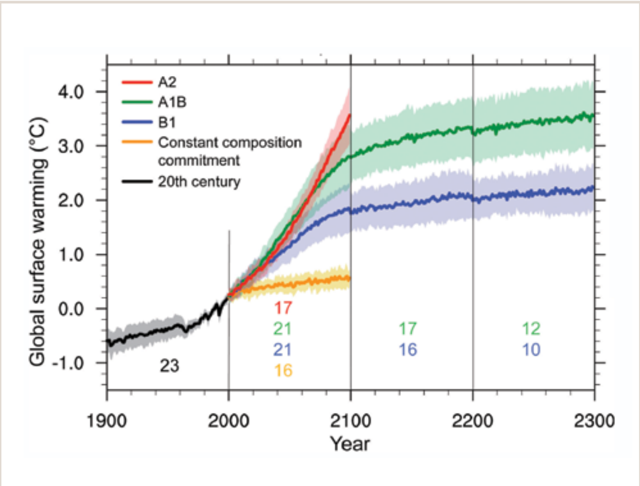
CHRISTIAN MOREL

To achieve its strategic scientific objectives, WCRP promotes a combination of model and field experiments together with long-term climate observations, largely coordinated by the Global Climate Observing System (GCOS).The goal of these activities is to characterize the components of Earth's climate system, and their behaviour so as to better understand and predict future changes.

WCRP has identified a number of socially relevant areas of scientific investigation requiring expertise and capabilities that transcend traditional environmental science disciplines. These areas of investigation include:

- anthropogenic climate change – contributions of human activities to changing climate;
- atmospheric chemistry and climate – contributions of changing atmospheric composition to climate and the impact of climate variability and change on the composition of the atmosphere;
- sea-level rise – causes and consequences of sea-level variability and change, especially for coastal communities;
- climate extremes – the magnitude, frequency and severity of extreme climate conditions (such as heatwaves, floods, droughts), and the probability of their occurrence;
- seasonal predictions – processes that control and shape seasonal climate and its variability and change;
- decadal predictions – the processes and phenomena that contribute to the variability of climate on decadal timescales and that affect its predictability;
- monsoons – the processes that contribute to the annual march of the monsoons and that determine their predictability.

WCRP implements its activities through the following core projects:

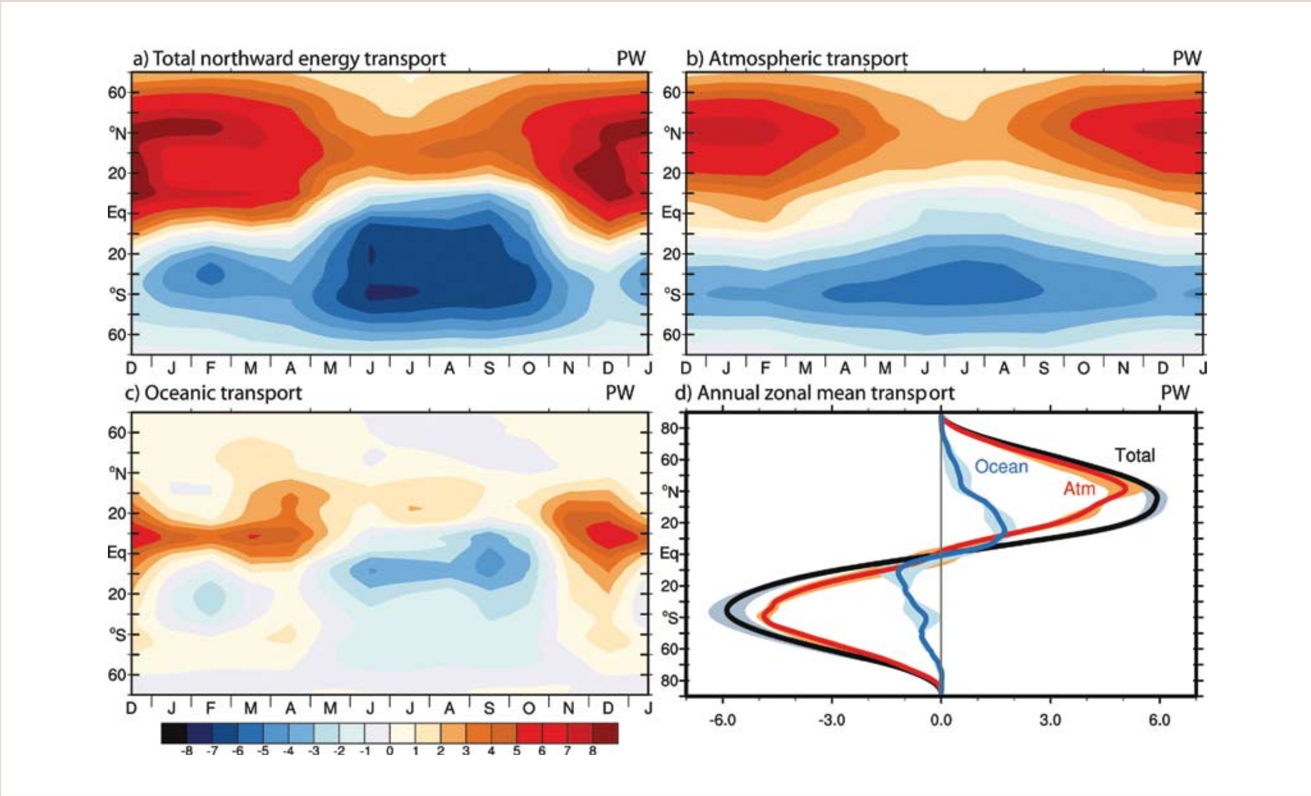


INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), FOURTH ASSESSMENT REPORT (AR4), WORKING GROUP ONE (WG1)

Multimodel means of surface warming (relative to 1980-1999) for different scenarios. Results from the Working Group on Coupled Modelling (WGCM) Coupled Model Intercomparison Project 3 (CMIP3) analysis, which includes, for the first time, a climate change commitment experiment stabilized for the year 2000 (orange line). Even when concentrations of greenhouse gases (GHGs) are held constant, the climate continues to warm due to the thermal inertia of the oceans.

- Climate and Cryosphere Project (CliC);
- Climate Variability and Predictability (CLIVAR);
- Global Energy and Water Cycle Experiment (GEWEX);
- Stratospheric Processes and their Role in Climate (SPARC)

As well as the Working Group on Coupled Modelling (WGCM) and the Working Group on Numerical Experimentation (WGNE).



FASULLO AND TRENBERTH, 2008

Total poleward energy transport (petawatts) from satellite observations is shown in the top left figure. The atmospheric component (top right) has been derived from atmospheric reanalysis, while the ocean component (bottom left) is calculated using all the ocean heat content observations from ocean reanalysis. The bottom right figure depicts the annual mean. This exemplifies the synthesis of multiple datasets including reanalysis of atmosphere and ocean observations, an international effort that is facilitated by the WCRP Observation and Assimilation Panel (WOAP).

ClIC
http://clic.npolar.no

The principal goal of CliC is to assess and quantify the impacts that climatic variability and change have on components of the cryosphere and its overall stability, and the consequences of these impacts for the climate system.

CliC works with partners to provide:

- enhanced observation and monitoring of the cryosphere and the climate of cold regions in support of process studies, model evaluation, change detection, and other applications;
- improved understanding of the physical processes and feedbacks through which the cryosphere interacts within the climate system;
- improved representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of climate variability and change;
- facilitation and support of scientific assessments of changes in the cryosphere and their impacts, in particular the IPCC Fifth Assessment Report.

Key scientific focus areas are sea level change and variability, the role of carbon and permafrost in the climate system, hemispheric differences in sea ice extent and seasonal predictability processes, and cryospheric input to the Arctic and Southern Ocean freshwater budgets.

CLIVAR
www.clivar.org

CLIVAR has four major objectives:

- to describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal, and centennial timescales; this is accomplished through the collection and analysis of observations and the development and application of models of the coupled climate system, in cooperation with other relevant climate research and observing programmes;

- to extend the record of climate variability over the time-scales of interest through the assembly of quality-controlled paleoclimatic and instrumental data sets;

- to extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models;

- to understand and predict the response of the climate system to increases of radiatively active gases and aerosols and to compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

The key scientific themes of CLIVAR are the El Niño Southern Oscillation (ENSO) and other modes of tropical variability; monsoons, decadal variability and the thermohaline circulation, anthropogenic climate change, and the role of the oceans in climate. These are aimed at making key contributions to the WCRP cross cutting activities of seasonal and decadal prediction, monsoon prediction, anthropogenic climate change, sea-level rise and climate extremes.

GEWEX
www.gewex.org

The goal of GEWEX is to observe, analyse, understand and predict the variations of the global energy cycle and hydrological regime and their impact on atmospheric and surface dynamics. GEWEX also seeks to observe and understand regional hydrological processes and water resources and their response to changes in the environment, such as increasing greenhouse gas concentrations and land use change.

The objectives of the GEWEX programme are:

- to 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 for use in climate system analysis and model development and validation;

- to enhance the understanding of and quantify how energy- and water-cycle processes contribute to climate feedbacks;

- to strengthen the predictive capability of key water- and energy-cycle variables by improving parameterizations so that they provide a better representation of geographical and seasonal hydrometeorological processes over land areas;

- to undertake joint activities with operational hydrometeorological services and related Earth System Science Partnership (ESSP) projects such as the Global Water System Project (GWSP), and hydrological research programmes to demonstrate the value of GEWEX research data sets and tools for assessing the consequences of climate variability and change for water resources.

SPARC
www.atmosp.physics.utoronto.ca/SPARC

SPARC addresses key questions in climate research in the context of three main themes:

- climate-chemistry interactions;

- detection, attribution, and prediction of stratospheric change;

- stratosphere-troposphere dynamical coupling.

SPARC co-leads, with the International Global Atmospheric Chemistry Project (IGAC) of the International Geosphere-Biosphere Programme (IGBP), the WCRP-IGBP joint research activity on atmospheric chemistry and climate, which has a leading role in the preparation of the WMO/United Nations Environmental Programme (UNEP) scientific assessments of ozone depletion. Through its assessments of stratospheric observations SPARC improves the quality and understanding of the observed record of variability and long-term changes in the stratosphere. Through its modelling and data assimilation activities SPARC is contributing directly to the knowledge base that supports the development of next generation weather analysis systems and weather and climate prediction mod-els. In addition, SPARC, through its research activities in stratosphere-troposphere dynamical coupling, contributes to the understanding that is required as the underpinning for the development of next-generation weather, climate and Earth system prediction models.

HIGHLIGHTS OF WCRP ACCOMPLISHMENTS

JULIO ETCHART, WORLD BANK

WCRP core projects and working groups provide the scientific and technical forums to identify high-priority climate research topics that require interdisciplinary and international cooperation. Through these WCRP forums, participants build consensus on international coordinated research activities that take full advantage of the synergies and expertise of participating organizations. The voluntary contributions from the WCRP community have been the primary source of the Programme's remarkable success since its inception 30 years ago.

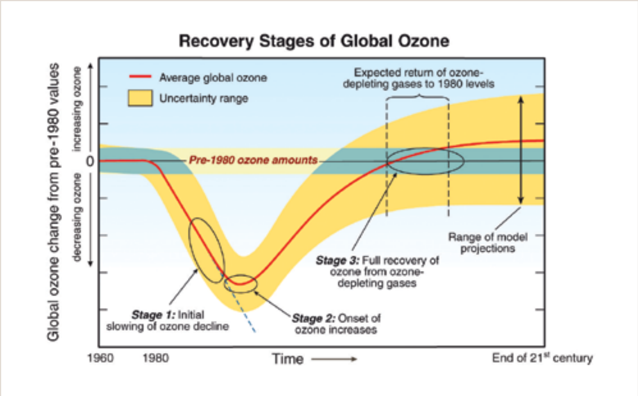
WCRP CONTRIBUTIONS TO ENVIRONMENTAL ASSESSMENTS

WCRP research results have been the main source of scientific knowledge for environmental assessments such as the WMO/UNEP Assessment of Ozone Depletion/Recovery and the IPCC assessment reports on climate change. WCRP products significantly contributed to the recently published reviews of the state of the cryosphere on polar climate. WCRP will also contribute to the assessment of sea-level variability and change.

Assessing the extent of depletion and recovery of stratospheric ozone

The depletion of stratospheric ozone during the latter half of the twentieth century is the result of long-lived chemicals that have been produced on the surface of the Earth by human activities. During the twenty-first century, stratospheric ozone is expected to recover due to a decline in the atmospheric burden of ozone-depleting substances. This decline will result from emission controls mandated by the Montreal Protocol on Substances that Deplete the Ozone Layer and its amendments and adjustments. It has become increasingly clear, however, that the future evolution of the ozone layer and its eventual recovery are linked to climate change associated with increasing concentrations of radiatively and chemically active substances in the atmosphere - substances produced by 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 timescales ranging from weeks to years. It is now understood, however, that stratosphere-troposphere dynamical coupling influences the troposphere as well.

Stratosphere-resolving chemistry-climate models have become key tools for understanding and predicting the evolution of ozone and its interaction with the rest of the climate system. The SPARC Chemistry-Climate Model Validation Activity (CCMVal, http://www.pa.op.dlr.de/CCMVal/) has taken on a leadership role in quantifying the evolution of stratospheric ozone and assessing its interaction with the climate system. The chemistry-climate modelling that is coordinated within CCMVal makes use of a comprehensive process-oriented diagnostic evaluation and validation programme, and it provides a basic underpinning for the WMO/UNEP Scientific Assessment of Ozone Depletion. These assessments are part of a process that was established at the beginning of the implementation of the Montreal Protocol to help the parties reach informed decisions on controls to protect the ozone layer. The first report was published in 1989 and since then major periodic assessments have been



WMO/UNEP SCIENTIFIC ASSESSMENT OF OZONE DEPLETION, 2006

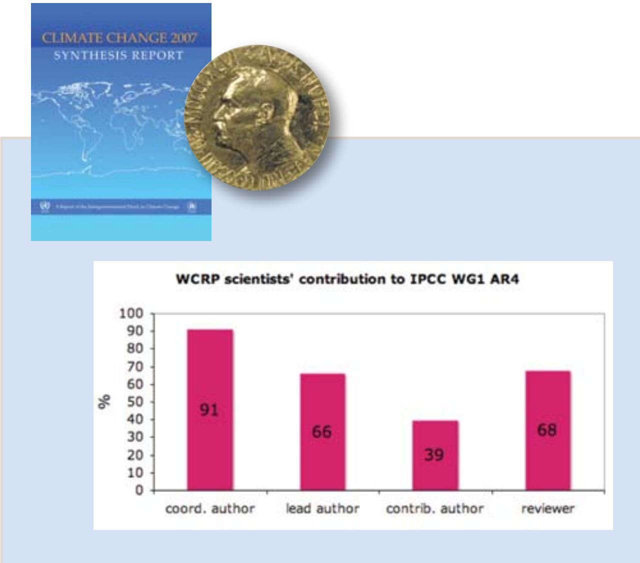
Model projections for stratospheric ozone recovery under reduced emissions of ozone-depleting substances as regulated by the Montreal Protocol. The large uncertainty range illustrates natural ozone variability in the past and potential uncertainties in global model projections of future ozone abundance. The evolution of anthropogenic climate change in the twenty-first century is one key source of uncertainty in the future projections .

published every four years (http://ozone.unep.org/Publications/Assessment_Reports/). SPARC-affiliated scientists have played leading roles in the preparation of these reports.

In addition to being a key feature of climate change, temperature trends in the stratosphere are also critically linked to stratospheric ozone variability and change. Because of their importance in this context, stratospheric temperature trends have been examined as part of the Scientific Assessment of Ozone Depletion. Attempts to evaluate the causes of the stratospheric cooling in the recent past, using models and observations, have suggested that the upper stratospheric trends are, in almost equal share, associated with ozone depletion and increases in carbon dioxide. While lower stratospheric cooling is mainly associated with ozone depletion, there may also be a contribution from changes in the stratospheric water vapour. Quantifying observed temperature trends and their uncertainty is a major focus of the SPARC Temperature Trends Working Group. Modelling recent stratospheric temperature trends and projecting of future temperature trends in the stratosphere have been key contributions of CCMVal Activity to recent ozone assessments.

