World Climate Research Programme: Scientific Foundation for Decision Making

Introduction

The World Climate Research Programme (WCRP) supports a number of high priority scientific research activities with the aim of facilitating analysis and prediction of Earth's climate system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

A major emerging theme from the successful WCRP Open Science Conference (OSC) (24-28 October 2011, Denver, Colorado, USA, http://conference2011.wcrp-climate.org) was the need for actionable science to support decision-makers who are confronted with the challenges and opportunities posed by changes in the environment, in energy consumption and in economic development associated with the impending rapid growth in world population. To ensure adequacy of such information and its timely access and use, WCRP has engaged in an active dialogue with these stakeholders and decision-makers in the design, development and dissemination phases of its research activities.

WCRP leadership has identified six scientific grand challenges for integrating the research activities coordinated by its four Core Projects thus providing a focus for the development of targeted research efforts with the likelihood of significant progress over five to seven years. The WCRP scientific grand challenges are:

- Provision of skilful future climate information on regional scales (e.g. decadal predictability);
- Regional sea-level variability and change;
- Cryosphere response to climate change (including ice sheets, water resources, polar predictability, permafrost and carbon);
- Improved understanding of the interactions of clouds and radiation (including the role of aerosols and precipitation and contributions to climate sensitivity);
- Past and future changes in water availability (with connections to water security and water-resources management);
- The science underpinning the prediction and attribution of extreme events.

WCRP has also focused its efforts on capacity development to ensure that future generations of affiliate researchers and their networks are equipped with the required expertise and capabilities to address these grand challenges. The WCRP strategy and approach to international research coordination in the future will also be responsive to the needs of its primary sponsors and their

major initiatives such as the Global Framework for Climate Services (WMO), Future Earth (ICSU) and the Integrated Framework for Sustained Ocean Observations (IOC).

a) On-Going WCRP Research Activities relevant to UNFCCC

Improving Climate Projections

Through its Climate Model Intercomparison Project-5 (CMIP5) WCRP is providing the framework for advancing climate change modelling research, improving climate projections and creating the basis for assessing climate variability and change in support of the next IPCC Assessment (AR5). More than 24 modelling groups from around the world are currently running the CMIP5 experiments that represent the most ambitious multi-model inter-comparison and analysis project ever attempted. The scope of CMIP5 is much broader than that of the previous intercomparison project (CMIP3) and includes four new representative concentration pathways (RCPs) to support developing mitigation scenarios in addition to the long-term concentration-driven Atmosphere-Ocean Global Circulation Model (AOGCM) experiments and emission-driven Earth System Model (ESM) experiments - some of those with partial coupling to explore sensitivity of the carbon-cycle feedback. Many experiments in CMIP5 explore the impact of various natural and human-induced changes on climate. The paleoclimatic experiments assess the ability of models to reproduce past climate conditions to better inform the credibility of the models' future climate projections; and some experiments investigate the role of atmospheric aerosols and chemistry-climate interactions with higher resolution AOGCMs (about 50 km resolution) and even higher resolution (about 25 km) atmosphere-only models. CMIP5 also provides many more capabilities and new types of climate-change information, such as account of impact of the stratospheric ozone change on climate change, decadal climate predictions, and cloud-radiation feedback, to name but a few.

Decadal Climate Predictability and Predictions

Near-term climate predictions (also known as decadal climate predictions) were included in CMIP5 in an attempt to satisfy a growing demand for climate information for several years to a few decades ahead. Skilful interannual-to-decadal climate predictions have been achieved by using changes in boundary conditions such as atmospheric composition and solar irradiance. The type of information that can be obtained from the decadal experiments have been explored within the framework of the ENSEMBLES project, funded by the European Union, by using two types of climate forecasts: a multi-model (mostly with full initialization) and a perturbed-parameter ensemble with explicit initialization. Both approaches have forecast skill over large regions – especially over the tropical oceans and North Atlantic – but also over large continental areas. Most of the prediction skill on temperature is due to external forcing, while the improvements in prediction skill due to initialization appear mostly over the North Atlantic and the subtropical Pacific. Atlantic multi-decadal variability, associated with the Atlantic Meridional Overturning Circulation (AMOC), presents multi-year predictability, which improves in both the multi-model averages and the ensemble averages from single models.

