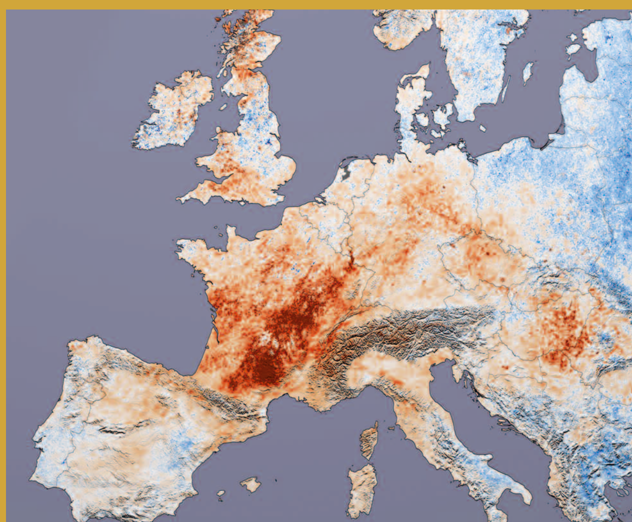
WCRP

WORLD CLIMATE RESEARCH PROGRAMME

The World Climate Research Programme Strategic Framework 2005-2015

Coordinated Observation and Prediction of the Earth System (COPES)



AUGUST 2005
WCRP-123
WMO/TD-No. 1291

WMO

IOC of UNESCO

ICSU International Council for Science

NOTE

WMO - ICSU - IOC

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The World Climate Research Programme (WCRP), sponsored by the World Meteorological Organization, the International Council for Science, and the Intergovernmental Oceanographic Commission of UNESCO, was established as a principal component of the World Climate Programme in 1980 with two major objectives: *to determine the extent to which climate can be predicted, and to determine the extent of human influence on climate*. The WCRP has made major advances in understanding specific components (ocean, land, atmosphere, cryosphere) of the climate system, and created many new opportunities and challenges for future climate research and its application for the benefit of society.

Progress in understanding the variability and predictability of individual components of the climate system makes it possible to address the predictability of the total climate system, one of the original objectives of WCRP, and to apply the results for the benefit of society. In particular, it is now possible for WCRP to address the seamless prediction of the climate system from weekly weather to seasonal, interannual, decadal and centennial climate variations and anthropogenic climate change. Advances in understanding and in new technology for observations and computing also make it possible to address the broader questions of Earth system modelling and the use of comprehensive Earth system models for investigating the habitability of our planet, and contributing to the socio-economic welfare and the sustainability of modern societies.

WCRP is pursuing a new strategic framework, Coordinated Observation and Prediction of the Earth System (COPES), to capitalize on past progress and on the ongoing activities of its projects. The aim under COPES is *to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society*. It will provide the unifying context and agenda for the wide range of climate science coordinated by and performed through WCRP projects and activities, and for demonstrating their relevance to society.

The new strategic framework, COPES, will help promote the creation of a comprehensive, reliable, end-to-end global climate observing system for the dual purpose of describing the structure and variability of the climate system, and of generating a physically consistent description of the state of the coupled climate system for numerical prediction of climate. COPES will require the identification of gaps and deficiencies in the existing observing systems, and will encourage and facilitate repeated reanalysis of *in situ* and space-based observations as synthesis tools improve.

Through its new strategic framework, and building on its existing projects and activities, WCRP will provide the soundest possible scientific basis for the predictive capability of the total climate system for the benefit of society, including an assessment of the inherent uncertainty in probabilistic prediction of climate on various space and time scales. A new generation of improved models will be necessary to enable better and more detailed prediction of the climate system.

WCRP will implement its new COPES strategic framework through its projects, working groups and other activities. Strong collaboration will be sought with other research programmes, and with development and applications programmes (especially the other principal components of the World Climate Programme), satellite agencies, numerical weather/climate prediction centres, and with a broad range of stakeholders and users of climate information, predictions and services. WCRP will continue to promote and depend on full international collaboration, coordination and commitment to ensure the successful definition, development and implementation of its activities. In particular, an increased involvement of scientists from developing countries will be actively sought and strongly encouraged. WCRP will cooperate with and strive to underpin the assessments of the Intergovernmental Panel on Climate Change and contribute to the development of the Global Climate Observing System and the Global Earth Observation System of Systems.

1. INTRODUCTION

The World Climate Research Programme (WCRP) is introducing a new strategic framework for its activities in the decade 2005-2015. This is in response both to the new scientific challenges posed by the understanding and prediction of the behaviour of the Earth system and to new opportunities for WCRP science to provide the basis for major applications for society. This strategic framework,

Coordinated Observation and Prediction of the Earth System (COPES)

has as its aim:

To facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

COPES is possible because of the previous 25 years of WCRP progress since its establishment as a principal component of the World Climate Programme (WCP; see **Appendix A**) in 1980, under the joint sponsorship of the World Meteorological Organization (WMO) and the International Council for Science (ICSU). Since 1993 WCRP has also been sponsored by the Intergovernmental Oceanographic Commission (IOC) of UNESCO. A WMO/ICSU/IOC Joint Scientific Committee (JSC) is responsible for formulating the overall scientific concepts and goals of the WCRP and for organizing the required international co-ordination of research efforts. Within the COPES strategic framework there will need to be continuing discussion of detailed strategy, including themes, specific objectives and priorities, in the JSC and throughout the WCRP projects.

Since its inception, the two major objectives of the WCRP have been

- **to determine the predictability of climate**
- **to determine the effect of human activities on climate**

To achieve these objectives, the WCRP promotes and coordinates essential research into understanding the behaviour of the various components of the climate system and their interactions, and their relations to the broader Earth system and the needs of society (see **Box I**).

The objectives and research aims of WCRP were reaffirmed at the Conference on the WCRP: Achievements, Benefits and Challenges, Geneva, August 1997 (WMO/TD-No.904, June 1998), with the immediate research priorities:

Box I. Particular foci of the WCRP include:

- to measure changes in the atmosphere, oceans, land and cryosphere;
- to improve our knowledge and understanding of global and regional climate variability and change, and of the mechanisms responsible;
- to assess the evidence of significant trends in global and regional climates;
- to develop and improve numerical models capable of simulating and assessing the predictability of the climate system over a wide range of space and time scales and suitable for operational predictions;
- to investigate the sensitivity of the climate system to natural and human-induced forcings and to estimate the changes resulting from specific disturbing influences.

- to assess the nature and predictability of seasonal to interdecadal variations of the climate system at global and regional scales, in order to provide the scientific basis for operational predictions of these variations for use in climate services in support of sustainable development;
- to detect climate change and attribute causes, and project the magnitude and rate of human-induced climate change, its regional variations and related sea-level rise, as needed for input to the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), and other such Conventions.

WCRP has a broad-based scientific programme offering a wide scope for investigation of important physical, and physically related aspects of climate, its variability and change. This programme is executed through its projects, working groups and activities that focus on particular aspects of the climate system or its study. The projects, working groups and other activities of WCRP (**Box 2**) are described, with some recent highlights in each area, in **Appendix B**. During the 25 years of WCRP's existence, its activities have produced many achievements consistent with its aims, especially by advocating and coordinating research programmes among nations (**Appendix C**). A summary of the development of the new COPES strategic framework for WCRP is given in **Appendix D**.

Box 2. The Projects and Working Groups of WCRP

The current core projects of WCRP are:

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

WCRP co-sponsors the IGBP core project, Surface Ocean-Lower Atmosphere Study (SOLAS).

In addition WCRP has three working groups:

- Working Group on Numerical Experimentation (WGNE, joint with the WMO Commission for Atmospheric Sciences)
- Working Group on Coupled Modelling (WGCM, also with a CLIVAR role)
- Working Group on Surface Fluxes (WGSF)

WCRP co-sponsors with GCOS, the Atmospheric Observation Panel for Climate (AOPC)

WCRP co-sponsors with GCOS and GOOS, the Ocean Observations Panel for Climate (OOPC)

WCRP also sponsors a number of joint activities as a member of the Earth System Science Partnership (ESSP); see **Box 4.**

2. THE STRATEGIC FRAMEWORK

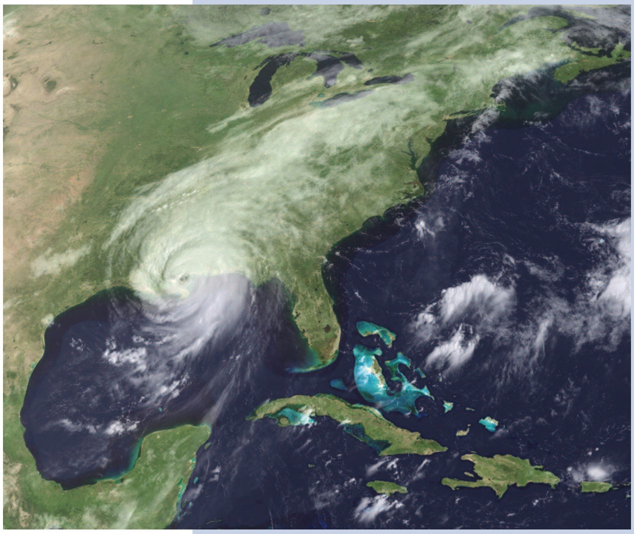
2.1 Societal needs and benefits

The potential socio-economic benefits of quantitative predictions of the climate/Earth system (see **Box 3**), allied to realistic measures of uncertainty, are huge. The time-scales for the predictions range from weeks to decades and to projections of climate change over decades to centuries. The ability to quantify with confidence and reliability the likelihood of extreme weather and climate events on all time-scales is vital to society. WCRP, through its projects and working groups, is seeking to ensure that the predictions have application in the protection and management of the environment around us, including water resources and agriculture, in disaster reduction and in the promotion of human health and well-being. The climate-change projections provide the basis for adaptation to climate change and for deciding the mitigation efforts that should be pursued in international negotiations. A fuller discussion of WCRP's role in relation to climate information and predictions and related services and applications is given in **section 3**.

Developing countries are in particular need of the best quantitative information, as is recognised by the new WMO Natural Disaster Prevention and Mitigation Programme.

Box 3. Prediction of the climate/Earth system

Following the pioneering work in weather forecasting, significant progress has been made in quantitative predictions of the climate system that are dependent on the initial conditions. As in all science, an estimate of uncertainty makes the prediction much more useful and this is increasingly obtained by performing an ensemble of predictions with slightly different initial conditions or model parameters. The quantities predicted include the means, trends and statistical characteristics of a large number of quantities that may be of practical use such as surface temperature, wind, precipitation, atmospheric chemical state, ocean state, soil moisture, snow cover, sea ice, and El Niño-Southern Oscillation. The time-scales for the predictions range from weeks to decades and to projections of climate change over decades to centuries. Beyond the time-scale of weather forecasts, the ability to predict depends on the behaviour of the slower parts of the climate system and the forcings. For a decade or longer it also depends on human behaviour and the consequent emissions to the atmosphere and changes to the land surface. Scenarios for these anthropogenic effects lead to predictions that are usually referred to as projections, recognising their dependence on the postulated scenarios.



Hurricane Katrina 2005. WCRP research will help to determine if hurricanes and other extreme weather events will become more frequent or intense in the future. [Earth Obervatory/NASA]

2.2 Scientific challenges and opportunities

The recent advances that have been achieved in research and in observational and computational technology have increased the scope for delivering associated benefits to society. This, coupled with the ever-increasing demand for reliable climate predictions and related products and services to safeguard life and property and to better manage climate-sensitive systems and sectors, provides exciting, new challenges and opportunities for WCRP scientific research in the next decade. In particular, such considerations give the impetus and the necessity for the new WCRP COPES strategic framework.

The seamless prediction problem. There is now a new perspective of a continuum of prediction problems, with a blurring of the distinction between shorter-term predictions and longer-term climate projections. Increasingly, decadal and century-long climate projection will become an initial-value problem requiring knowledge of the current observed state of the atmosphere, the oceans, cryosphere, and land surface (including soil moisture, vegetation, etc.) in order to produce the best climate projections as well as state-of-the-art decadal and interannual predictions. However, the climate projections also depend on scenarios for anthropogenic influence on the climate system and some factors, such as changes in the sun and volcanic eruptions, are not predictable but can be immediately taken into account if observed. The shorter time-scales and weather are known to be important in influencing the longer-time-scale behaviour. In addition, the regional impacts of longer-time-scale changes will be felt by society mainly through the resulting changes in the character of the shorter time-scales, including extreme events. In recognition of this, climate models are being run with the highest possible resolutions, resolutions that were employed in the best weather forecast models only a few years ago. There is also increasing emphasis on traceability, the ability to relate the structure, parametrizations and performance of models used on different time-scales. Even though the prediction problem itself is seamless, the best practical approach to it may be described as unified: models aimed at different time-scales and phenomena may have large commonality but place emphasis on different aspects of the system.

Prediction of the broader climate/Earth system. The detailed physical prediction models of the coupled atmosphere, ocean and land system developed and used within WCRP are increasingly being extended to include atmospheric chemistry, the carbon cycle including evolving vegetation, and interactive marine ecosystems. It can be expected that full coupling with additional components of the Earth system will sometimes lead to quite different behaviour, as has been found for coupled ocean-atmosphere models.

Predictability of the climate/Earth system. An important underpinning of the progress in weather forecasting has been the development of chaos theory and the notions of predictability. An essential aspect of the move to making predictions of the broader climate/Earth system is to further develop these ideas to provide a firm foundation, giving ideas on what predictions to attempt and what techniques to use. The possibility that the increasing breadth of models may lead to compounding the uncertainties in them, and therefore increasing the uncertainty in model predictions, provides a challenge that will require new theoretical and observational approaches.

Analysis of climate system behaviour. There is a continuing and urgent need to analyse the behaviour of the climate system, assess what has occurred, define anomalies and trends in the climate system, and determine the extent to which these can be attributed to human activity or to natural variation.

Application of WCRP science to socio-economic problems and demonstration of the usefulness of WCRP-enabled analysis and predictions. There is increasing use of weather and climate information and prediction services and products on the time-scale of weeks to seasons, but much more work is needed to improve these products. For longer time-scales, the IPCC requires the best possible climate science and climate projections to provide the scientific basis for its periodic assessments and hence its advice to the Parties to the UNFCCC. Most impacts of climate change depend on its regional manifestation and there is great political and social demand for more confidence in such products.

Coordination and implementation of new activities to demonstrate and exploit:

Data from CryoSat, scheduled for launch in late 2005, will be used to determine variations in the thickness of continental ice sheets and sea-ice cover. [ESA]

- **new and increasing data streams**. Enormous quantities of data will be available from the environmental satellite missions already launched or planned. Also, the Argo system of ocean profiling floats, developed under WCRP's earlier World Ocean Circulation Experiment (WOCE) and now co-sponsored by CLIVAR, is becoming an increasingly important source of oceanographic data and an integral part of a developing ocean observing system for climate. These and other *in situ* data are being integrated under the framework of GEOSS, the Global Earth Observation System of Systems, in order to reduce redundancy and optimize information products and services. They must be used in process studies and also turned into quality-controlled climate data sets, requiring continuing pressure for observational data of climate quality and the continuous knowledge of data calibrations. Accuracy to uniform international standards must be maintained as the observing system evolves (see **section 2.3**).
- **the growth and availability of computing power**. The computing power becoming available means the ability to run global models with resolution of a few kilometres (as required for many practical applications), very large model ensembles to assess uncertainty, simulations of palaeoclimates with fully coupled global climate models, and, increasingly, highly-resolved regional models in response to the demand to develop adaptation policies and measures at the regional level.

Powerful new computers such as the Earth Simulator in Japan will make possible major advances in climate modelling. [Earth Simulator Center/JAMSTEC]

- **an increase in the number of groups running global models.** As the result of the importance of climate issues there are now more groups capable of running climate models thus allowing the use of multi-model ensembles to overcome systematic deficiencies in single-model ensembles. It also increases the necessity to document the variety of model behaviour and understand the reasons for it.
- **the increasing complexity and realism of models.** High-resolution models including detailed physical parametrizations, cloud-resolving capabilities, and other detailed representations of relevant climate processes are being developed.
- **modern data assimilation techniques applied to the Earth system**. Numerical weather prediction has shown that maximum value can be obtained from the various streams of data by analysing them together in prediction models that are sufficiently accurate. This framework allows optimal state assessment based on past as well as present data. In the process, valuable information on model deficiencies can be obtained. Such data assimilation will increasingly be possible for the components of the coupled climate system and for the wider Earth system.

Benefit from increased collaboration. The broadening of the climate/Earth system interest of WCRP necessary for climate prediction and projection implies the need for closer collaboration and synergy with the International Geosphere-Biosphere Programme (IGBP) and with the other Earth

System Science Partnership (ESSP) Programmes (**Box 4**). The seamless nature of the prediction problem and of many of its applications implies that close collaboration and coordination are also needed with the WMO World Weather Research Programme project THORPEX (**Box 5**). The desire to ensure that WCRP-related science is used in an appropriate and timely fashion for an increasing number of practical applications requires close collaboration with, in particular, the other principal components of the World Climate Programme (see **Appendix A**). See s**ection 2.7** for discussion of these and other collaborations..