Contribution to IPCC AR4

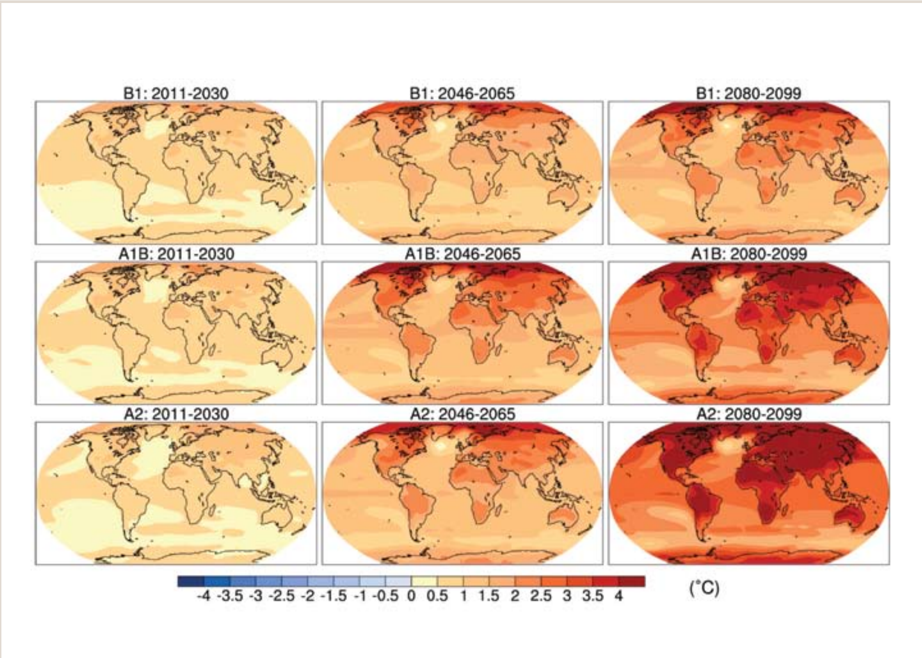
The IPCC (http://www.ipcc.ch/) was established in 1988 by WMO and UNEP to assess the scientific information



WCRP-affiliated scientists made significant contributions to the IPCC AR4 WG I assessment.

related to anthropogenic climate change. Its latest assessment report (AR4) was published in November 2007 and IPCC was honoured, along with Mr. Albert Gore, with the Nobel Peace Prize for "the efforts in building-up and disseminating greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change". WCRP activities contributed significantly to the scientific basis for the landmark findings in all IPCC reports, including the AR4. Notably WCRP played a key role through the work of its affiliated scientists that coordinated, led, authored and reviewed the various chapters in the WG I report. As testified by S. Solomon, co-chair of IPCC AR4 WG I, "WCRP serves an irreplaceable role for coordination within the science community, which in turn is invaluable to the IPCC".

The WCRP WGCM initiated the CMIP3 in 2004, and in 2005 facilitated the collection and archiving of all of the global climate model simulations undertaken for the IPCC AR4, as well as the organization of access to them. This unprecedented collection of model output is officially known as the WCRP CMIP3 multimodel dataset and comprises a set of twentieth and twenty-first century coordinated climate change experiments from 19 groups in 11 countries with 24 global coupled-climate models. About 36 terabytes of model simulations were collected by the team at the Program for Climate Model Diagnosis and Intercomparison (PCMDI http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). The model outputs are openly available, and have been accessed by over 2000 scientists who have produced over 500 peer-reviewed papers on various



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), FOURTH ASSESSMENT REPORT (AR4), WORKING GROUP ONE (WG1)

A summary of the multimodel results for changes in surface air temperature for different scenarios and periods is provided above. WGCM CMIP3 showed a pattern of warming that is very similar for all periods and all scenarios but with amplitudes differing for each: continents warm more than oceans, the high-latitude northern hemisphere warms more than elsewhere, and there is less warming in the North Atlantic and Southern Ocean topics including African monsoon variability, drought in Australia, hydrology in the Mekong River, Pacific Island climate change detection, Arctic contribution to sea-level rise, and anthropogenic impact on Antarctic oceanography.

Many scientific questions remain unanswered and they represent the challenges for future climate change assessments:

(1) In which region is society most vulnerable to climate change?

(2) When and how fast will the changes occur?

(3) What are the thresholds beyond which potentially "dangerous" changes will occur?

Currently, the next phase of CMIP (CMIP5) is under development. The major challenges for the new set of climate models to be utilized in CMIP5 include identifying the regional climate changes to which human societies will have to adapt over the next few decades and quantifying the magnitude of the robust feedbacks in the climate system, such as those associated with clouds and the carbon cycle.

Cryospheric and polar climate assessments

CliC – affiliated scientists led the preparation of the cryosphere-dedicated chapter in the IPCC AR4, which presented the first holistic look at the simultaneous changes taking place in various parts of the cryosphere. The AR4 analysis of the state of the cryosphere was further developed under the Global Outlook for Ice and Snow published by UNEP in 2007, which also included key contributions of many experts associated with CliC. The impacts of cryospheric changes are expected to be very significant. For example, melting of mountain glaciers and polar ice sheets contribute to the increased pace of the global sea-level rise, while accelerated thawing of permafrost alters the land surface in northern latitudes and affects the hydrological regime and carbon cycles. Through its impacts on weather, climate, and hydrologic conditions, the cryosphere affects transportation, fresh-water supply, agricultural planning, recreation and wildlife.

After the seminal Arctic Climate Impact Assessment (ACIA) of 2005, a new level of knowledge on the changes in the Arctic climate has been achieved, and the World Wide Fund for Nature (WWF) published an update since ACIA in 2008.

US NATIONAL SNOW AND ICE CENTER

With few exceptions, the glaciers around the world are retreating at unprecedented rates. Some ice caps, glaciers and even an ice shelf have disappeared. The left-hand photo of Muir Glacier, Alaska USA was taken on 13 August 1941 by O. Field; the right photo was taken on 31 August 2004 by B. F. Molnia of the United State Geological Survey.

The new level of knowledge on the state of and changes in the cryosphere made it possible for the cryosphere science community to embark on as assessment "Climate Change and Cryosphere: Snow , Water, Ice, and Permafrost in the Arctic" (SWIPA), which has been commissioned by the Arctic Council and co-sponsored by the AMAP, IASC, CliC and IPY. In this project not only observed changes in the cryosphere will be reviewed but also a prediction will be given for their evolution under a warming climate, based on the climate predictions available in the WCRP CMIP3-5 archive.

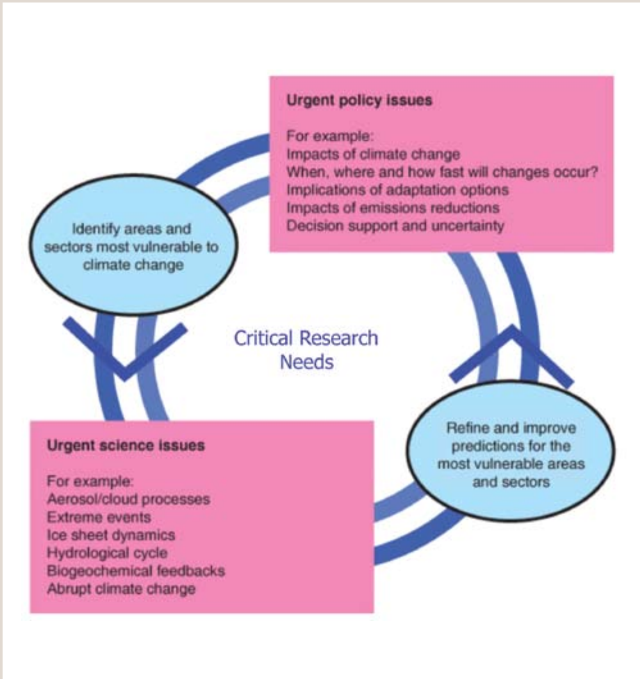
WHAT SHAPES THE EARTH'S CLIMATE SYSTEM: COMPLEX INTERACTIONS AMONG THE ATMOSPHERE, OCEANS, CRYOSPHERE, LAND AND BIOSPHERE

WCRP has been at the forefront of climate research in understanding and predicting climate variability and change; in particular, WRCP has focused on extending climate projections to predictions. The need for environmental prediction is becoming increasingly important and is predicated on the recognition that the climate system is inextricably linked to the Earth's biogeochemistry and human activities. Not only is WCRP working in partnership with other international programmes to tackle challenging interdisciplinary questions related to Earth system science, but its core projects are also engaged in research on regional aspects of the climate system.

Learning from the IPCC AR4 process

Together with IGBP and GCOS, WCRP organized a workshop in Sydney, Australia in 2007 to help guide future strategies for climate change observations and research. The workshop participants examined gaps in observations and basic science as identified by the IPCC (WGs I & II), and deficiencies in the way information about climate change can be used for estimation of impacts, design of adaptation measures and assessment of regional vulnerability.

The workshop also identified research activities required to improve performance of regional climate models. To support decision-making, climate information should



FUTURE CLIMATE CHANGE RESEARCH AND OBSERVATIONS: GCOS, WCRP AND IGBP LEARNING FROM THE IPCC FOURTH ASSESSMENT REPORT WMO/TD NO. 1418, 2008.

This schematic model illustrates how the regional vulnerability to climate change may be linked to future climate research strategies and observational needs in order to address societal concerns.

be provided at a high spatial resolution and with a realistic representation of extreme events. Currently, such information is obtained either by downscaling the output of global models to the regional level or by using regional climate models. Thus, strengthening the interaction between the global circulation models and the regional climate change models, as well as further improvement of these models were identified as major research priorities. Obtaining appropriate data to further develop and test the accuracy of models, especially regional models, is essential.

In 2008 WCRP established the Task Force on Regional Climate Downscaling (TFRCD), which aims to:

(1) develop a framework to evaluate and improve RCD techniques for use in downscaling global climate projection;

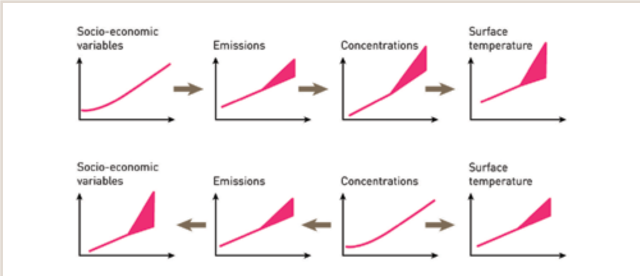
(2) design an international coordinated effort to produce a new generation of RCD-based high-resolution climate change projections over regions worldwide for use in impact and adaptation studies;

(3) promote increased interactions among climate modellers, specialists in downscaling and end-users to better support impact and adaptation activities, fostering, in particular, greater involvement of scientists in developing countries.

TFRCD organized two workshops on evaluating and improving regional climate projections: one was held in February 2009 in Toulouse, France and the other in May 2009 in Lund, Sweden. The Task Force also launched the COordinated Regional climate Downscaling EXperiment (CORDEX) to develop a set of regional domains at high spatial resolution (30-50 km), essentially covering all land areas of the globe. The African domain was selected for the initial focus of obtaining regional forecasts from several regional modelling centres worldwide.

Enabling multidisciplinary research on climate/ Earth system models

WCRP and IGBP collaborate to define a strategy for the new Earth system modelling components in terms of aerosols, atmospheric chemistry, carbon cycle and the dynamics of the vegetation, which are subjects of intensive development and implementation in climate models. At the Aspen Global Change Institute (August 2006) representatives of WCRP and IGBP proposed a new approach for the next generation of coupled-climate system models.



The schematic of the traditional forward approach starts with socio-economic variables to derive emissions, concentrations and then temperature and other climate changes from climate models (top). A new proposed methodology is also illustrated in which the starting point is concentrations run in climate models, which are then used to derive emissions and the socio-economic factors required to achieve those emissions (bottom).

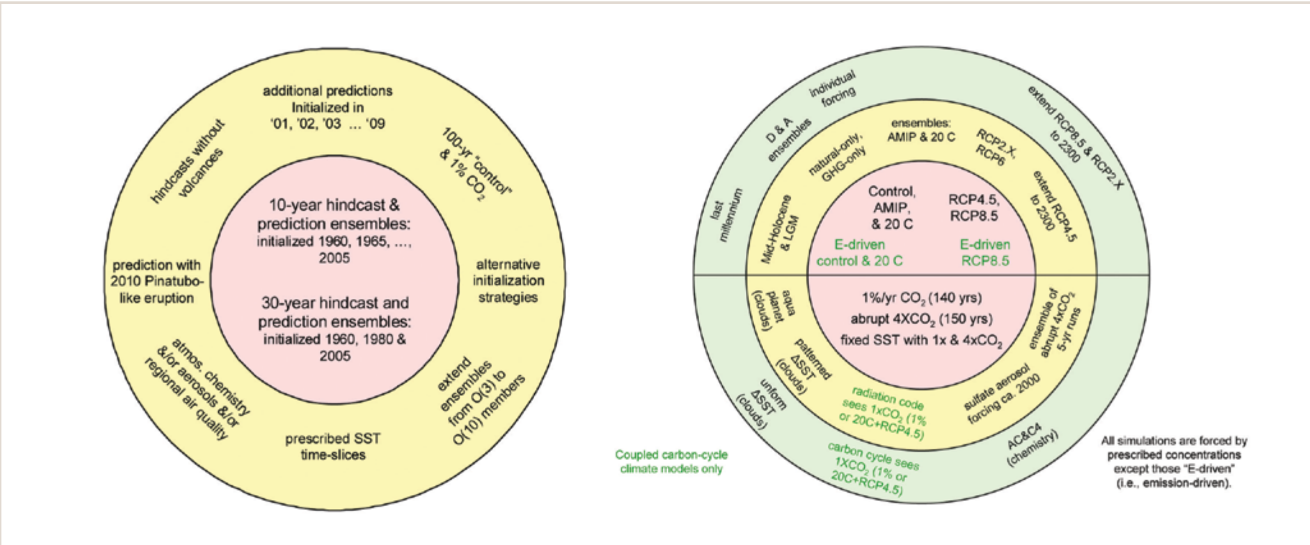
The new approach uses the Representative Concentration Pathway (RCP) as the starting point to derive emissions; by so doing, there is no need to evaluate socio-economic factors before running scenarios in climate models. The socio-economic factors that produce emissions can be determined from the concentrations that have an associated climate change outcome. Thus, there may be multiple socio-economic pathways leading to similar concentrations, resulting in a rich ensemble of socio-economic scenarios. This approach also avoids the cascade of errors across climate and socio-economic models.

As part of CMIP5, the WCRP Working Group on Coupled Modelling is shaping the framework for climate change modelling experiments/projections that will be used for the next five years. Results from these experiments will provide the basis for the next IPCC assessment (AR5). The ensemble of CMIP5 experiments will enable a thorough evaluation of how realistic the models are in simulating the recent and longer past. They will also provide projections of future climate change on two time scales (decadal and centennial), and will facilitate the understanding of some of the factors responsible for differences in model projections.

The new strategy is based on the use of two classes of models to address two timeframes and two sets of science questions:

(1) long-term projections (to 2100 and beyond) to explore the magnitude of feedbacks;

(2) near-term projections (decadal predictions to 2035) to address regional climate and extremes.



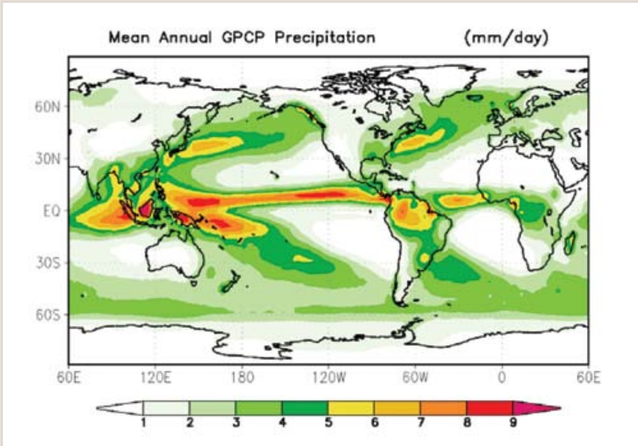
Schematic summary of CMIP5 decadal (left) and long- term (right) prediction experiments

The decadal prediction studies point toward the possibility of routine predictions of sufficient skill and higher spatial resolution to be used by planners and decision-makers. The challenge is to identify the mechanisms associated with some specific regions that exhibit predictability on the decadal timescale.

