WCRP IMPLEMENTATION PLAN 2010-2015

WCRP
World Climate Research Programme

The World Climate Research Programme
Implementation Plan 2010-2015

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WMO/TD-No. 1503

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

CONTENTS

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FOREWORD

In 2008 the sponsors of the World Climate Research Programme (WCRP) (the International Council for Science (ICSU), the World Meteorological Organization (WMO), and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO)) commissioned an independent review of WCRP. They appointed an international panel of experts to evaluate the extent to which the international global change research programmes such as WCRP add value to their respective areas of research and to the national programmes that contribute to them. They asked the Panel to answer the question "What do scientists, sponsors and the end-users get out of participating in and supporting these international programmes that they would not have gained if the international programmes did not exist?". The Panel has completed its review and the final report can be found at http://www.icsu.org.

The major recommendations resulting from the independent review together with the internal discussions among the WCRP leadership (including the Joint Scientific Committee (JSC) that has the overall responsibility for defining, overseeing, and evaluating the scientific and technical activities of the Programme, the Chairs and Directors of WCRP Core Projects, and Chairs of the Working Groups and Panels who implement the programme activities), resulted in an overall programme assessment and planning activity that is currently continuing. The WCRP team decided to focus their deliberations on two time horizons: an intermediate period (2010-2015), and a long-term period (post 2015). The intermediate-term discussions resulted in this Plan.

This Implementation Plan describes the major research activities and initiatives that WCRP will promote and undertake during the next several years. These activities/initiatives are based on the scientific challenges and opportunities of interest identified by the scientists involved in the Programme, as well as on the national and international scientific priorities that would most benefit from the coordination and integration that can be uniquely provided by the WCRP Projects and the Working Groups. In addition to the interdisciplinary research and modelling initiatives identified, the themes of regional climate assessments and climate information for decision-makers also emerged from these discussions as requiring special emphasis by WCRP in the intermediate- and long-term. Indeed, there were considerable discussions on the means and modes for delivery of climate information to decision-makers, and the role that WCRP can and should play in this process. The major issue debated was how best WCRP should spend its limited resources and make use of its network of volunteers in the continuum that begins with observation, research, analysis, modelling and prediction and ends with synthesis and assessment and delivery of the climate information and knowledge to decision-makers. In short, what are the most effective translation and hand-off mechanisms for climate information resulting from WCRP coordinated activities? The general view is that WCRP must continue to support and enable excellence in climate observations and research, but also promote and enable a comprehensive climate information system for timely and efficient delivery of the resulting knowledge to decision-makers. Partnerships are essential to WCRP success in both areas.

The following sections of this Plan provide an overview of the direction to be taken by WCRP and its Core Projects, the activities and initiatives that are to be supported, and the expected output and outcomes from these efforts over the next several years. We have been selective in providing only some specific examples of such activities/initiatives rather than a comprehensive compendium of WCRP activities. We hope that this plan, in conjunction with the recently published WCRP Accomplishments Report [WMO/TD-No. 1499, August 2009], conveys the solid scientific foundation that WCRP has established during the first 30 years of its research on climate variability and change and that forms the basis for future challenges and opportunities in delivering the resulting information and knowledge to decision-makers for developing strategies and options for climate adaptation, mitigation and risk management across the major social and economic sectors and regions of the globe.

To implement these activities and initiatives, the WCRP functions and organizational structure will continue to evolve during the ensuing decade(s). A companion document entitled "WCRP Long-Term Strategy: Functions and Structure" is currently under preparation and it will describe in detail areas of scientific focus and organizational structure for the Programme, beyond the next decade.

Ghassem R. Asrar
Director

Antonio J. Busalacchi
Chair,
Joint Scientific Committee

INTRODUCTION

The World Climate Research Programme (WCRP), sponsored by 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 Organisation (UNESCO), has the major objectives to: 1) determine the predictability of climate; 2) determine the effect of human activities on climate; and 3) make this information available for use in an increasing range of practical applications of direct relevance, benefit and value to society. The central focus of the WCRP Strategic Framework for the years 2005-2015 [WMO/TD-No. 1291, WCRP-123, August 2005] is to translate achievements in fundamental understanding of climate processes into a range of products, predictions, projections and climate assessments of high societal value for a broad range of users. WCRP aims to ensure that its sponsors and nations around the world have the most up-to-date tools, methods and information necessary to meet their climate-related mandates and programmatic objectives.

WMO UNESCO IOC ICSU International Council for Science

An important milestone for WCRP in 2009 was the completion of the jointly sponsored independent review of WCRP. The full text of the Review is available on the ISCU website (http://www.icsu.org).

The Review recommended that the WCRP should:

- Immediately focus the 2005 WCRP Strategic Framework to better capture the WCRP role in providing the science that underpins research on climate predictability, adaptation, and mitigation, thus strengthening the links with key end-user groups.
- Rapidly implement its focused Strategic Framework, paying special attention to societal needs while maintaining its science-driven approach.
- Introduce clear priorities into WCRP as a whole, collaborating with other Global Environmental Change (GEC) programmes to take into account urgent science required for IPCC and other societal demands.
- Lead the initiative on Earth system modelling, in collaboration with the International Geosphere-Biosphere Programme (IGBP) and other Programmes.
- Consolidate and strengthen its focus as a user and promoter of observations as well as its support of the components of the Global Climate Observing System.
- Set specific strategy and goals for building its scientific capacity in diversity of age and gender and for participation of developing country scientists in planning and research.
- Build its resource capacity by enhancing support for coordination and advocacy for research and infrastructure needs. This will necessitate expanding its funding sources outside traditional targets and working through IGFA.

- Expand its strategic outreach activities to target greater visibility and encourage better use of WCRP scientific results by the climate research community, the policy world and private sector, and more broadly the general public.

- In partnership with other GEC programmes, develop a framework for future joint research operation, with the initial focus on the elements identified in [this] Review.

The Review also recommended that WCRP's sponsors should meet regularly to review their mutual responsibilities for the Programme in light of society's increasing need for climate understanding, mitigation, and adaptation.

The Joint Scientific Committee for the WCRP has taken into account the Review's recommendations in executing its two-tiered planning for the future of WCRP. This report represents the first part – the development of an implementation strategy for the next six years that will ensure WCRP activities contribute to societal goals while maintaining the highest standards of scientific excellence and objectivity and continuing to advance our understanding of the basic processes that control the Earth's climate system. Across all WCRP activities there will be an increased emphasis on determining the regional variability of climate and climate change, as well as engaging more scientists from the regions in the climate research enterprise.

Chapter 2 of this document gives an overview of the WCRP organization; Chapter 3 describes the overall objectives of the Programme for the next six years in the context of the interfaces between the various domains of the climate system and the interactions among them. The complexity of the natural Earth system requires multidisciplinary research, but historically environmental research has been carried out in a disciplinary mode. Thus there is a continuing challenge to transition from disciplinary to interdisciplinary modes, ultimately embracing the whole Earth system. Chapter 4 describes activities that will be carried out over the next six years by the WCRP enterprise in support of key deliverables, as well as those activities that integrate across and support the various activities. The list of activities in each section of Chapter 4 is meant to provide a representative sampling of the major thrusts and is by no means exhaustive. This list will undoubtedly evolve as new scientific activities emerge from the major climate related events such as the OceanObs'09 Symposium, World Climate Conference-3, the Conference Of the Parties (COP-15), and post-Kyoto deliberations later this year, and over subsequent years.

PROGRAMME OVERVIEW

In order to achieve its primary objectives, WCRP is organized as a network of core and co-sponsored projects, working groups and cross-cutting initiatives. The current core projects of WCRP are:

- Climate Variability and Predictability (CLIVAR): CLIVAR's mission is to observe, simulate, and predict the Earth's climate system with a focus on ocean-atmosphere interactions in order to better understand climate variability, predictability and change.

- Global Energy and Water Cycle Experiment (GEWEX): GEWEX focuses on the atmospheric and thermodynamic processes that determine the global and regional hydrological cycle, radiation and energy transitions and their involvement in global changes such as increases in greenhouse gases.

- Stratospheric Processes And their Role in Climate (SPARC): SPARC has as its principal focus research on the significant role played by stratospheric processes in the Earth's climate, with a particular emphasis on the interaction between chemistry and climate.

- Climate and Cryosphere (CliC): The principal goal of CliC is to assess and quantify the impacts of climatic variability and change on components of the cryosphere and their consequences for the climate system, and to determine the stability of the global cryosphere.

WCRP jointly sponsors, with IGBP, the Scientific Committee on Oceanic Research (SCOR) and the Commission on Atmospheric Chemistry and Global Pollution (CACGP), the Surface Ocean - Lower Atmosphere Study (SOLAS) on biogeochemical interactions between the ocean and atmosphere. WCRP co-sponsors, with the IGBP International Global Atmospheric Chemistry Project (IGAC) and SPARC a joint research activity on Atmospheric Chemistry and Climate. IGBP and WCRP also co-sponsor research on water and energy in a changing climate by GEWEX and the Integrated Land-Ecosystem-Atmosphere Processes Study (iLEAPS). They also coordinate their coupled climate/Earth system modeling activities through the Working Group on Coupled Modelling (WGCM) and IGBP's Analysis Integration and Modelling of the Earth System (AIMES) project. WCRP together with other Global Environmental Change Programmes (i.e. IGBP, International Human Dimension Programme (IHDP) and Diversitas) form the Earth System Science Partnership (ESSP) whose main goal is to deliver results from the integrated study of the Earth System in support of global and regional sustainability. The key tasks of ESSP are to: (i) identify and define Earth system science challenges, (ii) enable integrative research, (iii) inform society, and (iv) carry out capacity building. The global environmental change research community also faces an increasing challenge to present research results in more accessible and informative ways to stakeholders, especially to policymakers. In response, the ESSP is developing new activities and products that include: (i) knowledge products, (ii) Earth system science fora, (iii) a journal, and (iv) collaborative research.

WCRP engages the international climate research community in a number of cross-cutting initiatives through the implementation of task forces and working groups in areas such as seasonal prediction, decadal variability, anthropogenic climate change, monsoons, chemistry and climate, climate extremes and risks, sea-level rise, and, most recently, regional climate downscaling and modelling. Cross-cutting initiatives are intended to bring together scientists from the various WCRP projects and panels with other key stakeholders such as policymakers, national and international government agencies and private industry specialists in order to address specific problems or research questions of immediate societal concern. These activities illustrate the complexity of the scientific and technical challenges facing climate research

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 the increase in greenhouse gases and land use change.

The objectives of GEWEX are to:

- Produce consistent research quality data sets, complete with error descriptions, of the Earth's energy budget and water cycle and their variability on short time and space scales (3h and 25 km) appropriate for process studies to decadal and beyond for use in climate system analysis and model development and validation.

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

- Improve the predictive capability for key water and energy cycle variables and feedbacks through improved parameterizations to better represent hydrometeorological processes, and determine the geographical and seasonal characteristics of their predictability over the land areas.