Box 4. The Earth System Science Partnership (ESSP)

The Earth System Science Partnership consists of the global change programmes, all having ICSU parentage:

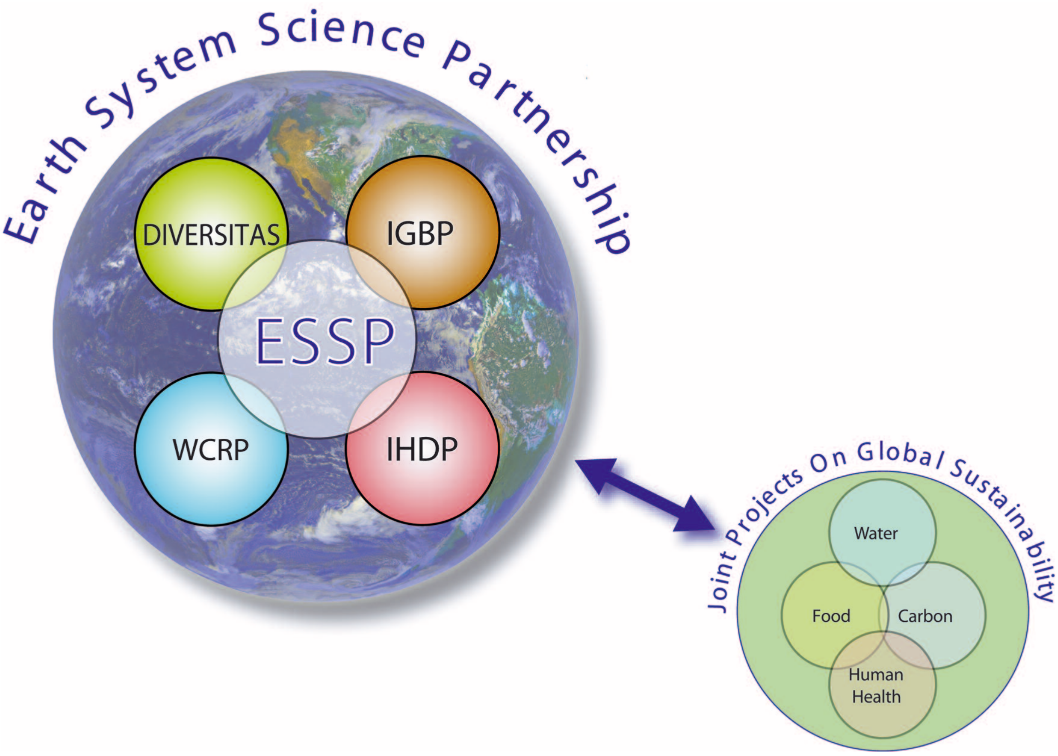
- World Climate Research Programme (WCRP)
- International Geosphere-Biosphere Programme (IGBP)
- International Human Dimensions Programme on Global Environmental Change (IHDP)
- DIVERSITAS

The ESSP currently has four joint projects:

- Global Carbon Project (GCP)
- Global Environmental Change and Food Systems (GECAFS)
- Global Environmental Change and Human Health
- Global Water System Project (GWSP)

WCRP, IGBP and IHDP also sponsor the global change SysTem for Analysis, Research and Training (START).

See **Appendix B**, Sections **B.10** and **12**, for more discussion of ESSP and START, respectively.



Box 5. THORPEX: a World Weather Research Programme

THORPEX (THe Observing system Research and Predictability EXperiment) was established in May 2003 by the Fourteenth World Meteorological Congress under the auspices of the WMO Commission for Atmospheric Sciences (CAS). It is a 10-year international research and development programme to accelerate improvements in the accuracy and the social, economic, and environmental benefits of 1-day to 2-week high-impact weather forecasts. Its research topics include: global-to-regional influences on the evolution and predictability of weather systems; global observing system design and demonstration; multi-model ensemble predictions; targeting and assimilation of observations; and, social and economic benefits of improved weather forecasts. It is a component of the WMO World Weather Research Programme (WWRP), and is also sponsored by the JSC/CAS Working Group on Numerical Experimentation (WGNE).

A desired outcome from THORPEX is an increased fundamental understanding of the dynamics and predictability of the atmosphere. In that context it will be necessary to determine how such predictability depends on larger space- and time-scale phenomena such as the variability of the organization of tropical convection in the intra-seasonal oscillation, and to investigate the ability to predict weather between one and two weeks ahead. Another desired outcome is the development of much improved global and regional forecast systems. For these and other reasons, close collaborations are being developed between THORPEX and WCRP activities.

In response to the ever-increasing demands of society for accurate and reliable climate predictions and related applications and the new opportunities and challenges, and also recognising the need to refocus its activities towards its original two aims, the WCRP has adopted the strategic framework **Coordinated Observation and Prediction of the Earth System (COPES)** for its activities in the period 2005-2015. This name is appropriate: 'Coordination' is an essential ingredient of what WCRP provides for its science; 'Observation' and quantitative 'Prediction', along with process understanding, are the pillars of WCRP science; 'Earth System' expresses the increasing breadth of its climate system interest necessary for climate prediction and projection.

The aim of this new WCRP strategic framework, COPES, is: to facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

This aim combines the two overall objectives of WCRP, in a manner consistent with the seamless nature of the prediction problem.

COPES provides the framework to:

- integrate the breadth of WCRP's projects and other activities;
- address the new challenges;
- allow the JSC to review and assess progress towards achieving the WCRP aims, thus providing feedback to the projects;
- set specific objectives in the context of those aims;
- guide existing and stimulate new scientific activities within WCRP;
- increase recognition and visibility for the scientific and societal relevance and importance of WCRP outputs.

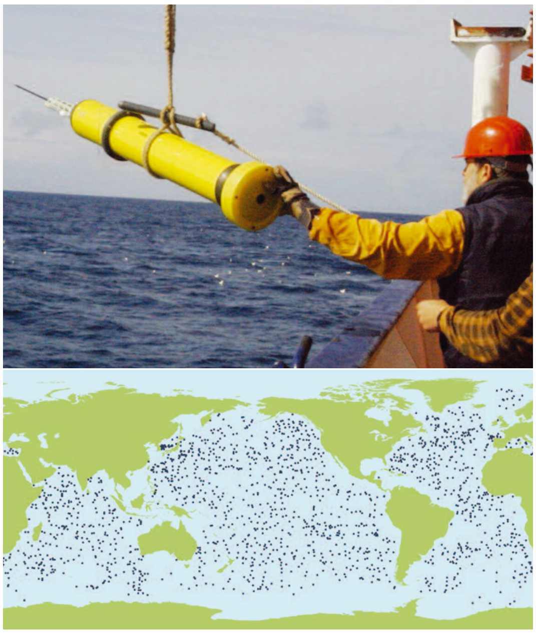
The projects of WCRP will continue to play the central role in executing its science. The WCRP overarching strategic framework COPES builds on, and provides a context for, existing (and future) WCRP projects. Wherever possible, new experiments, studies, and observational activities will be carried out through the existing WCRP programme structure. It is also essential that the WCRP structure continues to evolve, as it has in the past.

2.3 Observational issues for COPES

The aims of COPES require research involving the use of many different types of observations. For instance, research on how observations of important climate variables contribute to the increased information on and predictability of climate at various time- and space-scales. It is helpful to divide the observations into three categories:

The NOAA Ship Ronald H Brown performing turbulent flux measurements for research on the transfer of gases between the ocean and atmosphere in the equatorial Pacific.

1. process study observations – required to augment the network of sustained observations for understanding key processes;
2. enhanced monitoring – observations that are needed to fill the gap between the "sustained" and "process" categories. These could be enhanced monitoring in time or space to resolve features of importance for climate modelling and prediction, or enhancements to study processes of a longer-term nature;
3. sustained observations – acquired throughout the lifetime of COPES and beyond and designed and implemented in collaboration with the Global Climate Observing System (GCOS).



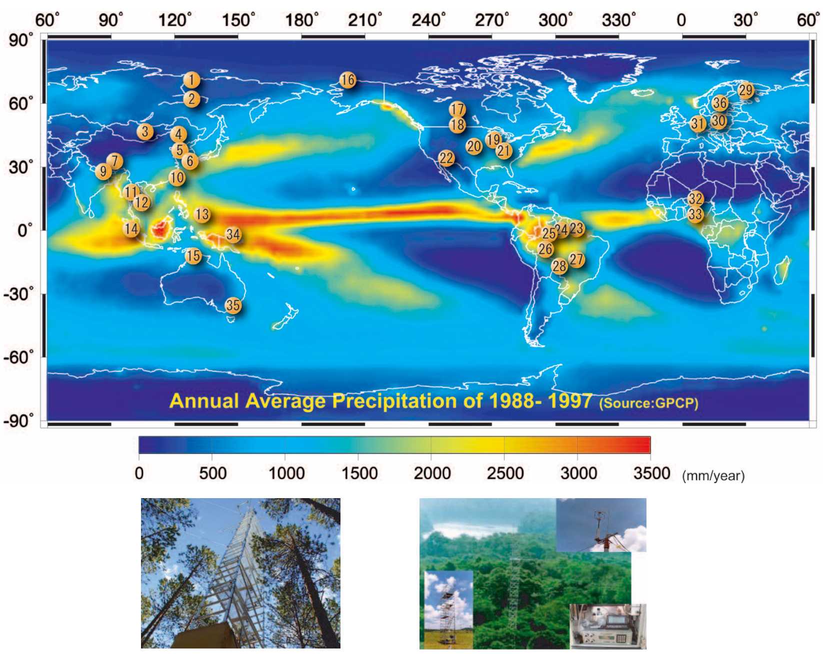
An Argo float launch and float distribution in April 2005.

The observational issues of COPES will require the coordinated collection, analysis and reanalysis of *in situ* and satellite climate observations to describe the structure and variability of the climate system. This will allow the generation of descriptions of states of the coupled climate system that are consistent with both the observations of all variables and the physical framework provided by models, both for the numerical prediction of climate and for documenting the climate record. Special efforts will be required to obtain, analyse and assimilate data from the new generation of environmental satellites.

In addition to the longer-term data for monitoring and analysis of time-dependent climate variations, there will be a need to collect, analyze and archive high spatial and temporal resolution data of physical variables and chemical constituents using *in situ* as well as remote-sensing methods. Many such data will likely be obtained for short periods from observational campaigns designed within the WCRP projects for process studies. Data from these observational components will help formulate, evaluate, and parametrize processes that go into the global models and also help validate satellite data. There may be increasing use of special observational sites and joint experiments that bring the community together in an efficient way, giving maximum opportunity for the cross-WCRP collaboration and synergy that are essential in the COPES strategy.

The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC (GCOS-82, WMO/TD No.1143, April 2003) provides a basis for supporting operations and for the further development of the global observing systems (see **section B.7**, **Appendix B**; and also the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, GCOS-92, WMO/TD No. 1219, October 2004). WCRP scientists were actively involved in the preparation of the Global Climate Observing System (GCOS) adequacy report of 2003 and in the subsequent development of the implementation plan published in 2004. It will be a task within COPES to utilise the effort within WCRP projects and activities to work closely with GCOS to build on this report and to specify with more precision the observations needed to improve the realisable predictability of climate at various temporal and spatial scales. In this context, it is important also to recognise the role of the WMO World Climate Data and Monitoring Programme (WCDMP; see **Appendix A**) for its crucial efforts in data management and data rescue, to fill in national and regional data gaps, and to help build the long-term datasets needed for climate research and modelling.

A task under COPES is to continue to provide a coordinated WCRP input into the international process of defining the *in situ* and space observing systems for the next decade required for climate studies, particularly to address the aims and objectives of WCRP, and the implementation of the COPES strategic framework. Consideration needs to be given to identifying gaps and deficiencies in existing observing systems, encouraging reprocessing and reanalysis of past data, and addressing other shortcomings which may have resulted in reduced skill of existing prediction schemes. WCRP will position itself to help argue for the climate observational system that will be required in future for both assessments of the climate system and for prediction. The Coordinated Enhanced Observing Period (CEOP) (see **section B.3**, **Appendix B**) led by the WCRP Global Energy and Water Cycle Experiment (GEWEX) should be viewed as an example of coordinated global observational activity in the context of COPES.

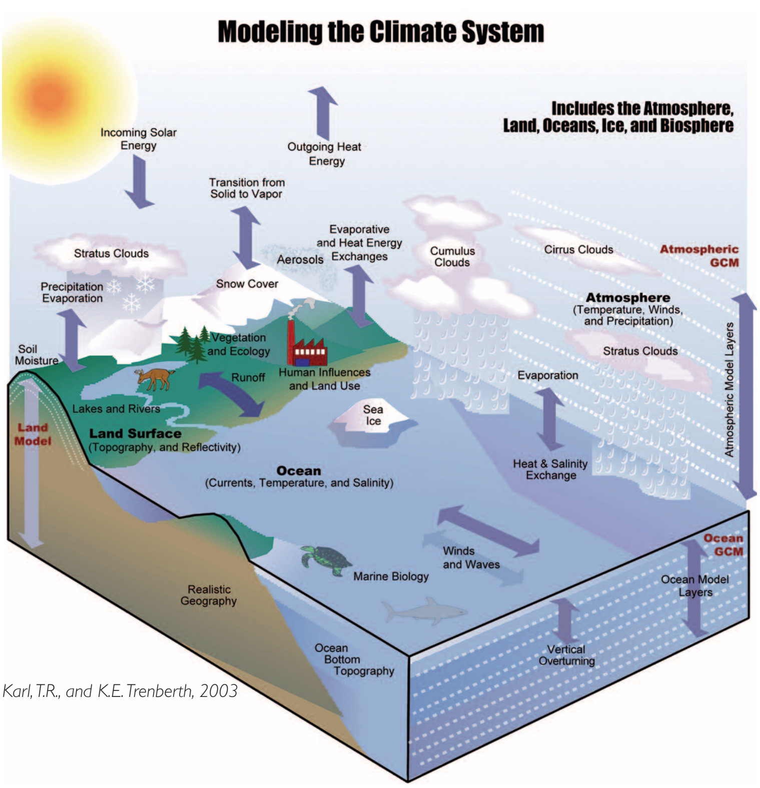


Map of annual average precipitation for the period 1988-1997 generated by the WCRP Global Precipitation Climatology Project showing the location of the 36 joint meteorological-hydrological stations established under the Coordinated Enhanced Observing Period (CEOP) project. Data from these stations have been anaylzed along with satellite data and model output to create a reference data set for global water cycle research.

Observations should adhere to the GCOS observing principles, thereby ensuring that they are useful for multiple purposes, including climate change. A commitment is required for the progressive, coordinated, ongoing analyses and periodic reanalyses of observations, which are necessary to incorporate lessons from new measurements and research. Commitment is also required for the stewardship, archival and access of data, as well as the support to enable institutions to do these tasks. A balance is needed between new observations and the need to achieve more effective exploitation of current and planned observations (especially from satellites), the latter being achieved through increased international cooperation on developing integrated analyses and products. The transition from research to operational systems is also an important practical issue.

The *ad hoc* Group on Earth Observations (GEO) and the related Earth Observation Summits (EOS) were welcome developments for WCRP in the context of the observational needs and aspirations of COPES (see **section B.7**, **Appendix B**). As a recognised Participating Organization, the WCRP will continue to provide informed and comprehensive input into the succeeding intergovernmental GEO operations, which will implement the Global Earth Observation System of Systems (GEOSS) 10-year Implementation Plan following EOS-III, Brussels, 16 February 2005. In addition, many of the observational issues of COPES will be addressed through the Integrated Global Observing Strategy Partnership (IGOS-P) and the Committee on Earth Observation Satellites (CEOS).

2.4 Modelling issues for COPES



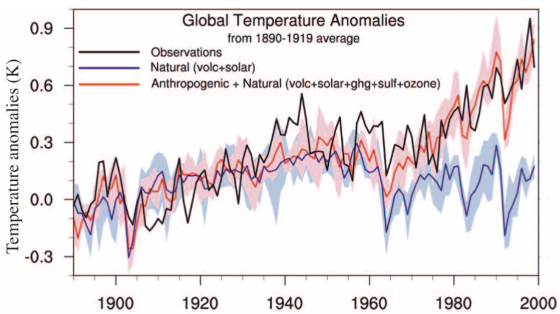
Karl, T.R., and K.E. Trenberth, 2003

The essence of WCRP science is observation, diagnosis and modelling of the physical climate system leading to a better understanding of the mechanisms that determine the mean climate and its variability. However, an ultimate objective is that WCRP will provide the soundest possible scientific basis for a predictive capability for the total climate system to meet society's needs, including an assessment of uncertainty in predictions on various time- and space-scales.