Sub-seasonal, Seasonal and Interannual Climate Forecasts

From the end-user perspective, the sub seasonal time scale (2 weeks to 2 months) is a very important one, because it lies between the well-established and routine use of weather forecasts in diverse areas on the one hand, and the developing use of seasonal forecasts on the other. Many management decisions, such as in agriculture, fall into the intervening time period. The Pakistan floods (2010), concurrent with the Russian heat wave, were two extreme events with very high societal impact and for which reliable and skillful sub seasonal forecasts for this period could have been of considerable value. Despite the potential value, forecasting for this time range has

so far received much less attention than medium-range and seasonal prediction primarily because making forecasts on this time range is a greater challenge since the lead time is sufficiently long that much of the memory of the atmospheric initial conditions is lost and it is too short a time range for the variability of the ocean to have a strong influence. However, recent research has indicated important potential sources of predictability for this time range such as from the Madden Julian Oscillation, stratospheric initial conditions, land/ice/snow initial conditions, and sea surface temperatures. Recent improvements in computing resources and model development may also make it possible to develop a better representation of these sources of sub seasonal predictability. Hence WCRP with its sister programme on World Weather Research has launched a project that aims to improve forecast skill and understanding on the sub seasonal to seasonal timescale, and promote its uptake by operational centres and exploitation by the applications community. Specific attention will be paid to the risk of extreme weather, including tropical cyclones, droughts, floods, heat waves and the waxing and waning of monsoon precipitation.

A WCRP community-wide assessment on the state of the science for seasonal climate prediction led to a consensus on some best practices for producing, using and assessing seasonal forecasts with the aim of improving seasonal prediction, as well as determining the extent to which seasonal prediction is possible. This assessment pointed to the need for a suite of performance metrics and a common language to be applied systematically for assessing prediction skill. It was agreed that the skill must be evaluated both in terms of forecast quality and forecast value, where quality refers to the technical measurement of forecast performance and value relates to the practical benefits achieved through decisions made according to forecast information, usually in conjunction with other information. Progress in seasonal climate prediction depends on improvements in the building blocks of seasonal prediction systems: the models, observations and data-assimilation systems, as well as improved forecast verification and a more effective transfer of information to forecast users, increasing forecast value. WCRP is coordinating a multi-model, multi-institutional set of hindcast experiments – the Climate system Historical Forecast Project (CHFP) – for this purpose. CHFP aims to explore the untapped sources of predictability on seasonal-to-interannual timescales arising from interactions and memory associated with all the elements of the climate system (atmosphere-ocean-land-ice). These experiments provide a baseline assessment of current seasonal prediction capabilities using the best available models of the climate system and data for initialization, as well as of IPCC-class climate models in seasonal prediction mode. They provide a framework for assessing current and planned observing systems and a test bed for integrating process studies and field campaigns into model improvements with the ultimate goal of enhancing operational forecast skill.
The WCRP Working Group on Seasonal to Interannual Prediction (WGSIP) provides an effective interface between the operational community engaged in long-range predictions (weeks to months) and the research community engaged in exploring new sources of prediction skill, improvements in long-range prediction methodologies, and other scientific questions of relevance. Improvements in seasonal prediction skill that are derived from the implementation of best practices are expected to be quasi-immediate. Improvements in the building blocks of seasonal prediction systems will continue in the next years and longer and ongoing research into new sources of predictability in the climate system are expected to lead to operational improvements on the longer term.