- Undertake joint activities with operational hydrometeorological services, related ESSP projects like the Global Water System Project (GWSP), and hydrological research programmes, to demonstrate the value of new GEWEX prediction capabilities, data sets and tools for assessing the consequences of global change.

and the need for increased coordination and collaboration across disciplines to meet them, as well as the need to translate the resulting scientific understanding into a form usable for decision-making. WCRP envisions even greater needs for such interdisciplinary research coordination and collaborations among its core Projects, and with its partner organizations IGBP, IHDP and others, in the future. This need will undoubtedly require further evolution of WCRP and its projects to achieve their scientific objectives in the most effective and efficient manner.

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 time-scales, 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 and to explore the potential for decadal 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.

Key science themes for CLIVAR are focused around 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. CLIVAR is 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.

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 IGBP International Global Atmospheric Chemistry Project (IGAC), the WCRP-IGBP joint research activity on Atmospheric Chemistry and Climate, which has a leading role in the preparation of the WMO/UNEP Scientific Assessments of Ozone Depletion. 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 models. In addition, SPARC, through its research activities in stratosphere-troposphere dynamical coupling, contributes to the understanding that is required to underpin development of the next-generation weather, climate and Earth system prediction models.

CliC
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 intends to achieve its principal goal by working 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 to scientific assessments of changes in the cryosphere and their impacts, in particular to the IPCC Fifth Assessment Report.

CliC is focused on five integrative and cross-cutting research topics: (i) cryospheric inputs to the Arctic and Southern Ocean freshwater budgets, (ii) the role of carbon and permafrost in the climate system, (iii) hemispheric differences in sea-ice extent and seasonal predictability, (iv) regional climate modelling and improved parameterisation of cryospheric processes, and (v) ice-sheet dynamics and the role of the major ice sheets in sea-level rise.

THE INTERDISCIPLINARY NATURE OF CLIMATE SCIENCE

Progress in understanding the various components of the Earth system that contribute to climate has revealed the complexity of the system. From its inception, WCRP science has focused on the physical components of the climate system, i.e. the oceans, the cryosphere, the water and energy cycle and the atmosphere. Major scientific challenges span these components and must also deal with the complex interactions within and among them. Improving climate models and their predictive capability requires better understanding of the entire system, particularly the processes that link the system components. Hence the WCRP approach is to focus on interdisciplinary research at the interface of the Earth system domains.

ATMOSPHERE, OCEANS AND CLIMATE

The atmosphere plays a key role in the energy balance of the Earth. It scatters or reflects about 30% of the incoming solar radiation through molecular scattering and the presence of aerosols and clouds. Some of the incoming radiant energy at the surface of the Earth is reflected but the rest is transformed into long-wave radiative flux, and sensible and latent (evaporative) heat fluxes, the portioning depending on the nature of the surface. The atmosphere also modulates the escape of long-wave radiation to space. While some of the long-wave radiation leaving the Earth's surface is transmitted relatively unimpeded through the atmosphere, the bulk of the radiation is intercepted and re-emitted both up and down. The resultant emission to space occurs at much higher and colder levels than the surface, a manifestation of the greenhouse effect. Human activities have changed the carbon balance of the atmosphere to increase the greenhouse effect, creating an imbalance between absorbed and emitted radiant energy that is producing global warming of the Earth's surface and lower atmosphere. Clouds also absorb and emit thermal radiation and have a blanketing effect similar to greenhouse gases. But clouds are also bright reflectors of solar radiation and thus act to cool the surface. The net effect for the current atmosphere, based on satellite observations, is a small cooling of the surface. However these two opposing effects on the global radiation balance bring considerable uncertainty into the feedbacks associated with cloud processes in the context of global warming. Other feedbacks also manifest themselves as part of the atmosphere's role in climate, for example through increased atmospheric water vapour content, itself an important greenhouse gas, in a warming atmosphere.

The distribution of land and ocean, and the incoming solar radiation, also contribute to the formation of certain patterns/phenomena that are observed both in weather and climate time frames, often referred to as regimes. For example, in the northern hemisphere, the dominant circulation pattern is the North Atlantic Oscillation (NAO) and the closely related Northern Annular Mode (NAM) that reflect changes in the westerly winds across the Atlantic into Europe, while in the southern hemisphere the Southern Annular Mode (SAM) is active year round and depicts changes in the strength and latitude of the prevailing westerly winds and storm tracks. These appear to be predominantly atmospheric phenomena, but important questions arise concerning how they contribute to the changes in the climate system, and also how they may, in turn, be affected by climate change. Understanding these regimes and representing them properly in climate models is essential.

At present, the oceans absorb approximately one-third of the total amount of greenhouse gases emitted to the atmosphere. This leads to ocean acidification, which is being observed in the oceans globally. As a result of the high thermal capacity of the water and the huge mass of the ocean, the oceans have accumulated more than 90% of the surplus heat associated with increasing greenhouses gas concentrations since the 1950s. This has correspondingly reduced the associated heating effect on the atmosphere, but implies a long-term warming commitment even if the rate of emission of greenhouse gases were to be reduced to zero. The ocean sequesters heat and moves heat, salt, and chemicals through the ocean currents, releasing them in different places and times. How ocean circulation is affected as the climate changes is a key issue, addressed in section 4. Because of the large mass (average depth 3,800m), high thermal capacity of water and areal extent of oceans, ocean-atmosphere interactions and ocean responses involve slow processes that are predictable over a variety of timescales.

For the prediction of future climate on secular timescales, one of the most difficult but unavoidable science questions is how the carbon storage in the oceans will evolve in time. Most predictions expect that the future capacity of the oceans to absorb carbon will diminish. To evaluate further the oceans' capacity to absorb and store carbon, one needs to develop a reliable physical and biogeochemical description of the world oceans. Our understanding of the ocean is rapidly evolving due to activities of several research projects, such as CLIVAR (WCRP), SOLAS (IGBP, SCOR, WCRP, and CACGP), and IMBER (IGBP and SCOR), the Ocean Carbon Coordination Project (IOC, SOLAS, IMBER, CLIVAR) and advances in ocean observations. Also contributing is the ESSP Global Carbon Project, which develops and issues assessments of the current geographical and temporal distributions of the major components and fluxes in the global carbon cycle.

For all numerical climate predictions on timescales from several months to years and out to decades, there is a need to represent the initial observed state of the atmosphere and oceans to the optimal extent possible for any particular application. Two past WCRP experiments (the Tropical Ocean Global Atmosphere, TOGA, project and the World Ocean Circulation Experiment, WOCE) enabled better understanding of ocean circulation and its interactions with the atmosphere. TOGA, in particular, helped to improve predictions of the El Niño/Southern Oscillation and exploit this predictability in a variety of seasonal predictions. WOCE provided an unprecedented snapshot of the global ocean circulation. Availability of satellite observations, global deployment of the autonomous floating Argo buoys, successful demonstration of the capability to assimilate ocean information under the framework of the Global Ocean Data Assimilation Experiment (GODAE), and increasing accuracy of pioneering ocean data syntheses by CLIVAR are enabling better observations and understanding of the role of the ocean in climate variability and change and the prospects for climate prediction across a variety of timescales. In order to exploit the predictability of the coupled climate system, it is imperative to correctly represent in models the fluxes of momentum, heat, moisture, gases and particles between ocean and atmosphere, to which SOLAS, CLIVAR and GEWEX contribute, and to cover gaps in global ocean observations including areas covered by sea ice. This last challenge is being addressed by the WCRP CliC project and its partners.

CRYOSPHERE AND CLIMATE

The term "cryosphere" collectively describes elements of the Earth system containing water in its frozen state. It includes snow cover and solid precipitation, sea ice, lake and river ice, glaciers, ice caps, ice sheets, permafrost and seasonally frozen ground. Ice shelves and icebergs are included in these categories. The cryosphere is an integral part of the Earth system and particularly sensitive to warming climate. Consequently its state parameters provide informative indicators of change in the climate system. Through its influence on surface energy and moisture fluxes, clouds, precipitation, hydrology, and atmospheric and oceanic circulation, the cryosphere plays a significant role in the global climate system. Changes in the cryosphere are involved in the strong positive feedback of a warming climate associated with a decreasing surface albedo as snow and ice melt. Recently intensified melting of glaciers is now considered to be the main cause of the increased pace of global sea-level rise. The potential for accelerated melting of various parts of the Greenland and Antarctic Ice Sheets, which could lead to several meters of sea-level rise, is a matter of great societal concern, and hence is a high priority research area for WCRP.

It is crucial to assess and quantify the impacts that climatic variability and change will have on components of the cryosphere and its overall stability, and, in turn, the consequences of the resulting changes in the cryosphere for further changes in the climate system. CliC is working closely with GEWEX and CLIVAR to advance this research. It is essential to continue the development and validation of physically based land-atmosphere-cryosphere process models, including permafrost-hydrology and carbon cycle interactions, with appropriate complexity for their use in coupled climate models across a range of time and space scales. Improvement of regional climate models with interactive climate-cryosphere-hydrosphere schemes is vital to allow assessments of (i) impacts of climate variability and change on the terrestrial cryosphere and water resources, and (ii) the effects of changes in the cryosphere on regional climates for the mountain and watershed systems. The role of river- and lake-ice processes in watershed hydrology over the cold regions, particularly in the Arctic region, should also be examined.

ATMOSPHERIC CHEMISTRY AND DYNAMICS

The temperature of the Earth's stratosphere is largely determined by a balance between the absorption of UV radiation by stratospheric ozone and outgoing infrared radiation, modified locally by dynamical heating. The radiative balance results in an increase of air temperature in the stratosphere with altitude, which makes this layer dynamically stable. The UV absorption processes provide a mechanism for variations in the solar forcing of climate. The concentrations of major stratospheric gases, principally ozone, carbon dioxide and water vapour, determine significant radiative forcing terms, yet ozone and water vapour are not long-lived gases and unlike carbon dioxide, their distribution is strongly shaped by transport within the stratosphere.

The depletion of the stratospheric ozone layer since the 1970s, which is especially strong in polar regions, has had direct consequences on the troposphere and the Earth's surface. This decrease in ozone concentrations and the concomitant increase in the abundance of long-lived greenhouse gases have led to a general decrease in stratospheric temperatures. The resulting temperature patterns are a combined effect of chemically induced ozone loss and global warming. Furthermore, the troposphere and stratosphere interact dynamically. The so called "sudden" stratospheric warming and cooling phenomena are known to affect the troposphere below, especially in polar regions, but also feed back to the tropical stratosphere.

Better understanding of the complex dynamical and chemical processes in the stratosphere, their representation in models, and sensitivity to initial conditions, together with fuller exploitation of the predictability of longer timescales of processes dominating in the stratosphere, should result in an increased skill of predictions on the timescales from medium-range weather forecasting up to decades. The strong radiative-chemical coupling through the sensitivity of ozone abundance to temperature, two-way interaction between stratospheric and tropospheric dynamics mediated by wave propagation and dynamical heating, and, as well, marked ongoing changes in the stratosphere, make this layer an ideal springboard for systematic research of the full scope of interactions between atmospheric chemistry and dynamics. The Stratospheric Processes and their Role in Climate Project (SPARC) core Project is rapidly expanding its research to embrace the full scope of dynamical and chemical processes in the whole atmosphere. SPARC collaborates with the IGAC project of IGBP to coordinate research on atmospheric chemistry and climate.