The new WCRP strategic framework, COPES, will require an integrated approach whereby the roles of atmosphere, ocean, land and cryosphere be considered in comprehensive models of the climate system, which are also capable of assimilating weather and climate observations. This implies the need for a continued sustained research effort in the validation and development of climate models and data assimilation techniques and tools for the coupled system. These climate models should be validated through their ability to simulate past climate variations, including abrupt climate changes. In turn this also requires improved knowledge of forcings of the climate system.

There are several different strands of modelling activities relevant to COPES:

1. Long integrations that can provide improved statistical description of processes, phenomena and their interaction.
2. Perturbed integrations that can document the sensitivity of the system to a process, parametrization or feedback.
3. Initial-value and perturbed boundary condition integrations for prediction on a large range of time-scales.
4. Combined model/data analyses to obtain an optimal interpolation in time and space between incomplete data sets.



The inclusion of anthropogenic greenhouse gases into model runs makes it possible to reproduce the observed warming trend in the late twentieth century. [Courtesy G.A. Meehl et al., 2004]

Under COPES, WCRP modelling groups will continue to play a key role in focusing such activities. As indicated earlier, while WCRP has, and will continue to have, a firm foundation in the physical climate system, it will also increasingly consider quantitative modelling of the wider Earth system. This will be done in close collaboration, in particular, with IGBP. Similarly, in order that the science addressed in WCRP should be in support of the Millennium Development Goals in the short term and the sustainable development of societies in the longer term, WCRP will need to nurture closer collaborations with IHDP and other international projects relevant to the welfare of the global society.

The WCRP approach to modelling the Earth system is characterized by the expansion of detailed models for the physical climate system (global climate models - GCMs) to encompass chemical and biological aspects of the Earth system. In particular, detailed models for the atmospheric chemistry and the carbon cycle, including dynamic vegetation modules and interactive marine ecosystems, are now being developed for and used in GCMs. Earth system Models of Intermediate Complexity (EMICs) offer a complementary approach for long-term simulations, and more highly parametrized, exploratory models are being developed for the investigation of the interaction of human societies with the other components of the Earth system.

Improvement of the present modelling capability thus requires a co-ordinated hierarchical approach with a suite of different models. In partnership with other ESSP members there is a need for:

1. Experimentation with current GCMs to:
    a. provide the scientific basis and material for IPCC and other international assessments through sensitivity studies, climate hindcasts and projections of future change;
    b. assimilate and predict the coupled system on intraseasonal to interannual (and eventually longer) time-scales.
2. Continued experimentation (including 'retrospective predictions' at various time-scales) and process studies with current GCMs and comparison with observations to improve and validate the models used in 1.
3. Development of the ability to perform more detailed global modelling of the carbon cycle, hydrology, evolving vegetation, tropospheric and stratospheric chemistry, ocean biology, lateral transport of elements and a range of other biogeochemical processes (requiring observations, process studies and modelling of the individual systems).
4. Work on extending GCMs to include each of these additional components of the Earth system in turn, as a basis for the studies in 1. This includes the coupling of different models and the assimilation of data in the coupled models.
5. Development of and work with more highly parametrized models (including EMICs) to:
    a. study the interactive aspects of the natural system;
    b. simulate longer time-scales, *e.g.* Ice Age Cycles;
    c. compare and validate with GCMs.
6. Development of models of the interaction between the human and natural systems based on the more highly parametrized models.
7. Use of simpler models to help in the design and diagnosis of the more complex coupled models.

The effective development and implementation of such a modelling programme will require a range of separate but coordinated and collaborative activities in ESSP, with WCRP's expertise with global data sets and in the coordination and implementation of major global and regional modelling activities enabling it to make a major contribution.

Based on experience and track-record to date, WCRP is taking the lead for activities 1 and 2 above, through its projects and Working Group on Coupled Modelling (WGCM), drawing on the expertise of IGBP projects as appropriate.

IGBP continues its lead, in partnership with WCRP, in activity 3, which builds on the work of the IGBP projects and draws, as appropriate on the expertise of WCRP projects.

Item 4 is being implemented through the existing partnership between WCRP's WGCM and IGBP's Analysis, Integration and Modelling of the Earth System (AIMES) activity. This productive partnership provides a common platform for a broad range of communities to collaborate as complex models of the physical climate evolve towards more complex and integrated Earth system models.

IGBP leads activity 5, which will provide inputs to activities 2 and 3, linking closely with WGCM, WCRP Climate Variability and Predictability (CLIVAR) project and IGBP's Past Global Changes (PAGES) project.

Activity 6 should be implemented through collaborative activities among WCRP, IGBP and IHDP. WCRP's initial contribution will be in one-way interactions, such as in climate-crop, climate-economic and climate-health models, but with a view to playing an increasingly more active and direct role in the development, use and evaluation of such model components.

Activity 7 is relevant for each of the ESSP programmes.

There is an increasing realisation that there are many advantages in moving towards a common climate/Earth system model infrastructure. This will help centres develop their own models, exchange model components, perform multi-model experiments and generally improve collaboration and efficiency. Common infrastructure will also help the interaction with the super-computer industry. There are developments in complementary aspects of the problem in North America and in Europe . Under WCRP auspices best practice should be shared and a truly international approach developed.

The ability to simulate weather systems accurately and to produce predictions on time-scales of weeks are common interests of WCRP and the new WMO THORPEX programme. One aspect of this common interest is the performance of one or more coupled atmosphere-ocean-land models at extremely high, few-kilometre resolution. The use of such models could point to resolutions that may be more generally possible and deemed necessary in a few years, could isolate phenomena for which more detailed data are required, and could help in understanding how to parametrize processes in lower-resolution models.

Regional climate models with their high resolution and focus on local interactions and applications also provide a test-bed for future global models. The development of techniques for performing such regional, applications oriented modelling and the understanding of the skill that can be expected from them will continue to be important research areas within WCRP.

The improvement of global coupled models of the physical climate system continues to be a central and essential objective of WCRP. This will necessitate the development of new physical parametrizations based on diagnosis of model and observed behaviour, and special process study observations. New numerical techniques giving more accurate and faster representation of the dynamics and better linkages between the dynamics and physical parametrizations will be required.

Underlying all prediction activities there will be a need for a firm theoretical basis in predictability. Guided by chaos theory and physical understanding, and using experimentation with models there will need to be a search for what may be predictable and on what time-scale. Questions such as what is the structure of attractors and are there rapid changes in system behaviour in parameter space reminiscent of bifurcation points will need to be addressed.

2.5 The essential synergy between observations and models

The very strong interaction of observations and models is central to COPES, with observations giving the basis for evaluating and improving models, and models providing the framework and impetus for deciding what observations to take. Observations also enable the bias removal and downscaling that are required for the application of model predictions. There is one extremely important and intimate interaction that has already been mentioned but will now be highlighted.

More complete exploitation of observations and improvement of models necessitate a major activity in climate/Earth system data assimilation. This is already occurring in some operational centres as an extension of numerical weather prediction procedures. It requires the best climate/Earth system models and is an excellent test of them. Maximum possible value of observations is obtained by combining them with other observations in the context of the model. The resulting products are essential for providing our best estimates of the current state of the climate and for many uses in the context of the development, use and evaluation of climate models. Independent observational data sets and analyses are also required to make an independent check of both models and analyses.

Data assimilation has been developed in the context of weather forecasting. It is also being used to determine the initial state of the ocean for seasonal predictions, but atmospheric and oceanic data assimilation are currently performed separately. Combining them will require an understanding of the interactions so that the different timescales present in the coupled problem can be separated. Similarly, other component models, such as those for atmospheric chemistry, carbon and hydrology will require advanced treatment when combined in a single data assimilation system.

As recognised above, another major challenge for the future is to limit the possible compounding of uncertainties associated with the increasing breadth of Earth system models. This could be done by the development and use of macro-scale observational constraints on the system. Also it must be recognised that uncertainty is not necessarily Gaussian in nature, that it evolves in time and that models are not perfect and have biases, etc. There are also issues around the use of the very large amount of new observational information that present a technical problem and may also modify the character of the analysis and forecast errors. Another area of increasing importance is that of inverse modelling – the inference using data assimilation methods of other environmental information such as the sources and sinks of trace gases, e.g. surface carbon sources and sinks.

2.6 Data access

In order to optimise the new framework for WCRP activities provided by COPES, it is necessary that there is unrestricted and open access to data, and it is desirable to move towards a more unified system of data management and access in the WCRP projects. A fundamental principle in any data management scheme is that observational data must be managed in ways that facilitate reprocessing and reanalysis (including the large satellite data sets), and in the full expectation that these may need to be repeated many times. Equally, results from model runs should be easily accessible so that experts in various disciplines and regions can diagnose them.

There has always been a tension between the convenience for each WCRP activity to develop and use its own scheme and the enabling of collaboration across a wider area of WCRP through the use of common techniques. To date, each project has dealt independently with this issue. For example, a unified data management scheme was essential for the World Ocean Circulation Experiment (WOCE; see **section C.2**, **Appendix C**) in its depiction of the three-dimensional state of the world oceans. More recently the Coordinated Enhanced Observing Period (CEOP) has put a large effort into this area and so also has the new Climate and Cryosphere (CliC) Project.

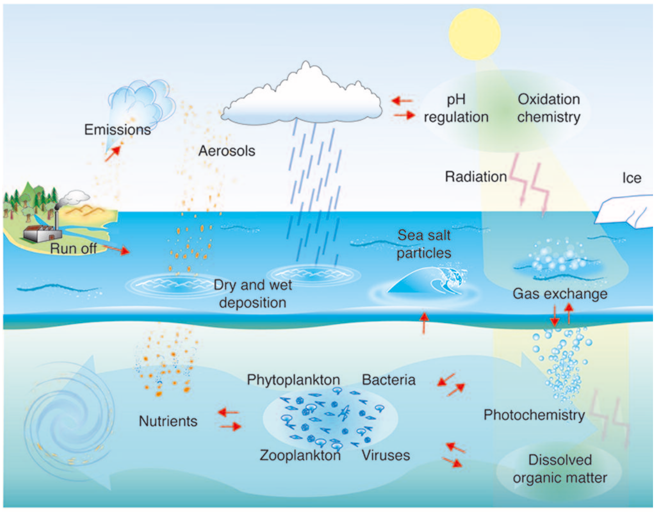
A rigorous and unified data management scheme enabled production of the WOCE Atlas Series

In developing a WCRP-wide data management policy and practice, it is important for WCRP not only to build on its own experiences to date but also to work closely with the relevant programmes of WMO, including the WWRP THORPEX project, and the data management activities that will need to evolve in GEO/GEOSS. Advice and input should also be sought from other projects, such as the Global Ocean Data Assimilation Experiment (GODAE), that have been active in this area.

2.7 Collaboration

Throughout the above sections there have been references to collaborations that already occur or that will be required in future. In particular, the sponsorship by WMO, ICSU and IOC will continue to ensure that WCRP has both a solid scientific basis as well as a firm governmental framework that encourage and facilitate collaborations with other appropriate components of the sponsors' programmes.

In the context of WMO, WCRP will continue to work closely with the other complementary components of the wider World Climate Programme (see **Appendix A**). A new and important emerging collaboration is with THORPEX, which is managed by the WMO Atmospheric Research and Environment Programme (AREP) Department. As described in **Box 5**, THORPEX has a weather prediction focus that includes the predictability of extremes, the sensitivity of prediction skill to large-scale phenomena such as the tropical intra-seasonal oscillation, and gaining forecast skill for more than one week. Given the COPES challenge of the seamless prediction problem, recognising the importance in longer-term predictions of the statistics of severe weather, the feedback of weather and phenomena (such as the intra-seasonal oscillation) onto the longer time-scale, and also given the complementary predictability time-scales, it is clear that there is much common interest between the WCRP in its COPES phase and THORPEX. WCRP is therefore cooperating fully with THORPEX to ensure that the necessary, mutually beneficial collaborations are recognised and developed. Collaborations will also be actively pursued in areas of applications, for example with those involved with seasonal prediction, with the monitoring and service-oriented components of the World Climate Programme, and also with WMO's Hydrology and Water Resources Programme and its new Natural Disaster Prevention and Mitigation Programme.



SOLAS domain

Within the ICSU family, WCRP will continue to play a full and influential collaborative role within the recently formed Earth System Science Partnership (ESSP). In that context, the largest such collaboration has been and, under COPES, will increasingly be with IGBP. WCRP aims to build more aspects of the Earth system onto the existing firm physical foundation and predictive capability. IGBP has developed the expertise in many aspects of the biogeochemical Earth system. Atmospheric chemistry and palaeoclimate simulation are particularly strong current links between these two global environmental change Programmes. The WGCM-AIMES link should be strengthened by IGBP membership of the new WCRP Modelling Panel (see **section 4.4**) and the synergistic activities described in the Earth system modelling area (see **section 2.4**). The latest IGBP ocean-atmosphere interface project, Surface Ocean – Lower Atmosphere Study (SOLAS), is co-sponsored by WCRP. New collaborations should naturally emerge and will be encouraged.

ICSU also has programmes and activities, in addition to those in the ESSP, with which WCRP collaborates and will seek increasing collaboration where relevant. The linkage with the Scientific Committee on Oceanic Research (SCOR) is mainly through CLIVAR, and CliC has strong ties with the Scientific Committee on Antarctic Research (SCAR). There is general interest in the work of the Scientific Committee on Problems of the Environment (SCOPE). The Assemblies of the Unions of ICSU, in particular those of the International Union of Geodesy and Geophysics (IUGG) and its Associations provide fora for community involvement in WCRP science that WCRP will increasingly seek to use.

The support of the international oceanographic research community as represented by the IOC will also clearly remain of vital importance to the continued success of the WCRP and the implementation of its new strategic framework, COPES. This relationship facilitated the successful organization of implementation of WOCE (see **section C.2**, **Appendix C**). The major project of the WCRP now addressing the oceans is CLIVAR (see **section B.2**, **Appendix B**), the natural and planned successor to WOCE. However, many other WCRP activities contribute to the achievement of IOC goals and there is joint implementation with the IOC of a number of activities, including those of the Ocean Observations Panel for Climate (OOPC), the Indian Ocean Panel, and the carbon hydrographic activities of the International Ocean Carbon Coordination Project.

As discussed earlier, there are many collaborations with observational agencies and organizations, particularly in the satellite area, that must be continued or strengthened. A new important opportunity is the International Polar Year (IPY) 2007/08 being organized jointly by ICSU and WMO. This is envisioned as an intensive burst of internationally coordinated, interdisciplinary, scientific research and observations focused on the Earth's polar regions, which will enable nations to make major advances in knowledge and understanding of the high latitudes. At its 25th session in Moscow, March 2004, the JSC assigned the Climate and Cryosphere (CliC) project (see **section B.5**, **Appendix B**) to stimulate and coordinate WCRP contributions to the IPY and WCRP is well represented on the appropriate IPY planning groups. The IPY initiative provides an excellent opportunity for the early stages of the implementation of CliC activities.

WCRP will also continue, through collaborative ventures, to be a major contributor to providing the scientific basis for the assessments of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC), and to the development of the Global Climate Observing System (GCOS) and the new Global Earth Observation System of Systems (GEOSS), and other such activities.

3. CLIMATE INFORMATION AND PREDICTIONS AND RELATED SERVICES AND APPLICATIONS

3.1 Pathways from observations to users

Understanding the climate and Earth system provides intellectual challenges that are arguably as great as in any other area of science. However, the potential usefulness to society of the information products and the predictions and projections that become possible because of WCRP research is very large and is highlighted by the aim of COPES.

As a result of its success, WCRP is now being asked to provide a broader suite of products and services to a larger group of users and to measure the societal benefits of its activities. One of the primary WCRP pathways to users and societal benefits has and will continue to be the use of observations to generate new understanding, leading to improved modelling of the climate system and improved societal benefits from predictions. As **Figure 1** illustrates, these products and services flow directly from observations, from empirical models based on observations as well as from dynamical models that require data for their development, testing and application. As the global observational records from *in situ* data and from satellite remote sensing have grown longer and new applications have gained credibility, the direct and empirical approaches to critical climate products and services become more viable.

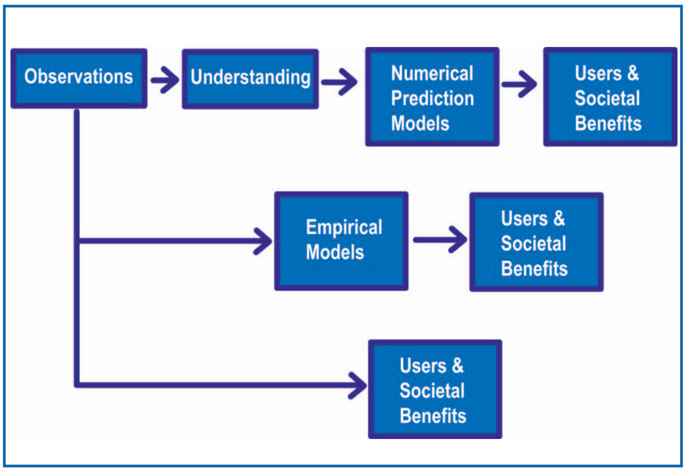


Figure 1. Pathways from observations to users and societal benefits. (For simplicity a number of arrows in reverse directions are not shown).