Regional Climate Information

The provision of climate information on regional to local scales is an important requirement to support decision-making in response to potential climate change. Such information is needed to assess the impacts of climate variability and change on human and natural systems, enabling the development of suitable adaptation and risk-management strategies at the regional to local level. Despite recent advances in the horizontal resolution of most global climate models, there are still

limitations in their ability to represent important local forcing features, such as complex topography, land-surface heterogeneity, coastlines and regional water bodies, all of which can modulate the large-scale climate on regional to local scales. Coarse spatial resolution of current models also precludes an accurate description of extreme weather events, which are of fundamental importance in assessing the socio-economic impacts of climate variability and change. In order to coordinate international regional climate modelling, WCRP developed a framework for the Coordinated Regional Climate Downscaling Experiment (CORDEX, http://wcrp-cordex.ipsl.jussieu.fr/). The framework is facilitating the evaluation and, where possible, the improvement of regional climate downscaling techniques for use in many regions worldwide, and to support the vulnerability, impact and adaptation analyses and assessments. Many CORDEX regions are already self-organizing and are developing matrices of regional climate change projections. In some regions, one example being Africa, access to reliable regional climate-change information is particularly limited. It is in these regions that the greatest benefits from the collaboration developed through CORDEX are anticipated. The international community therefore has targeted Africa for intensive collaboration and the effort is already producing a significant amount of information on African climate, both to support the IPCC Fifth Assessment Report (IPCC AR5) and to provide useful climate information to decision-makers involved in African climate risk management and adaptation planning.

Attribution and Prediction of Extreme Events

Unusual or extreme weather and climate-related events are of great public concern and interest, yet there are often conflicting messages from scientists about whether such events can be linked to climate change. This was one of the themes discussed at the WCRP OSC, where the development of a carefully conducted analysis of observed weather- and climate-related events could serve as a powerful tool for identifying the factors contributing to the occurrence of such events. New scientific results have shown examples of where there has been an increased risk of extreme weather attributable to human influence on climate. For example, new research has reconciled the results of previous studies by providing scientific explanations concerning the extent to which the 2010 Russian Federation heat wave could be attributed to human-induced climate change. In fact, the same event can be both mostly internally generated in terms of magnitude but also externally driven – through human influence on climate – in terms of probability of occurrence.

An ad hoc group completed an overview report "Drought predictability and prediction in a changing climate: assessing current predictive knowledge and capabilities, user requirements and research priorities" (http://www.clivar.org/organization/extremes/resources/dig). The report examines current prediction capabilities and user needs for drought-related information with the aim of identifying actionable research areas that would benefit from international coordination. Three major action items resulted from the WCRP workshops on this topic: (a) to develop a drought catalogue; (b) to carry out coordinated analyses of high impact droughts; and (c) to develop a drought early warning system. The workshop participants established three subgroups to implement these recommendations. These efforts, together with a worldwide survey of user drought information needs and capabilities are now part of the planning for an experimental global drought information system. This initiative is moving forward by building upon extensive worldwide investments in drought monitoring, drought-risk management, drought research and climate-prediction capabilities.

b) Emerging issues in climate change research

Regional Sea-Level Variability and Change

Analysis, assessment and prediction of sea-level variability and change, especially at the regional level, is a key area of focus for WCRP. A dedicated WCRP Workshop hosted by UNESCO-IOC in