Assessing global precipitation observations

Coordinated by GEWEX, the Global Precipitation Data Assessment was conducted by an international group of scientific experts in the measurement and analysis of precipitation using remote sensing and in situ observations. This report details the state-of-the-art techniques used to measure global precipitation, a major component of the global water and energy cycle that significantly influences the Earth's climate system. The report describes in detail how these precipitation records are developed, the underlying assumptions in sampling and processing procedures, their spatial and temporal resolution, and the potential sources of errors and anomalies in these records. The report also reviews current satellite techniques for estimating precipitation and the characteristics of long-term in situ datasets.

The reader will find in the report new information about the distribution and variability of global precipitation, particularly over the oceans. The report offers useful insights and guidelines for improving current records through both observations and processing, and for expanding these records in the future to capture the full three-dimensional structure of clouds and hydrometeors based on the emerging polarimetric and multi-frequency active/passive microwave sensors. The Global Precipitation Data Assessment identifies, as a high priority, the need to improve observations of snow rate and precipitation in complex terrain. The report also highlights the unique capabilities and contributions of the Global Precipitation Measurement (GPM) constellation of satellites. Under development in the United State of America, Japan and Europe, these satellites will provide routine updates of global precipitation over 80 per cent of the Earth once every three hours.

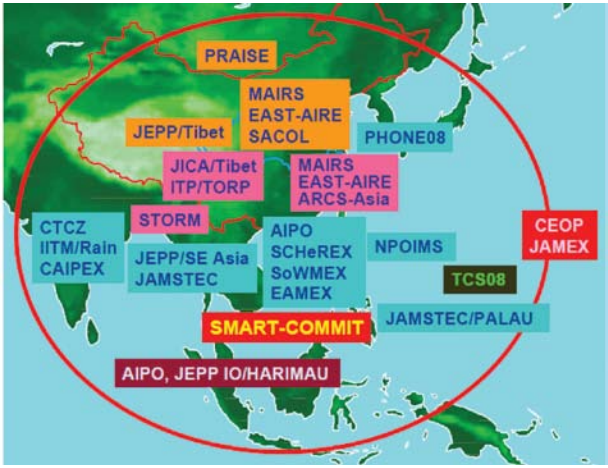


The figure illustrates the average for the period 1979-2003, in mm per day, of the satellite-gauge combined precipitation product as measured by the GEWEX Global Precipitation Climatology Project (GPCP). The average position of the inter-tropical convergence zone (ITCZ) is clearly indicated by the broad band of high precipitation. The wettest parts of the planet are the tropical West Pacific, the maritime continent and extreme tropical eastern edge of the Indian Ocean, and the tropical East Pacific extending into the Amazon Basin. In the northern hemisphere, mid-latitude storm tracks along the Kuroshio Current and the Gulf Stream produce areas of high precipitation.

UNDERSTANDING THE REGIONAL CAUSES AND CONSEQUENCES OF GLOBAL CLIMATE CHANGE

Advancing research on monsoon systems

More than 70 per cent of the Earth's population lives under the influence of monsoon climates and frequently experiences natural disasters such as floods or severe water deficits, both of which may be caused by the variability of monsoons. Monsoon systems are potentially very sensitive to the anthropogenic impacts associated with the global warming. Through the research activities and contribution to various assessments, WCRP contributes to improved understanding of these factors.



National/regional projects that participate in the The Asian Monsoon Years (AMY 2007-2012)

Monsoons are the result of land-atmosphere-ocean interactions and involve a big variety of processes of different temporal (from diurnal to decadal) and spatial (from local through regional to continental) scales. Due to our insufficient understanding of these processes and interactions, large uncertainties exist in monsoon prediction. Comprehensive observations are the pre-requisite for understanding the key monsoon processes and for representing these processes in models, either explicitly or through physical parameterizations. With improved models we will be able to achieve better predictive capabilities.

Through the joint efforts of CLIVAR and GEWEX, WCRP has played a major role in launching studies in the monsoon areas (Asia, Africa and America). In Asia, major monsoon research activities and field projects are being planned between 2008 and 2010 in China, Japan, India and Korea, as well as other Asian countries and surrounding regions. WCRP took a lead role in integrating these scientific programmes under the Asian Monsoon Years (AMY) initiative (http://www.wcrp-amy.org/). AMY implementation includes 24 regional field projects and model integration studies to improve understanding and prediction of the Asian monsoon system.

The Monsoon Experiment in South America (MESA; http://www.eol.ucar.edu/projects/mesa/) was established by the WCRP/CLIVAR Variability of the America Monsoon Systems (VAMOS) programme with the aim of investigating the characteristics and variability of the South American Monsoon System (SAMS). A core activity of MESA has been the South American Low-Level Jet Experiment (SALLJEX; http://www.eol.ucar.edu/projects/salljex/), a field campaign that took place between 15 November 2002 and 15 February 2003. Special in situ measurements were made in Bolivia, Paraguay, central and northern Argentina, and western Brazil, to address observational gaps and to describe many aspects of the low-level jet. The SALLJEX data are providing quantitative information on the regional errors of global re-analyses and confirming that regional models are capable of simulating the basic features of low-level warm season circulations over tropical South America, but have difficulties in reproducing the observed diurnal cycle. These data also improved our knowledge of the processes leading to heavy rainfall events and evidenced the important role of initial surface conditions for prediction of rainfall associated with low-level jet. Scientists, collaborators, students, and local volunteers from Argentina, Brazil, Bolivia, Paraguay, Chile, Uruguay, Peru, and the United States participated in SALLJEX activities in an unprecedented manner. SALLJEX is the first WCRP/CLIVAR international campaign carried out in South America. Its results are being used extensively in modelling studies of the South American monsoon system.

The North American Monsoon Experiment (NAME, http://www.eol.ucar.edu/projects/name/) is also a component of CLIVAR-VAMOS aimed at determining the sources and limits of predictability of warm-season precipitation over North America. It focuses on observing and understanding the key components of the North American Monsoon (NAM) system and their variability within the context of the evolving land surface-atmosphere-ocean annual cycle. NAME activities culminated in the design and execution of an intensive continental scale field campaign, or Enhanced Observing Period (EOP), over north-western Mexico and the south-western United States during the boreal summer of 2004. NAME-EOP made use of several operational networks, as well as research vessels and aircrafts, a polarized research radar, supplemental rain-gauge networks and several wind profilers. The 2004 EOP collected information that was more detailed than ever before on the exchange and transport of energy and water within the NAM system and provided the first opportunity to assimilate this information into operational climate models and prediction products.

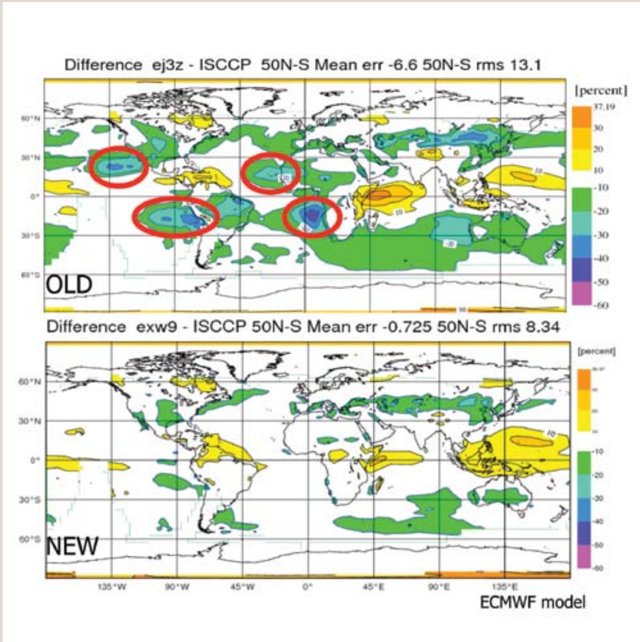
The African Monsoon Multidisciplinary Analysis (AMMA), co-sponsored by GEWEX and CLIVAR, is an international project whose goal is to improve the understanding of the West African monsoon (WAM) and its variability. The project focuses on the daily-to-interannual timescale. AMMA stems from an interest in fundamental scientific issues and from the need for improved prediction of the WAM in order to mitigate its impacts on West African nations. AMMA benefits from the contributions of more than 500 scientists, 140 institutes and 30 countries. Scientists collaborate in various key areas including the coupled atmosphere-ocean-land system, interactions between aerosols and the monsoon, and multi-scale analysis of the water cycle. The ultimate goal is to understand how West African society, environment and climate interact. A major achievement of AMMA is the implementation of the long-term observation period 2001-2009 and research field campaigns in 2005-2007 that included several intense observing periods. The project resulted in huge improvements in the regional radiosounding network. AMMA continues to maintain a number of sustained observations that are key for long-term monitoring and analysis of the West African monsoon. These include the multidisciplinary surface measurements made at mesoscale sites in

Benin, Mali and Niger, the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) oceanic network and the meteorological network (soundings and GPS). AMMA has created a unique multiscale and multidisciplinary database that is used by weather and climate research/operational centres all over the world, especially in Africa.

From weather to climate

Reliable weather prediction is critically important for the protection of life and property, particularly under extreme conditions. While short-range weather forecasting depends primarily on the model initialization, an extension to medium- and long- range weather forecasting introduces the coupling of land surface processes and the role of soil moisture feedback and other surface-atmosphere coupled processes. This necessitates the creation of a "seamless" prediction system that accumulates all predictability existing on shorter time scales to predict the Earth system on longer time scales. Developing a unified approach to weather, climate, water and environmental prediction requires a broad Earth system perspective that extends beyond the traditional atmospheric science disciplines. Such a prediction system will be predicated on highly sophisticated technological solutions and will build on the meteorological prediction research coordinated by WMO.

The establishment of the Working Group on Numerical Experimentation (WGNE) in 1985 by WCRP and the WMO Commission for Atmospheric Sciences (CAS) strengthened WCRP cooperation with weather research and operations centres. WGNE is responsible for providing expert advice to numerical weather forecast centres worldwide, and acts as a catalyst for the development of numerical experimentation aimed at improving the numerical models used by the climate and weather



The figures illustrate errors in the simulation of fractional cloud cover in two versions of the European Centre for Medium-Range Weather Forecasts (ECMWF) model. The older model (top panel) shows large errors, particularly in regions of marine stratocumulus (that is, red circles), where the model significantly underestimates cloud cover. Improvements to the representation of clouds that were facilitated by the activities of the GEWEX Cloud System Study (GCSS) has led to major reductions in error in the more recent model (bottom). The dataset used for comparison was generated by the International Satellite Cloud Climatology Project, which is itself a GEWEX project.

prediction communities. Many of the processes that are important to weather and climate act on scales smaller than the grid sizes of contemporary models used in numerical weather prediction (NWP), seasonal prediction and climate simulation. The collaboration of the GEWEX Modelling and Prediction Panel, WGNE and WGCM/ Cloud Feedback Model Intercomparison Project (CFMIP) resulted in significantly improved parameterizations of clouds and convection that have been widely used in the main NWP and climate centres.

The realistic representation of tropical convection in global models is a long-standing, grand challenge for both numerical weather forecasts and climate projection. Incomplete knowledge in this area limits the modelling and prediction of prominent phenomena of the tropical atmosphere on regional and global scales. Examples of such phenomena include the InterTropical Convergence Zone (ITCZ), the El Niño-Southern Oscillation (ENSO), the Tropical Biennial Oscillation (TBO), monsoons and their active/break periods, the Madden-Julian Oscillation (MJO), subtropical stratus, upper-ocean properties, easterly waves, and tropical cyclones. Furthermore, as a result of various convection–wave interactions, tropical convection has far-reaching effects on the stratospheric-tropospheric exchange, the large-scale circulation of the upper–atmosphere, and the dynamics of the extra-tropics. To address this challenge, WCRP and the World Weather Research Programme (WWRP)/The Observing System Research and Predictability Experiment (THORPEX) have initiated a year of coordinated observing, modelling and forecasting with a focus on organized tropical convection, its prediction and predictability (Year of Tropical Convection or YOTC http://www.ucar.edu/yotc/). The intent is to exploit the vast amounts of existing and emerging observations, expanding computational resources and the development of new, high-resolution modelling frameworks. The ultimate success of YOTC will require coordination and collaboration among the operational prediction, research laboratory and academic communities. YOTC will thus help advance diagnosis, modelling, parameterization and prediction of multiscale tropical convection and two-way interaction between the tropics and extra-tropics, placing emphasis on the intersection between weather and climate. YOTC activities were initiated in the middle of 2008 and will contribute to the Asian Monsoon Years (AMY) and the THORPEX Pacific Area Regional Campaign (TPARC), as well as to the United Nations Year of Planet Earth.

Understanding and characterizing the changes in climate extremes

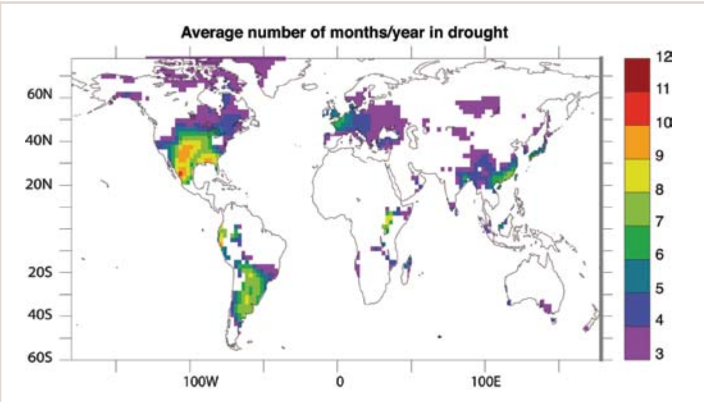
The Expert Team on Climate Change Detection and Indices (ETCCDI; www.clivar.org/organization/etccdi/etccdi.php) was established to respond to the need for long-term daily climate records and internationally recognized indices of climate extremes. The expert team is jointly sponsored by the WMO Commission for Climatology (CCl), the WCRP/CLIVAR and the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). The specifications for the 27 agreed indices developed by ETCCDI are available at http://cccma.seos.uvic.ca/ETCCDI along with software to calculate the indices. Many of the models used for the IPCC AR4 computed a subset of these indices, in part because they provide a metric for validation of how well the models simulate extremes. In addition, projected changes in the indices are indicative of the impacts of future climate change on extremes.

ETCCDI organized a series of regional workshops involving participants from neighbouring countries as well as several well-qualified experts from around the world to provide guidance on the analysis of climate data. Participants in the various workshops presented data from a few of their countries' sites to be quality controlled, checked for homogeneity and analyzed. Workshop participants were able to quickly assess the data availability across a given region, and thus recognize the benefits of preparing a consistent regional analysis based on a set of national databases. This was a key contribution of the regional workshops to capacity building and knowledge development.

GEWEX has made substantial progress in understanding drought phenomena through a Canadian project known as the Drought Research Initiative (DRI; www.drinetwork.ca). DRI was established in 2005 "to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction through a focus on the recent severe drought that began in 1999 and largely ended in 2005". This five-year interdisciplinary effort addressed five complementary research themes, namely quantification, understanding and better prediction of a specific drought as well as comparisons with other droughts, and assessments of implications of drought for society. The project also included the analysis of data and the assessment of indices used to characterize the drought. Field studies were conducted to collect the unique datasets required to establish and quantify the critical meso- and microscale processes responsible for maintaining the drought. These data are also used in the evaluation of model performance under drought conditions and to develop the improved parameterizations in regional and hydrological models needed to predict drought and its impacts. DRI has established a substantial dialogue with its user community through its Drought Early Warning System (DEWS) simulations.

The CLIVAR programme in the United States (US CLIVAR, http://www.usclivar.org/) took the lead in facilitating the prediction of long-term (multi-year) drought over North America and other drought-prone regions of the world.

KIRSTEN L. FINDELL, AND THOMAS L. DELWORTH



This figure depicts the average number of months/years in drought based on five different atmospheric models (relative to the climatology of each model's control run) forced using the same idealized SST anomalies simulating La Niña (cold) conditions in the Pacific and warm conditions in the Atlantic. The figure shows that North American drought is heavily influenced by SST patterns in the Pacific and the Atlantic. (Also true for southern South America and to a lesser extent, much of Europe and South-East Asia.)