In its COPES strategic framework, WCRP encourages the development of all three pathways from observations to applications. The direct uses of observations can realize benefits sooner if these data products are prepared with the end-use in mind. These direct uses also provide a baseline against which to measure the progress made by the developing model-based prediction systems. In the longer term, it is expected that the use of numerical models will provide the most robust predictions for societal benefit.

African farmers listen to climate forecasts via radio.

3.2 Climate predictions

Although WCRP results enable climate predictions, they are generally produced routinely by operational centres. Through existing channels, such as those provided by the WMO World Climate Applications and Services Programme (WCASP; see **Appendix A**) and, in particular, its Climate Information and Prediction Services (CLIPS) project, WCRP can take advantage of this route through to the users. WCRP will also be more pro-active in interacting with user communities and other agencies, particularly at regional and national levels to communicate directly current abilities, to assess potential applications and to stimulate the necessary science. This includes, for example, the development of direct links of climate models with economic models. A two-way interaction is essential to ensure an adequate appreciation of the user/stakeholder requirements and for these product needs to also drive the research agenda. One new route deserving future consideration is through the emerging Regional Climate Centres being encouraged and supported by WMO.

Bangledesh monsoon, August 2004. [E. Al-Majed]

On the shortest WCRP time-scale of weeks, the link to the Numerical Weather Prediction (NWP) centres that are extending their forecasts to week-2 and beyond is through the joint WMO Commission for Atmospheric Sciences/JSC Working Group on Numerical Experimentation (WGNE) and THORPEX. THORPEX has the direct involvement of NWP centres and is developing a comprehensive and active socio-economic component. WCRP collaboration with THORPEX should include activity in this area.

Many operational centres are producing seasonal forecasts. WCRP research, particularly that on ENSO conducted previously by TOGA and now by CLIVAR, has played a major role in the fact that such forecasts are performed and that they have some skill. A major COPES specific objective that is already being pursued is to assess the skill that is possible and useful in all regions of the globe with currently available models and data. Much WCRP activity has the potential for increasing this skill. The application of seasonal forecasts is occurring through the operational centres, through the CLIPS project of the WMO WCASP, through institutions such as the International Research Institute for Climate Predictions (IRI) and through an increasing number of private companies.

Application models that depend on weather and climate data have usually been run off-line (*i.e.* separately from the NWP and climate models themselves), often using data that are averaged in time or are at sparse time-intervals. However, increasingly surface hydrological, crop-growth, economic and other models are being linked directly with the climate prediction model. In addition, the ensemble approach will enable statistical information to be obtained for the particular application. However, the coarse spatial resolution and biases of the weather/climate model, and in the spread in the ensemble are all problems that will have to be tackled. The international Hydrological Ensemble Prediction Experiment (HEPEX), associated with GEWEX, aims to demonstrate how reliable "engineering quality" hydrological ensemble forecasts can be performed and used as decision support in areas crucial for the economy and for public health and safety. WCRP will interact with those performing and demonstrating such applications.

3.3 Climate variability and change

Anthropogenic climate change has been identified by many world leaders as one of the biggest threats to human activity and well-being. In particular, The Gleneagles Communiqué on 'Climate Change, Energy and Sustainable Development' (G8 Summit, Gleneagles, Scotland, July 2005) states explicitly that, "Climate change is a serious and long-term challenge that has the potential to affect every part of the globe". In COPES, WCRP will increase and make more visible its focus on its second original aim: to determine the effect of human activities on climate. Adaptation to variability and change on decadal and longer time-scales, whether natural or anthropogenic in origin, requires accurate predictions and an intimate knowledge of the skill of predictions of specific variables in particular regions. WCRP will play a crucial role in both increasing the skill and estimating the uncertainties of these predictions and in the detection and attribution of changes in the physical climate system. Results from WCRP research provide a large part of the material assessed periodically by Working Group I of the Intergovernmental Panel on Climate Change (IPCC) in their advice to the UN Framework Convention on Climate Change.

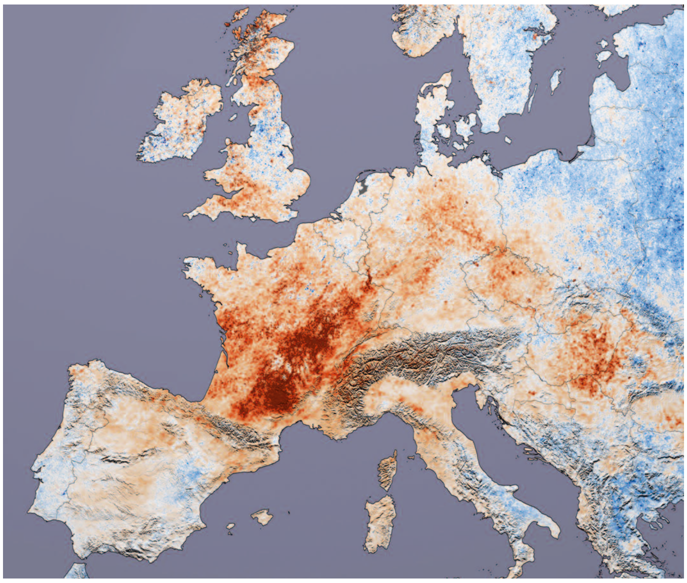


Image derived from satellite data showing the European regions which experienced a major heat-wave in summer 2003. Deep red indicates areas where the temperatures were 10 degrees Celsius warmer in 2003 than 2001. [R. Stockliard, R. Simmon/NASA]

Detection of climate change requires the climate observing capability discussed in **section 2.3**. The attribution of trends in, for example, globally averaged surface temperature to natural or anthropogenic related forcing is important and will continue. However, there is increasing requirement to also attribute climate variability and change at regional and more local scales, including particular events such as the European summer heat wave of 2003 or regional long-term droughts. The attribution in this case is not confined to that of the role of human influences, but is also focused on evaluating the different contributions to the atmospheric circulation anomalies from ocean and sea surface temperature anomalies, sea ice, soil moisture, and other influences. Such attributions and the information necessary for robust impact assessment and adaptation strategies require probability information on predictions of climate variables on regional scales, ensembles of model runs, well-tested methods for determining regional detail and a full understanding of patterns of climate variability on all time scales. The increasing understanding of and confidence in likely climate change and in the possibility of regional, if not global, thresholds in the climate system will enable a better political determination of the likelihood of "dangerous climate change" for different levels of greenhouse gas emissions.

Scenarios for the emission of greenhouse gases and other human impacts form the basis for climate projections. As the climate projection models include interactive modules that deal with the carbon cycle more comprehensively, they will improve the ability to translate the carbon emissions into atmospheric concentrations. Also, the assimilation of satellite and other data in Earth system models is likely to improve the ability to monitor regional greenhouse gas emissions and their sources, as well as the take up of carbon dioxide by the oceans and biosphere, an activity that will be essential in the verification of any global agreement to limit their production.

3.4 Increasing the participation of developing-country scientists

An important aspect of both the scientific research of WCRP and the applications of that research should be the involvement of developing-country scientists in the evaluation of both useful seasonal forecasting skill and climate model simulation skill in their regions. Such evaluations will feedback onto the scientific research of WCRP and the IPCC and other assessments, involve the developing-country scientists in that research, and give a basis for future use of seasonal forecasts and climate projections for their regions. This involvement could occur through the infrastructures and networks provided by the WMO WCASP, START, the Asia-Pacific Network for Global Change Research (APN), the Inter-American Institute for Global Change Research (IAI), the European Network for Research in Global Change (ENRICH), The Academy of Sciences for the Developing World (TWAS), the New Partnership for Africa's Development (NEPAD), and others.

The ability to quantify with confidence and reliability the likelihood of extreme weather and specific climate events on all time-scales is vital to society. Developing countries are in particular need of the best information, as is recognised by the new WMO Natural Disaster Prevention and Mitigation Programme. The last decade has, for example, seen significant advances in the ability of numerical weather prediction models to predict tropical cyclone tracks. Through its COPES strategic framework, WCRP will be in a position to provide further impetus to build on these advances through an increased emphasis on the development of new generation models and more complete exploitation of data.

4. IMPLICATIONS FOR WCRP STRUCTURE AND MODE OF WORKING

4.1 Introduction

The purpose of the new WCRP strategic framework, COPES, is to provide a refocusing and stimulation for its activities. Consistent with this, the main implication for WCRP structure is a reassessment of the roles of the JSC, the projects and the existing committees. Given the need for a coordinated approach to modelling and observations, groups in these areas that had previously been *ad hoc* or occasional will be formalised. Also, closer interaction will be sought with institutions that are central to the ability of WCRP to achieve the aim of COPES.

4.2 Role of the JSC

The members of the JSC are appointed to lead WCRP and are the custodians of its COPES strategic framework. It is the responsibility of the JSC to take account of the overall aims and objectives in guiding the development and implementation of COPES, and to use these aims and objectives as the 'yardstick' by which the performance of WCRP is measured and assessed. JSC members must play an active role, with specific members taking on roles and responsibilities for its projects and other activities, and with a view to paying particular attention to fulfilling the aims and objectives of WCRP.

The evaluation of the progress in implementing COPES will require a clear formulation of goals and deliverables. It will also be enabled by a change in the nature of JSC sessions, especially with respect to reporting on each core project and other activities of the WCRP. Issues will still be discussed that arise from the reports of the wide range of research being performed in projects and other activities, recognizing that this fundamental core research is necessary for the long-term development of climate science and that it contributes to future specific objectives for WCRP. However, JSC meetings will focus more on progress towards the main aims and objectives of the WCRP. Under the COPES framework, there will be increasing focus on specific topics and issues where assessment and advice are needed from the JSC. In particular, projects will report each year to JSC on research progress relevant to analysis, attribution, prediction and assessment on all time-scales.

4.3 Core projects and other activities

The core projects and other activities of WCRP will remain central to its *modus operandi* and will continue to play an essential role in determining and pursuing the objectives of WCRP. Wherever possible, new experiments, studies, and observational activities will be carried out through the existing and evolving WCRP programme structure but with due regard to the need to collaborate where appropriate with others. Existing core projects and other activities will themselves develop and direct their scientific programmes and structures so as to enable them to make their full and proper contributions towards the agreed WCRP aims and objectives under COPES. With such a concentration, responsibilities among projects should be clear and interactions stronger.

The JSC and the WCRP projects and other activities will need to work closely together to define the evolving COPES strategy and to implement it. As part of the progress of WCRP towards its aims and the evolution of its programme, all current projects have end-dates in the period before 2015. WCRP already has a good record of concluding major core projects following their successful implementations [*i.e.* TOGA (1985-94), WOCE (1982-2002) and ACSYS (1994-2003)], and of initiating new follow-on projects [*i.e.* CLIVAR (1995) and CliC (2000)]. See **Appendices B** and **C** for further details.

4.4 WCRP Modelling Panel (WMP)

All the WCRP core projects have modelling working groups. In recognition of the central role of modelling in COPES, and the overriding need for coordination of this activity (including linking process modelling to GCMs), JSC-XXV (March 2004) approved the establishment of a WCRP Modelling Panel (WMP). Its prime role is to promote, coordinate and integrate modelling activities across WCRP with the purpose of meeting the WCRP objectives, especially in the context of COPES. It will be necessary to assess models against metrics and periodically evaluate progress. Its members include specified JSC members, one of whom chairs the Panel, the Chairs of WGNE, WGCM, WOAP (see **section 4.5**) and the project modelling groups, and IGBP and IHDP have each been invited to provide a representative.

Terms of reference for the WCRP Modelling Panel are:

a. to coordinate modelling activities across WCRP and facilitate collaborations where appropriate;

b. to focus on the prediction and projection aspects of COPES and effective use of coupled models for identification of climate system predictability;

c. to act as a focus for the development of new generation models;

d. to liaise closely with the WCRP Observations and Assimilation Panel (WOAP, see **section 4.5**) on the requirements for and uses of observations in models (*e.g.* issues of data analysis, reanalysis, assimilation, model initialization, identifying observational gaps and deficiencies in relation to predictive skill and to understanding and parametrizing processes);

e. to oversee data management in WCRP modelling activities;

f. to coordinate international efforts to move to a common modelling infrastructure;

g. to liaise with the modelling activities of IGBP, IHDP and THORPEX.

The WCRP Modelling Panel reports to the JSC.

4.5 WCRP Observations and Assimilation Panel (WOAP)

In recognition of the WCRP need as expressed in COPES to also provide a focus on and coordination of the observational aspect of its activities, JSC-XXV (March 2004) also approved the establishment of the WCRP Observations and Assimilation Panel (WOAP). The co-sponsored Atmospheric Observation Panel for Climate (AOPC) and the Ocean Observations Panel for Climate (OOPC), are recognised as key parts of WCRP. It is important to note therefore that the responsibilities and tasks of the WOAP will be fully complementary to, and closely interactive with, those of GCOS, the Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS), and also with the corresponding observational and assimilation groups and efforts within existing WCRP projects and other activities. Its members include specified JSC members, one of whom chairs the Panel, representatives of project observational activities, the Chair of the WCRP Modelling Panel (see **section 4.4**), representatives from major reanalysis centres, and possibly other experts as necessary and appropriate.

Terms of reference for the WCRP Observations and Assimilation Panel are:

a. to define observational requirements for climate system analysis and prediction and assist in optimization of observational strategies for sustained observation and to act as a focal point for WCRP interactions with other groups and programmes;

b. to promote and coordinate synthesis of global observations from the atmosphere, oceans, land and cryosphere, and for the fully-coupled system, through analysis, reanalysis and assimilation activities across WCRP, including the Modelling Panel (see **section 4.4**);

c. to promote and coordinate WCRP information and data management activities, including development of web sites, in liaison with WCRP projects.

JSC-XXV (March 2004) approved that any further activities of the *ad hoc* WCRP Satellite Working Group should be part of the remit of the WOAP, including the need to maintain and develop further close and strong working relationships with space agencies.

The WCRP Observations and Assimilation Panel reports to the JSC.

4.6 Data issues

The WMP and WOAP will need to interact closely and collaborate with each other, as well as with the WCRP projects and other activities, to develop a comprehensive and workable data policy and framework for WCRP. This must include mechanisms and structures necessary for management, stewardship and access of data, climate system data assimilation, synthesis and reanalysis, and model initialisation. The need to get observations of the wider climate system analysed and reanalysed in the context of models of the system is absolutely central to the COPES strategy. Where appropriate, these data issues will be tackled *via* expert study groups, workshops and conferences involving experts in: *in situ* and space observations of the Earth system; assimilation and modelling of the coupled climate system; continued reanalysis of climate observations; and, dynamical prediction of weather and climate as an initial-value problem.

Based on its own experiences and taking account of data management activities in WMO, including THORPEX, GEO/GEOSS and GODAE, WCRP will determine a policy for its data management, with a set of principles including free and open access, a strategy for its development and implementation, and a set of requirements for data stewardship, archiving and access.

4.7 Specific WCRP objectives within the context of COPES

Under COPES, the JSC for the WCRP will identify a number of activities with defined specific objectives that have a clear rationale for their importance and relevance, with associated time-scales for achieving them, and milestones and metrics to map out and measure their progress. At the end of the time-period for each objective, probably 1-3 years, a publication synthesizing the scientific status and understanding of the topic should be produced.

These specific objectives will be in areas where rapid progress is both needed and possible and will often be in areas where contributions from more than one project or working group are required for rapid progress. The specific objectives will be designed to increase understanding, determine predictability, to improve the representation of key processes in models and to improve the models' ability to simulate and predict climate.

Today the WCRP consists of four major core projects, several working groups, and various cross-cutting and co-sponsored activities (see, for example, **Boxes 2** and **4**) that are designed to improve scientific understanding and knowledge of processes that in turn result in better models. These activities play the central role in WCRP and many of the specific objectives being identified and discussed are already being addressed to some extent within WCRP's existing core projects and other activities (see **Appendix B**). Initial topics for such objectives already being considered by the JSC include aspects of seasonal prediction, monsoons, atmospheric chemistry and climate, sea-level rise, and anthropogenic climate change. The necessary effort to achieve specific objectives related to these and other topics will, in general, continue to be promoted through the WCRP projects. However, the JSC envisages a greater involvement of the wider community, including decision makers and stakeholders whose participation from the beginning will help determine what avenues of research and experimental products might be of the greatest value.

Under COPES, a number of new themes, topics and objectives should emerge reflecting the opportunities and challenges outlined in **section 2.2**. For example:

Atmospheric chemistry-climate interactions
Exploitation of new data streams
Extreme events
Earth system models
Earth system data assimilation
Development of new generation models
Variability and change in the water cycle.