WATER, ENERGY AND CLIMATE

Solar energy is the fundamental driver of the Earth's climate system, while infrared emission is the system coolant. Net heating in equatorial regions and net cooling in polar regions drive both atmospheric and oceanic circulations. It is water, however, in all its three phases that provides much of the complexity and variability in the Earth system, as well as being the fundamental determinant of habitability for most of the biota. Energy and water are inextricably intertwined in the climate system on spatial scales from the molecular to planetary and on timescales from the instantaneous to millennia. External forcing of climate, whether by solar variability or changes in atmospheric composition or volcanic eruptions, alters the energy and the water cycle, as well as the complex relationships between them. These alterations provide feedbacks in the climate system that both amplify and dampen aspects of the original change. It is these feedbacks and their coupling to the non-linear dynamics of the ocean-atmosphere system that are the most challenging issue in understanding climate and predicting the magnitude of climate change in this century. Consequently there is an urgent need to increase understanding of these complex processes and their interactions in climate system and improve their representation in climate models.

GEWEX currently leads WCRP's studies of the dynamics and thermodynamics of the atmosphere, the atmosphere's interactions with the Earth's surface (especially over land), and the global water cycle. The oceans play a major role in energy and water cycle, and the lead has been with CLIVAR (see 3.1). Key questions for the future include:

- How are the Earth's energy budget and water cycle changing?

- Can we quantify feedback processes in the Earth system and determine how these processes are linked to natural variability?

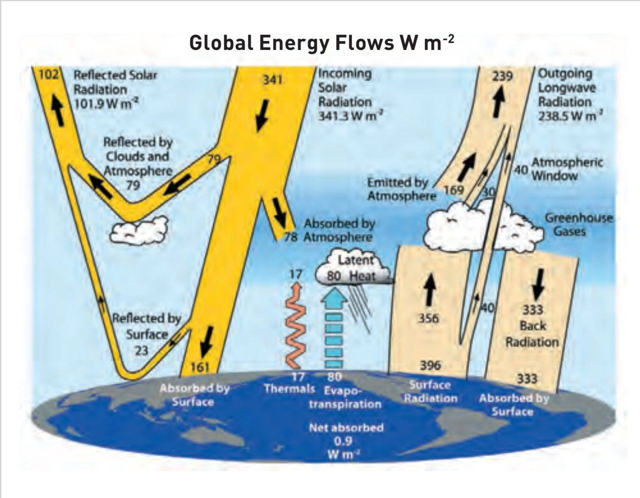
- Can we predict climate variability on the seasonal to interannual timescale?

- What are the impacts of climate variability on these timescales on water resources?

- How does anthropogenic climate change couple with natural climate variability to alter regional water and energy budgets, particularly with regard to means and extremes?

- Can we track the flow of energy through the climate system and understand the nature of global warming?

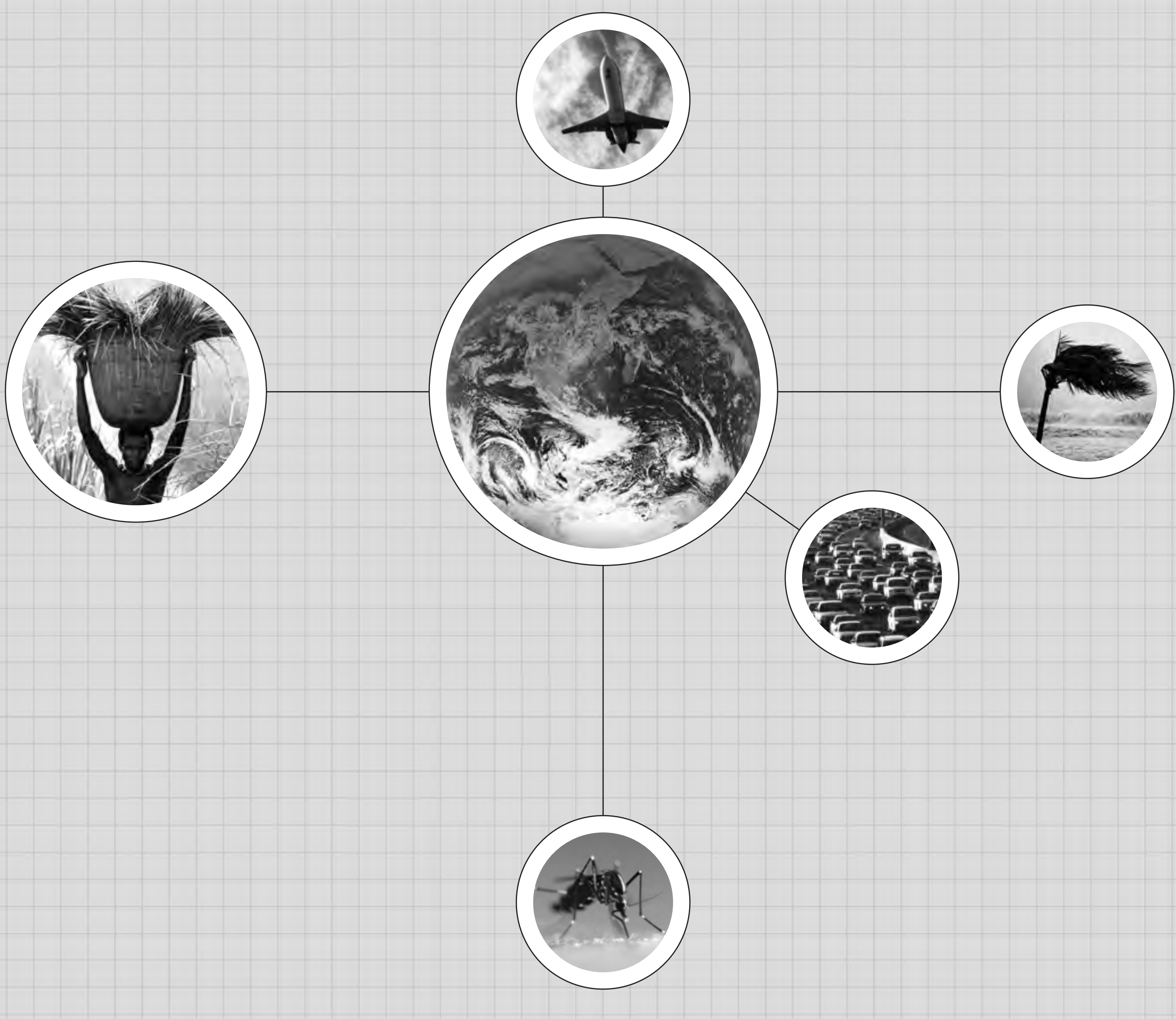
These brief discussions of the climate system interactions illustrate the complexity of each of the variations and changes in the climate system components. Understanding the forcing and feedbacks among them requires a greater integration of the Programme than ever before. WCRP has a strong history of bringing together researchers to study the different components and the interactions among them, and it will continue to do so in the future. The following sections describe the contributions by the WCRP Core Projects, modelling groups and cross-cutting panels that will be coordinated and integrated to advance our understanding of the climate system and to deliver scientific knowledge that will be of use and benefit to all social and economic sectors worldwide.



K.E. TRENBERTH ,J.T. FASULLO AND J. KIEHL 2009 BULL. AMER. MET. SOC 90, 311-323

Figure 1. *The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m−2). The broad arrows indicate the schematic flow of energy in proportion to their importance*

MEETING THE INFORMATION NEEDS OF SOCIETY



ACTIVITIES IN SUPPORT OF KEY DELIVERABLES

This chapter describes high priority activities that WCRP will implement in the next several years to reach its goal of delivering science in support of societal needs. Each section identifies an area of scientific investigation that will lead to deliverables of direct benefit to practitioners and decision-makers who will need the resulting climate information. The first four topics, on decadal predictability, sea-level rise, climate extremes and atmospheric chemistry-climate interactions, are relatively new thrusts for WCRP and we anticipate that the implementation plans for these will develop substantially in the coming years. The remaining topics, climate change projections, seasonal predictions and monsoons, are areas where WCRP has had ongoing activities during the past decade, but where we believe significant scientific progress is still needed to meet the climate information needs of decision-makers.

Decadal Variability, Predictability and Prediction

For the next several decades the natural variability of the climate system could be of the same order of magnitude as the response to external forcing (e.g., greenhouse gases, aerosols and land-cover changes). Adaptation and mitigation strategies require decadal forecasts of the combined natural variability and the climate system response to additional greenhouse gases and aerosol forcing. Currently there is little scientific understanding as to whether climate can be predicted up to a few decades in advance. Collaboration between the Working Group on Coupled Modelling (WGCM), the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP) and the CLIVAR Atlantic Panel (for which the issue of decadal variability and predictability of the Atlantic meridional overturning circulation is a primary focus) has resulted in an experimental protocol for assessing prospects for decadal prediction and estimating the limits of decadal predictability. Ensuring the implementation of this experimental protocol, the understanding of the results and design of follow-on experiments will be the major thrusts of CLIVAR activities in the intermediate- and long-term, in collaboration with the other WCRP core projects.

It is equally important to identify the role of atmosphere-ocean interactions and associated feedbacks for decadal variability. Observing the Atlantic thermohaline and wider meridional overturning circulation to understand their role in decadal variability and possible predictability will entail major field activities.

Some primary questions to be addressed over the next five years include:

- What is the optimal observing system for providing initial conditions and verification of decadal predictions?
- What are the variables that exhibit highest predictive skill?
- How do we initialize coupled models for decadal predictions?
- How predictable are the modes of variability and what are their regional impacts?

- How do we validate decadal predictions, given the limitations of the instrumental record?

- What are the potential applications and how can WCRP help to develop interfaces between decadal predictions and society?

A key issue for decadal prediction is the determination of the initial conditions for the state of the climate system, and the ocean in particular, and a number of ocean data assimilation approaches have been employed to provide needed information for describing realistically initial ocean conditions. The activities of CLIVAR in promoting and evaluating ocean synthesis activities provide an essential input to the decadal prediction activity.

The stratosphere exhibits multi-year variability associated both with internal stratospheric processes (e.g. sudden stratospheric warmings and the quasi-biennial oscillation (QBO)) and with responses to external forcings (volcanic eruptions, decadal-scale variations in solar irradiance, and anthropogenic effects such as ozone depletion/recovery from halogens and increased GHG concentrations). The wintertime Arctic also exhibits decadal variability, much of which is presumably associated with forcing from sea-surface temperatures, and there is the potential for multi-year memory in stratospheric tropical zonal winds. Teleconnection pathways coupling stratospheric and tropospheric variability are now recognised as major factors contributing to tropospheric predictability. Decadal predictability of stratospheric ozone and the role of the stratosphere (and stratospheric ozone) in decadal predictability are priority research topics. SPARC will address them in several ways.