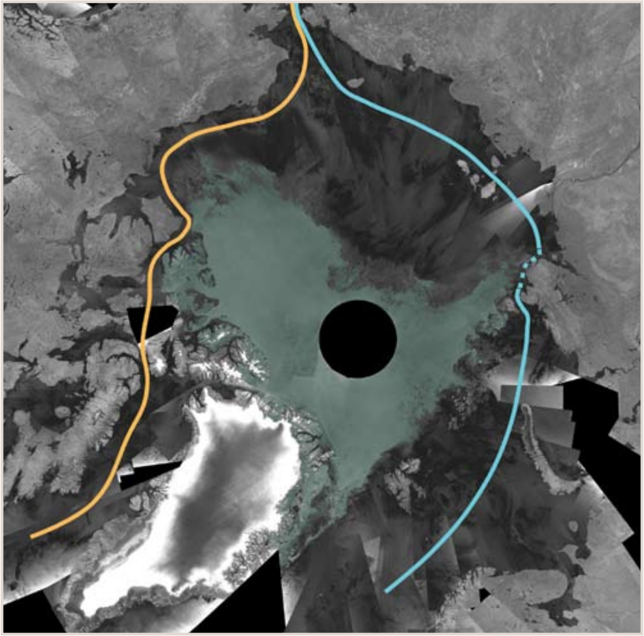
CLIVAR also assessed the impact of global change on drought processes. Drought, especially prolonged multi-year drought, has tremendous societal and economic impacts on the United States and many other countries throughout the world. Recent population growth in water-limited regions have increased vulnerability to drought, while at the same time climate change projections are suggesting that dry conditions may prevail more frequently in the twenty-first century. Drought is marked by commonalities, both in terms of the forcing elements and the factors that make some regions more susceptible to drought than others. An ad hoc CLIVAR working group in the United States focused recently on drought and the role of sea-surface temperature (SST) anomalies in generating drought conditions over land. This working group coordinated an experiment with major United States climate models to understand how these models respond to important observed SST patterns, that is, those observed in connection with El Niño Southern Oscillation and the North Atlantic Oscillation (NAO).

Lake Mead (United States) in October 2007 showing the effects of the drop in water levels from 1999 owing to drought.

Contributing to the success of IPY

With more than 50 000 participants from approximately 60 countries, the International Polar Year 2007-2008 (IPY) was one of the biggest scientific environmental campaigns in the history of science. WCRP supported and participated in the early discussions on the concept of IPY and helped to formulate its programme. The CliC Project led the overall coordination of WCRP input to IPY. The State and Fate of the Polar Cryosphere project managed by the CliC Scientific Steering Group was the IPY umbrella project for the cryosphere. All WCRP projects proposed one or several projects for consideration by the IPY Joint Committee, and more than 20 such projects were approved as major research clusters including the CLIVAR-led Climate of Antarctica and Southern Ocean (CASO) umbrella project.

The CliC-led IGOS Cryosphere Theme made several recommendations on the development of the polar and cryospheric observing systems and identified the IPY time frame as the first phase of their implementation. One of the recommendations formulated by the Cryosphere Theme was implemented through the Global Interagency IPY Polar Snapshot Year (GIIPSY). Proposed and coordinated jointly with leading satellite agencies, this project contributed to strengthening cooperation among space agencies in polar observations and led to the implementation of the first virtual constellation of satellites for polar regions. The resulting data archive, especially of the Synthetic Aperture

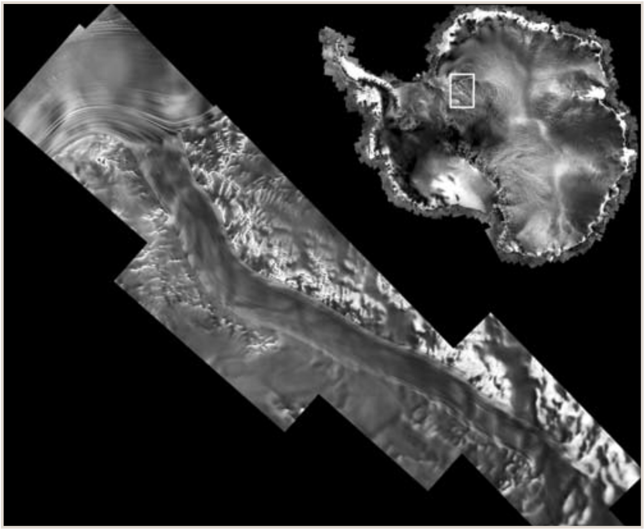


ESA

This ESA Envisat ASAR mosaic of sea ice in the Arctic Ocean for early September 2007 depicts its minimal cover for the entire period of sea-ice observations from space. The dark grey colour represents the ice-free areas, whereas the green colour represents areas with sea ice. The Northwest Passage is open (orange line), and the Northeast Passage is only partially blocked (blue line).

Radar (SAR) data, represents a unique snapshot of the polar cryosphere and provides a rich source of data for future cryospheric studies. Working with and through partners, WCRP made marked advances in the establishment of the integrated Arctic Ocean Observing System (iAOOS) and Southern Ocean Observing System (SOOS). In cruises conducted before and during the IPY, a significant warming of the Southern Ocean was detected and confirmed. This warming will likely play a significant role in determining the pace of the future sea-level rise.

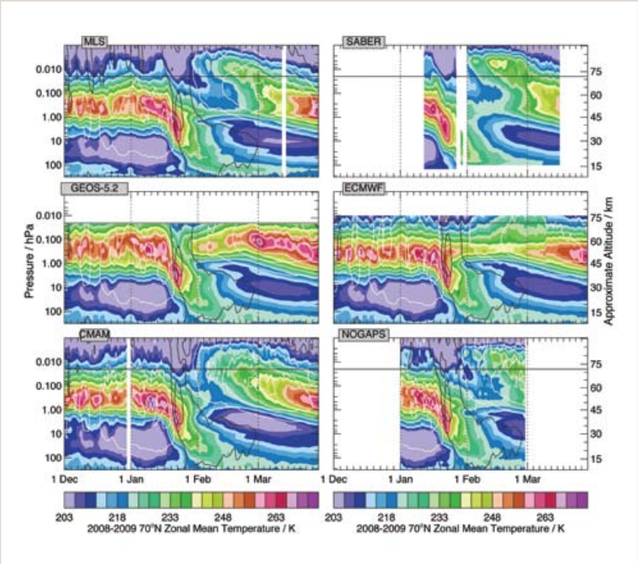
Precipitation is one of the key components of the hydrological cycle and it is also a very important variable in global change analyses. A change in precipitation produces a major impact on hydrology, climate and ecosystems. Significant (up to 100 per cent) systematic errors (biases) exist in the gauge-measured precipitation records and these biases must be documented and corrected in order to obtain a compatible, accurate dataset for large-scale hydrological and climatic studies.



CREDITS: DANA FLORICIOIU, GERMAN AEROSPACE CENTER (DLR)

The above mosaic of the tributary ice stream of Recovery Glacier in Antarctica (centre) was computed from TerraSAR-X acquisitions between November 2008 and January 2009. The area located at 82.5°S 19°W (see insert upper right) is about 250 km by 70 km and was imaged with a spatial resolution of 3.0 m.

The climate of the high latitudes is characterized by low temperatures, generally low precipitation and high winds. Because of the special conditions in high latitudes, the biases in gauge precipitation observations are even greater than at low latitudes and these biases must be borne in mind. During IPY, the CliC Project and associated research groups focused on addressing the problem of biases in precipitation measurements in high-latitude regions. Experiments were carried out to evaluate and define the accuracy in precipitation measurements and to implement consistent bias-correction methodologies for high-latitude regions (Alaska, northern Canada, Siberia, northern Europe, Greenland and the Arctic Ocean). As a result of these efforts, bias-corrected and compatible precipitation datasets (including grid products) and climatology are now available for the pan-Arctic.



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Time evolution of the vertical profile of zonal mean temperature at 70°N during January-March 2009. A stratospheric sudden warming in late January in shown. Data are from two satellite instruments (Microwave Limb Sounder and SABER) and four analyses in the SPARC-IPY archive: two of these (GEOS-5.2 and ECMWF) are operational products one (CMAM) is from a research assimilation system with no observations above 50 km; and one (NOGAPS) is from a research system assimilating MLS and SABER observations. This comparison shows the benefits of having well-resolved stratosphere and an accurate representation of gravity-wave drag, which has direct implications for model development.

The IPY activity titled "The Structure and Evolution of the Polar Stratosphere and Mesosphere and links to the troposphere during IPY" (SPARC-IPY) was led by SPARC and linked to a number of other IPY activities. A major goal of this programme was to document to the extent possible the dynamics and chemistry of the polar stratosphere during the IPY period. To complement results provided by new measurement programmes, SPARC-IPY also collected and archived objective analysis products from major centres during the IPY period, including the archiving of chemical species from those assimilation systems that include active chemistry components.

Current observational activities of WCRP contribute to preserving and further developing the IPY legacy. These activities will be coordinated under the Sustaining Arctic Observing Networks Initiative (SAON), the Pan-Antarctic Observing System (PAntOS) and the Global Cryosphere Watch (GCW). Building on these improved observations and enhanced knowledge of the polar processes, WCRP will continue to cooperate with the World Climate Programme in establishing a

Polar Climate Outlook Forum (PCOF). The goal of this forum is to disseminate the best available scientific knowledge regarding the polar regions to support policy and management decisions that will sustain the polar ecosystems and environment.

THE NEXT GENERATION OF EXPERTS: BUILDING CAPACITY

WCRP is conscious of the need to develop the intellectual capacity to lead the programme into the future. Given the complexity of the climate problem, a multidisciplinary approach is required to fully understand the implications of climate variability and change - the global, regional and local impacts on people, ecosystems, economies and the environment.

WCRP has identified an ongoing need to train scientists to analyse and interpret climate information in order to better inform adaptation planning and risk management. In July 2006, the WCRP/CLIVAR Panel on African Climate Variability organized a workshop on Predictability and Prediction of southern and eastern African climate variability and impacts of the neighbouring oceans (Dar es Salaam, Tanzania, 2006). The workshop was co-sponsored by the System for Analysis, Research and Training (START) and targeted senior operational staff in National Meteorological and Hydrological Services (NMHSs) responsible for long-range forecasting.

WCRP jointly organized an international training seminar with the International Centre for Theoretical Physics (ICTP, which operates under a tri-partite agreement among the Italian Government, UNESCO and the International Atomic Energy Agency) in Trieste, Italy, in 2007. The seminar focused on the analysis and interpretation of the ensemble of climate simulations for the twentieth and twenty-first centuries. The 30 participants from developing nations worked on their own projects utilizing the WCRP Coupled Model Intercomparison Project (CMIP3) archive in a way that was relevant to their respective countries or organizations. In a follow-up workshop held one year later (Trieste, Italy, 2008) they also learnt to assess the uncertainties of regional climate change projections by regional climate models (RCMs).

WCRP facilitated the participation in workshops and conferences of a record number of early-career scientists, and in particular those from developing countries. For example, 53 students, of whom 32 were nationals of developing countries, were sponsored by WCRP to participate actively in the most recent SPARC General Assembly, In August 2008 in Bologna, Italy. With WCRP support, these students made oral and written contributions to the Assembly.

WCRP, together with the IGBP projects Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) and Global Ocean Ecosystem Dynamics (GLOBEC) and the EUR-OCEANS network, held the Climate and Ecosystem (ClimEco) Training Seminar for Young Marine Scientists, which was the first of its kind (in Brest, France, April 2008). This seminar introduced young scientists working in multiple disciplines to the Earth system research and focused on the interactions among physical climate, marine biogeochemistry and ecosystems.

WCRP together with IGBP/Past Global Changes (PAGES) project organized a summer school on ENSO Dynamics and Predictability (in Hawaii, United States, June 2008). Sixteen graduate students in oceanography, meteorology and geology from 10 countries gathered to learn about a broad range of ENSO-related topics. The students conducted research projects in addition to the three to four hours of daily lectures. In teams, they studied the effects of ENSO on the Antarctic Peninsula, the rapid termination of the 2008 La Niña event that was induced by easterly wind bursts, the geographical reaches of a tropical megadrought some 4200 years ago, the effects of state-dependent noise on the predictability of ENSO, the dynamics of warm pool El Niño events, the effects of Atlantic multidecadal SST variability on ENSO, and the role of equatorial waves in the ENSO recharge mechanism.

The National Center for Atmospheric Research (NCAR) Advanced Study Programme is organizing, together with WCRP and GLOBEC, a 2009 Summer Colloquium on the Marine Ecosystem and Climate. This colloquium provides climate and marine ecosystem graduate students with a comprehensive introduction to and hands-on experience with observational datasets and state-of-the-art marine ecosystem modelling in the context of climate change. An integrated approach to studying climate-ecosystem interactions is typically not offered in standard university courses; accordingly, the colloquium offers the students a unique opportunity to study and apply these research tools. And significantly, this colloquium fosters collaboration among graduate students that are studying the marine ecosystem, climate and climate impact sciences (http://www.asp.ucar.edu/colloquium/2009/CGD/index.php) .

OBSERVATION AND ANALYSIS OF THE CLIMATE SYSTEM

Design and improvement of the integrated observing system

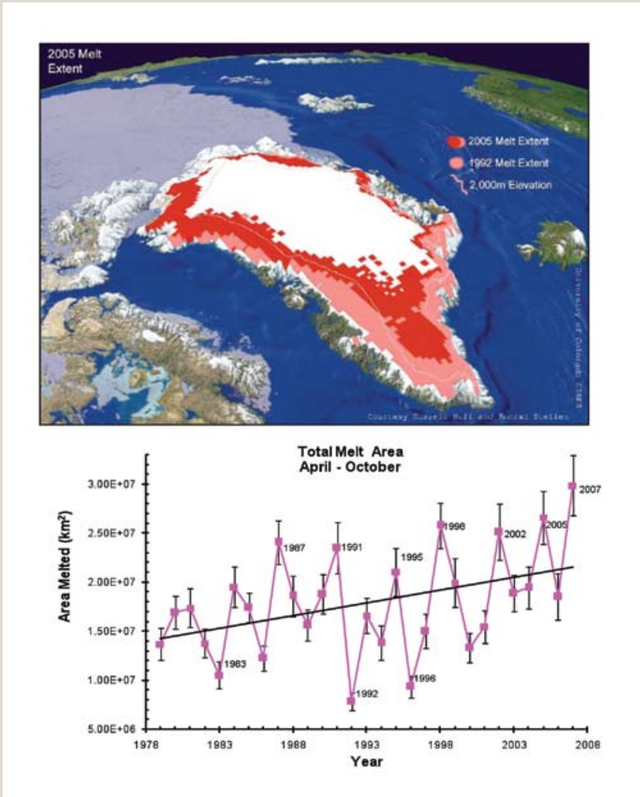
Climate observations provide a solid foundation for climate research, and they are also used for initializing the future climate projections. Therefore, the continuity of climate records and their homogeneity are vitally important for assessing climate variations and change over multiple decades. While the Earth-observing network is improving, challenges persist in establishing and maintaining global measurements of essential climate variables. There is therefore a need for formal international coordination of these measurements across agencies and missions, in liaison with user groups from the climate community. WCRP has been an advocate for a sustained global climate observing system by supporting the activities promoted by the Ocean Observations Panel for Climate (OOPC), the Atmospheric Observation Panel for Climate (AOPC) and the Global Terrestrial Observing System (GTOS) through the WCRP WOAP. These activities are conducted jointly with GCOS to ensure that the observations meet the national and international requirements for climate research, analysis and prediction, and that the climate-related data and information are identified, obtained, preserved and made widely available without any restrictions.

WOAP was formed to facilitate cross-cutting activities related to observations and data assimilation, and its key task is to provide a WCRP interface with GCOS and associated programmes. WOAP has markedly increased the visibility of WCRP in this area, and is now a player in the international dialogue on new observations, priorities for observations and related activities in the climate arena. WOAP has contributed to coordinating the development of research datasets and assimilation techniques within WCRP projects, and has allowed the preparation of WCRP-wide positions on observations with respect to partner programmes, such as GCOS, and within the wider Earth Observation community, particularly the Group on Earth Observations (GEO) and Committee on Earth Observing Satellites (CEOS).