Paris in 2010 reviewed the state-of-the-knowledge in sea-level observations, research and modelling in great detail. The outcomes of the Workshop helped to formulate sea-level projections of the IPCC Fifth Assessment Report that will be published in 2013. A monograph entitled "Understanding sea-level rise and variability" (edited by J. Church et al.), resulting from a previous WCRP-sponsored workshop, was published in 2009. Major progress is being made in improving the observing networks and developing models capable of capturing essential processes that contribute to changes in the cryosphere, such as ice-sheet, sea-ice and glacier dynamics and changes in snow cover and extent. For example, significant efforts are being devoted to measuring and modelling all contributing factors to sea-level variability and change using a variety of techniques and technologies. For the first time, there is a remarkable convergence among independent estimates of the actual rate and magnitude of sea-level change, based on observational records since the 1970s. Another recent observation-based finding is enhanced net mass loss from the major ice sheets: if it continues at recent rates, the contribution of ice sheets to 21st century sea-level rise will be more than from any other contributing factor (e.g. glaciers). To manage the potential risks of sea-level changes and develop adaptive measures, it is imperative to know not only the global mean sea-level value but also its regional and temporal variations. WCRP is supporting research on understanding the underlying physical and dynamical processes that contribute to the patterns and magnitude of sea-level variability and change on regional scales. These studies have revealed some patterns of such variability, showing clearly that, while sea level is rising on the global average, it may be rising more in some regions of the world and falling in others, owing to the specifics of ocean dynamics and other geophysical processes. Regional sea-level rise increases the risk of coastal flooding, which also depends on local tides, storm-surges, precipitation, and local hydrological conditions. The outcomes of the WCRP sea-level studies will serve as valuable input to future assessments and will, in turn, help to shape future WCRP-coordinated sea-level research.

Atmospheric Chemistry and Climate Connections

With focus on stratospheric ozone, the impact of climate change on atmospheric chemistry and, conversely, the impact of changes in atmospheric chemistry and composition on climate have been highlighted in the recent WMO/United Nations Environment Programme (UNEP) report Scientific Assessment of Ozone Depletion: 2010. Major contributions to this assessment derive from SPARC's activity in chemistry-climate model validation (http://www.sparc-climate.org/activities/ccm-validation/) efforts. According to the IPCC (2007), methane, ozone and halocarbons are the greenhouse gases that directly follow carbon dioxide in terms of strongest increase in radiative forcing owing to anthropogenic activities since the industrial revolution. Changes in tropospheric composition alter stratospheric composition via changes in the input to the stratosphere and, conversely, changes in the stratosphere affect the troposphere via changes in the input of ozone from the stratosphere and also changes in ultraviolet radiation.

Aerosols are also climate-forcing agents. Effects of anthropogenic aerosols on the climate may offset part of the increased radiative forcing of greenhouse gases due to their cooling effect. Aerosols can perturb atmospheric radiation through a direct effect of scattering and absorption of radiation. The effects of aerosols depend critically on their chemical composition and mixing state. Aerosols can also have an indirect effect via interaction with clouds (water, ice and cirrus clouds) by acting as cloud condensation nuclei (CCN). Further, clouds can modify aerosols, their optical properties, their size distributions and their ability to act as CCN. The indirect effect, which is a strong function of chemical and physical properties of aerosols, can perturb clouds and the hydrological cycle, two pivotal components of the climate system and its sensitivity to such changes. Stratospheric aerosols greatly alter the chemistry at the regional level region and lead to such changes as the Antarctic ozone hole, with major consequences for global climate.

Several important meetings on stratospheric processes have led to assessment of lifetimes of ozone-depleting substances, guidance to space agencies on the needs for stratospheric and chemical observations from space and on issues related to data processing, an international initiative of research of sulfur in the atmosphere, and an update on stratospheric temperature trends. Two state-of-the-art assessments of available global cloud and radiative flux data sets (WCRP Report No. 23/2012, Nov 2012 and WCRP Report No. 19/2012, Dec 2012, http://www.wcrp-climate.org/index.php/resources-room/wcrp-reports) advance our understanding of what is happening to the Earth's climate and assist climate modellers in improving their ability to predict and project future climate conditions.