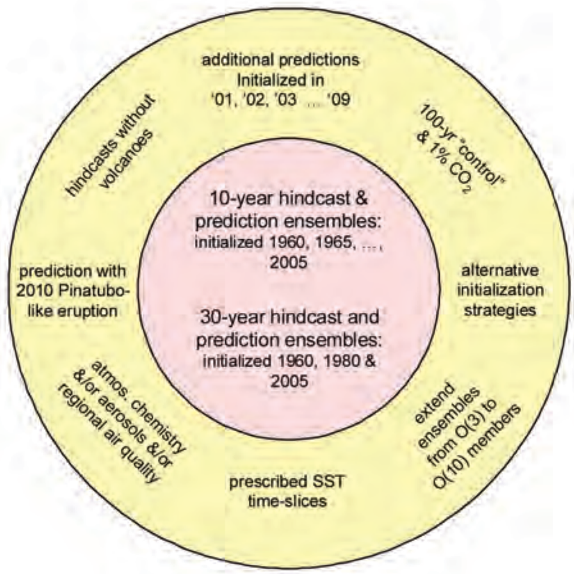


Figure 2. *Schematic summary of the WCRP-led CMIP5 decadal prediction experiments.*

Key Activities

Understanding Key Processes

Globally, a fully coordinated monitoring system for the meridional overturning circulation (MOC) will depend on sustained basin-wide observations, including measurements from space. Analysis of data and model products, process studies and Observing System Simulation Experiments (OSSE) will be necessary to determine the most efficient and cost-effective way to achieve this and to determine the ocean observing system needed globally for climate prediction.

A particular focus for CLIVAR in the Atlantic will be the establishment of a continuous record of the zonally-integrated, full water column, trans-basin fluxes of heat, mass and fresh water transported by the global MOC in order to assess the variability and influence of the MOC on the climate system and potential decadal predictability arising from the ocean. This will be realized through facilitating coordination of major field programmes including the US-led "Atlantic MOC" (AMOC), the UK-led "Rapid Climate Change – Will the Atlantic Thermohaline Circulation Halt?" (RAPID-WATCH) and the EU-sponsored "ThermoHaline circulation at Risk" (THOR) programmes.

For the Atlantic there will also be the need to discern the meridional connectivity of MOC variability through encouraging the development and implementation of additional (beyond those presently deployed) trans-basin measurements in the sub-polar North Atlantic and subtropical South Atlantic, as well as the flows through Drake Passage and around the tip of South Africa. The Arctic-Subarctic Ocean Fluxes (ASOF) study will continue to monitor fluxes between the Arctic and North Atlantic to extend our knowledge of their long-term (decadal timescale) variability.

In the other ocean basins, CLIVAR will focus on:

- Observed decadal variation and warming trends in the upper Indian Ocean including studies of circulation and the Indian Ocean heat budget and the interbasin exchanges of mass and heat;

- Decadal predictability in the Pacific climate system, including a better understanding of the nature and predictability of climate regime transitions impacting, for example, on ENSO and other regional patterns of decadal variability; and

- The role of the Southern Ocean in decadal variability.

In addition, in the Pacific the Kuroshio Extension System Study (KESS) aims to identify and quantify the processes governing the oceanic circulation in the Kuroshio region and how these relate to the intense air-sea heat exchange in this region, a potential contributor to decadal variability (http://uskess.org/index.html). In the Atlantic, the CLIVAR Mode water Dynamics Experiment (CLIMODE) is investigating the region to the south of the Gulf Stream where key air-sea and ocean processes that govern ocean mixing and transfer of properties into the deep ocean are poorly understood and poorly represented in ocean climate models (http://www.climode.org/index.html). These complementary investigations are helping unravel a range of complex ocean-atmosphere processes that may be responsible for shifting storm patterns.

Investigations will also be continued to determine, for example, how decadal changes in ocean temperatures, especially sea-surface temperatures, impact the occurrence and frequency of long-term regional drought, such as that of the Dust Bowl of the 1930s in the United States.

Modelling

A suite of coordinated experiments will be carried out to explore decadal predictability and prediction out to 2035 using coupled models run from initialized atmospheric and oceanic states and with changing climate forcing. These are now part of the IPCC AR5 experimental protocols and are a major component of the newly-configured fifth Coupled Model Intercomparison Project (CMIP5, see also page 29) which provides a five-year framework not only for predictions to 2035, but also for hindcasts to assess predictability and for long-term (century) timescale climate model simulations. Legacy datasets from these runs will be managed and organised through the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at the Lawrence Livermore National Laboratory in the United States and the outputs will be available for analysis and inclusion in IPCC Fifth Assessment.

In order to assess how models simulate decadal variability, and what initialized predictions could offer over uninitialized radiatively-forced projections, it is necessary to untangle natural and anthropogenically-forced variability. A United States led working group on Decadal Predictability will assess the best approaches to distinguish natural decadal variability from anthropogenically-forced variability and to quantify their relative magnitudes. Additionally, the group will also develop a framework for understanding decadal variability through metrics that can be used as a strategy to assess and validate decadal climate prediction simulations.

Modelling of the role of stratosphere-troposphere coupling for decadal scale predictions, the importance of horizontal/vertical resolution and vertical domain, and the role of parameterization of unresolved processes (e.g. gravity-wave drag) in modelling stratospheric variability will be a subject of research in the context of the SPARC DynVar activity and Gravity-Wave initiative. The importance of changes in atmospheric composition (especially ozone depletion and recovery, which has a strong decadal timescale signature), solar variability and volcanic eruptions, will be studied as part of the SPARC CCMVal (Chemistry-Climate Model (CCM) Validation) activity.

Sea-Level Variability and Change

A significant uncertainty exists in the available projections of the mean sea-level change and its regional impacts in the 21st century. At present the mean sea

Sea – Level Rise (mm yr-1)		
Source	1961-2003	1993-2003
Thermal expansion	0.42±0.12	1.6±0.5
Glaciers and ice caps	0.50±0.18	0.77±0.22
Greenland Ice Sheet	0.05±0.12	0.21±0.07
Antarctic Ice Sheet	0.14±0.41	0.21±0.35
Sum	1.1±0.5	2.8±0.7
Observed	1.8±0.5	3.1±0.7
Difference (Observed – Sum)	0.7±0.7	0.3±1.0

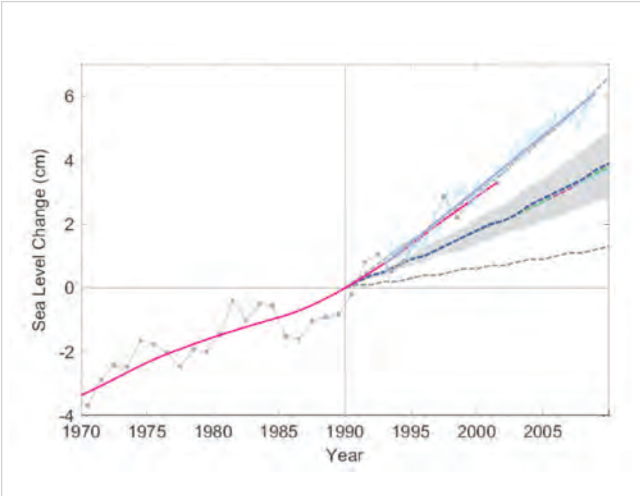
IPCC, AR4, WG 1, CH. 5

Table 1. *IPCC AR4 estimates of contributions to the global mean sea-level change for 1961 to 2003 and 1993 to 2003 compared with the observed rate of rise. Glacial isostatic adjustment was applied to data from tide gauges and satellite altimetry. The error for the sum was calculated as the square root of the sum of squared errors of individual contributions. The thermosteric sea level change was calculated taking into account temperature changes in the upper 3000 m of the ocean only.*

level is rising more rapidly than projected in the IPCC AR4 report (see Table 1) and the factors contributing to the sea-level variability and change are major foci for WCRP research.

An important contributing factor is thermal expansion of ocean waters. Recent studies have made it possible to identify and reduce the errors associated with the measurements of temperature in the upper ocean, but more measurements in the deeper ocean are needed to allow for accurate estimates of changes throughout the water column. The recent increase in the pace of sea-level rise up to approximately 3.2 mm per year is being attributed to the contribution of melting glaciers, ice caps and ice sheets. This contribution will not remain steady during the 21st century and its variation with time needs to be projected. Changes due to water storage on land and isostatic motions of the ocean basin also need to be assessed.

The largest concern and uncertainty in estimating sea-level rise is associated with changes occurring at the margins of continental ice sheets and the possibility that their contribution to sea-level rise may increase rather quickly. There are several processes that are poorly studied but hypothetically important in this regard. They include reduction, disintegration and removal of ice shelves, which tend to reduce ice flows toward the oceans, and basal sliding of ice sheets due to accumulation of melt-water beneath them, which decreases the basal friction. Both these processes contribute to mass loss of the Antarctica and Greenland ice sheets. Quantitative assessment of the role of these processes and prediction of their future evolution are currently very difficult because existing ice-sheet models lack their representation. The situation is complicated even further because of changing and increasing impact on the ice sheets and ice shelves by the warming air and especially the ocean waters. Warming of the Southern Ocean has been observed during the recent ocean cruises including ones conducted during the International Polar Year 2007-2008. Changes in ocean dynamics near the coasts of Antarctica and the Antarctic Peninsula remain poorly known and are not included in climate models.



RAHMSTORF, S., CAZENAVE, A., CHURCH, J.A., HANSEN, J.E., KEELING, R.F., PARKER, D.E., AND R.C.J. SOMERVILLE, 2007: RECENT CLIMATE OBSERVATIONS COMPARED TO PROJECTIONS. SCIENCE 316 (5825): 709-709.)

Figure 3. *Change in sea level from 1970 to 2008, relative to the sea level at 1990. The solid lines are based on observations smoothed to remove the effects of interannual variability (light lines connect data points). Data in most recent years are obtained via satellite-based sensors. The envelope of IPCC projections is shown for comparison; this includes the broken lines as individual projections and the shading as the uncertainty around the projections.*

Practical measures aimed at adaptation to rising sea levels require information on regional scales. Changing ocean dynamics leads to regional variations of sea levels. Special attention should be paid to the combined elements affecting future sea-level changes, including long-term rise, storms, storm surges and tides, and especially their extremes. This information is key for coastal defences and coastal-zone management.

Key Activities

WCRP will lead research activities to cover the gaps in scientific knowledge mentioned above through process studies, observations and modelling. Syntheses of these activities will be produced as a contribution to future, substantiated sea-level change projections. Together with partners such as IOC, WCRP will facilitate assessment of the global and regional sea-level changes and communication of resulting information to interested parties.

CliC will carry out observations and improve representation in models of spatial and temporal variability of mass budget of ice sheets, ice caps and glaciers. This will include an assessment of the Greenland and West Antarctic ice sheet stability and vulnerability to climate change, including sudden and potentially irreversible changes.

Ocean thermal expansion with a warming climate, including abyssal region warming, is an important contributor to sea-level rise. CLIVAR's focus on the development of the sustained ocean observation system provides an important contribution to the datasets needed for studies of sea-level rise.

GEWEX will contribute information on the global water budget, including understanding of changes in water storage terms over land and in the atmosphere. The continuing effort to close the global water budget will also contribute in this area by quantifying the partitioning and changes of the various components of water over land.

Climate Extremes

In recent decades, climate extremes and climate variability have had increasingly noticeable impacts on societies throughout the world. The IPCC Fourth Assessment report states: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones." One of the most critical concerns for society is whether or, more probably, how the occurrence and severity of extremes will change in the future.

WCRP is developing a cross-cutting activity on climate extremes. Initial objectives are to:

- summarize, compare and assess definitions of climate extremes and develop a common language amongst researchers and end-users;

- design an intercomparison framework through which both observations and climate model representations of extremes and projections of climate can be assessed, and by which changes in climate extremes can be better evaluated;

- accelerate progress on the prediction of climate extremes with a focus on developing capabilities and products which facilitate practical applications for stakeholders in regions around the world;

- assess the observational and dataset framework for study of global extremes;

- determine whether extremes are changing and, if so, why.