Droughts such as this one in Australia in 2005 cause widespread economic loses and suffering. WCRP will work towards better understanding of droughts and their predictability. [Aus Gov DFAT]

Some examples of specific objectives related to ongoing research topics within the WCRP core projects and other activities, and also other suggested possible topics and objectives are listed in **Appendix E**. The JSC specifically invites comments on the tentative specific objectives listed in **Appendix E** and welcomes further suggestions (**Appendix F**). Suggestions for new specific objectives proposed from the WCRP projects and more generally from the wider community will be considered by the JSC at its annual meeting, usually held in March, and a small number will be selected for further development.

4.8 Early WCRP actions stimulated by the COPES strategy

Many objectives will be squarely in the area of an ongoing component of a single WCRP core project or other activity. However, Workshops and Task Forces (or Limited-life Working Groups) drawing from across WCRP will be appropriate for achieving, or helping to achieve, other objectives.

The first major action by JSC under the developing COPES strategic framework was the decision at JSC-XXIV (March 2003) to establish a limited-term WCRP Task Force on Seasonal Prediction (TFSP). This recognised the importance of seasonal prediction as a specific objective. Consistent with the philosophy of COPES, the TFSP is led by an existing group, the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP), and has drawn on the expertise in all WCRP activities. The prime aim of the TFSP is to determine the extent to which seasonal prediction of the global climate system is possible and useful in all regions of the globe with currently available models and data. To this end, the TFSP organized an expert workshop (Hawaii, USA, November 2003) to help assess the extent to which seasonal prediction is possible and to help identify the challenges that need to be addressed within the international framework and research agenda of the WCRP. Subsequently, JSC-XXV (March 2004) welcomed and endorsed the TFSP's proposal for a 'Total Climate System Prediction Experiment', and requested that this should be further developed. A further TFSP workshop towards planning the implementation of this proposal was duly held in Trieste, Italy, August 2005.

Another early example of the application of the COPES philosophy at JSC sessions was the consideration at JSC-XXVI (March 2005) of WCRP monsoon studies informed by a joint report from the CLIVAR and GEWEX Scientific Steering Groups. In welcoming this, the JSC also approved a WCRP-wide Monsoon Workshop that was held at the University of California, Irvine, USA, June 2005. Because of the way the WCRP projects have developed, there are significant efforts on monsoon systems world wide in several major WCRP activities – especially CLIVAR, GEWEX and CEOP. The purpose of the workshop was to bring all the relevant WCRP activities together to develop a coordinated strategy for addressing monsoons in the future. This is clearly very much within the spirit and intention of the COPES strategic framework.

WCRP aims to reduce the uncertainty in sea-level rise projections by determining how best to estimate the thermal expansion of ocean water, glacier and ice sheet melt and storage of water on land.

JSC-XXVI (March 2005) also approved, as a COPES initiative, a proposal to hold a workshop aimed at understanding sea-level rise and variability. A Steering Committee has been established with a view to organizing the workshop at IOC/UNESCO, Paris, in 2006.

A recent activity towards the major topic of Earth system data reanalysis was the workshop on ocean data reanalysis (Boulder, USA, November 2004) organized by the CLIVAR Global Synthesis and Observations Panel (GSOP). Other workshops aimed at aspects of the suggested specific objectives were the WGNE/WGSIP/WGCM Workshop on Ensemble Methods (Exeter, UK, October 2004) and the WGNE/WGCM Workshop on Regional Climate Modelling (Lund, Sweden, March 2004). Another good example of what is now embraced in the COPES strategy was the Workshop on Climate Feedbacks (Atlanta, USA, November 2002), which was held jointly between the GEWEX Radiation Panel (GRP) and WGCM, in order to foster development of integrative data analysis methods. This was in direct response to the JSC's recognition that the complicated and unresolved issues of clouds and their interactions with radiation and therefore the climate should be examined afresh and jointly by the GRP and the WGCM as a matter of urgency.

Other topics for possible new and repeated workshops should follow from consideration of the specific objectives for WCRP. In some cases, these might be organized by, or lead to the establishment of, limited-term Task Forces.

4.9 Improving communications with key partners

The observation and prediction that lie at the centre of COPES emphasise the central role that satellite agencies and NWP and climate modelling centres have played to date and must continue to play in future WCRP activities. In order that there should be a highly effective, two-way flow of information, the JSC will consider more effective communications mechanisms, including the notion of a high-level 'WCRP Partners Board', which such agencies and centres could be invited to join. Any such new initiatives would need to be consistent and compatible with the overall governance of the WCRP as laid down by WMO, ICSU and the IOC.

5. CONCLUDING COMMENT

COPES is the strategic framework for WCRP and its projects and activities over the next decade (2005-2015) that will enable it to rise to the scientific challenges posed by the understanding and prediction of the behaviour of the Earth system, and to the practical challenges of ensuring the reality of the societal benefits that should flow from this science. All past and existing WCRP activities have been conceived and developed with the help of a wide community of climate scientists. This tradition will prevail within the COPES strategic framework because of the need for continuing discussion of detailed strategy, including themes, specific objectives and priorities, in the JSC, throughout the WCRP projects and more widely. While this process may be difficult, the significant potential benefits for society are so great that these challenges must be pursued vigorously and successfully.

APPENDIX A

THE WORLD CLIMATE PROGRAMME

The First World Climate Conference in 1979 drew attention to climate as an issue of international importance, recognising the impacts of climate extremes and the potential for climate change. As a consequence, in 1980 the World Climate Programme (WCP) was established as an inter-agency, interdisciplinary effort of the United Nations and the International Council for Science (ICSU) to address the major climate issues.

The WCP has four principal components:

1. The World Climate Data and Monitoring Programme (WCDMP) of WMO;
2. The World Climate Applications and Services Programme (WCASP) of WMO;
3. The World Climate Impact and Response Strategies Programme (WCIRP) of the United Nations Environment Programme (UNEP)
4. The World Climate Research Programme (WCRP) of WMO, ICSU and the IOC of UNESCO.

WCDMP exists to develop all-round climate data management systems, and to make the best data from global climate observing systems readily available to WMO Members. It produces results in formats suitable for use in modelling climate processes as well as detecting and monitoring climate change and variability and assessing their impacts, all with practical applications and services in mind.

The purpose of WCASP is to help WMO members and relevant international organizations maintain public safety, health and welfare, alleviate poverty and promote sustainable development by extending the applications of climate science and related services. The main vehicle for activities over the medium term is the Climate Information and Prediction Services (CLIPS) project.

WCIRP is implemented by UNEP. Within WMO, activities relevant to WCIRP are managed mainly under WCASP, bearing in mind the intimate linkages between climate impact assessments, applications and measures designed to mitigate adverse impacts of climate change and variability.

WCRP exists to develop the basic scientific understanding needed to determine the extent to which climate can be predicted and the extent of human influence on climate. It investigates scientific uncertainties surrounding the Earth's climate system. Its work also reflects the scientific priorities of the IPCC, including continuous improvement of physical mathematical models for simulating and assessing the predictability of the climate system under differing conditions.

The WCP's structure within WMO also includes subsidiary programmes for coordinating activities that serve the Climate Agenda, and support for activities related to climate change (in particular the IPCC), as well as for operating and developing the Global Climate Observing System (GCOS).

APPENDIX B

WCRP CURRENT ACTIVITIES

B.1 Programme organization

The range of studies involved in climate research requires input from many scientific disciplines, and co-operation among governmental and non-governmental organizations and the academic community. Such co-operation is therefore formally recognised and promoted by the Agreement among the World Meteorological Organization (WMO), the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, which makes the WCRP a collaborative undertaking of the three organizations. A WMO/ICSU/IOC Joint Scientific Committee (JSC) has the responsibility of formulating the overall scientific concepts and goals of the WCRP, as well as organizing the required international co-ordination of research efforts. The latter responsibility is undertaken with the assistance of a small permanent Joint Planning Staff, located in WMO, Geneva, and a few (currently four) International Project Offices dedicated to the WCRP core projects.

WCRP pursues its objectives through a number of large-scale research, observational and modelling projects, and related activities, focused on aspects of the climate problem that require international commitment, co-ordination and collaboration. This *modus operandi* is reflected in the current main WCRP core projects, namely: the Climate Variability and Predictability (CLIVAR) project; the Global Energy and Water Cycle Experiment (GEWEX); the Stratospheric Processes And their Role in Climate (SPARC) project; and the Climate and Cryosphere (CliC) project. Also, jointly with the International Geosphere-Biosphere Programme (IGBP), the Scientific Committee on Oceanic Research (SCOR), and the Commission on Atmospheric Chemistry and Global Pollution (CACGP), the WCRP co-sponsors the Surface Ocean-Lower Atmosphere Study (SOLAS). Additionally, the development and application of comprehensive computer models of the full global climate system is a major cross-cutting, unifying and integrating theme running through the WCRP, pulling together and building on the scientific and technical advances achieved in each of the individual projects. All these projects have been conceived and developed with the help of a worldwide community of climate scientists.

WCRP also promotes and sponsors a wider range of joint projects and other activities within the Earth System Science Partnership (ESSP); see **section B.10**.

B.2 Climate Variability and Predictability (CLIVAR) Project

CLIVAR is concerned with the natural variability of the coupled climate system and the changes in response to natural processes and human influences. A particularly important CLIVAR focus is on the role of the ocean in climate. CLIVAR is the planned natural successor to both TOGA (1985-94) and WOCE (1982-2002) (see **sections C.1** and **C.2**, respectively, of **Appendix C**). CLIVAR addresses these issues on all climate timescales from seasons (monsoons) to centuries (anthropogenic influence).

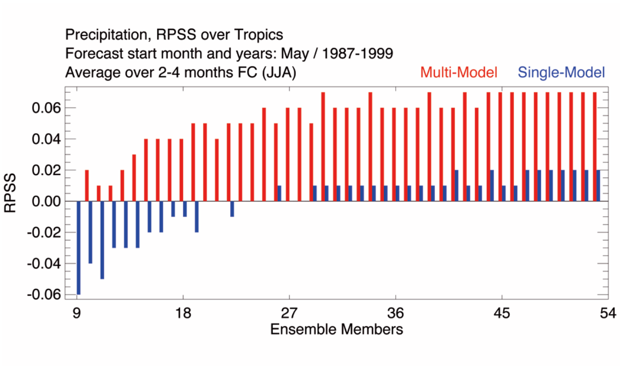
The specific objectives of CLIVAR are:

- 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 palaeoclimatic and instrumental data sets;
- to extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models;
- to understand and predict the response of the climate system to increases of radiatively active gases and aerosols and to compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

CLIVAR will help to answer questions such as:

- Will there be an El Niño next year?
- What will next summer be like in Asia and will the next monsoon there cause droughts or floods?
- What will the next winter be like in northern Europe, 'warm and wet' or 'cold and dry'?
- How is the planet warming from human influences?
- How much sea-level rise will there be in the 21st century?
- Will there be more extreme weather events because of global warming, and will these be more intense and widespread?
- Could climate make a sudden switch?

CLIVAR has a particular focus on the world's monsoonal systems. Specific recent advances include: preparation of an atlas of African climatology; establishment of an Indian Ocean Panel, jointly with IOC, to help drive forward the implementation of ocean observations in the region; and, the successful execution of the SALLJEX (South American Low-Level Jet Experiment) field campaign, which was a major contribution to the Variability of the American Monsoon System (VAMOS) project. Major studies of the role of the oceans in climate are also being organized, in particular: variability of the thermohaline circulation in the Atlantic; dynamics and predictability of the Atlantic inter-tropical convergence zone and its regional influences on climate; atmospheric forcing and upper-ocean teleconnections and feedbacks involving tropical sea surface temperature; the Kuroshio extension; and, Pacific upwelling. Increased emphasis is being placed on ensuring the application of CLIVAR results. To this end, the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP) is leading a major preliminary initiative under the WCRP Coordinated Observation and Prediction of the Earth System (COPES) strategy (see **section 4.8** of the main text) to determine the extent to which seasonal prediction is possible and useful in all regions of the globe with currently available models and data.



Relative performance, as measured by probabilistic skill, of the DEMETER multi-model (red bars) and the ECMWF coupled model (blue bars) ensemble predictions of boreal summer precipitation over the tropics as a function of the ensemble size. The DEMETER multi-model ensemble is based on 7 coupled models. Note that the multi-model ensembles perform better than the single model ones even at small ensemble sizes. [Palmer et al., 2004]

The First International CLIVAR Science Conference, Baltimore, USA, June 2004, assessed progress to date and identified continuing and new challenges for CLIVAR. A major topic of the Conference was how best to deliver the knowledge, products and information achieved by CLIVAR research to end-users, decision and policy makers. Recognizing the opportunity presented by the conference, the CLIVAR Scientific Steering Group (SSG) initiated an assessment of CLIVAR for consideration at the SSG meeting that followed immediately. The objectives of that exercise were to measure what progress had been made to date against the CLIVAR objectives and to provide the SSG with the necessary input to determine what steps might be necessary to ensure future progress. For example, whether changes to the project structure might be desirable or if certain CLIVAR panel efforts should be redirected. The outcome was a set of comprehensive and helpful critical assessments from an international team of expert assessors, which influenced significantly the discussions and decisions of the CLIVAR SSG.

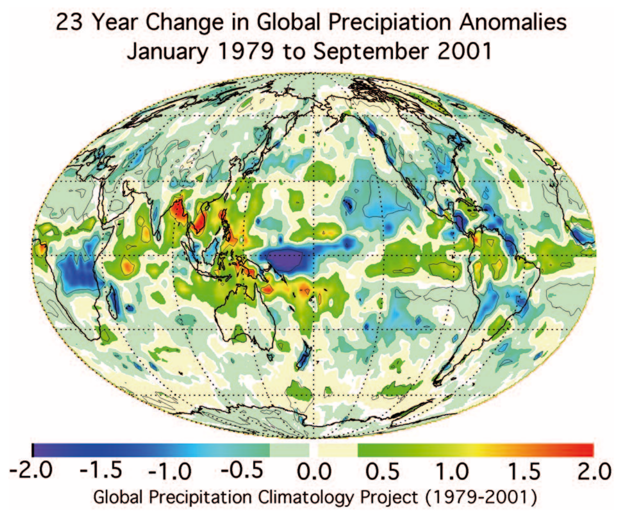
The CLIVAR agenda of maintaining or developing the necessary observational systems [together with the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS)], process studies and modelling is also advancing at a healthy pace. Recent advances include the global expansion of the Argo profiling float network, transition of the WOCE Data Assembly Centres into CLIVAR, launching of an unprecedented number of satellites with ocean observing missions, and two new missions with ocean relevance that have been selected for further development.

B.3 Global Energy and Water Cycle Experiment (GEWEX)

GEWEX provides the scientific focus in WCRP for studies of atmospheric, hydrologic and thermodynamic processes that determine the global hydrological cycle and energy budget and their natural variability, and their adjustments to global changes such as the increase in greenhouse gases. A crucial issue is: 'Can the Earth system provide adequate water resources for human and other requirements in the future?' Related principal scientific questions that guide the international research effort are:

- is the rate of cycling of water through the atmosphere changing as a result of climate change?
- to what extent are variations in local weather, precipitation, and water resources responses to global climate change (rather than climate variability)?
- how well can precipitation be predicted on temporal and spatial scales of interest for hydrological applications?
- how can the cumulative outcome of wet atmospheric processes be accurately taken into account (parametrized) in weather forecasting and climate models?

Significant improvements in modelling and predicting precipitation have been realized from GEWEX research into land-atmosphere interactions and related model parametrizations. However, in general, weather and climate models still cannot predict precipitation with sufficient resolution and accuracy (both in spatial and temporal resolution) to be effective in many water resource applications. GEWEX has also made substantial contributions to understanding the requirements for data to support climate trend analysis based on the experience gained in producing and analyzing global data sets for key water cycle variables from over 20 years of satellite data. GEWEX research is now focusing on the land surface and hydrologic processes and cloud and precipitation mechanisms and their representations in models to improve such model predictions.



23 year change in global precipitation anomalies, January 1979 to September 2001, as obtained by the Global Precipitation Climatology Project (units are in mm/day). Observations used in this data set include data from over 6000 rain gauges (provided by the Global Precipitation Climatology Centre), infrared data from NOAA polar orbiting satellites and microwave data from the US Defense Meteorological Satellite Programme.

GEWEX has now begun a new major phase of its implementation, aimed at a fully global description of the Earth's water cycle and energy budget, at the development of improved capabilities for forecasting of precipitation on climate time scales and for predicting changes in the water cycle associated with global change, and at the development of closer links with the water resource and applications communities. This approach requires greater integration between *in situ* and satellite observations, models and data assimilation capabilities.

An excellent illustration of this evolution is evident in the development and implementation of a major new component of GEWEX and the wider WCRP, the Coordinated Enhanced Observing Period (CEOP). CEOP is compiling a comprehensive data set (from *in situ*, satellite and modelling sources), in order to achieve a global description of the various components of the water cycle for the years 2002-2004, as a basis for simulation and prediction experiments. It has been endorsed by the Integrated Global Observing Strategy Partnership (IGOS-P) as a pilot study contributing to the IGOS Integrated Global Water Cycle Observations Theme, in which WCRP plays a leading role. CEOP could also prove to be an instructive preliminary campaign in the context of the emerging COPES strategy (see **section 2.3** of the main text).