In addition, WOAP has also served as a leader in identifying observational requirements for reanalysis. Such global analyses act as a powerful driver for the development of extended, sustained, optimized and standardized Earth observations in the atmosphere, ocean and terrestrial domains. Recognizing the importance of the emerging reanalyses for climate along with the need to improve corresponding observation datasets, GEO allocated a specific task for these activities in its work plan for 2009-2011.

Coordinating cryospheric observations and products

In 2003-2007, the WCRP/CliC Project, together with the Scientific Committee on Antarctic Research (SCAR), led the preparation of the Integrated Global Observing Strategy (IGOS) Cryosphere Theme Report, which was approved by the IGOS Partnership in May 2007, three months into the IPY period. The report is co-authored by 80 experts in various disciplines associated with the cryosphere and proposes a plan for the future development of cryospheric observations based on the general consensus among the cryospheric research community. The implementation of the IGOS Cryospheric Observing System (CryOS) was proposed to be phased in three time intervals: 2007-2009 (the IPY period), 2010-2015 (the period during which available satellite missions were known), and beyond 2015 (the period during which satellite missions are yet to be proposed or require further elaboration). The IGOS Cryosphere Theme Report helped to shape the IPY programme, led to the



K. STEFFEN CIRES/UNIVERSITY OF COLORADO

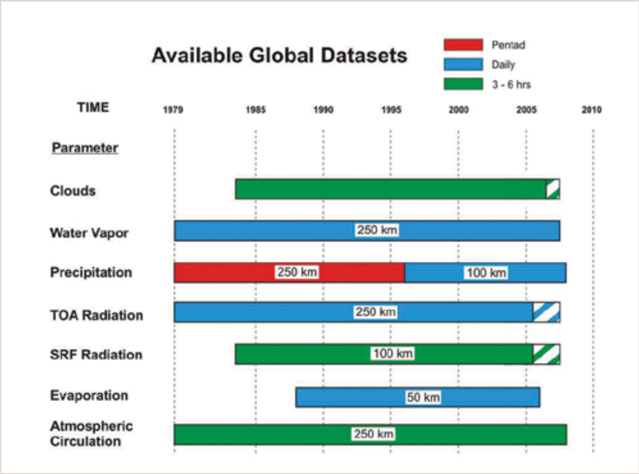
Greenland melt extent: records derived from remote sensing. It demonstrates the increasing trend of melted area from 1978 to 2007.

proposal to establish a WMO Global Cryosphere Watch, was instrumental in satellite mission and cryospheric research planning, and helped ensure that sufficient emphasis was placed on the cryosphere in the GCOS planning activities.

In 2007, the Fifteenth WMO Congress welcomed a proposal by Canada to establish a WMO Global Cryosphere Watch (GCW) as an IPY legacy. The proposal largely followed the recommendations of the IGOS Cryosphere Theme. The WMO GCW will provide the international mechanism for supporting all key cryospheric in situ and remote-sensing observations. It will also include cryospheric monitoring, assessment, product development, prediction, and related research. It aims to provide authoritative, clear, understandable and useable information on the past, current and future state of the cryosphere for use by the media, the public and decision- and policy makers. GCW will also directly benefit society at large. In tandem with its partners, WCRP will continue to support the development of the GCW concept and planning of its initial activities.

In June 2006 together with one of its sponsors, IOC of UNESCO, WCRP organized a workshop called Understanding of sea-level rise and variability (Paris, France). The 150 participants summarized the state of the science and outlined future research and observational requirements for assessment and prediction of sea-level rise. The future sea-level rise was estimated taking into account the contributions from the ocean thermal expansion, glaciers, ice-sheets, vertical motion due to glacial isostatic adjustment and tectonic motions, and terrestrial water storage. Uncertainties in each of these factors were analyzed to derive the integral uncertainty of the projection. The implications of sea-level rise in terms of changes in the frequency and intensity of extreme events were also considered. A book summarizing the current state of knowledge on sea-level rise is being prepared for publication in 2009. Following the workshop, a plan for future work was developed, and in June 2009 the Twenty-fifth Session of the IOC Assembly endorsed the establishment of a joint WCRP and IOC Working Group on Sea-level Variability and Change. The working group will prepare and publish regular updates on the state of knowledge and predictions of sea level, including its geographical variations.

From its inception, GEWEX, primarily through the efforts of the GEWEX Radiation Panel, has focused on a global analysis of the climate system using satellite data products. One of the earliest efforts was the International Satellite Cloud Climatology Project (ISCCP), which now has produced a record of global cloud properties over more than 20 years. Similar climate records have been compiled by the Global Precipitation Climatology Project (GPCP), the GEWEX Global Water Vapour Project (GVAP) and the GEWEX Aerosol Climatology Project (GACP). Time series covering a long period are also available for the top-of-atmosphere radiation budget. More recently, efforts have been made to determine energy and water fluxes at the surface of the Earth. Most notable among these are the Surface Radiation Budget Project, the Baseline Surface Radiation Network, SeaFlux and LandFlux. These legacy datasets will be invaluable for understanding key Earth system processes; for developing, testing and evaluating climate models; and for assessing past climate variability and change.

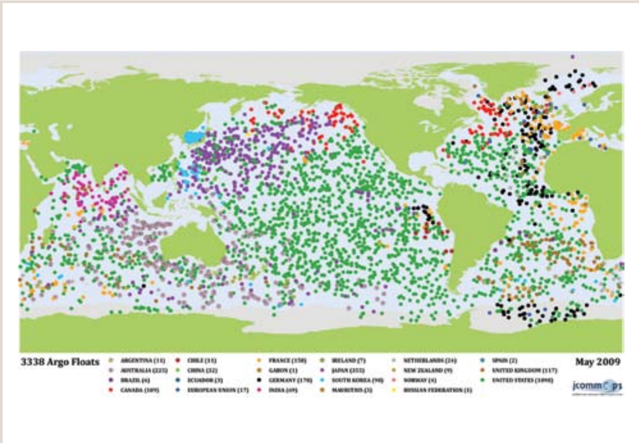


Available global datasets endorsed as GEWEX Radiation Panel (GRP) products are depicted above. GRP products conform to a high standard of production and documentation, consist of a blend of available satellite and in situ observations, and are continuously evaluated against other products.

Maintaining and enhancing ocean observations

Based on recommendations developed primarily by the WCRP community, scientists have made considerable progress during the past 30 years in implementing an initial global ocean observing system for climate. The three completed WCRP research projects (TOGA, 1985–1994; WOCE, 1990-2002; and ACSYS, 1994–2002) included strong oceanographic components that resulted in our ability to predict El Niño, a better understanding of the ocean interaction with the atmosphere, an unprecedented one-time survey of the ocean, and an increased understanding of the role of the Arctic in climate. Building on the legacies of TOGA and WOCE, CLIVAR advocates for the sustained ocean observing system, as a foundation for developing the initial conditions for seasonal-to-decadal climate forecasts; studying and monitoring variability and change in the overturning circulation of the ocean and the oceanic transports of heat, freshwater and carbon; and providing air-sea flux reference information for characterizing the oceans' impact on the Earth's climate system. In particular, CLIVAR has been a keen promoter for developing and deploying the global array of profiling float (Argo) system which has now reached its target of 3 000 floats, and allows monitoring of the temperature and salinity structure of the top 2 000 m of the ocean.

Globally, there are about 8 000 ocean in situ platforms that at present are maintained by the international



Argo active floats in May 2009 are depicted above. The Argo concept was initiated during the time of WOCE in the mid-1990s and became a global array thanks to CLIVAR and other partners in international ocean research (http://www.argo.ucsd.edu/).

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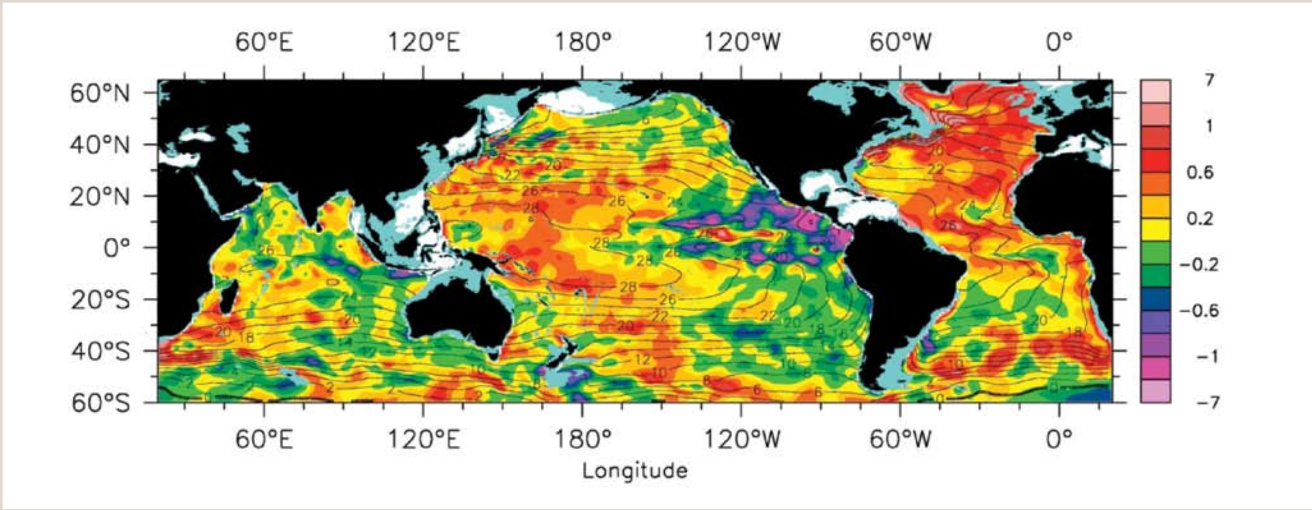
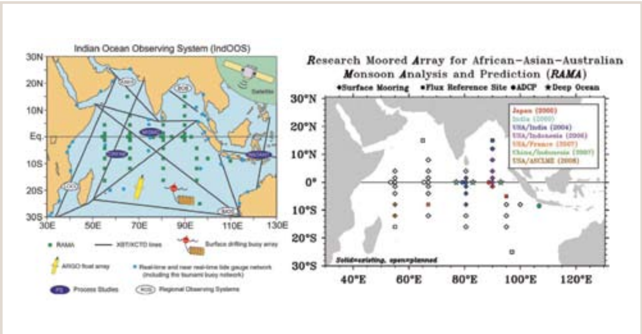


The figure depicts temperature anomalies in the upper 100 m of the oceans obtained by subtracting the climatological values (World Ocean Atlas 2001) from the five-year mean temperatures from in the Argo database. Argo data show the pattern of multi-decadal ocean warming.

community. They include surface drifting buoys, a tropical moored buoy network, Argo profiling floats and ships-of-opportunity. Together with the satellites, these platforms deliver continuous, long-term, climate quality and global ocean records required for climate research.



Schematic of IndOOS (left) and RAMA (right) (filled symbols indicate occupied sites)

WCRP, through its CLIVAR Project, is actively seeking to develop the regional components of the global ocean observing system with other partners. An example is the sustained observing system in the Indian Ocean and the ongoing development of the monitoring system for the Meridional Overturning Circulation (MOC) of the Atlantic. The Indian Ocean, despite its importance to the regional and global climate system (monsoons, ENSO and NAO), is the most poorly observed and the least understood of the three tropical oceans. CLIVAR, in collaboration with IOC and the Global Ocean Observing System (GOOS) established an Indian Ocean Panel

(IOP,http://www.clivar.org/organization/indian/indian.php) in 2004 to design and guide the implementation of a basin-scale integrated Indian Ocean observing system for climate research and forecasting. The IOP focused on developing a strategy for in situ measurements to complement existing and planned satellite missions. The resulting system, referred to as the Indian Ocean Observing System (IndOOS http://www.clivar.org/organization/indian/IndOOS/obs.php), is based on proven technologies, including moorings, Argo floats, ship-of-opportunity measurements, surface drifters and tide gauges. A key element of IndOOS is the basin-scale moored buoy array, referred to as the Research moored Array for African-Asian-Australian Monsoon Analysis and prediction (RAMA). RAMA is designed specifically for studying large-scale ocean–atmosphere interactions, mixed-layer dynamics, and ocean circulation related to the monsoons on intraseasonal-to-decadal timescales. Implementation of RAMA will result in a global network of tropical moored buoy arrays, which also incorporate the Tropical Atmosphere Ocean (TAO/TRITON) array in the Pacific and the Prediction and Research Moored Array (PIRATA) in the Atlantic.

Climate models suggest that the Meridional Overturning Circulation (MOC) in the Atlantic and the accompanying oceanic heat flux vary considerably on interannual timescales. In addition to the potential for abrupt climate change in which the MOC could virtually cease, according to some models, the "normal" inter-decadal variation may range from 20 to 30 per cent of its long-term mean value. Until recently, however, no direct measurement system had been implemented that could provide regular estimates of the MOC to determine its natural variability or to assess these model predictions. Such a system is now deployed along 26.5°N in the Atlantic as part of the joint United Kingdom/United States RAPID Climate Change-Meridional Overturning Circulation and Heatflux Array (MOCHA) program, which has been continuously observing the MOC since March 2004 (http://www.noc.soton.ac.uk/rapid/rapid.php). The overall strategy for monitoring the MOC relies on deep water moorings on either side of the basin to monitor the basin-wide geostrophic shear, combined with observations from clusters of moorings north of the western (Bahamas) and along the eastern (African) continental margins, and direct measurements of the flow though the Straits of Florida. Moorings are also included on the flanks of the Mid-Atlantic Ridge to resolve flows in the two sub-basins. Ekman transports derived from satellite winds are then combined with the geostrophic and direct current observations and an overall mass conservation constraint to continuously estimate the basin-wide MOC strength and vertical structure. Precision bottom-pressure gauges are also employed to monitor absolute transports including barotropic circulation. Atlantic MOC-related initiatives are coordinated by the CLIVAR Atlantic Implementation Panel (http://www.clivar.org/organization/atlantic/atlantic.php).

Assessing observations of water vapour and aerosols in the upper troposphere and stratosphere

Water vapour and aerosols play important roles, both radiatively and chemically, in the upper troposphere and stratosphere, yet measurements of both quantities are challenging and subject to considerable uncertainties. To make the observations more useful and allow better quantification of the long-term changes in the upper atmosphere, SPARC has performed peer-reviewed assessments of the various observational datasets of both quantities. These assessments have required the involvement and significant efforts of dozens of scientists, acting both as authors and reviewers.

An assessment of Upper Tropospheric and Stratospheric (UTS) Water Vapour was published as SPARC Report No. 2 in 2000 (WCRP No. 113, WMO/TD-No. 1043). The report describes and compares relevant datasets using in situ hygrometers and remote sensing instruments from laboratories all over the world in order to create a suitable dataset, including historical data that go back to the 1940s. The data presented in the report are available at the SPARC Data Centre (http://www.sparc.sunysb.edu/). This report has been widely used and cited, and has served as an important reference for observational programme decision making and for IPCC and WMO/UNEP assessments. Following the release of the report in 2000 and per its recommendations, climatological measurements have continued, new campaigns to investigate UTS water vapour have been carried out, new satellite observation programmes have been launched, and many model and laboratory studies have been conducted to explain the observations and to identify previously unknown processes.

As a result of these observations, new questions regarding the UTS water vapour have emerged. Addressing these questions requires the verification of the absolute accuracy of the measurements and not simply an assessment of the relative discrepancies among different sensors. The need to verify the absolute data accuracy led to a requirement that well-established and recently developed hygrometers, both in the field and in the laboratory, be cross-validate. SPARC conducted these analyses and is updating the 2000 water vapour assessment.In addition, SPARC addressed questions concerning the observed record of stratospheric aerosols, including the determination of the 'background' level of aerosol. In 2006 the project presented its assessment of stratospheric aerosol as SPARC Report No. 4 (WCRP-124, WMO/TD- No. 1295), which was used in the 2006 WMO/UNEP Ozone Assessment.