CLIVAR and GEWEX together lead this activity and have chosen to place the initial focus on drought because of its global nature and the potential value of drought early warnings. This effort will build on many ongoing national and multinational activities on drought monitoring and research and will aim to understand drought predictability and prediction in a changing climate. Research suggests there is predictability for some regions and timescales, but there is a need for continued research and international coordination to more rigorously assess this predictability.

Many WCRP activities will contribute to advancing our understanding of climate extremes. Modelling groups will carry out assessments of how well present climate models represent and predict extreme events, which new observations are needed to initialize such predictions, which processes/parameterizations need improvement in support of predicting extreme events, and the added value to the characterization of extremes from ensemble predictions. The aims of the near-term climate experiments described on pages 21–22 include assessing the potential to provide guidance up to decadal timescales of the changing risk of extremes. GEWEX modelling and prediction subgroups will carry out studies of the connections between surface moisture and drought and the processes that affect precipitation in clouds. The GEWEX Coordinated Energy and Water Cycle Observation Project (CEOP) also has a cross-cutting activity on extremes that is producing regional and global datasets on hydrometeorological extremes and assessing the capabilities of reanalyses and other products to infer trends in the occurrence of extremes. The CLIVAR Variability of the American Monsoon System (VAMOS) panel has developed a document that outlines its approach to regional studies of climate extremes. CliC will contribute to cryospheric extremes research, with a focus on risks associated with dangerous events in a changing climate and cryosphere. In particular, it will facilitate development of datasets and analysis tools to document changes in discharge from mountain glaciers which impact water reserves of many countries, risks of the sudden collapse of ice shelves and increased melting of ice sheets in several areas of the Greenland and West Antarctica, and some other major changes such as permafrost in the high latitude regions.

Key Activities

Analysis of results from CMIP5 near-term climate experiments will be carried out to characterize climate extremes and their predictability.

Assessment of outputs from US-CLIVAR led modelling experiments will be made to characterize sources of predictability of multi-season drought.

The GEWEX Hydrological Applications Project in conjunction with the Hydrological Ensemble Predictions Experiment will carry out experiments in selected water basins to determine what is needed for drought and flood monitoring and forecasting in several regions in the world.

GEWEX will continue its activity to compare the factors that generate hydrometeorological extremes in different regions of the world and assess the capabilities of observations to account for these and of models to simulate them.

The WMO-CCl/WCRP-CLIVAR/WMO-IOC JCOMM Expert Team on Climate Change Detection and Indices will develop new indices for monitoring climate extremes using both observed and model-generated data, enhancing the global data base of climate indices.

Reanalysis products will be assessed to discover how well they depict extremes. WCRP together with GCOS will work to improve historical data sets (reanalysis and reprocessing) and to define adequate monitoring systems for extremes to provide the basis for the assessment of the likely causes of any trends in extremes.

Through CCMVal, SPARC will assess the likelihood of extremes in Polar Stratospheric Cloud (PSC) occurrences that lead to extremes in ozone depletion.

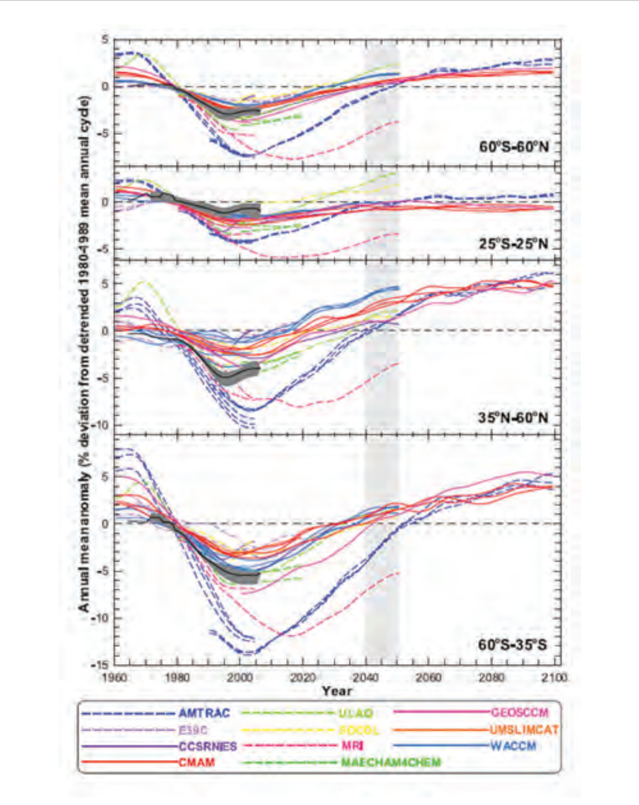
WCRP will collaborate with the new ICSU/ISSC/UNISDR Integrated Research on Disaster Risk (IRDR) programme towards better assessment and prediction of disaster risk from climate extremes.

Atmospheric Chemistry and Dynamics

The full scope of climate-chemistry interactions and the links between global warming and air quality are important research topics for improving climate predictions and projections. This activity serves as direct input to the WMO/UNEP Scientific Assessments of Ozone Depletion as well as to the IPCC Assessments. WCRP will achieve its objectives in this area through the further development of the corresponding SPARC activities and the joint WCRP/SPARC and IGBP/IGAC Atmospheric Chemistry and Climate (AC&C) cross-cutting initiative.

A major ongoing focus of SPARC is on quantifying the evolution of stratospheric ozone and its interaction with climate change. Through its Initiative on Halogen Chemistry it will clarify recent laboratory results concerning the role of key interactions in ozone depletion and provide direct input to the 2010 WMO/UNEP Ozone Assessment. The SPARC CCMVal activity will continue to improve understanding of the performance of Chemistry-Climate Models and their underlying general circulation models through process-oriented evaluation, along with coordinated analysis of science results. Key diagnostics with respect to radiation, dynamics, transport, and stratospheric chemistry and microphysics, following from atmospheric constituent distributions, will be used to compare model outputs with robust relationships found in observations.

The AC&C initiative will couple this effort with model studies of the impacts of climate on atmospheric chemistry, the impact of atmospheric chemistry on climate, and the impact of climate on air quality. AC&C will help the scientific community to identify a set of high priority science questions around atmospheric chemistry and climate that require integration and synthesis across the projects. Through a set of common diagnostics that can be used to address the uncertainties, the modelling and measurement communities will cooperate to constrain the models and use them to inform measurement planning. AC&C will also evaluate emissions inventories and undertake an effort to harmonize them and create a platform for their coordinated development in the future.



EYRING, V., ET AL. (2007), MULTIMODEL PROJECTIONS OF STRATOSPHERIC OZONE IN THE 21ST CENTURY, J. GEOPHYS. RES., 112, D16303, DOI:10.1029/2006JD008332.

Figure 4. *Annual mean zonal total column ozone anomalies from CCMs (coloured lines) and from four observational data sets (thick black line and gray shaded area show the mean and range of observed anomalies).*

The tropopause region (including both the tropical and extra-tropical tropopause layers) is the location of major exchanges of radiatively and chemically active species (e.g. water vapour, methane, ozone depleting substances, ozone itself, and other radiatively important species) between the troposphere and stratosphere. Understanding the physical and dynamical processes governing and constraining this region, for instance processes determining the location and magnitude of the cold-point temperature, is critical to evaluating and modelling climate sensitivity as well as for modelling of very short-lived species. These issues will be addressed through the SPARC Tropopause Initiative and SPARC-GEWEX-IGAC collaborative activities on modelling the role of deep convection in stratosphere-troposphere coupling and exchange, particularly in the region of the tropical tropopause.

Key Activities

SPARC will continue the Chemistry-Climate Model Validation Activity (CCMVal) to coordinate the contribution of stratosphere-resolving Chemistry-Climate and Earth System Models to the WMO/UNEP Ozone Assessment and IPCC Assessment Reports, and to advance the quantification of model uncertainties. This will include the production of a peer-reviewed SPARC report in 2010.

The SPARC Initiative on Halogen Chemistry will study recent laboratory results concerning the role of key interactions in ozone depletion.

SPARC will carry out analysis of radiosonde and satellite records to identify sources of uncertainty in the measurements of stratospheric temperature and to quantify temperature trends that are consistent across data sets.

The WAVAS-2 activity will update the SPARC Water Vapour Assessment to include more recent measurements, and provide a consolidated evaluation of current understanding concerning processes affecting stratospheric water vapour and its evolution. WAVAS-2 will result in another peer-reviewed SPARC report, encompassing the topics of instrument accuracy, supersaturation in the upper troposphere, radiative effects of water vapour in the upper troposphere/lower stratosphere, and long-term trends in stratospheric humidity.

SPARC will document the state of the polar vortices during the IPY period.

The SOLARIS (Solar Influence study for SPARC) activity will evaluate and improve understanding of solar influences on climate.

The SPARC DynVar Activity will evaluate the ability of general circulation models to represent the large-scale dynamical coupling between the stratosphere and troposphere on a wide range of timescales and assess its importance for climate prediction.

AC&C will carry out hindcasts in an attempt to replicate the observed changes in chemical composition over the past 20 years and understand what processes have acted to change the tropospheric chemistry of the atmosphere, particularly ozone and aerosols. SPARC and IGAC together will study controls on aerosol/gas distribution in the troposphere between the height of five kilometers and the tropopause.

Centennial Climate Change Projections

Human activities have changed Earth's climate over the past century, and further change is expected over the next several decades, even if strong mitigation actions are taken. Thus, it is imperative to undertake predictive science that aims to inform the decisions that we must collectively make to mitigate adverse impacts, and to adapt and manage the potential risks of climate variability and change. We must improve our ability to predict the future state of the climate system, including variations in

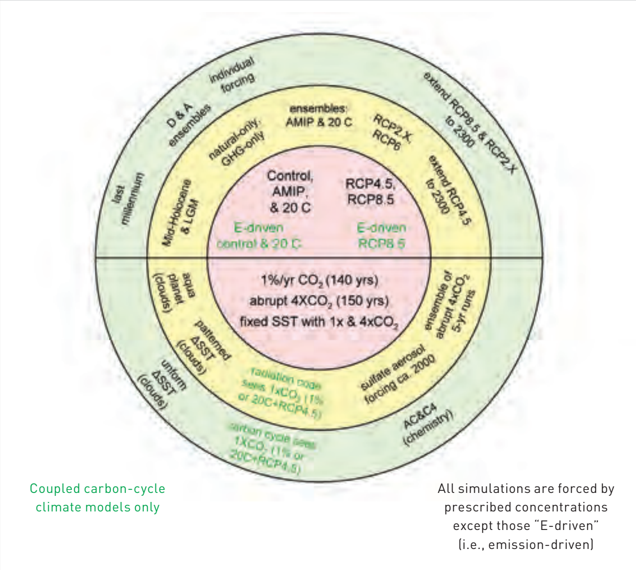


__Figure 5.__ Schematic summary of CMIP5 long-term experiments.

the likelihood of extremes such as droughts and floods and in the availability of water, on timescales of seasons to decades and longer. In particular, we must develop a better understanding of how human influences on the climate system affect these variations on regional to global scales. This will require improved understanding of the processes that govern the natural variability of the climate system and of how these processes are affected by human influence.