CEOP's main observation and data collection period was completed at the end of 2004. In conjunction with other components of the WCRP, CEOP and GEWEX aim to assess the influence of continental heat and moisture sources and sinks on the global climate system. Data from the first CEOP enhanced observation period, July-September 2001, have already been archived at the CEOP Data Centre at the University of Tokyo, and the first composite products are available on the Internet and are already being used to assess the quality of operational numerical weather forecasting and climate models. In a relatively short time, CEOP has established three unique capabilities. Firstly, it has established a prototype of the global water cycle observation system of systems, cooperating with the 36 CEOP reference sites, the space agencies and 11 operational numerical weather prediction centres. In this context, leading CEOP scientists have been instrumental in the development of the global water requirements for the intergovernmental GEO, as reflected in the 10-year implementation plan for the GEOSS (see **section B.7**). Its other unique capabilities are:

- the establishment of an international framework for archiving these data and providing them to the international science community. This involves data archived at three locations: the UCAR/JOSS Central Data Archive, USA; the Max-Planck Institute for Meteorology and the German Computing Centre, Hamburg; and the Satellite and Data Integration System, University of Tokyo.
- the establishment of distributed and centralized data integration functions whereby users can access all kinds of data through a web interface. The facilities available in this context have recently been opened to the international community.

Another major activity, sponsored by both GEWEX and CLIVAR, is the African Monsoon Multidisciplinary Analysis (AMMA) being planned as a follow-up to, and extension of, the earlier CATCH (Coupling of the Tropical Atmosphere and Hydrological Cycle) project. The other GEWEX continental-scale experiments continue to be pursued and to make greater contributions to cross-cutting activities such as precipitation analysis, water and energy budgets and water resource applications.

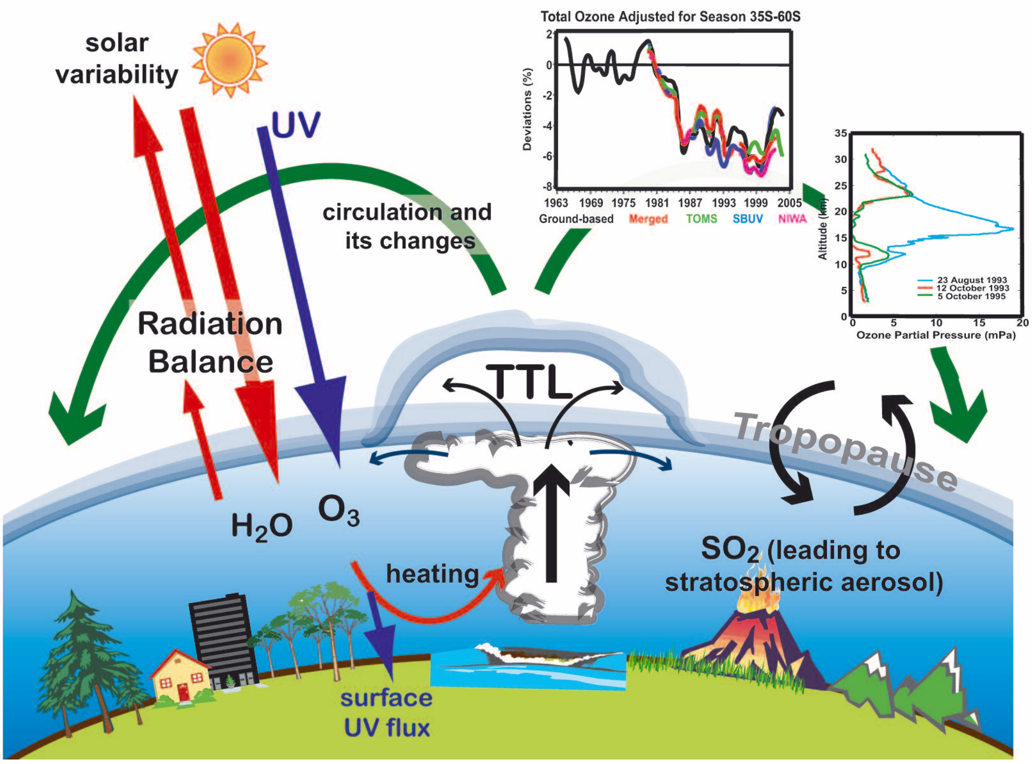
Monsoons are a global phenomenon and monsoonal precipitation is significant not only for the Asian-Australian region, but also for North and South America and West Africa. Monsoon onset, intraseasonal variability, withdrawal and prediction have great societal implications. GEWEX continental-scale experiments and the related CEOP are providing data and a research focus to address these issues, in collaboration with the corresponding and complementary monsoonal studies promoted under CLIVAR.

WCRP, through GEWEX, and UNESCO jointly sponsored a workshop on the 'Applicability of Climate Research for Water Management in Semi-arid and Arid Regions', which was held in Cairo, Egypt, April 2005. This was in part response to concerns expressed to WMO some time ago by the League of Arab States that more attention should be paid to the research needed to understand the climate processes and effects of climate change in arid and desert regions. The workshop attracted water managers and other stakeholders from a good number of Arab States and also other experts from within the WCRP and UNESCO communities.

The 5th International Scientific Conference of the Global Energy and Water Cycle, organized by GEWEX, was held in Costa Mesa, California, USA, June 2005. It attracted participants from 27 countries.

B.4 Stratospheric Processes And their Role in Climate (SPARC) Project

The WCRP SPARC project has the objectives of investigating the influence of the stratosphere on climate and the coupled chemical, dynamical and radiative processes that control changes in the stratospheric circulation and composition, including particularly ozone depletion and increased penetration of ultra-violet radiation into the troposphere. SPARC continues its significant efforts in the detection of stratospheric trends, which could indicate climate change or could affect climate. In particular, SPARC studies of long-term changes of temperature, water vapour and ozone in the stratosphere have underlined that trends in one variable are closely linked to those in others, and that an integrated approach is required to understand stratospheric changes. It is generally acknowledged that the first decade of SPARC research has generated significant and important results and the project has received wide international recognition.



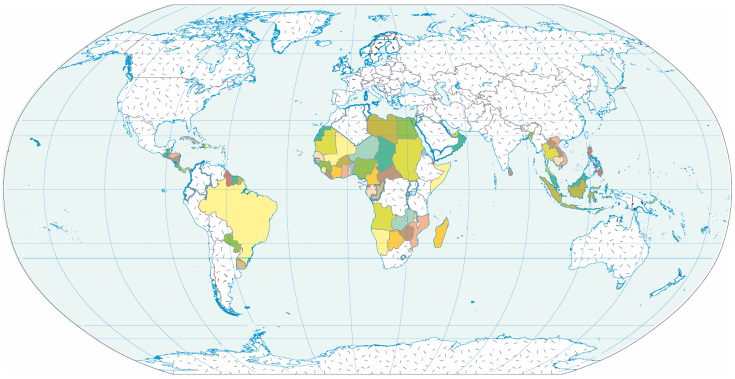
Various influences of the stratosphere on climate, which form the core of SPARC research, are depicted.

SPARC has recently elaborated new strategic areas of research, namely: the detection, attribution and prediction of stratospheric changes; stratospheric chemistry-climate interactions; and, stratosphere-troposphere coupling. Recent SPARC activities have been concerned with stratospheric indicators of climate change and their interpretation, various assessments and development of stratospheric data assimilation. In addition, SPARC has led to international efforts to identify and remedy deficiencies in the representation of the stratosphere in climate models. Through the analysis of observations and modelling, evidence has been obtained of a significant impact of stratospheric processes on tropospheric predictability. It has been possible to use the new generation of models to reproduce the appearance of the ozone hole in the polar stratosphere. New techniques for blending data from different sources have generated a basis for new assessments of stratospheric trends including the so far unexplained positive water vapour trend in the lower stratosphere. SPARC has conducted an assessment of stratospheric aerosol and a further new SPARC initiative will be an assessment of polar stratospheric clouds.

A critical issue is the change of atmospheric composition and its impact on climate. This has not yet been addressed sufficiently but plans are in place to combine the effort, experience and expertise in both WCRP and IGBP to move towards a better description of the role of atmospheric chemistry in climate change and the development of full chemistry-climate models. Jointly with the International Global Atmospheric Chemistry (IGAC) Project of IGBP, SPARC is supporting the development of a new system for verification of global climate models that have a comprehensive atmospheric chemistry module. 'Chemistry-climate interactions' was the central topic of the third General Assembly of SPARC, Victoria, Canada, August 2004.

B.5 Climate and Cryosphere (CliC) Project

The cryosphere comprises those portions of the Earth's surface where water is in solid form (*i.e.* all kinds of ice and snow and frozen ground such as permafrost). It is strongly influenced by temperature, solar radiation and precipitation and, in turn, influences each of these properties. It also affects the exchange of heat and moisture between the Earth's surface (land or sea) and the atmosphere, the clouds, the river flow, and the atmospheric and oceanic circulations. Parts of the cryosphere are strongly influenced by changes in climate and may therefore act as early indicators of both natural and human-induced climate changes.



Strippled areas indicate countries where cryosphere is present.

The new WCRP core project, Climate and Cryosphere (CliC), is a sequel to ACSYS (see **section C.3**, **Appendix C**) and aims to systematically enhance monitoring, understanding and modelling of complex processes through which the cryosphere interacts with the global climate system. Studies have already indicated recent significant changes in the Earth's cryosphere including: record low multi-year sea-ice extent in the Arctic Ocean, with lowest levels in September 2002 and 2003; extensive melting of the Greenland ice sheet since satellite observations began in 1980; break-up of the Larsen B ice shelf in the West Antarctic peninsula in 2002; and, the accelerated melting of mountainous glaciers on all continents. CliC is expected to cover several important gaps in global climate research and observations including investigation of the possibility of additional releases to the atmosphere of greenhouse gases from frozen soils. The first CliC Science Conference was held in Beijing, China, April 2005, and contributed significantly to establishing an international community of scientists, including many young scientists, for the implementation of this important and newest core project – especially in the context of the forthcoming International Polar Year (IPY) 2007-08. Through the leadership of CliC, WCRP is contributing significantly to the planning of the IPY in which climate research and related observations are expected to form a major part.

International research projects like CliC (and ACSYS) not only improve our knowledge of local and global factors of global change but also cover a wide set of temporal scales. Ongoing changes in the Arctic are relatively rapid in climate terms. However, changes in Antarctic and Greenland ice sheets are happening on a timescale of thousands of years. Both short- and long-term predictions of climate change are impossible without at least adequate account of cryospheric processes. Prediction of sea-level rise is another factor of crucial relevance for the IPCC assessments. CliC has an important contribution to make here since a significant fraction of the sea-level rise is likely to be due to the melting of grounded ice. Other global issues of relevance to CliC include: thermohaline circulation (freshening of outflows into the North Atlantic); changes in the Southern Ocean circulation; snow and ice albedo feedbacks; accurate description and representation in models of climate for the regions with permafrost and snow cover; advances in measurement and analysis of solid precipitation.

Since 1995, WCRP has been supporting its International Programme for Antarctic Buoys (IPAB). This has proved its high value in filling gaps in surface meteorological observations in the Southern Ocean. Further, recent assessments have shown that IPAB buoys have helped to reduce uncertainties in the analysis of mean-sea-level pressure in that region and created a significant positive impact on the accuracy of satellite altimetry. All appropriate parties are encouraged to support this programme by co-ordinated deployment of drifting buoys, which report their observations through the WMO Global Telecommunication System.

B.6 Climate modelling

The development of comprehensive global climate models, building on the scientific advances in the WCRP projects and other activities, is an essential unifying theme running through WCRP. Such models are the fundamental tools for understanding and predicting natural climate variations and for providing reliable estimates of anthropogenic climate change. WCRP activities in this area are centred on two main groups: the joint WMO Commission for Atmospheric Sciences/JSC Working Group on Numerical Experimentation (WGNE) and the JSC/CLIVAR Working Group on Coupled Modelling (WGCM).

Efforts continue to be devoted to a wide range of internationally-coordinated model intercomparison exercises as a means of identifying errors in climate simulations and to find ways of reducing errors. In particular, coupled (ocean-atmosphere) model intercomparison projects have been organized, and standardised experiments with coupled models are being undertaken, which should help in reaching consensus on climate change. The results produced by these activities in WCRP have been a key input to all the IPCC Assessments. WCRP will continue to strive to further reduce the uncertainty of global change predictions and to broaden the scope of considered properties thus producing a sounder scientific basis for decision making in all areas where adequate management is dependent on the current and future state of the environment. In particular, the closer collaboration established with the Global Analysis, Integration and Modelling (GAIM), now Analysis, Integration and Modelling of the Earth System (AIMES), element of IGBP is working well, especially in respect to the organization of the Coupled Carbon Cycle Climate Model Intercomparison Project (C4MIP). Also, the Second Coupled Model Intercomparison Project Workshop was held in Hamburg, Germany, in September 2003. Other studies include assessing the dependence of errors in atmospheric models on their basic dynamical cores.

B.7 Climate data

A prerequisite to designing and implementing a comprehensive, integrated and sustained global climate observing system is to identify the principal uses and users of the observations in order to justify such a costly, long-term, internationally collaborative operation. Such uses are:

- monitoring the climate in order to quantify natural climatic fluctuations on a range of temporal and spatial scales and to detect climate change;
- attribution of climate change to particular causes, in particular to human-related causes;
- detection (and attribution) of the environmental impacts of climate change;
- diagnostic studies to advance understanding of the behaviour of the climate system and its components, including the mechanisms of natural climate variability;
- development and testing of hypotheses relating to local and global climate variations and to the degree of predictability of climatic phenomena;
- process studies. Special data are needed for detailed research into a wide variety of complex dynamical, physical, chemical and biological processes, which help govern the state and evolution of the climate system. These often need to be highly resolved in time and space and therefore gathered for a limited period over a restricted area. Note, however, that continuous global data sets provide an excellent and often necessary context for the more focused process-study field campaigns;
- a wide range of uses for climate models, including boundary conditions, initialization, data assimilation, and validation, leading to their improvement, including for seasonal-to-interannual climate predictions.

A very wide array of observations of all elements of the climate system is needed for these highly specialised and important purposes.

Since it began in 1980, the WCRP has been both a major user and provider of climate data and products and one of the main drivers in the planning and development of new Earth Observation instruments, surface-based experiments and satellite missions. In particular, WCRP sponsors with

GCOS, the Atmospheric Observation Panel for Climate (AOPC) and, with GCOS and GOOS, the Ocean Observations Panel for Climate (OOPC).

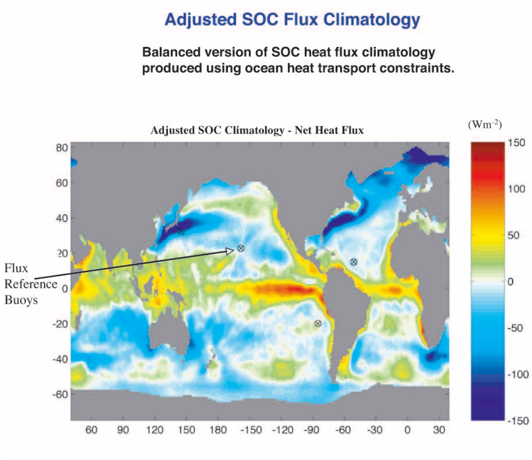
Climate research requires not only exploratory and often short-lived observational field experiments and satellite missions to improve understanding of climate processes, but also long-term monitoring programmes (including analysis, re-analysis cycles) essential to assess the characteristics of the present climate, for use in experimental climate prediction studies, and to detect natural and human-induced climate trends. Future satellite instrumentation will produce very large quantities of new, more detailed and better quality information on the usual meteorological and oceanographic state variables, aspects of the land surface and atmospheric composition. At the same time the *in situ* observational capability is increasing in its possibilities, but not necessarily in its execution. The Argo initiative, an outgrowth from the global array of WOCE subsurface floats, will routinely provide a large increase in the detailed information about the ocean outside the area of sea-ice cover, as an integral part of a developing ocean observing system for climate.

An important context for the observational aspects of WCRP is the Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC (GCOS-82, WMO/TD No.1143, April 2003), which gives lists of specific and detailed requirements for essential climate observations for the atmosphere, oceans and land, and a corresponding list of variables that depend heavily on satellite observations. The report concludes that although there have been recent improvements in implementing the global observing systems for climate, especially in the use of satellite information and the provision of some ocean observations, nevertheless, serious deficiencies remain: *e.g.* atmospheric networks are not operating with the required global coverage and quality; ocean networks lack global coverage and commitment to sustained operation; global terrestrial networks are not fully implemented. Note that satellite data are still not being analyzed and therefore exploited to a sufficient degree. The report also prescribes twenty **GCOS Climate Monitoring Principles**. The 'ten basic principles' were adopted by the UNFCCC in 1999. Ten further principles are aimed specifically at satellite systems. A widespread, disciplined adherence to these principles is necessary to achieve the homogeneous climate record needed for future use, especially for assessing climate change. The 'Second Adequacy Report' also concludes that internationally-coordinated reanalysis activities need to be enhanced and sustained by the involved Parties to meet the requirements for monitoring climate trends, to establish ocean reanalysis for the recent satellite era, and to include variables related to atmospheric composition and other aspects of climate forcing.