Reanalyses and climate data products

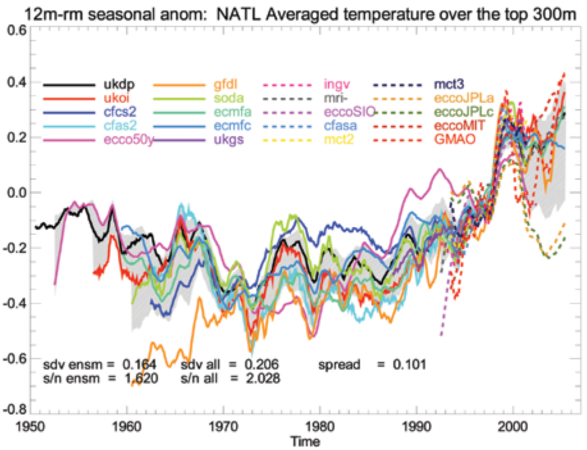
Key to creating climate data records is the need to reprocess past data and re-analyse all the data, recording them in a globally consistent manner. Reanalysis of the observations -with more complete data, improved quality control, and a state-of-the-art assimilating model and analysis system - greatly improves the homogeneity of the record and makes it useful for examining climate variations. Global atmospheric reanalyses have provided the basis for advances in many areas, including an accurate assessment of current climate ("climate nowcasts") and diagnostic studies of various features and phenomena such as weather systems, monsoons, ENSO, and other natural climate variations. They have helped advance seasonal prediction and assess climate predictability. Global atmospheric reanalysis is also the foundation for regional reanalysis projects and downscaling where detailed climatologies can be prepared to support studies of local climate and climate impacts.

Efforts are now being made to develop ocean reanalysis/synthesis through the assimilation of oceanic data into ocean models as a precursor to the development of combined atmosphere-ocean-land data assimilation into global coupled models. Achieving this objective requires a significant development of the in situ and satellite observing capabilities, together with improved modern coupled models and enhanced computational capabilities.

The WCRP World Ocean Circulation Experiment combined all ocean observations to generate a consistent description of the global ocean circulation. Ocean state estimation serves as an important tool to describe and investigate the time-varying ocean and its interaction with the climate system. These results are especially useful for describing phenomena that cannot be observed directly such as large-scale ocean circulation and transport, as well as air-sea interaction. In addition, ocean state estimates may eventually provide the best initial conditions for climate predictions.

Today, several global ocean data assimilation products are available (http://www.clivar.org/organization/gsop/synthesis/synthesis.php). Prerequisite to improving estimates of the time-varying ocean state and its transport is understanding the uncertainties in each estimate through intercomparison of all available products. Understanding the strengths and shortcomings of each ocean state estimate will result in weighted ensemble means that are more accurate than any single product. This work has been initiated under the auspices of the CLIVAR state estimation evaluation effort, which was co-sponsored by the Global Ocean Data Assimilation Experiment (GODAE). Many ocean reanalysis projects have participated in this effort to compare their reanalysis products with observations. Since 2006, three workshops on ocean synthesis evaluation have been organized by CLIVAR and GODAE (http://www.clivar.org/organization/gsop/gsop.php).

In the stratosphere, where observations are relatively rare, the quality of reanalyses can be problematic. To address this issue, SPARC performed a quantitative assessment of the available reanalysis products and compared their representation of the seasonal cycle and long-term changes with other analyses and satellite measurements. The resulting SPARC Report No. 3 (WCRP No. 116, WMO/TD-No. 1142), published in 2002, provided an assessment of the strengths and weaknesses of the different datasets.



The plot illustrates the North Atlantic sea-surface temperature anomaly (0-300m) from the ocean reanalysis. All models show a surface warming in the last decade.

Integrating regional datasets into global products

The merger in 2008 of the GEWEX Hydrometeorology Panel and the Coordinated Enhanced Observing Period into the Coordinated Energy and Water Cycle Observations Project (CEOP http://www.ceop.net) has resulted in a state-of–the-art information system. This system is managed by CEOP and incorporates the findings of regional experiments being carried out in different climate regions of the world. The merger has accelerated the adoption of standards for observations and facilitated the common regional science priorities among the studied areas. Regions have been identified where an urgent effort is needed to promote principles of data sharing. CEOP provides a platform for bringing together global observations and the measurements of extreme events that can produce highly localized impacts. The project is well positioned to help develop the link between global information on climate change and the understanding, prediction and monitoring of extremes at regional/local scales.

IMPROVING PREDICTIVE CAPABILITIES

Climate variability, predictability and prediction

Adapting to climate change while pursuing sustainable development will require accurate and reliable predictions of changes in regional weather/climate systems, especially extremes. Yet current climate models have serious limitations in simulating regional climate variations and therefore in generating the requisite information about regional changes with a level of confidence required by society. In this context, WCRP held a World Modelling Summit for Climate Prediction (http://wcrp.ipsl.jussieu.fr/Workshops/ModellingSummit/index.html) in May 2008 (Reading, England) with a view to developing a strategy to revolutionize prediction of the climate to address global climate change, particularly at regional scales. The primary emphasis of the summit was on the simulation and prediction of the physical climate system. Since advances in climate modelling and prediction build strongly on those in weather forecasting, and because the inclusion of biogeochemical cycles in longer-term projections of climate change requires improved representations of the physical system, the summit was cosponsored by WWRP and IGBP. The experts at the summit concluded that climate modelling will need- and is ready- to move to fundamentally new high-resolution approaches to capitalize on the seamlessness of the weather–climate continuum.

The participants identified four major objectives/priorities: (1) developing models that represent realistically all aspects of the climate system; (2) comparing observations with these models to evaluate their adequacy, accuracy and shortcomings; (3) obtaining computational capabilities that are three to four orders of magnitude greater than the best available capabilities today; and (4) establishing a world climate modelling project/programme to achieve these priorities that benefits from the expertise and investments of countries worldwide. The participants recognized that the four objectives exceed the resources and capabilities of any single country and thus identified the need for global coordination and cooperation in the field of modelling for climate prediction. The summit strongly endorsed the initiation of a Climate Prediction Project coordinated by WCRP, in collaboration with WWRP and IGBP, and involving the national weather and climate centres as well as the wider research community. The goal of the project is to provide improved global climate information to underpin global mitigation negotiations and to support regional adaptation and decision-making in the twenty-first century.

To enable the national centres to accelerate progress in improving operational climate prediction at all timescales, especially at decadal–to–multi–decadal lead times, the Climate Prediction Project proposed the creation of a climate research facility for climate prediction. The central component of this world facility will be one or more dedicated high-end computing facilities. Such facilities will enable climate prediction at the highest possible model resolutions and levels of complexity given our present technology and scientific knowledge.

Seasonal predictions

About a third of the world's population lives in regions that are significantly vulnerable to climate anomalies/extremes. Many of these regions include developing and/or least developed countries whose economies are largely dependent upon their agricultural and fishery sectors. The climate forecast successes of the 1980s and 1990s brought great promise for societal benefit in the use and application of seasonal forecast information. This promise of societal benefit has not been fully realized, however, in part because there have not been adequate interactions between the physical scientists involved in seasonal prediction research and, applications scientists, decision makers and operational seasonal prediction providers.

One of the overarching objectives of the WCRP is to benefit the society by facilitating the analysis and prediction of Earth system variability and change. To help meet this objective, in 2005 WCRP commissioned a two-year assessment by the Task Force on Seasonal Prediction (TFSP) of current seasonal prediction capability and skill. This assessment addressed the development and implementation of numerical experimentation to enhance seasonal prediction skill and the use of seasonal forecast products.

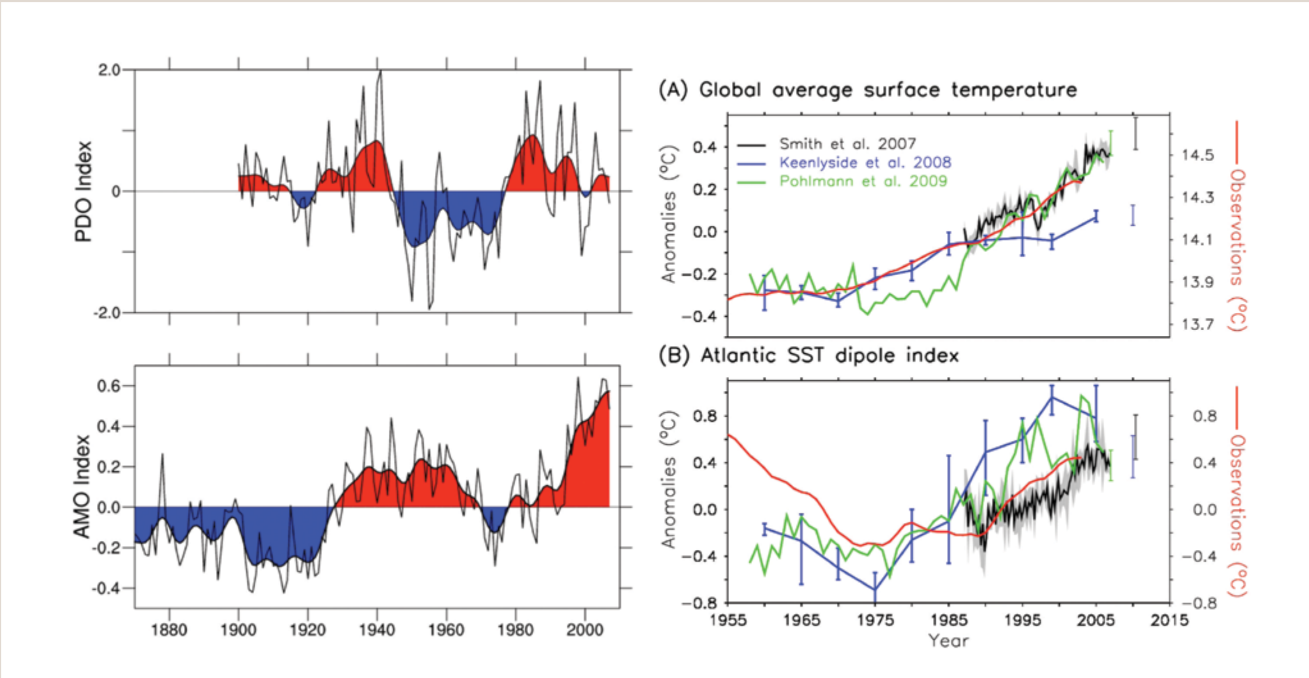
As part of the seasonal prediction capability assessment, TFSP, in collaboration with the WCRP core projects and the World Climate Applications and Services Programme/Climate Information and Prediction Services (CLIPS) project organized the first WCRP Seasonal Prediction Workshop, which was held in June 2007 (Barcelona, Spain). The main outcome of the workshop was a consensus on the requirements for producing, using and assessing seasonal forecasts.

The maximum predictability of the climate system has yet to be achieved in operational seasonal forecasting. Model error continues to limit forecasting skill and since not all interactions in the climate system (land–atmosphere interactions and stratosphere–troposhere interactions are two examples) are currently fully resolved, there may still be untapped sources of predictability. TFSP launched the Coupled Historical Forecast Project (CHFP, http://www.clivar.org/organization/wgsip/chfp/chfp.php), a multi–model and multi–institutional experimental framework for subseasonal–to–decadal complete physical climate system prediction. The goal is to leverage, coordinate and synthesize ongoing activities into a focused seasonal prediction experiment that incorporates all elements of the climate system.

GEWEX has contributed to the conceptual underpinning and rationale for an integrated satellite and in situ soil moisture monitoring capability through its coordinated soil moisture research. These studies have revealed the importance of soil moisture and its influence on the prediction of precipitation at timescales of up to seasonal in some continental regions of the globe. In particular, these studies were a significant factor in the recommendations by the United States National Academy of Sciences that the United States should reinstate the measurements of soil moisture from space as one of its highest Earth observation priorities for the next decade.

Decadal variability, predictability and predictions

Global warming will continue over at least the next several decades under any plausible emission scenario and will inevitably be accompanied by regional variability, which can have profound impacts on all sectors of the global economy. Examples include the US Dust Bowl drought of the 1930s, the Sahel drought of the 1970s and 1980s, the ongoing droughts in the south-western US, Australia, and the Middle East and decadal–scale changes in Atlantic hurricane activity. These impacts are associated with differences in land and ocean temperatures, as well as differences among the oceans. A



Observed decadal climate variability in Pacific and Atlantic sectors (left) and first attempts to make decadal predictions (right) central challenge of climate science is to understand and attempt to predict such regional–scale climate variability and change across the timescales of decades. At the regional–scale, where most planning decisions are made, anthropogenic climate change signals will be strongly modulated by natural climate variability, and especially that driven by ocean circulation that varies slowly on the decadal timescale.

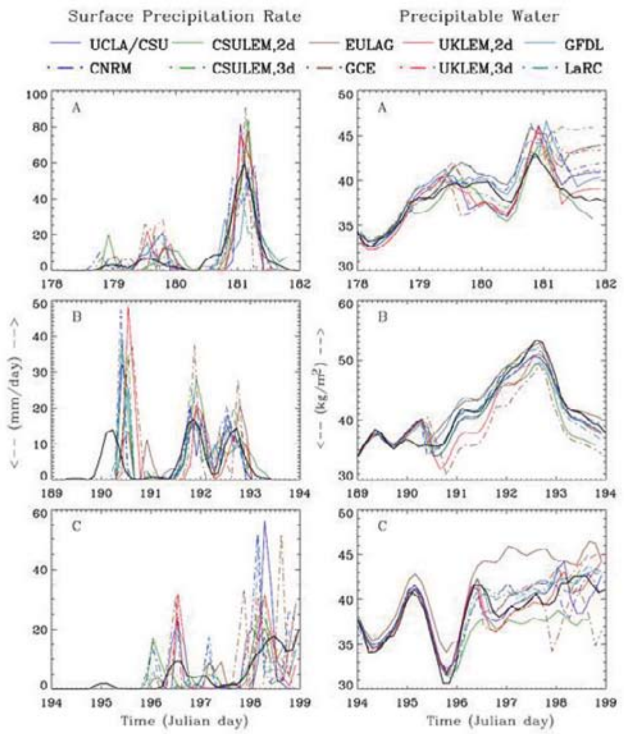
Opportunities exist for major advancements in decadal climate prediction over the next several years. As part of the WCRP Coupled Model Intercomparison Project 5 (CMIP5; Taylor and others, 2009), modelling centres around the world are planning coordinated suites of decadal hindcast and prediction experiments covering the period from 1960 to 2035. The results from these prediction experiments will be available to the international research community, and analysis of these results should prove valuable in advancing our understanding of decadal scale variability and predictability. Forced sources of decadal predictability such as ozone recovery are also taken into consideration in CMIP5.

These initialized climate predictions will complement suites of longer-term simulations that will explore other aspects of climate system change, including the carbon cycle and biogeochemical processes and feedbacks that will determine the ultimate degree of climate change in the second half of the twenty-first century. Ultimately, combining such approaches, including the use of higher–resolution models capable of simulating regional–scale climate phenomena, including changes in air quality, will provide the key to improving decadal–to–centennial climate change prediction.

Improving the energy and water cycle representation in models

Many of the processes that are important to weather and climate act on spatial scales that are smaller than the grid sizes of contemporary models used in climate simulation or models that are likely to be used in the next decade. Examples of such processes are turbulence, convection in both the atmosphere and the ocean, cloud and precipitation processes, and processes related to the energy, water and biogeochemical exchanges at land and ocean surfaces. It is generally accepted that the key deficiencies, and hence uncertainties, in our current climate projections are directly related to our inability to represent these processes adequately. In the WCRP parameterization development activities, the GEWEX Modelling and Prediction Panel (http://www.gewex.org/projects-GMPP.htm) and the WGCM Cloud Feedback Model Intercomparison Project (CFMIP http://www.cfmip.net) have been instrumental in facilitating the improved representation of the energy and water cycles in climate models.