The extent to which we undertake mitigation measures such as curtailing the emission of greenhouse gases in the atmosphere, will have a profound impact on the climate that will be experienced by our children and grandchildren in this century and beyond. Thus it is imperative that we undertake science that informs policymakers about the constraints that natural variability, physical and biogeochemical feedback processes, and human activities that alter feedback processes (such as land-use change), impose upon policy choices in areas such as energy usage, land use, and long-term water use planning.

All WCRP projects will make important contributions to this activity. The WGCM, in conjunction with its IGBP partner AIMES (Analysis, Integration and Modelling of the Earth System), will play the lead role in incorporating the knowledge gained to improve climate projections. A major thrust for the next several years will be to investigate the regional impacts of climate change and to improve and coordinate regional climate modelling and downscaling to inform regional and local climate change assessments and decisions. WCRP will also facilitate a concerted effort to develop measures of the uncertainty associated with climate projections and the means to best communicate them.

Key Activities

WGCM will coordinate long-term (centennial) and, as outlined on pages 21–22, near term (decadal prediction) climate change experiments as part of CMIP5, aided by PCMDI for dataset management and distribution. CMIP5 will promote a standard set of model simulations in order to evaluate model realism in simulating the recent and longer past, provide projections of future climate change on two timescales, near-term (out to about 2035) and long-term (out to 2100 and beyond), and understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle. These activities will be carried out through WGCM projects such as the Cloud Feedback Model Intercomparison Project (CFMIP) and the Paleoclimate Model Intercomparison Project (PMIP), and in close association with other WCRP & IGBP projects such as the Chemistry-Climate Model Validation Activity of SPARC (CCMVal) and the Coupled Carbon Cycle Climate Model Intercomparison Project (C4MIP).

CFMIP, in collaboration with the GEWEX Cloud System Study (GCSS) will take the lead to develop a new focus on cloud feedback studies that spans observations and modelling to address the dominant uncertainty in climate sensitivity identified in each IPCC report, namely the cloud-radiation feedback problem.

WCRP will develop a framework to evaluate regional climate downscaling techniques for use in downscaling global climate projections and will foster international coordinated efforts to develop improved downscaling techniques and to provide feedback to the global climate modelling community. The initial focus will be a coordinated set of regional experiments for Africa (Coordinated Regional climate Downscaling Experiment, CORDEX).

Analysis of regional response to changing climate forcing will be carried out by all WCRP projects as diagnostic subprojects of the archive at PCMDI.

Some of the regional hydroclimate projects such as BALTEX (Baltic Sea Experiment) will study local and regional anthropogenic influence on the climate and environmental system. The CLIVAR VAMOS panel has developed an approach to regional studies of anthropogenic climate change, particularly those over the Americas. Further such regional efforts will be encouraged.

SPARC will develop comprehensive ozone data sets and projections for use in the CMIP5 climate predictions, and will also undertake its own projections of the future interaction between ozone recovery and climate change using stratosphere-resolving chemistry-climate models under the CCMVal activity.

CliC will facilitate and support scientific assessments of changes in the cryosphere and their impacts, in particular for the IPCC Fifth Assessment Report. A joint CliC and AIMES (IGBP) activity will focus on the role of permafrost and frozen ground in the carbon cycle to estimate the magnitude of the positive feedback between the warming climate and additional emission of greenhouse gases into the atmosphere from natural sources, particularly from thawing permafrost.

WMO-CCl/WCRP-CLIVAR/WMO-IOC JCOMM Expert Team on Climate Change Detection and Indices (ETC-CDI) will carry out analysis of extremes using daily meteorological and oceanographic data.

CLIVAR will extend the climate record into the past as joint activities with the IGBP PAGES (Past Global Changes) project.

Seasonal Climate Prediction

The ability to predict the seasonal variations of climate improved significantly from the early 1980s to the late 1990s with the advent of dynamical coupled model forecast systems, primarily due to higher predictability of El Niño/Southern Oscillation and some of its global teleconnections. Since the late 1990s, the skill of seasonal predictions has reached a plateau with only modest subsequent improvement in skill. This is particularly true for seasonal fluctuations of the monsoon systems throughout the globe. Nevertheless, scientists are convinced that maximum predictability has not yet been achieved and there is opportunity for greater progress in this area. During the next five years WCRP will make a concerted effort to improve seasonal forecast skill and to define the limits of predictability. This will involve including all the interactions among the relevant components of the climate system (atmosphere (including stratosphere), land, cryosphere, and ocean) and hence each WCRP project will contribute to this effort. WCRP groups and projects will work closely with the operational climate forecasters in the national meteorological services to implement improvements in seasonal prediction systems. This interaction will take place largely through the representation of the major predictions centres in the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP) and through enhanced involvement of climate researchers in the WMO's Regional Climate Outlook Fora (RCOFs) which bring together climate forecasters and practitioners from developing and developed countries. Regional groups like VAMOS also have close links with the operational forecasting centres in their region.

Difficulties on the sub-seasonal timescale are likely impacting our ability to predict seasonal monsoon fluctuations and tackling this will require close cooperation with projects such as THORPEX whose focus is on weather timescales. Prediction strategies for the future will be largely based on multi-institutional international collaborations involving multi-model ensembles to adequately resolve model error and forecast uncertainty.

Key Activities

Understanding Key Processes

Process studies, involving observations, analysis and modelling, will be carried out to improve the understanding of climate system dynamics and to address model biases. Studies will focus on key topics such as ENSO dynamics and prediction, the roles of the Indian Ocean dipole and tropical Atlantic variability on monsoon prediction and African climate, respectively, and the importance of soil moisture to initialize forecasts.

GEWEX and CLIVAR together are carrying out the Global Land-Atmosphere Coupling Experiment (GLACE-2) project that will examine, with a wide variety of models, the degree to which subseasonal precipitation and air temperature forecasts improve through more accurate initialization of soil moisture and other land surface state variables. The design is built around a comprehensive suite of 60-day forecasts that are evaluated against observed precipitation and air temperature fields.

The Tropical Atlantic Climate Experiment (TACE), running from 2006 to 2010, is designed to improve coverage of surface and subsurface data and facilitate dedicated process studies in the eastern tropical Atlantic through extension of the Prediction and Research Moored Array in the Atlantic (PIRATA), French cruises (EGEE), United States and German programmes, extended Argo coverage and a meteorological station at Sao Tome. Working with WGSIP, the CLIVAR Working Group on Ocean Model Development (WGOMD) and the African Multidisciplinary Monsoon Analysis (AMMA), TACE is providing data in the tropical Atlantic that will be used for model-data intercomparisons and model validation and improvement. TACE ocean data will be available to the community through various data centres (http://www.clivar.org/organization/atlantic/TACE/).

The goal of South Pacific Ocean Circulation and Climate Experiment (SPICE) is to observe, model and understand the role of the Southwest Pacific ocean circulation in: (a) the large-scale, low- frequency modulation of climate from the Tasman Sea to the equator, and (b) the generation of local climate signatures whose diagnosis will aid regional sustainable development. The major fieldwork associated with SPICE is expected to take place between 2008 and 2011 with continued monitoring afterwards. A legacy archive will be developed (see http://www.clivar.org/organization/pacific/pacific_SPICE.php).

Currently underway, the VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS) includes the VOCALS Regional Experiment (VOCALS Rex) to better understand physical and chemical processes central to the climate system of the Southeast Pacific region, including the climatic importance of aerosol-cloud interactions, as well as atmosphere, ocean, and land feedbacks that affect the stratocumulus clouds that are not well simulated in coupled climate models. For data archiving see http://www.eol.ucar.edu/projects/vocals/.

SPARC and CliC will explore predictability in the climate system that is associated with the 1) relatively long timescales of stratospheric variations, 2) impact of specific stratospheric phenomena such as sudden warming and cooling on the troposphere, and 3) known influence of the cryospheric anomalies on the atmospheric circulation. This activity will result in specification of more comprehensive initial conditions for climate models used in seasonal prediction, which will be based on observations in the stratosphere and of cryospheric variables. The focus of this initiative will be on polar regions, and its main idea is to attempt to detect predictability in the climate system that originates from mechanisms other than El Nino and the tropical teleconnections.

Modelling

The Climate System Historical Forecast Project (CHFP), led by CLIVAR, will carry out a series of modelling experiments designed to explore the limits of seasonal (and decadal) predictability by including all relevant components of the climate system, including extension to the decadal timescale. This project represents a major scientific research cross-cut throughout WCRP, requiring interactions among SPARC, CliC, GEWEX and CLIVAR. As it also includes a sub-seasonal focus there will be collaboration with the WMO World Weather Research Programme (WWRP). Further information on CHFP can be found at http://www.clivar.org/organization/wgsip/chfp/chfp.php.

GEWEX will develop better assessments of seasonal water and energy cycle variability through improved observational datasets and analysis and parameterization of hydrometeorological processes and feedbacks in atmospheric circulation models. Modelling experiments will be carried out to determine the geographical and seasonal characteristics of the predictability of key water and energy cycle variables over land areas.

CliC project will explore poorly understood cryospheric processes and parameters, such as the role of sea ice and snow cover, that contribute significantly to improve climate predictability for seasons to decades and longer. This work will focus on identifying and explaining potentially significant teleconnections, such as the influence of Tibetan snow cover on the Asian monsoon and a possible influence of late winter East Asian snow cover on North American spring conditions. CliC will continue to work on quality control and assessment of data available for the initialization of sea-ice and snow conditions in seasonal and longer-range forecasts.

Improved representation of sea-ice processes in climate models is necessary for better simulation of both the mean state and interannual-to-decadal variability of sea ice, and enhanced prediction of future climate variability and change. CliC will work with modelling communities to examine the inability of models to reproduce adequately the observed loss of summer sea ice over the Arctic Ocean. CliC will coordinate experiments to identify all possible feedback mechanisms related to the marine cryosphere and their interactions with the oceans and atmosphere. There is also a need for improved models of the atmosphere and oceans in regions affected by sea ice. Better numerical modelling of the three-dimensional ocean circulation and thermohaline circulation in sub-ice shelf cavities is essential to improve our knowledge of the exchange of mass and heat at the base of ice shelves, which are expected to respond sensitively to changes in ocean temperature. Such models must ultimately be coupled to sea-ice models in order to adequately simulate the seasonal variations of temperature and salinity in the adjoining ocean. Experiments involving the comparison of the various available ice-shelf-cavity models are also a priority. Modelling of the ice-shelf dynamics should proceed in parallel with the modelling of ice-shelf cavities. Ultimately, coupled ice-shelf/cavity models will be refined to simulate the changes of shelf geometry and ice flux resulting from changes in basal melting and freezing induced, in turn, by changes in ocean and atmospheric properties.

Predictability of the general circulation in the polar regions is a challenge. Studies have shown that SST-related predictability of the southern hemisphere winter lower-atmospheric circulation in Antarctica is reasonably high. Key questions are how the low-frequency forcing agents like sea ice, sea-surface temperature, snow cover, stratospheric conditions and oceanic heat anomalies affect the predictability of polar climate on seasonal to longer timescales. CliC will work with regional and national efforts, such as the Arctic System Model (ASM) intiative and others, to improve model-based predications of various timescales over the cold regions. CliC will assist in coordinating regional projects in the context of an international framework.