Observations from satellites require some special considerations. Since it began in 1980, WCRP has been a major user of satellite data and one of the main drivers in the planning and development of new Earth Observation (EO) instruments and space missions. In particular, a prime practical aim of WOCE was the development of improved ocean models for use in climate studies, but this was envisaged within the context of collecting global *in situ* and satellite data sets to validate and initialize these models. The required revolutionary satellites were launched in the early 1990s. ERS-1 was launched in 1991 and Topex-Poseidon was launched in 1992 and still operates successfully today. A WCRP *ad hoc* Satellite Working Group has produced an 'Update of Space Mission Requirements for WCRP' (January 2003, with further comments in October 2003), which highlights priorities for future space missions and related data management. In particular, the second report (October 2003) of this Working Group has emphasised the needs for a reanalysis of climate-related data sets making full use of all available satellite-borne sensors over the last 20-30 years.

The WCRP was represented at the first Earth Observation Summit (EOS-I), 31 July 2003, and at the inaugural session of the *ad hoc* Group on Earth Observations (GEO-1), 1-2 August 2003, both held in Washington D.C. In particular, an invited short paper ('The Need for a Comprehensive, Integrated and Sustained Climate Observational System') was submitted to EOS-I. WCRP remained directly involved with the *ad hoc* GEO process, especially through two of the five subgroups that GEO-1 initiated, namely, User Requirements and Outreach, and Data Utilization and through the Implementation Plan Task Team. It will continue to provide scientific and technical input to the intergovernmental GEO and to the implementation phase of the Global Earth Observation System of Systems (GEOSS) that were established by EOS-III, Brussels, 16 February 2005.

B.8 Surface fluxes



Global estimates of the annual mean net heat input to the oceans from in situ measurements. [Courtesy S. Josey, National Oceanography Centre, Southampton]

Quantitative analysis and understanding of the underlying physical mechanisms as well as intercomparison and validation of surface energy and mass fluxes are needed in a wide range of WCRP projects. In particular, in recent years a major study and workshop on air-sea fluxes was conducted by a joint WCRP/SCOR Working Group on Air-Sea Fluxes, which provided a comprehensive assessment of physical parametrizations and available flux products from different sources, including both *in situ* and remotely-sensed observations and from analyses produced by numerical weather prediction models. WCRP's continuing interests in surface fluxes are now being served by its co-sponsorship of the IGBP core project, SOLAS, with its focus on the physical and biogeochemical fluxes at the air-sea interface, and by the formation of a new WCRP Working Group on Surface Fluxes, which deals with WCRP's wider requirements and efforts on all relevant fluxes resulting from the interaction of the atmosphere with underlying surfaces of all types.

B.9 Reanalyses

WCRP is a strong advocate of multi-year reanalyses of the atmospheric circulation with state-of-the-art assimilation/analysis schemes. Several operational and research centres are now conducting major reanalysis projects, in particular, ECMWF in Europe, NCEP, NASA, NCAR and DOE in the USA, and the Japan Meteorological Agency. Such reanalyses are essential for a wide range of climate diagnostic studies in support of not only WCRP-related research, but also many operational services and applications and are highly sought after and used by the international research and operational communities. The comprehensive, now 45-year (1957-2002), ECMWF reanalysis (ERA-40) was completed in April 2003 and a wide range of ERA-40 products are now available on the Internet. Also, the Japan Meteorological Agency's 25-year reanalysis (JRA-25 for 1979-2004) is progressing well.

In addition, there is a growing need and interest within WCRP to encourage, promote and coordinate other types of major reanalyses, specifically, for the oceans and for special regions such as the Arctic and for the total climate system. In particular, a major ocean reanalysis would produce a potentially very effective long-term time series for studies of ocean climate variability worldwide.

B.10 Earth System Science Partnership (ESSP)

The essence of WCRP science is understanding, observation, quantification, prediction and projection of the climate system. Whilst WCRP research has a firm foundation in the physical system it is increasingly concerned with the more complete climate system that includes the two-way interactions with the chemical and biological systems and, more widely, with the effect of human activities upon the global climate and other global environmental changes. In this context, significant progress is being made under the banner of the Earth System Science Partnership (ESSP), which was initiated by WCRP, IGBP, IHDP and DIVERSITAS (an international programme of biodiversity science) following the successful Global Change Open Science Conference, 'Challenges of a Changing Earth', Amsterdam, July 2001. The Proceedings of that conference, edited by W. Steffen, J. Jäger, D. J. Carson and C. Bradshaw, were published by Springer, 2002. The ESSP has been established to further the integrated study of the Earth system, the changes that are occurring to the system, and the implications of these changes for global sustainability. At this early stage of its development, the ESSP is undertaking three types of activity: joint projects; regional activities; and, global change open science conferences. The first four ESSP joint projects are: Global Carbon Project (GCP); Global Environmental Change and Food Systems (GECAFS); Global Environmental Change and Human Health; and Global Water System Project (GWSP). In each case, the goal is to identify the challenges caused by global change, understand the implications of human-driven change, and build a research agenda of direct relevance for societies. A milestone in the evolution of the ESSP was the publication of the Science Framework and Implementation document of the Global Carbon Project (2003) as the first 'ESSP Report'. The corresponding documents for GECAFS (ESSP Report No.2) and GWSP (ESSP Report No.3) followed in 2005. The ESSP is also organizing a second Global Environmental Change Open Science Conference, entitled 'Global Environmental Change: Regional Challenges', which will be held 9-12 November 2006, Beijing, China.

B.11 WCRP support of the Intergovernmental Panel on Climate Change (IPCC)

The JSC intends to reinforce the WCRP's efforts in the research priority areas signalled in the IPCC Third Assessment Report (especially those listed under modelling and process studies), and is actively seeking improved and more direct involvement with IPCC to identify additional issues that might be taken up by the WCRP. It is a prime intention of the JSC to achieve better integration of the IPCC requirements with the research performed under the WCRP. In particular, the JSC is keen that relevant expertise and results from WCRP activities should be made available in the preparation of the IPCC's future assessment reports.

B.12 Development of climate research capabilities at the regional level

The WCRP continues to promote the development of regional climate research capabilities through the active involvement of scientists worldwide in its activities in order to meet its scientific challenges and to deliver research results relevant to the entire global community. In particular, WCRP has achieved this through: the GEWEX continental-scale experiments being conducted in Africa, Asia, Australia, the Americas, and Europe; through the 36 active reference sites associated with the CEOP, which has extended the geographical distribution of experimental sites related to the continental-scale experiments; and through the major CLIVAR and GEWEX studies of monsoon systems in Africa, the Americas, Asia and Australia. Also, WCRP continues to co-sponsor the global change SysTem for Analysis, Research and Training (START), in partnership with IGBP and IHDP, and is seeking to strengthen its links with other programmes and organizations involved directly with developing scientifically-relevant research networks in developing countries [*e.g.* WMO WCASP, Asia-Pacific Network for Global Change Research (APN), Inter-American Institute for Global Change Research (IAI), European Network for Research in Global Change (ENRICH), The Academy of Sciences for the Developing World (TWAS), and the New Partnership for Africa's Development (NEPAD)]. Of necessity, this is being done within the limits of available resources within WCRP and with due regard to the full range of WCRP priorities.

APPENDIX C

WCRP ACHIEVEMENTS

During the 25 years of its existence, WCRP has enabled many achievements consistent with its aims, especially by advocating and coordinating research programmes among nations.

C.1 Tropical Ocean and Global Atmosphere (TOGA) Project

The WCRP TOGA project (1985-94) established the physical basis for the understanding and predictions of El Niño temperature signals and associated changes in the global atmospheric circulation from a season to a year in advance. This was a major breakthrough in (operational) seasonal forecasting and the TOGA project is widely recognized as being the first major success of the WCRP. The substantial progress it achieved is reflected in the present skill levels in seasonal-to-interannual predictions. In particular, it provided:

- improved physical understanding of the climate system. A new depth of understanding of the El Niño - Southern Oscillation (ENSO) phenomenon was achieved; theoretical models for the mechanism of ENSO were proposed, and the relationships between tropical sea surface temperature (SST) perturbations and the atmospheric response in middle latitudes began to be unravelled;
- a new capability to measure the upper ocean, using both enhanced *in situ* observations and remotely-sensed measurements, particularly for the previously poorly-sampled tropical Pacific;
- the development of increasingly realistic coupled ocean-atmosphere models particularly of the tropical Pacific Ocean, some of which now demonstrate skill in predicting tropical SSTs months to a year or so in advance; in particular, the predictability of El Niño (at least on some occasions) has been demonstrated;
- the availability of long (in many cases multi-decadal) data sets with stringent quality control, in particular for global SSTs and reanalyses for the atmosphere; and
- more-advanced techniques, not only for providing observations but also for their analysis and assimilation into atmospheric and ocean models.

In 1998, the American Geophysical Union published nine extensive review articles summarising the development of knowledge and capabilities during the TOGA project. These were reprinted from the *Journal of Geophysical Research*, in a special issue entitled, 'The TOGA Decade: Reviewing the progress of El Niño research and prediction', and edited by D. L. T. Anderson, E. S. Sarachik, P. J. Webster and L. M. Rothstein.

C.2 The World Ocean Circulation Experiment (WOCE)

A highlight of WCRP was the successful conclusion of the World Ocean Circulation Experiment (WOCE), the oldest of WCRP's projects, which was formally completed at the end of 2002. Through its planning, observational and analysis phase, WOCE lasted two decades and was by far the biggest and most successful global ocean research programme to date. Its legacy includes: significantly improved ocean observational techniques (both *in situ* and satellite-borne); a first quantitative assessment of the ocean circulation's role in climate; improved understanding of physical processes in the ocean; and, improved ocean models for use in weather and ocean forecasting, and in climate studies. In particular, it is most commendable that within four years of the last data being collected, the WOCE data resource (about 20 Gbytes) had been quality-controlled and freely distributed on DVDs and *via* the Internet. WOCE results are documented in almost 1800 refereed publications, a highly-regarded 'WOCE book', 'Ocean Circulation and Climate: Observing and Modelling the Global Ocean', was published in 2001 (edited by G. Siedler, J. Church and J. Gould, Academic Press, 2001), and a four-volume WOCE Hydrographic Atlas is near to completion. The first volume for the Southern Ocean was published in April 2005. The second volume, on the Pacific Ocean, is expected to be published by the end of 2005. The final two volumes, for the Indian Ocean and the Atlantic Ocean, will be completed in 2006. This publication represents a valuable oceanographic product from WOCE, and therefore from the WCRP. Much remains to be done in the exploitation of WOCE observations and in the further development of schemes to assimilate data into ocean models. These aspects of ocean research and model development are now being incorporated, as planned, into the WCRP Climate Variability and Predictability (CLIVAR) project, which was designed as the successor to both the TOGA project (1985-94) and WOCE (1982-2002).

C.3 Arctic Climate System Study (ACSYS)

Another recent highlight was the successful completion of ACSYS, which was established in 1994 to better understand the role of the Arctic in the global climate system. It has examined the complex, interrelated pieces of the Arctic climate puzzle, to find out how delicately balanced the Arctic climate system is, and to ascertain its role in global climate change. It has addressed such questions as: what are the roles of Arctic Ocean water and sea-ice in driving the deep Atlantic Ocean circulation; what are the global consequences of natural or human-induced changes to Arctic climate; is the Arctic climate system as sensitive to increased greenhouse gas concentrations as climate models suggest? ACSYS finished with a final international science conference, 'The ACSYS decade and beyond', held in St. Petersburg, Russia in November 2003. The achievements of the 'ACSYS decade' include: creation of a basis for improved numerical simulations and reanalysis studies of the complex system involving polar atmosphere, oceans, sea-ice, and land; active deployment of sea-ice based drifting buoys by the International Arctic Buoy Programme, declassification of a large number of submarine sea-ice observations, deployment of moored sonars, intensification of ship-based studies, generation of new satellite products, and collection and upgrading of circumpolar data sets; providing a rationale for maintaining meteorological observing networks in remote locations; stimulation of enhanced regional (Arctic) process studies; intercomparison projects which have led to advances in modelling of the polar environment and created a better basis for projections of amplified impact of the climate change in the polar region (an important aspect of the IPCC assessments).

C.4 Global Energy and Water Cycle Experiment (GEWEX)

The completion of the first phase of GEWEX was celebrated at its fourth International Scientific Conference, held in Paris in September 2001. GEWEX Phase I accomplishments include 10-25 year global datasets of clouds, precipitation, water vapour, surface radiation, and aerosols.These have served as a first global reference for such fields and provide new insights about seasonal, interannual and regional variability. These global data sets, which now cover up to 20+ years making use of both *in situ* as well as remotely sensed data, with participation by the major environmental satellite agencies, have supported the assessment of present climate and the validation of climate change models. Also, implementation of improved land-surface and cloud parametrizations, developed through GEWEX research, in many regional and global weather forecasting and climate models has led to improved representation and prediction (in operational models) of precipitation. On a regional basis, the first five major GEWEX continental-scale experiments have made significant progress towards the closure of the regional water and energy budgets and are helping determine the importance of 'recycling' and diurnal processes for regional predictions. The GEWEX continental-scale experiments have been extended in order to document most major climate patterns, and now include semi arid regions in Australia and the Sahel. These experiments enable the comprehensive modelling and evaluation of the components of the water cycle over large river basins. Throughout its Phase I, GEWEX scientific results have led to over 20 special issues of respected journals, a dozen or so review articles, over 5000 citations and the widespread distribution of over 15,000 CD-Roms of GEWEX data. A brochure summarising the accomplishments of GEWEX Phase I was published in 2005 and is available on request from the International GEWEX Project Office, Silver Spring, Maryland, USA.

C.5 Stratospheric Processes And their Role in Climate (SPARC) Project

SPARC was established as a WCRP project in 1992. Its major achievements to date include the careful assessments of trends in stratospheric temperature, vertical distribution of ozone, and upper tropospheric and stratospheric water vapour, and their inter-relationships. Of particular note in this context was the award of the Norbert Gerbier-MUMM International Award for 2003 to an international team of 17 SPARC scientists for their paper, 'Stratospheric temperature trends: observations and model simulations' (V. Ramaswamy *et al*., *Reviews of Geophysics*, 39, 71-122, 2001). SPARC has also provided much needed input to the WMO ozone and IPCC climate assessments and has fostered the expertise needed to do so. This type of basic information is necessary for any future scenarios and decisions, international and national assessments and strategy developments, especially in the light of the 'ozone hole' surprise.

C.6 Climate-change assessments and projections

Improved understanding of key climate processes has led to significantly improved climate models, and also operational weather and ocean forecasting models. Co-ordinated data analyses and climate model simulations provide the basis for our understanding of natural climate variability. In particular, improved modelling of the coupled physical climate system through systematic model diagnoses and intercomparisons has provided increasingly accurate simulations and predictions of natural climate variations, giving more confidence in models and their projections of human-induced climate change. Such results feed directly into the scientific assessments of the IPCC and contributed significantly to the conclusion in the IPCC Third Assessment Report that, 'there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities'. In turn, the IPCC assessments provide the most authoritative, up-to-date scientific advice needed to inform the UNFCCC. In this way, WCRP has helped provide the direct scientific underpinning of the political process. WCRP will continue to play a most important role in helping to provide increasingly reliable climate-change scenarios and making them (and their likely consequences) immediately available (by various means) to decision makers, the media and the general public. These are critical contributions to deliberations on sustainable development.

C.7 Observations and global data sets

Comprehensive field measurements and the provision of essential global and regional climatological data sets are major components of all WCRP projects. Some of these have evolved into new operational climate observational and data collection systems. In particular: the buoy array in the tropical Pacific is crucial for monitoring and for initialising model predictions of ENSO events; systematic observations of the ocean's three-dimensional structure, combined with satellite altimetry have provided the basis for establishing key elements of a Global Ocean Observing System (GOOS) and, in turn, also the Global Climate Observing System (GCOS). Indeed, the on-going Argo initiative for a worldwide network of operational ocean profiling floats is a direct outgrowth from the global array of subsurface floats that was established in WOCE.

C.8 Atmospheric reanalyses

WCRP has provided strong support for the initiation and execution of atmospheric reanalyses projects. Such activities are now well established, with the completion of the 45-year ECMWF reanalysis (ERA-40), the NCEP regional reanalysis covering the period 1979-2003 over the USA, and the Japan Meteorological Agency's 25-year reanalysis for 1979-2004. Two major WCRP International Conferences on Reanalyses were held, which highlighted the value of reanalyses for an impressive range of studies and applications.