Clouds play a critical role in the Earth's climate system through their regulation of the radiation budget, generation of precipitation, and linkages to the large-scale atmospheric circulation at both planetary and regional scales. In addition, clouds are strongly coupled to human activity through anthropogenic aerosol-induced climate forcing. GEWEX plays a central role in both observing and modelling global cloud properties. With regard to observations, GEWEX has been a strong and consistent advocate for new technologies for cloud studies, such as those introduced by the United States Department of Energy Atmospheric Radiation Measurement Program,

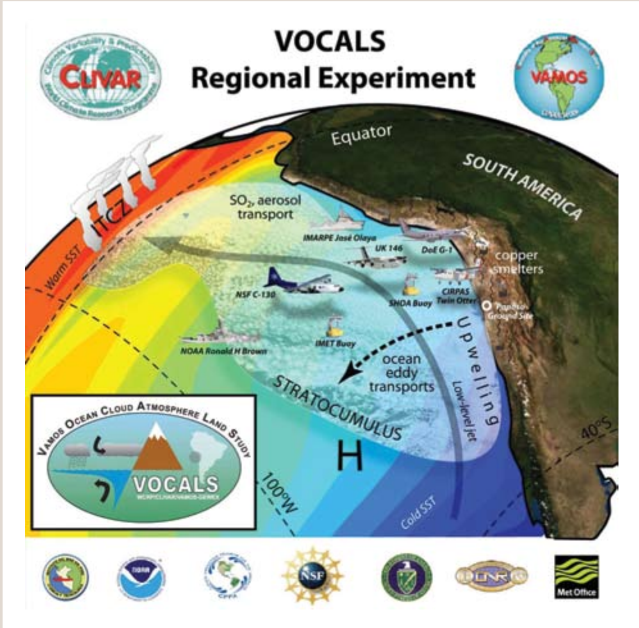


A comparison of precipitation rates (left column) and water vapour amounts (right column) computed by 10 cloud-resolving models for a summer period at the Southern Great Plains atmospheric radiation measurements site. Data are shown in black. The models exhibit good agreement with each other and the data. The models tend to delay the onset of precipitation in each of the three cases. Cloud properties and mass fluxes produced by the models are quite similar. Results such as these are being used to develop and test convective parameterizations for climate and weather forecasting models.

the European Union CloudNet Project, and the NASA CloudSat and CALIPSO satellites. The CFMIP Observations Simulator Package (COSP) is a community tool designed to facilitate the comparison of clouds simulated by climate and Numerical Weather Prediction (NWP) models with different satellite observations, including the new generation of cloud observations derived from radar and lidar remote sensing (CloudSat and CALIPSO). COSP has successfully bridged the modelling and observations communities. The package has been distributed to NWP and climate modelling centres, and will be used in some CMIP5 experiments. Model evaluations based on the use of COSP will make it possible to unravel systematic errors and error compensations in the simulation of radiation and precipitation fields by climate and NWP models.

In parallel, the GEWEX Cloud System Study (GCSS; http://www.gewex.org/gcss.html) is developing better parameterizations of cloud systems for climate models by improving our understanding of the physical processes that are important in different types of cloud systems. The strategy of the GCSS working group is to conduct process-oriented studies based on field experiments using high-resolution models as a virtual laboratory. Observational data are collected and analyzed for specific field programs. A variety of model studies are being carried out ranging from high resolution or cloud-resolving models to single-column climate models to global climate and weather models. The model results are compared among themselves and with data to elucidate model strengths and shortfalls. This process has led to a much better understanding of physical processes in cloud regimes, improved and consistent process models and improved parameterizations in climate and weather forecasting models.

WGCM/CFMIP and GEWEX/GCSS have collaborated closely during the last few years with the aim of achieving a better assessment and understanding the physical processes that control the response of clouds to climate change. This includes systematic comparisons between large-eddy simulation or cloud-resolving models with single-column simulations from general circulation models, both in present-day conditions and in idealized climate change experiments. A particular focus has been boundary-layer clouds that have been identified, for the current generation of climate models, as the main contributors to the inter–model spread of climate sensitivity estimates.



Schematic illustrating the major platforms and scientific focuses of the VOCALS Regional Experiment

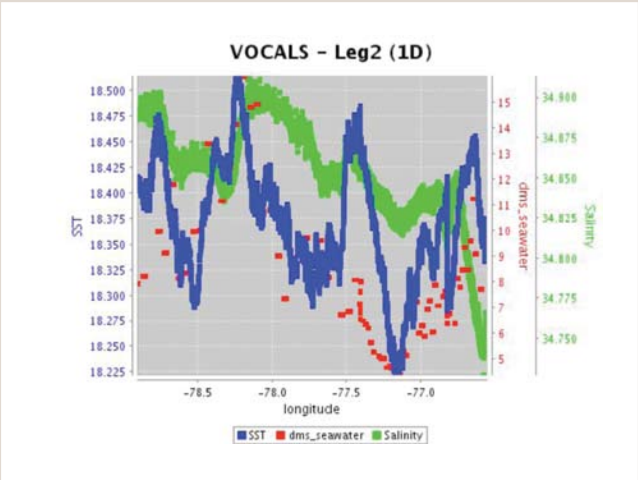
Measuring and improving the performance of climate models

The CLIVAR/VAMOS Ocean–Cloud–Atmosphere-Land Study (VOCALS, http://www.eol.ucar.edu/projects/vocals/) is an international project whose major goal is to promote scientific activities leading to the elimination of Global Climate Models (GCM) systematic errors and improving model simulations of the coupled ocean–atmosphere–land system in the south-east Pacific (SEP). In addition, VOCALS aims to improve understanding and regional/global model representation of aerosol indirect effects over the SEP.

VOCALS comprises two closely coordinated components: a Regional Experiment (VOCALS-REx), and a Modelling Project (VOCALS-Mod). Extended observations provide important additional contextual datasets that help to link the field and the modelling components. The coordination through VOCALS of observational and modelling efforts is currently accelerating the rate at which field data can be used to improve simulations and predictions of tropical climate variability.

A multidisciplinary dataset was obtained during the intensive observational period that took place during October–November 2008. Several platforms, including five aircrafts, two research vessels and two surface land sites collected data over a six-week period. This unprecedented dataset will be used to (1) improve understanding of aerosol–cloud–drizzle interactions in the marine boundary layer (MBL) and the physicochemical and spatiotemporal properties of aerosols; and (2) improve understanding of the chemical and physical couplings between the upper ocean, the land and the atmosphere.

The SPARC Chemistry-Climate Model Validation (CCM-Val) Activity (http://www.pa.op.dlr.de/CCMVal/) has pioneered the concept of process-oriented validation for chemistry-climate models (CCMs). The activity proposed a table of core processes, diagnostics, and datasets for CCM validation, focusing on the models' ability to predict future stratospheric ozone abundance and distribution. To facilitate this process-oriented validation of CCMs, SPARC provides all interested scientists with access to diagnostic software packages. The goal in supplying such software is to simplify the tasks of quality control of model output, calculation of more complex model diagnostics, statistical evaluation of model/data differences and graphical display of results. This will further facilitate development of the science of model evaluation using quantitative performance metrics, as well as the use of such evaluations to reduce the uncertainty of multimodel projections.

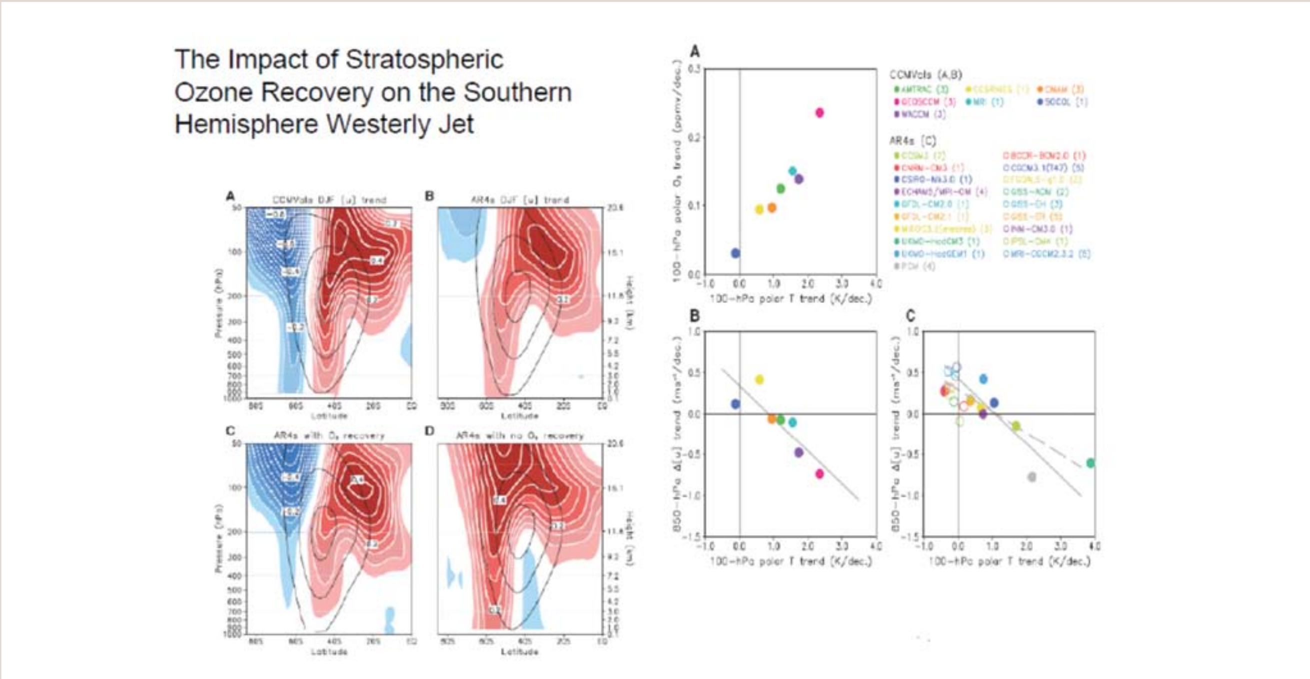


Depicted above are preliminary results from VOCAL-Rex regarding the correlation of seawater dimethylsulfide (DMS) with the upper ocean's temperature and salinity variations. DMS was elevated around the edge of the cyclonic eddies likely due to the entrainment of nutrients into the upper–ocean mixed layer. These regions also displayed more elevated values of atmospheric DMS and thus play a role in offshore aerosol production.

The SPARC CCMVal Activity has also compared the projections of the stratosphere-resolving chemistry–climate models with those of the AR4 models. This comparison has shown that the effect of the expected ozone-hole recovery on southern hemisphere high-latitude surface climate, including surface winds, is not captured in the AR4 projections. This points to the need for an accurate representation of ozone–climate coupling in future climate projections.

The GEWEX Radiation Panel dataset products serve as key climate model comparison tools for evaluation of the IPCC AR4 models. The models are routinely evaluated against the top-of-atmosphere radiation budget, cloud coverage, aerosol amounts, and so forth. These evaluations are vitally important for assessing the ability of climate models to simulate current climate. They are equally important in identifying model shortcomings and thus in model improvement. Diagnostic studies have shown that land surface fluxes of heat and moisture, and thus soil moisture, are strongly coupled with land-based convection and moisture recycling. The GEWEX Land/Atmosphere Study System (GLASS) has pioneered research on land–atmosphere coupling with a focus on improving surface flux representations in climate models through model comparison studies such as the Global Land-Atmosphere Coupling Study (GLACE).

The CLIVAR Tropical Atlantic Climate Experiment (TACE, http://www.clivar.org/organization/atlantic/TACE/tace.php) includes enhanced observations and modelling studies in the tropical Atlantic spanning a period of approximately six years (2006-2011). The results of TACE are expected to contribute to the final design of a sustained observing system for the tropical Atlantic. The main focus of TACE is improving the model representations of key dynamical processes forming the climate system in the eastern tropical Atlantic and understanding its predictability. The ocean has a major influence on tropical Atlantic variability mainly through



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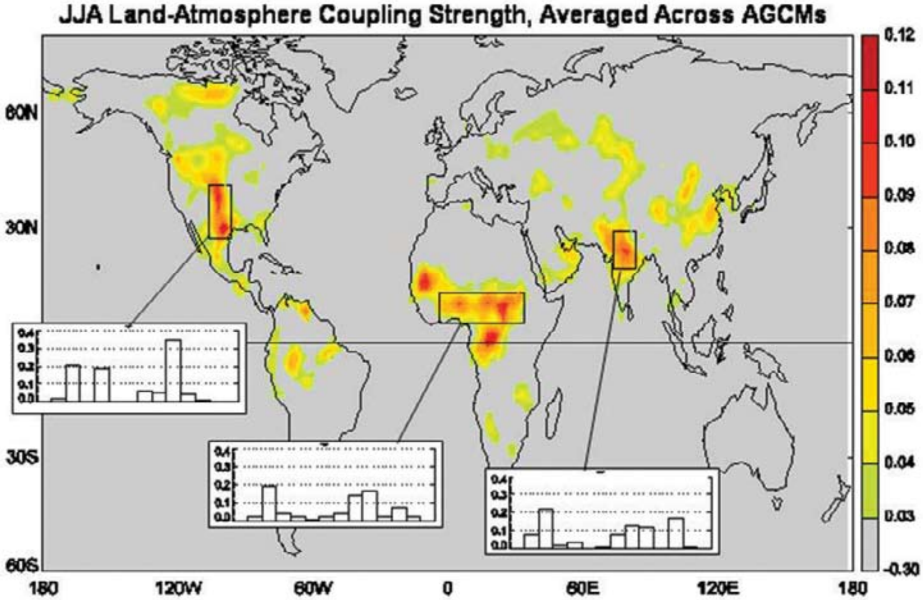
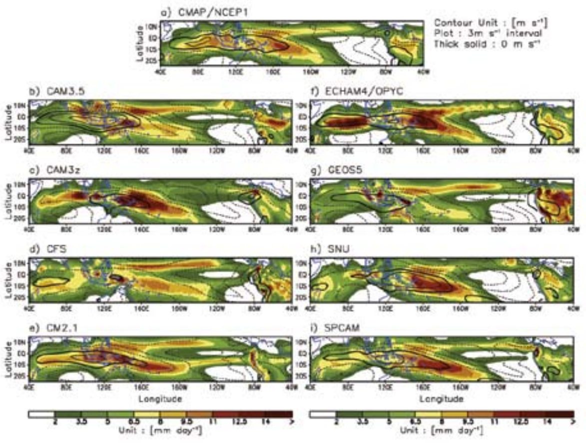
The left-hand figures illustrate the trends in December-to-February (DJF) zonal–mean zonal wind and the multi-model mean trends between 2001 and 2050: CCMVal models (A), AR4 models (B), AR4 models with prescribed ozone recovery (C), AR4 models with no ozone recovery (D). The black solid lines are isopleths of the DJF zonal–mean zonal wind averages from 2001 to 2010.

The figures on the right depict the relationships among southern hemisphere polar-cap ozone trend at 100 hPa, polar-cap temperature trend at 100 hPa, and extra-tropical zonal wind trend at 850 hPa: ozone and temperature trends simulated by CCMVal models (A), zonal wind and temperature trends simulated by CCMVal models (B), and zonal wind and temperature trends as simulated by AR4 models (C).



Depicted above are the averaged results from 12 climate models that compute values of a land–atmosphere coupling strength diagnostic for the northern hemisphere summer. It roughly corresponds to the fraction of precipitation variance associated with soil moisture variations only. Thus, higher values of the diagnostic identify areas where soil moisture strongly influences precipitation. The areas of most intense influence are seen in the central Great Plains of North America, the Sahel and Equatorial Africa, and India. The small insets show the value of the diagnostic averaged over the area of the boxes shown on the map. The large intermodel variation in the areas of strong coupling illustrates the extent of model uncertainty and the need to better understand land–atmosphere processes in these regions.

the influence of tropical Atlantic SST on variations of the Atlantic marine ITCZ complex. The most notable climate impacts involve the variability of rainfall over North-east Brazil and the coastal regions surrounding the Gulf of Guinea, and the fluctuations in rainfall and dustiness in sub-Saharan Africa (Sahel). Many studies indicate a high degree of potential predictability for climate variations in the tropical Atlantic region. Progress in tropical Atlantic climate prediction has been slow, however, due to insufficient understanding of ocean–atmosphere processes that determine climate variability, lack of adequate data to initialize forecasts, and systematic errors in the models used for prediction. Working with the AMMA programme, TACE is providing



In the figure above, the plots are the November–April mean observed (top) and simulated (eight different climate/forecast models) precipitation (shaded) and contours of mean 850hPa zonal wind. The unit is mm day-1 for precipitation and m s-1for 850hPa zonal wind. Wind contour interval is 3 m s-1, with the zero values represented by a thick solid line.

data in the tropical Atlantic that will be used for model validation and improvement.