The SPARC project, through its DynVar activity, will attempt to improve representation of stratosphere processes in seasonal prediction models that would reduce systematic errors, such as under-prediction of the stratospheric jet, that may be associated with inadequate resolution and modelling of stratospheric circulation anomalies and their downward influence. The ability of models to simulate downward propagation of circulation anomalies from the stratosphere into the troposphere on timescales of several weeks will open a possibility to exploit potential predictability associated with timescales and memory in the stratosphere that are typically longer than those in the troposphere. Together, these activities will also contribute to the development of coupled climate system models.

Monsoons and Climate

Monsoons are a central component of the global climate system, large enough to influence it yet small enough to have distinct regional characteristics and be responsive to the global circulation. Monsoonal circulations dominate Southeast Asia and are also significant in Africa and the Americas. WCRP will continue to carry out major regional activities aimed at improving our understanding of, and ability to predict, monsoon phenomena. CLIVAR and GEWEX have the lead in organizing the WCRP monsoon activity. CliC will contribute to this effort by facilitating research to understand the contribution of snow cover to monsoon phenomena over the Asian regions, including the northern regions in eastern Siberia.

A major focus for the coming years for the Asian monsoon region will be implementation of the Asian Monsoon Years (AMY - 2007-2012) projects with contributions from many national and multinational programmes, notable amongst them the Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHASRI). AMY will study both the weather and climate aspects of the monsoon and hence will also involve the WMO World Weather Research Programme (WWRP). The long-term goal of AMY is "to improve Asian monsoon prediction for societal benefits through coordinated efforts to develop our understanding of Asian monsoon variability and predictability". It seeks to integrate about two dozen regional projects over the Asian-Australian Monsoon region together with existing WCRP activities under CLIVAR and GEWEX, and to provide links to a number of other programmes including MAIRS, the Monsoon Asia Integrated Regional Study under the global change SysTem for Analysis, Research and Training (START) and the ESSP.

Key Activities

Analyses of data collected from the GEWEX Regional Hydroclimate Projects will advance understanding of monsoons in many regions of the world, including the West African Monsoon region (AMMA) and the La Plata Basin in South America (La Plata Basin Regional Hydroclimate Project (LPB)).

The VOCALS (VAMOS Ocean-Cloud Atmosphere-Land Study) will improve understanding of indirect aerosol effects over the South-eastern Pacific Ocean and improve model simulations and predictions of the coupled climate in the regions, with a focus on diurnal to inter-annual timescales.

The Intra American Study of Climate Processes (IASCLIP) will bridge the gaps between climate research for North America under the VAMOS North American Monsoon Experiment (NAME), South America (under the VAMOS Monsoon Experiment South America/LPB), the Pacific (VOCALS) and Atlantic. IASCLIP will investigate the role of the intra-American seas in the climate variability of the Americas, and will act as a scientific connection among all the American monsoon investigations already established.

The WCRP/THORPEX Year of Tropical Convection (YOTC) will play a key role in development of the emerging WCRP/WWRP project on "Reproduction and Prediction of Monsoon Intraseasonal Oscillation". Investigations of the Madden-Julian Oscillation and its role in monsoon dynamics will be carried out as part of the YOTC.

GEWEX will expand analyses of the long-term global data sets compiled under the GEWEX Radiation Panel to describe the role of clouds, radiation and precipitation in the monsoon systems. These analyses will be coupled with surface-flux data sets now being developed under the SEAFLUX and LANDFLUX efforts. These datasets will provide the opportunity to study regional monsoon circulations and compare them across the globe.

The mountain cryosphere is known to modulate the Asian monsoon and vice versa. It is possible to anticipate similar dependencies in other monsoon regions such as South America. CliC's contribution to the WCRP monsoon research will therefore be channelled through its regional activities such as Asia CliC and a similar initiative in South America. The focus will be on Asian regional snow cover measurements, dataset generation and modelling, and the relationship between snow and precipitation and the monsoons. These efforts will contribute to the Asian monsoon studies, VAMOS and the CEOP High Elevations activity.

ACTIVITIES IN SUPPORT OF WCRP INTEGRATING THEMES

WCRP carries out many activities that support research efforts across the whole spectrum of the Programme and which serve as integrating themes. These include acquiring observations and undertaking their analysis and interpretation, developing coupled models and Earth system models for projections and prediction, and synthesizing and assessing the collective knowledge for decision-makers. Education and capacity building are keys to the success of the entire effort because without intellectual leadership and scientific and technical knowledge these efforts cannot succeed.

Climate-Quality Data Sets and Analyses

Our ability to analyse climate variability from limited climate data sets which are spread in space and time depends fundamentally on our ability to bring all available data into a state of self-consistency. The core of this effort is the detailed comparison among overlapping time series, but increasingly it is also being achieved through assimilation of data in models. WCRP scientists will work with the Global Climate Observing System (GCOS) to help evaluate observations and promote their reprocessing and reanalysis into global fields as a key activity in dataset development. WCRP will help enable development of new products, often high-level value-added derived products, for use in understanding and analysing climate variability and change, and for evaluating models. Emphasis will be placed on product evaluation, including determining and resolving key uncertainties in the data sets, and on sustained dialogues with the worldwide user community to refine requirements for these products.

The WCRP Observations and Analysis Panel (WOAP) will continue to advocate for atmosphere, ocean and coupled reanalyses. Plans are for atmospheric reanalyses to be carried out at several major modelling centres. CLIVAR will continue to assess and facilitate ocean synthesis activities with the perspective of reducing model systematic errors and developing assimilation techniques for climate models. Collaboration with the GODAE Oceanview project is planned to test ocean analysis and assimilation systems in an operational context, and to provide feedback on the performance of assimilation methods. CLIVAR will join WOAP and other components of WCRP to develop coupled assimilation approaches.

WCRP will continue to advocate improved observations and analyses suitable for climate (satisfying the climate principles that are designed to ensure continuity and quality of records), working closely with GCOS, the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS). To ensure climate-quality data for research purposes, WCRP scientists will be involved in defining the scientific requirements for instrument development as well as design of the observing networks, and the evaluation of the algorithms for transferring instrument measurements to climate parameters. Development and validation of satellite retrievals of climate variables will continue to be done in the context of the creation of global data sets that merge in situ and satellite observations. The global products produced by GEWEX for radiation, precipitation, clouds and land-surface fluxes will be further refined, updated and assessed for use in developing and evaluating global climate models, studying climate trends, performing attribution studies and enhancing our understanding of climate process. GEWEX will strengthen its activities in the area of data integration and the use of integrated data sets in scientific investigations. New products will be generated; for example, aerosols products will be developed as part of a joint activity with IGBP. SPARC will continue to develop and assess data sets for stratospheric ozone, temperature, and water vapour, and initiate new activities in the assessment of data sets of other species.

CLIVAR, GEWEX and CliC will all be engaged in the assembly and analysis of regional data sets. CLIVAR will facilitate and coordinate ocean measurements, including monitoring of the meridional overturning circulation and tropical Atlantic variability, implementation of the Indian and Southern Ocean Observing Systems (with GOOS and SCAR respectively), studies of western boundary currents, including the Kuroshio and the Gulf Stream, and autonomous measurements of the deep ocean basins (deep Argo). CLIVAR, with the International Ocean Carbon Coordination Project (IOCCP), IGBP IMBER and SOLAS, will develop a strategy for future ocean hydrography, carbon and biogeochemistry measurements based on the Global Ocean Shipbased Hydrographic Investigation Panel (GO_SHIP) activity and the outcomes of the OceanObs09 Conference. Projects such as those organized under the auspices of the CLIVAR/VAMOS will collect atmospheric, land-based and oceanographic data sets from field experiments. GEWEX will continue to build regional data sets of hydrometeorological parameters at each of its Regional Hydroclimate Project sites. These data are being combined with that from CEOP reference sites around the globe in a major integrated data archive that will serve as an important resource for climate research. CliC will work towards 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. The focus will be on improved long-term ice-sheet, ice-cap, and glacier monitoring systems (including more measurements in data-sparse, thick-ice areas, and also relevant atmospheric parameters), together with an inventory and related databases for assessing the mass balance of ice sheets and associated uncertainties. Other important data sets include river and lake ice over the northern regions, and snowfall and snow cover data from in situ and remote sensing observations. GEWEX and CliC together will evaluate and improve the accuracy of measurement and model prediction of solid precipitation in high latitudes and high elevations, both for model validation and calibration of satellite precipitation data and products. All WCRP projects will be engaged in the ongoing analysis of International Polar Year (IPY) data.

The volume of model output data has increased dramatically in recent years. In order to derive maximum benefits from these modelling efforts, WCRP projects and working groups are developing strategies to collect, archive, integrate and analyse this important data resource, for instance, through the CEOP Data Integration and Analysis System (DIAS) which will also serve as part of a distributed data-sharing network for the CMIP5 data. PCMDI will manage this network and it is expected that these model output data will be made available widely for a wide range of climate studies, as has been the case in the past. The Climate System Historical Forecast Project (see p. 32) is developing a distributed archive with nodes already identified in at the University of Buenos Aires and the Asian Pacific Climate Centre in South Korea. Archive sites for regional climate products generated under the CORDEX project (see p. 30) are currently being organized. The British Atmosphere Data Centre (BADC) archives that include outputs from CCMVal runs are being significantly enhanced through Phase 2 of the CCMVal activity.

WCRP will continue to place high priority on the archiving, availability, and synthesis of data sets as a key legacy from its projects. Availability of well-documented observational archives is important for assessing climate change and for serving as input to model simulations and experiments. WCRP will increasingly emphasize the importance of identifying and removing observational biases. Lastly, it will be important to develop capabilities to integrate Earth system observations to properly assess, model, and predict the global coupled climate system.

A New Generation of Climate System Models

Predicting the evolution of the climate system on timescales of seasons to decades and longer is vital today to inform the decisions that our society must take to adapt to natural climate variations or anthropogenic climate change. Climate models are the tools through which such predictions can be made. However, currently the skill of seasonal forecasts and the ability of modellers to deliver comprehensive and reliable information about regional climate change are substantially limited due to model uncertainties in the representation of atmospheric, oceanic, land-surface and cryospheric processes. Consequently, improving climate forecasts and projections requires better representations of the fundamental physical and dynamical processes that control the variability of the atmosphere, ocean, land-surface and cryosphere and their sensitivity to external perturbations. The development of Earth System Models makes this improvement even more imperative, as the interactions between biogeochemical processes (e.g. carbon, aerosols, and chemistry) and climate fundamentally depend on the representation of these processes (e.g., precipitation, snow cover, temperature, soil moisture and vegetation). The need for more integrated (and hence self-consistent) models is becoming increasingly apparent. For example, the adverse consequences for future climate predictions of not including interactive stratospheric ozone in climate models have been demonstrated by the SPARC CCMVal activity, and the WCRP-IGBP AC&C initiative is developing the methodology for an evolution towards atmospheric models with a full representation of the stratosphere and interactive (rather than off-line) chemistry.