C.9 Public awareness

It was the international community of physical climate scientists that alerted the world to the reality of global warming, the prospect of anthropogenic climate change and its consequences. It is this same community that has determined the most likely causes of the recent global climate change and which has the capability to provide increasingly reliable climate-change scenarios, which are crucial for many aspects related to planning for sustainable development. WCRP has helped bring such climate-related issues to centre-stage by carrying out policy-relevant science and raising the level of scientific, governmental and public appreciation of the importance of climate issues, through fostering much greater cooperation between hitherto distinct scientific disciplines in understanding the whole climate system.

C.10 Capacity building

WCRP has enabled scientists from countries with less developed scientific programmes to contribute to the global programme and to build up their research capability. The global change SysTem for Analysis, Research and Training (START) has been established by the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), and WCRP, to foster capacity building activities in developing countries, and thereby help them to become partners in international global change research.

APPENDIX D

THE DEVELOPMENT OF A NEW STRATEGY FOR WCRP

Since it started in 1980, the two major objectives of the WCRP have been to determine the extent to which climate is predictable and the extent of human activities on climate. These objectives were reaffirmed at the Conference on the WCRP: Achievements, Benefits and Challenges, Geneva, August 1997 (WMO/TD-No.904, June 1998) at which Professor W. L. Gates, then Chairman of the JSC for the WCRP, addressed the assembly on 'The WCRP strategy and future challenges'. In order to maintain, strengthen and broaden the application of WCRP results it is necessary to continue to identify and exploit new opportunities to address new challenges. In the process, to quote Professor Gates, the JSC needs to ensure that WCRP becomes "a more effective, a more coordinated, and a more relevant programme". In that spirit and with that intention, in February 2001, Professor P. Lemke, Chairman of JSC, invited JSC members to provide their views on the present and future state of the WCRP and the response of WCRP to the demands of society thereby initiating a major debate and review of the aims, priorities, future direction and structure of the WCRP.

In this context, at the JSC-XXIII session in Hobart, Tasmania (March 2002) Professor J. Shukla put forward two proposals. He suggested that WCRP should develop a comprehensive interdisciplinary project on predictability and prediction of seasonal-to-interdecadal variations at regional and global scales. He proposed that a new initiative could be centred round a major modelling and numerical experimentation effort designed to demonstrate the predictability and practical prediction of seasonal/interannual/decadal climate variations for the period 1979-2009. Professor Shukla additionally suggested that this prediction and predictability initiative could form the starting point and nub of a 'Global Climate Experiment' of which the ultimate goal would be to assist society and policymakers in formulating necessary socio-economic decisions taking into account regional climate variations in the context of overall global climate change. He noted that just as the Global Weather Experiment (or First GARP Global Experiment, FGGE) in 1979, had led to major advances in short-range weather forecasting with very substantial socio-economic benefits, a global climate experiment, with the establishment of global climate observing systems and the development of improved climate models, could be expected likewise to lead to major advances. Whilst acknowledging the tremendous progress made within the individual components of the WCRP in observing, diagnosing, understanding, modelling and predicting the components of the physical climate system, he urged that, in order to accomplish the original objectives and the subsequent specific tasks of the WCRP, it is essential that all the components of the WCRP keep working jointly and more closely through a coordinated and comprehensive programme of observational, modelling and process research, which is clearly focused on stated overall goals.

The above two proposals stimulated a vigorous discussion within the JSC, and a major strategic and programme-wide review of the overall development and structure of WCRP scientific activities taking into account emerging new issues and challenges.

Also at that JSC-XXIII session, Dr K. Trenberth gave a presentation on the need for a climate observing system. Stimulated by such presentations and extensive in-session discussion, the JSC formulated a proposal for a new 'banner' for the WCRP entitled Predictability Assessment of the Climate System, whose aim would be to achieve major steps forward in climate prediction. It also established a Task Force composed of Professor B. Hoskins (Vice-Chair of the JSC), Professor Shukla and Dr J. Church to develop ideas and proposals for implementation of a WCRP predictability assessment, including consideration of the changes that might be needed in the organization of the WCRP. The Task Force reported to the next session of the JSC (JSC-XXIV, Reading, March 2003) at which considerable further time was dedicated to: discussion of this crucial prospective advance in WCRP; review of the status of relevant research and the contributions expected from existing WCRP projects and activities; formulating decisions on the future strategy; and outlining a vision for WCRP after 2010.

The proposal produced by the Task Force for a new WCRP-wide Predictability Assessment of the Climate System was debated thoroughly at JSC-XXIV, resulting in significant decisions for the future scientific direction and structure of WCRP. In particular, the two original major objectives of the WCRP were again re-affirmed, namely, to determine to what extent climate can be predicted and the extent of human influence on climate. Those remain the general mission statement for WCRP and are consistent with the longer-term vision of 'seamless prediction', from weeks through decades to the longer-term projection of climate change. Variability on all shorter times scales, including the weather, is important both for its impact on the longer time-scale behaviour and because its statistical behaviour is a crucial part of the longer time-scale prediction. Increasingly, climate projection also will become an initial-value problem.

To meet these aspirations and needs and, in particular, in recognition of the renewed emphasis in WCRP on its prediction aims and the observational activities that are needed to fulfil them, JSC-XXIV (March 2003) decided to develop a major overarching and integrating framework, then tentatively called the 'Climate system Observation and Prediction Experiment', to be implemented over a decade up to about 2015. Substantive further deliberations took place within a limited sector of the WCRP community throughout 2003, in order to explore and develop the rationale and concept of the proposed activity, as perceived at JSC-XXIV, in the broader context of: WCRP objectives and research aims; WCRP's main achievements to date; current WCRP core projects and related activities; and, the JSC's responsibility to formulate the overall scientific concept and science goals of WCRP, with a particular requirement to look to the future. Further substantial discussions took place at, and immediately following, JSC-XXV (Moscow, March 2004) and led to the JSC's decision to establish a Task Force, Co-chaired by Professor Hoskins and Dr Church, for the further development of the re-focused and re-named strategic framework, Coordinated Observation and Prediction of the Earth System (COPES), which is described in this document.

In addition to the two Co-chairs, B. Hoskins and J. Church, representing the JSC, the formal members of the WCRP COPES Task Force (and their affiliations) were: R. Barry (CliC), B. Kirtman (TFSP & WGSIP), J. Matsumoto (CEOP), J. Mitchell (WGCM), K. Puri (WGNE), A. O'Neill (SPARC), J. Shukla (JSC & WMP), P.K. Taylor (WGSF), K. Trenberth (JSC & WOAP), M. Visbeck (CLIVAR), and E. Wood (GEWEX), supported by D. Carson, Director, WCRP. The final report of the COPES Task Force was presented and discussed at JSC-XXVI (Guayaquil, March 2005). The text of this subsequent final document took account not only of the discussions at JSC-XXVI but also additional inputs since from a number of individuals from within the WCRP scientific community and from other 'stakeholders' beyond. All such contributions were gratefully received and considered, and are duly acknowledged here.

APPENDIX E

EXAMPLES OF SPECIFIC WCRP OBJECTIVES WITHIN THE CONTEXT OF COPES

As discussed in **Section 4.7**, WCRP will identify specific objectives where rapid progress is both needed and considered possible within a limited period of 1-3 years. It is expected that a synthesis publication would be produced at the end of such a period. Some examples of specific objectives of this type related to ongoing research within the WCRP core projects and its other activities, and also other suggested possible topics and objectives, are listed below in **Tables 1-3**. Some such activities are already under way (**Table 1**). Other initial suggestions for high-priority topics have resulted from wide consultation and, by way of example only, are listed in **Tables 2** and **3**.

The JSC invites comments on the tentative specific objectives listed here and encourages and would welcome suggestions for further consideration (see **Appendix F**). Proposals for new specific objectives from within the WCRP projects and other activities, and more generally from the wider community of WCRP stakeholders, will be considered by the JSC at its annual meeting, usually held in March, and a small number will be selected for further development.

Table 1. Existing specific objectives

Objective	Action/Comment
1.1. Improve the understanding of monsoon climates worldwide and determine their predictability.	Ongoing discussion regarding pan-WCRP coordination of monsoon research, led by CLIVAR and GEWEX.
1.2. Improve understanding and modelling of stability and response to anthropogenic forcing of the thermohaline circulation [North Atlantic (NA) and Southern Ocean (SO)].	NA – in hand with WGCM and CLIVAR Atlantic panel. SO – in hand with SO panel.
1.3. Understanding and then reducing the range of uncertainty of climate sensitivity exhibited by models.	Relevance to precipitation as well as temperature. Including ability to simulate short-term climate variations and role of physical parametrizations. Workshop held and activity continuing in WGCM.
1.4. Improve understanding of interactions of aerosols, radiation, clouds and precipitation.	Essential for prediction of climate forcing by natural and anthropogenic aerosols. Progressed within GEWEX and SPARC. Good collaboration with IGBP needed.
1.5. Determine the expected skill of seasonal climate prediction in all regions with currently available models and data.	A Task Force for this has already been created. Need to compare with actual operational skill.
1.6. Encourage the development of Earth system data assimilation.	Responsibility of WOAP (see **4.5**). Initial ocean activity in CLIVAR. A scientific conference/workshop may be needed later. A particular focus could be data assimilation for fully coupled systems with different time-scales.

Table 2. Possible specific objectives for initial consideration	
Objective	**Action/Comment**
2.1. Gain an improved understanding of the tropical atmospheric intraseasonal oscillation and determine its predictability.	Very important for prediction on all WCRP time-scales. THORPEX link. Possible WCRP- THORPEX workshop.
2.2. Determine how modes of climate variability change in response to anthropogenic forcing.	Climate change associated with this is crucial. Relationship with changes in mean fields is important.
2.3. Increase the accuracy in projections of sea-level rise.	Link with Specifc Objectives 1.2, 1.3 and 2.4. A WCRP workshop is being organized for 2006 to raise awareness and produce a science plan.
2.4. Determine the scientific basis for, the best approaches to, and current skill of projections of regional climate change at several time-scales.	Consideration of regional climate models, use of ensembles of model runs and statistical down-scaling.
2.5. Improve understanding of extreme events and their predictability.	Link with regional climate change issue. Possible THORPEX link. Perhaps a workshop needed.

Table 3. Possible specific objectives for later consideration	
Objective	**Action/Comment**
3.1. Improve understanding of arid and desert climates and focus on the skill of climate predictions for them.	Often the descent component of monsoon circulations. A joint GEWEX-UNESCO workshop was held in April 2005.
3.2. Address reasons for decadal variability of ENSO (and other modes).	Mostly a CLIVAR issue: partly in hand.
3.3. Determine if there is a scientific answer as to what is 'dangerous' anthropogenic climate change.	This would include thresholds and the likelihood of crossing them. Links with variability and impacts, and with IPCC.
3.4. Diagnose model systematic errors and determine implications for new parametrizations.	Previous WGNE conferences should be repeated at intervals and feedback given to projects.
3.5. Produce simulations of Holocene using general circulation models and compare with data.	In cooperation with IGBP-PAGES.
3.6. Investigate and improve ability of models to simulate the diurnal cycle of tropical convection.	Current errors in the diurnal cycle may have implications for the simulation of many longer time-scale phenomena.
3.7. Improve ability to simulate and verify precipitation.	Building on WGNE-World Weather Research Programme study.
3.8. Improve understanding of multi-decadal to century time-scale natural variability and its model representation.	Vital for climate change detection and projections for this century.
3.9. Advance the theoretical basis for predictability of the climate/Earth system.	Possible workshop choice.

APPENDIX F

PROPOSING NEW COPES INITIATIVES

The JSC is encouraging proposals for new initiatives to be completed under the WCRP strategic framework, COPES. Such proposals should in general be high-priority issues where significant progress can be expected over a short period of time and should result in a synthesis or integration of research activities from across the breadth of WCRP, and possibly in collaboration with other programmes or institutions. The initiatives may be for limited-term task forces or workshops and are not meant to be ongoing WCRP projects, although they might lead to some evolution of the WCRP structure. The proposals should result in a specific report, paper, book or data base.

Proposals may be submitted at any time to the Director of WCRP. However, to allow for consideration by JSC members, and the appropriate scientific committees of WCRP core projects and its other activities, and for discussion at the annual JSC meeting, usually in March, the optimum time for submission of proposals is about December each year.

The proposals should be one to two pages in length and should contain:

- Title of proposal
- Rationale/Justification
- Specific objectives
- Description of activities
- Expected interaction of WCRP core projects and other activities with other programmes or institutions (if relevant)
- Time line for completion
- Funding arrangements

Note that proposed funding sources need to be identified for activities requiring significant resources.

Proposals will be considered by the JSC (generally at the annual meeting in March) after consultation throughout the appropriate WCRP committees and with other potential partners (where relevant) and responses provided to proponents.

Each approved initiative would be expected to provide progress reports to the JSC and a final WCRP report at the end of the activity.

ACRONYMS

ACSYS Arctic Climate System Study
AIMES Analysis, Integration and Modelling of the Earth System
AMMA African Monsoon Multidisciplinary Analysis
AOPC Atmospheric Observation Panel for Climate
APN Asia-Pacific Network for Global Change Research
AREP Atmospheric Research and Environment Programme
C4MIP Coupled Carbon Cycle Climate Model Intercomparison Project
CACGP Commission on Atmospheric Chemistry and Global Pollution
CAS WMO Commission for Atmospheric Sciences
CATCH Coupling of the Tropical Atmosphere and Hydrological Cycle
CEOP Coordinated Enhanced Observing Period
CEOS Committee on Earth Observation Satellites
CliC Climate and Cryosphere
CLIPS Climate Information and Prediction Services
CLIVAR Climate Variability and Predictability
COPES Coordinated Observation and Prediction of the Earth System
DOE U.S. Department Of Energy
ECMWF European Centre for Medium-Range Weather Forecasts
EMIC Earth system Model of Intermediate Complexity
ENRICH European Network for Research in Global Change
ENSO El Niño - Southern Oscillation
EO Earth Observation
EOS Earth Observation Summit
ESSP Earth System Science Partnership
FGGE First GARP Global Experiment
GAIM Global Analysis, Integration and Modelling
GARP Global Atmospheric Research Programme
GCM global climate model
GCOS Global Climate Observing System
GCP Global Carbon Project
GECAFS Global Environmental Change and Food Systems
GEO Group on Earth Observations
GEOSS Global Earth Observation System of Systems
GEWEX Global Energy and Water Cycle Experiment
GODAE Global Ocean Data Assimilation Experiment
GOOS Global Ocean Observing System
GRP GEWEX Radiation Panel
GSOP Global Synthesis and Observations Panel
GTOS Global Terrestrial Observing System
GWSP Global Water System Project

HEPEX	Hydrological Ensemble Prediction Experiment
IABP	International Arctic Buoy Programme
IAI	Inter-American Institute for Global Change Research
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Strategy
IGOS-P	Integrated Global Observing Strategy Partnership
IHDP	International Human Dimensions Programme on Global Environmental Change
IOC	Intergovermental Oceanographic Commission of UNESCO
IPAB	International Programme for Antarctic Buoys
IPCC	Intergovermental Panel on Climate Change
IPY	International Polar Year
IRI	International Research Institute for Climate Prediction
IUGG	International Union of Geodesy and Geophysics
JSC	Joint Scientific Committee
NA	North Atlantic
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NEPAD	New Partnership for Africa's Development
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OOPC	Ocean Observations Panel for Climate
PAGES	Past Global Changes
SALLJEX	South American Low-Level Jet Experiment
SCAR	Scientific Committee on Antarctic Research
SCOPE	Scientific Committee on Problems of the Environment
SCOR	Scientific Committee on Oceanic Research
SO	Southern Ocean
SOLAS	Surface Ocean-Lower Atmosphere Study
SPARC	Stratospheric Processes And their Role in Climate
START	SysTem for Analysis, Research and Training
SSG	Scientific Steering Group
SST	sea surface temperature
TFSP	Task Force on Seasonal Prediction
THORPEX	THe Observing-system Research and Predictability EXperiment
TOGA	Tropical Ocean and Global Atmosphere
TTL	tropical tropopause layer
TWAS	The Academy of Sciences for the Developing World
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VAMOS	Variability of the American Monsoon System

WCP	World Climate Programme
WCASP	WMO World Climate Applications and Services Programme
WCDMP	WMO World Climate Data and Monitoring Programme
WCRP	World Climate Research Programme
WCIRP	World Climate Impact and Response Strategies Programme
WGCM	Working Group on Coupled Modelling
WGNE	Working Group on Numerical Experimentation
WGSF	Working Group on Surface Fluxes
WGSIP	Working Group on Seasonal to Interannual Prediction
WMO	World Meteorological Organization
WMP	WCRP Modelling Panel
WOAP	WCRP Observations and Assimilation Panel
WOCE	World Ocean Circulation Experiment
WWRP	World Weather Research Programme

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