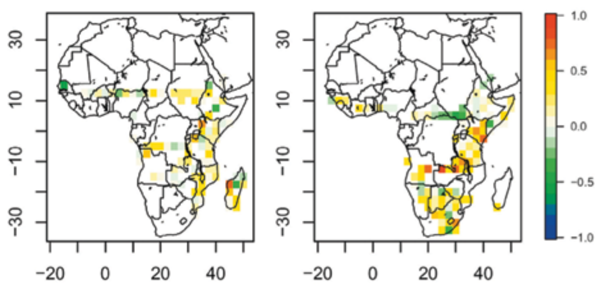
The CLIVAR MJO Working Group developed a series of increasingly complex and insightful MJO diagnostics. These diagnostics were used to detect MJO signals, construct composite life cycles, describe interannual variability of the MJO, and assess the ability of climate models in simulating the MJO. Additional analysis of more complex diagnostics shows that only a few models are able to simulate critical aspects of the MJO such as the gradual moistening of the lower troposphere that precedes observed MJO convection, as well as the observed geographical difference in the vertical structure of moisture. In addition to the MJO diagnostics, the working group developed a framework (using real-time forecast data from some operational numerical weather prediction centres) for assessing dynamical forecasts of MJO which could be helpful in an intraseasonal prediction. This led to a quantitative comparison of MJO forecast skill across operational centers. Such a framework could also be used to measure gains in forecast skill over time, and facilitate the development of a multimodel forecast of the MJO.

APPLYING THE SCIENCE

Detailed regional climate information, including current and future assessments of climate variability and change, is essential in formulating effective strategies for adaptation to climate change. Such information is critical in setting the agenda for climate risk management, especially in developing and least developed countries. WCRP is facilitating the development of an integrated climate information system on global and regional scales that makes observations, analyses, predictions and assessments available to decision makers. Such an information system provides essential input for decision makers and policy makers in all sectors of the economy, including agriculture and food, environment and health, energy and transport.

Malaria outbreak: climate conditions and malaria habitat

In many parts of the world, climate drives both the migration and spread of the parasite-carrying mosquito and the parasite that causes malaria and other infectious diseases. For example, years marked by a high incidence of malaria are associated with above-average levels of precipitation that fill the ponds and lakes where mosquitoes tend to breed; conversely, years with a low incidence of malaria are associated with a drier climate. This relationship has been used in the past to predict malaria epidemics. Such predictions were based on observations of the strength of the rainy season at that moment, however. Thus in case of a high-risk prediction, only two to four weeks were available to prepare for an epidemic. The project called Development of a European Multimodel Ensemble system for seasonal to inTERannual prediction (DEMETER) has been promoting the use of multimodel ensembles to predict the risk of malaria incidence far ahead of the rainy season. Skilful climate forecasts that predict not only the most likely evolution of climate, but also the uncertainty in such prediction provide early warning of risk in epidemic-prone regions where approximately 1.3 million humans die annually from malaria. In order to prepare for the maximal malarial risk, it is extremely important for health officials to know how "wet" the rainy season will be, not only on average, but at its estimated maximum. An increase in warning time of up to four months prior to the maturation of the mosquito gives health officials crucial time to optimize the allocation of limited resources.



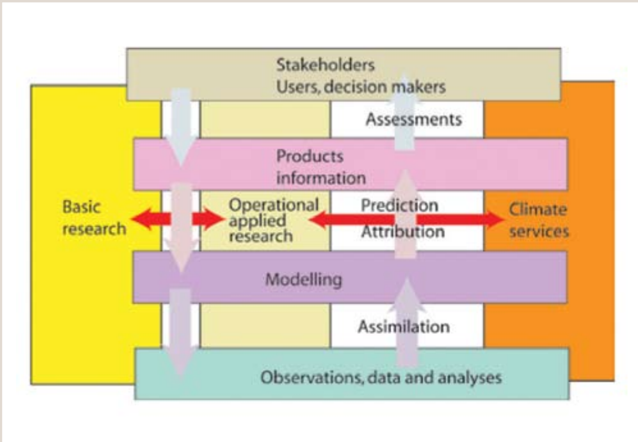
The skill score of DEMETER-driven ensemble malaria predictions is shown above. Illustrated are four-to-six-month forecasts for May (left) and November (right) corresponding to peak months for modelled malaria transmission in epidemic-prone regions of West and Southern Africa, respectively. There is potential skill for epidemic prediction in areas of Southern Africa, while low predictability is achieved in West Africa.

The WCRP/CLIVAR Panel on the Variability of the African Climate System is finalizing an African climate atlas (http://www.geog.ox.ac.uk/~clivar/ClimateAtlas/) that presents observed and modelled climate data grouped in seven parts. Parts I and II address the observed climatology over Africa and surrounding tropics and report on variables including the minimum temperature, maximum temperature, diurnal temperature range, water vapour and cloud cover. Part III discusses satellite observations of mineral aerosols. Part IV features components of the reanalysis products; and Part V presents the WCRP CMIP3 multimodel climate change data archive. Part VI contains Frequently Asked Questions on African Climate; and Part VII addresses climate change extremes and thresholds. The atlas is an accessible tool for African institutions and agencies and provides essential support for climate variability assessment studies and vulnerability reduction projects.

Linking climate research to adaptation measures

La Plata Basin (LPB) in south-eastern South America has long been of interest to the MERCOSUR countries (Argentina, Bolivia, Brazil, Uruguay and Paraguay) because of the role it plays in regional economies. With an area of 3.1 million km2, LPB is the world's second largest natural water reservoir and its hydropower production is among the highest worldwide. Given the socio-economic importance of the LPB, GEWEX and CLIVAR launched the LPB Regional Hydroclimate Project. This project aims to improve climate change impact prediction capacity for the region by defining a set of multidisciplinary scenarios; integrating the resulting observations and model predictions; and developing a set of adaptation strategies (specifically designed for land use, agriculture production, rural development, small farmers, hydropower, flood risk, wetlands ecological systems, river navigation, and near-river urbanization). These strategies reflect an analysis of probable climate change scenarios for the period 2010–2040 and will be disseminated to the regional and local decision-makers. The project collaborates with 20 partner institutions from South America and Europe including various private institutions and NGOs.

WCRP has been actively involved in planning the upcoming World Climate Conference-3 (WCC-3; http://www.wmo.int/wcc3/). WCC-3 will establish an international framework to guide the development of climate services, which will link science-based climate predictions and information with climate-risk management and adaptation to climate variability and change throughout the world. WCRP plays a major role in promoting climate research that provides essential input for decision-making. Reliable climate products and services stem from solid scientific research that includes making, assembling, analyzing and assimilating observations; establishing relationships among physical variables and the environmental



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Illustrated above is the flow of the climate information indicating how basic research feeds into applied and operational research, which in turn, contribute to the development of climate services. Climate observations are processed by the data assimilation and analysis systems and generate initial conditions for predictive models. Model simulations are used for attribution and prediction. Assembled, assessed and user-tailored information is disseminated to stakeholders, users and decision-makers. The recipients of the information products, in turn, provide feedback on their needs and how to improve the products.

impact; testing models and estimating model biases; developing predictions and projections; and downscaling and regionalizing the results. WCRP supports its partners in designing and implementing such climate research so as to fulfil the programme's aim of "facilitating analysis and prediction of Earth's climate system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society". WCC-3 marks an important step in these efforts.

WCRP CURRENT ORGANIZATION STRUCTURE

Sponsors:	WMO, ICSU, IOC-UNESCO
Core projects:	CLIVAR, GEWEX, CliC (co-sponsored by IASC and SCAR), SPARC
Working Groups:	WGCM, WGSF, WOAP, WMP
Co-sponsored activities:	SOLAS (with IGBP, SCOR and CACGP), WGNE (with WMO CAS), START (with IGBP and IHDP), AOPC (with GCOS), OOPC (with GCOS and GOOS), TOPC (with GCOS and GTOS)
ESSP partners:	IGBP, IHDP, DIVERSITAS
ESSP joint projects:	GWSP, GCP, GECAFS, GEC&HH
Ongoing collaborations:	IPCC, WWRP-THORPEX, UNFCCC, CEOS, CLIPS, DRR, GEO, World Bank, IRI

COMMUNICATION AND OUTREACH

WCRP Atlases

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Outreach

- The WCRP Web page is the primary source of information on the programme structure and ongoing activities (http://wcrp.wmo.int/wcrp-index.html). It features updated events and achievements of WCRP, together with partners and core projects, each of which maintain their own comprehensive Websites.

- The WCRP e-zine (http://wcrp.wmo.int/Newsletter_index.html) is the quarterly electronic newsletter.

- WCRP is committed to enhancing dialogue between scientists and climate change policymakers by attending the Subsidiary Body for Scientific and Technological Advice (SBSTA) events organized by the United Nations Framework Convention on Climate Change (UNFCCC).

Conferences

Understanding Sea-level Rise and Variability Workshop, Paris, June 2006.

Earth System Science Partnership (ESSP) Open Science Conference, Beijing, November 2006.

WGNE/PCMDI Workshop on Systematic Errors, San Francisco, February 2007.

Workshop on Seasonal Prediction, Barcelona, June 2007.

Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report, Sydney, October 2007.

Interpreting Climate Change Simulations, Trieste, November 2007

CFMIP/GCSS Workshop on Cloud-Climate Feedbacks, Paris, April 2007.

Third WCRP International Conference on Reanalysis, Tokyo, February 2008.

World Modelling Summit, Reading, May 2008.

Workshop on Climate Change and the Offshore Industry, Geneva, May 2008.

International Symposium on the Effects of Climate Change on the World's Oceans, Gijón, Spain, May 2008.

Summer School on ENSO Dynamics and Predictability, Puna, Hawaii, June 2008.

Second Pan-WCRP Monsoon Workshop (PWM2), held in conjunction with the WMO Fourth International Workshop on Monsoons (IWM-IV), Beijing, October 2008.

Workshop on Evaluating and Improving Regional Climate Projections, Toulouse, February 2009.

ACRONYMS

ACSYS	Arctic Climate System Study (WCRP)
AOPC	Atmospheric Observation Panel for Climate
AMMA	African Monsoon Multidisciplinary Analysis
AMY	Asian Monsoon Years
AR4	IPCC Fourth Assessment Report
CACGP	Commission for Atmospheric Chemistry and Global Pollution
CAS	Commission for Atmospheric Sciences
CASO	Climate of Antarctica and Southern Ocean
CCl	Commission for Climatology
CCMVal	Chemistry-Climate Model Validation Project
CEOP	Coordinated Energy and Water Cycle Observation Project (WCRP/GEWEX)
CEOS	Committee on earth Observing Satellite
CFMIP	Cloud Feedback Model Intercomparison Project
CHFP	Coupled Historical Forecast Project
CliC	Climate and Cryosphere Project (WCRP/SCAR/IASC)
CLIPS	Climate Information and Prediction Services
CLIVAR	Climate Variability and Predictability Project (WCRP)
CMIP	Coupled Model Intercomparison Project
COPES	Coordinated Observations and Prediction of the Earth System
CORDEX	Coordinated Regional Climate Downscaling Experiment
DEMETER	Development of a European Multimodel Ensemble System for Seasonal to Interannual Prediction
DEWS	Drought Early Warning System
DIVERSITAS	an international programme of biodiversity science
DRI	Drought Research Initiative
DRR	Disaster Risk Reduction
ECMWF	European Centre for Medium–range Weather Forecast
ENSO	El Niño Southern Oscillation
ESSP	Earth System Science Partnership
ETCCDI	Expert Team on Climate Change Detection and Indices
GACP	GEWEX Aerosol Climatology Project
GARP	Global Atmosphere Research Programme
GCOS	Global Climate Observing System
GCP	Global Carbon Project
GCSS	GEWEX Cloud System Study
GCW	Global Cryosphere Watch
GECAFS	Global Environmental Change and Food Systems
GEC&HH	Global Environmental Change and Human Health
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment (WCRP)
GHG	Greenhouse Gases
GLOBEC	Global Ocean Ecosystem Dynamics (IGBP)
GMPP	GEWEX Modelling and Precipitation Panel
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GPCP	Global Precipitation Climatology Project
GTOS	Global Terrestrial Observing System
GVAP	Global water Vapour Project
GWSP	Global Water System Project
iAOOS	integrated Arctic Ocean Observing System
IASC	International Arctic Science Committee
ICSU	International Council for Science
ICTP	International Centre for Theoretical Physics
IGAC	International Global Atmospheric Chemistry Project (IGBP)
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimension Programme
IGOS	Integrated Global Observing System
IGOS-Cryo	Cryospheric Theme of IGOS
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research (IGBP)
IOC	Ingergovernmental Oceanographic Commission (UNESCO)
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year 2007–2008
IRI	International Research Institute for Climate and Society
ITCZ	InterTropical Convergence Zone
JCOMM	Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
MESA	Monsoon Experiment in South America
MJO	Madden-Julian Oscillation
MOC	meridional overturning circulation
NAME	North America Monsoon Experiment
NAO	North Atlantic Oscillation
NWP	numerical weather prediction
OOPC	Ocean Observation Panel for Climate
PAGES	Past Global Changes (IGBP)
PCMDI	Program for Climate Model Diagnosis and Intercomparison
RCM	regional climate model
SAON	Sustaining Arctic Observing System
SBSTA	Subsidiary Body for Scientific and Technological Advice [of UNFCCC]
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee on Oceanic Research
SOLAS	Surface Ocean – Lower Atmosphere Study of WCRP/IGBP/SCOR/CACGP
SOOS	Southern Ocean Observing System
SPARC	Stratospheric Processes and Their Role in Climate
START	SysTem for Analysis, Research and Training
SST	Sea Surface Temperature
TACE	Tropical Atlantic Climate Experiment
TFRCD	Task Force on Regional Climate Downscaling
THORPEX	The Observing System Research and Predictability Experiment
TOGA	Tropical Ocean and Global Atmosphere Project
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VACS	Variability of the African Climate System, a WCRP/CLIVAR study
VAMOS	Variability of the American Monsoon System, a WCRP/CLIVAR study
VOCALS	VAMOS Ocean Cloud Atmosphere Land Study
WG	working group
WGCM	Working Group on Coupled Modelling
WGNE	Working Group on Numerical Experimentation
WGSF	Working Group on Surface Fluxes
WGSIP	Working Group on Seasonal to Inter-annual Prediction (WCRP/CLIVAR)
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WOAP	WCRP Observation and Assimilation Panel
WWRP	World Weather Research Programme
YOTC	Year of Tropical Convection

Becoming involved in WCRP

The great success of WCRP is directly related to the proactive involvement of leading climate scientists and effective partnering with organizations from around the world. The following are the primary means of partnering with this programme.

Sponsors: Sponsors support WCRP financially or sponsor scientists, our core projects and integrative research activities. Many WCRP workshops and meetings are possible thanks to the contributions from a variety of sources. For example, relatively small contributions can make it possible for scientists from developing countries to participate in WCRP regional and international capacity building efforts that would normally be beyond a country's means.

Partners: Partners contribute to WCRP initiatives by identifying joint scientific priorities, contributing scientific expertise and securing financial resources to conduct join projects. WCRP welcomes the opportunity to form partnerships with private industries, non-governmental and intergovernmental organizations, foundations and associations.

National Academies, Agencies and Climate Committees: WCRP greatly benefits from the active involvement of national agencies and national academies. The establishment of national climate committees as a mean of building a truly international network in support of integrated climate research is very helpful. The greatest benefit to all parties involved is the strengthening of complementary research and avoidance of redundant efforts.

Scientists: WCRP invites and encourages individual scientists to make the WCRP global secretariat aware of their ongoing research and to suggest ways to integrate national, regional and international initiatives. The WCRP Joint Scientific Committee, the core projects and the cross-cutting activities welcome proposals for new collaborative activities that support implementation of the WCRP Strategic Framework.

Interested Participants: Keep up-to-date with WCRP activities by subscribing to the programme's quarterly newsletter (e-zine) and submit news on recent research findings, publications, upcoming or successfully completed meetings for listing on the WCRP Web site.

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