Studies to improve understanding of key climate process with the aim of improving their representation in climate models will be carried out under all WCRP projects. For instance, the SPARC DynVar activity will aim to improve the ability of GCMs to reproduce the Quasi-Biennial Oscillation (QBO) and other modes of natural variability in the stratosphere. The WGCM CFMIP activity will evaluate the ability of climate models to simulate the distribution and the properties of clouds that are observed from the new generation of satellite observations, and will assess the physical processes that control cloud-climate feedbacks in current and future climates. GEWEX, in partnership with iLEAPS and IGAC, will study the lifecycle of aerosols and their interaction with the water and energy cycle in order to improve climate model parameterizations. The joint WCRP/WWRP-THORPEX Year of Tropical Convection initiative will seek to improve the representation of tropical convection in global atmospheric models in support of both numerical weather forecasting and global climate predictions. WCRP together with the WMO World Weather Research Programme (WWRP) will sponsor a task force to study the Madden-Julian Oscillation (MJO). This group will focus on model simulation, forecast improvements, and assessments of MJO predictability and forecast skill.

WCRP modelling groups will develop climate model metrics and evaluation methodologies that address model uncertainties and parameterization deficiencies. A WCRP community-wide consultation on model evaluation and improvement has recently been organized by WGCM, WGNE, WGSIP, WGOMD and JSC to help identify key deficiencies of climate and NWP models and requirements for enhanced coordination among modelling, observations, and process studies that must be addressed to accelerate the model improvement process. The results of this community survey will provide input into the strategic planning for model improvement activities that will be coordinated through the various working groups, projects and panels of WCRP.

WCRP will have as a major aim to facilitate the engagement between the process research community and the modelling centres with the intent of promoting model development and increasing the number of scientists engaged in model development. The Climate Process and modelling Teams (CPTs) sponsored by the United States are designed with this aim in mind - to improve the fidelity of global coupled climate models by bringing together theoreticians, observations experts, process modellers and modelling centers to facilitate the transfer of new understanding gained through field experiments, observations, and process modelling into climate models. Following a highly successful pilot CPT program, the United States intends to fund new CPTs beginning in 2010. Future WCRP activities will be firmly focused on applying model development techniques to alleviate major model shortcomings. Joint research activities, such as the one between the GEWEX Global Cloud System Study (GCSS) and WGCM in the area of cloud feedbacks in climate, will become the future paradigm of WCRP's model development and improvement activities.

Model intercomparisons will continue to be an important means to identify model deficiencies. Intercomparisons of global and regional climate models will be carried out under the auspices of the WGCM. In addition to intercomparisons focused on the current and future climate, this also includes an assessment of the ability of climate models to simulate past climate changes such as the last glacial maximum, the mid-Holocene or the last millennium (WGCM/PMIP). As part of the effort to improve the representation of the oceans in global climate models, the Working Group on Ocean Model Development (WGOMD) will carry out Coordinated Ocean-ice Reference Experiments (COREs) using a community-wide protocol for simulations of the ocean-ice system over the observational period starting in 1958.

Recognizing that the traditional boundaries between weather and climate are somewhat artificial, WCRP together with the WMO World Weather Research Programme, will work to develop an organized and coordinated effort to implement a framework for seamless prediction of weather and climate variability. This framework requires that the decadal and multi-decadal predictions using IPCC-class models should move towards consideration of climate change as an initial value problem. Some errors commonly seen in long term climate simulations may also be revealed after relatively short model integrations (a few days to a season) when models are run in a prediction mode. The Working Group on Numerical Experimentation (WGNE) and WGCM will thus encourage the evaluation of climate models in a prediction mode, to facilitate the testing of hypotheses about the origin of these errors (e.g. the representation of fast atmospheric processes associated with clouds and convection) and of likely remedies. This will ultimately require that the state of the ocean-land-atmosphere-cryosphere system be correctly initialized using observations.

Next Generation of Climate Experts: Building Capacity Regionally and Globally

One of WCRP's major objectives is to entrain as many climate scientists and practitioners into its activities as possible, and to foster their vocational training as well as their policy outreach. WCRP is pursuing this objective with its partners through a multi-pronged approach that includes providing opportunities for early career scientists and scientists in the developing world to attend training seminars and participate in WCRP-sponsored meetings, workshops and conferences. Summer schools and workshops will provide opportunities for young scientists to develop an Earth system science approach to climate research. Other activities will be targeted at helping climate practitioners to be able to better analyse and interpret climate information products for adaptation planning and risk management, and developing a dialogue with decision-makers, politicians and the development community to find common language and understanding of the latest climate research findings.

Specific activities will include joint training seminars with partners such as the International Centre for Theoretical Physics (ICTP of Italian Government, UNESCO, and the International Atomic Energy Agency), and START, topical workshops, summer schools and expert training (including "train the trainer" exercises). An excellent example is the two-week regional training course, organized under the auspices of the WCRP Climate System Historical Forecast Project (CHFP), on seasonal prediction and its applications that will be held at the University of Buenos Aires in July 2010.

WCRP will also seek to make its research results useful and easily accessible to the broad scientific community and to end-users such as adaptation planners, policy-makers and decision-makers in climate-sensitive sectors such as agriculture, energy and transportation. A few targeted workshops to bring together climate scientists and sector-specific user communities will provide the opportunity for communication, with a focus on developing a common understanding of uncertainty in climate projections/predictions. Workshops organized as part of a Horn of Africa project funded by the World Bank will be a first such opportunity; user interaction will be greatly facilitated by co-locating these workshops with the Regional Climate Outlook Fora organized by WMO and other organizations.

WCRP will organize the scientific research necessary to improved operational products delivered by national meteorological, hydrological and oceanographic services and as part of the Global Framework for Climate Services. Most, if not all, of the activities described earlier in this document will contribute to improved climate service delivery. In the coming years, special emphasis will be put on the transfer of products and techniques from research to operations. For instance, the joint CLIVAR/GEWEX La Plata Basin project includes as a major objective the transfer of its outcomes to operations in support to water resources management and agricultural practices. Similar efforts will be developed in form of forecast demonstration projects in response to the recommendations by the WMO Executive Council commissioned Research Task Team.

CONCLUDING REMARKS

Climate science has advanced significantly during the past three decades, yet many new scientific challenges lie ahead. The essential need is to make quantitative climate predictions on timescales from seasonal to multi-decadal, and to provide the resulting climate information and services in a useful and timely manner to decision-makers.

The societal need for authoritative information on climate variability and change demands increased research and development efforts. These include:

- advanced modelling at high spatial resolution to capture the regional aspects of climate variations/changes and for realistic representations of crucial climate processes (e.g., ice-sheet dynamics, cloud-climate feedbacks, regional-scale climate modelling, bio-geochemical-atmosphere interactions);

- capacity for gathering, processing, and sharing observational data for model evaluation and initialization;

- development of hardware and software capabilities for analysing and interpreting the model and observational results;

- the quantification of uncertainties in a probabilistic manner including recognition of the high-impact end of the distributions;

- streamlined transition to an operational mode including the generation of climate products and services;

- facilitation of feedback from the user community and providing inputs into the research priorities; and

- resources and skills to synthesize the information and meet user needs for decision-making at the global, regional and local levels.

While climate research over the past three decades has focused on the fundamental scientific aspects, a key element to underpin climate services will be the generation of a robust applied research programme that complements the ongoing climate research framework with the aim to facilitate the transition of mature capabilities from research to services in a timely manner.

The WMO-IOC-ICSU sponsored World Climate Research Programme (WCRP) is universally accepted as the primary international framework for cooperation in climate research and climate prediction and greenhouse-emission-scenario-based climate projection. It is complemented by the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP) and DIVERSITAS with the four programs collaborating under the framework of the Earth System Science Partnership (ESSP) in exploring issues such as climate vulnerability and impacts on physical, biological, ecological and social systems.

The WCRP and its partner research programmes are working towards a well-developed and coordinated research strategy for addressing the needs of the UNFCCC and the range of national and international needs for climate research and modelling more generally. For example, improved model development is essential for addressing both the adaptation and mitigation aspects of the UNFCCC agenda. In particular, a major emphasis in the WCRP's Strategic Framework for 2005-2015 is climate research for use in an increasing range of practical applications of direct relevance, benefit and value to society. A recent international cooperation between the WCRP and the WMO World Weather Research Programme (WWRP) that is aimed at achieving accelerated progress towards seamless weather and climate prediction has been established to underpin weather and climate services more generally.

For advancements in climate science to meet the expectations of society, significant enhancements in high performance computing are crucial. There is an equally pressing need for integrated space-based and in situ observational systems that accurately capture key climate variables, spanning from regional to the global scales, and are sustained over decades for a robust determination of climate trends and variations. Synthesis of modelling and observational results to provide accurate regional/global climate information, development of climate analyses, and use of model-based uncertainties to plan better observing system strategies, constitute important scientific underpinnings of any new climate information system and services. Accomplishing these tasks also requires the continuous infusion of highly-skilled scientific talent via training and capacity building, especially for young scientists and in the developing regions of the world.

The main requirements for the WCRP to be able to play its part, with its partner research programmes, are increased support for observations, greatly enhanced computing and modelling facilities, and improved mechanisms for the transfer of scientific progress into operational prediction systems. In summary, the WCRP, following its recent comprehensive international expert review, is well placed to play its role in enabling a global climate

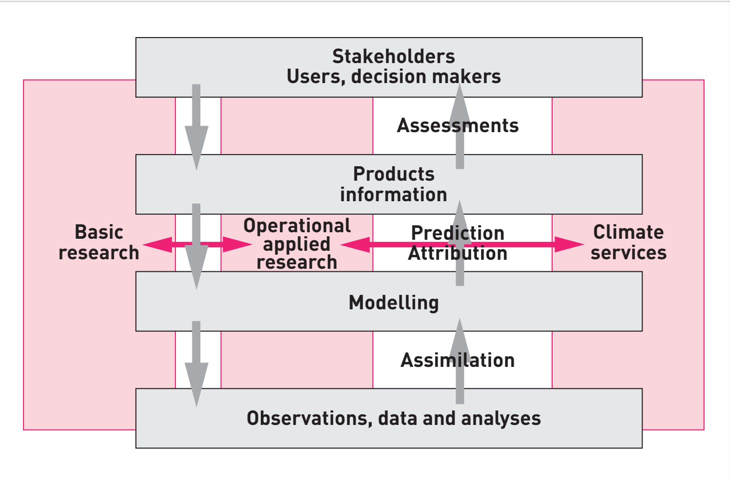


FIGURE BY KEVIN TRENBERTH, SLIGHTLY MODIFIED BY GHASSEM ASRAR

Figure 6. *Conceptual framework of a climate information system in which basic research feeds into applied and operational research that, in turn, contributes to the development of climate services. A main feature of such a system is the two-way interactions between and among the components of the system to enhance the transfer of information and knowledge throughout the system in an effective and efficient manner.*

information system for decision-makers dealing with adaptation, mitigation and risk management associated with climate variability and change. As demonstrated by past successes, WCRP can and will bring together the strengthened observational and monitoring datasets and research and modelling tools to advance the understanding and improve predictions of climate from seasonal-interannual to decadal and centennial timescales. The scope of activities will include spatial scales from the global to the regional, thus ensuring a sound, science-based and credible climate service for all the regions and nations of the world. The WCRP enterprise believes that this is the best legacy we can offer to our generation and those who will follow us.

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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