New Results from CORDEX and Regional Projects

The CORDEX community has grown to include 13 major geographic domains encompassing the entire globe, and is producing regional climate projections for most of these domains (visit: http://wcrp-cordex.ipsl.jussieu.fr). To facilitate the analysis and visualization of these large-scale data sets, the Jet Propulsion Laboratory, California Institute of Technology (JPL), and their Joint Institute for Regional Earth System Science and Engineering (JIFRESSE) with the University of California, Los Angeles (UCLA), have developed the Regional Climate Model Evaluation System (RCMES). At present, RCMES is being utilized for evaluating model results from CORDEX-Africa and CORDEX-North America (aka NARCCAP, used for US NCA), and the capacity development activities of CORDEX-South Asia, CORDEX-East Asia, CORDEX-Arctic, and CORDEX-Latin America and Caribbean regions. This is but only one of several regional evaluation activities that WCRP is promoting to assess the quality of climate information being developed for example for Africa, S. Asia, Central America, Arctic and Australia. In parallel, the WCRP in partnership with other sister programmes and organizations such as Asia Pacific Network (APN) and Inter-American Institute (IAI) is establishing a series of regional networks of experts to carry out such evaluations and ultimately assist with interpretation of the scientifically based climate assessments for decision-makers and practitioners in economic sectors of interest to their region.

Recognizing the pressing need to narrow the large gap that currently exists between decision-makers and climate science researchers, WCRP is organizing a series of regional projects, conferences, capacity development and training activities focussing on the role of science in climate services and risk management. The first one, 15-18 October 2013, in Arusha, Tanzania, will be on the State of the African Climate System, followed by a similar forum in Latin America in February 2014 in Montevideo, Uruguay. The overall goal of the African conference is the production of an actionable climate research agenda that will result in outputs to inform adaptation decisions in Africa by mid- to end of the 21st century. The conference is organized jointly with the African Climate Policy Center (ACPC) and will engage both well-established and early career scientists across the continent. Likewise, a joint WCRP-IPCC-EU International Conference on Regional Climate will be held 4-7 Nov 2013 in Brussels, Belgium. This event aims to showcase the main outcomes of IPCC AR5 WGI report, key scientific results of the first phase of CORDEX, and to identify the future research priorities in regional climate science. In 2014 there will be the WCRP conference on Climate and Society for Latin America and the Caribbean to identify gaps and ways to overcome limitations in the chain of knowledge going from basic to applied climate science and to inform policy and decisions for the region. It is expected that the conference will contribute to further development of the emerging regional climate services.

Data Analyses and Global Observations

Unprecedented volumes of data containing climate historical simulations, climate predictions and projections, and observational datasets and their-reanalyses are being made available openly to scientists and other users through the Earth System Grid Federation (ESGF) archive. These data include the results from the Coupled Model Intercomparison Project, Phase 5, the Climate system Historical Forecast Project (CHFP) focused primarily on seasonal climate forecasts, the Coordinated Regional Climate Downscaling Experiment (CORDEX), the four major international re-analysis products from USA, Japan and Europe, and observation-based data sets prepared by the U.S. National Aeronautics and Space Administration (NASA) for inter-comparison with some of the CMIP5 model results. The ESGF is a highly distributed system with nodes in all major continents around the world to ensure ease of access to these large scale data sets on one hand, and consistency of protocols, formats, projection maps, documentation, etc. on the other hand to enable more effective analysis and intercomparison among them, as warranted. WCRP is promoting a pilot effort to improve the connection between data experts and scientists involved in climate model development and evaluation. The Obs4MIPs (http://obs4mips.llnl.gov:8080/wiki) initiative will greatly improve intercomparisons of models and observational datasets. The overarching goal is to enable the two expert communities to develop and document some datasets based on space-based observations from the past several decades, consistent with the format and standards of the CMIP5 model output to be made available on the Earth System Grid Federation (ESGF) for use by all researchers around the world.

The Obs4MIPs datasets match in time and space the model simulations developed as a part of the CMIP5 experiments. This technical alignment of observational products with climate model output will greatly facilitate model-data comparisons. Guidelines have also been developed for Obs4MIPs product documentation that is of particular relevance for model evaluation. Products available via Obs4MIPs are:

- Directly comparable to a model output field defined as part of CMIP5;
- Open to contributions from all data producers that meet Obs4MIPs requirements;
- Well documented, with traceability to track product version changes; and
- Served through ESGF for ease of access by all interested researchers.

In partnership with the Global Climate Observing System (GCOS), WCRP continues to advocate for the development of Essential Climate Variables (ECVs), including those for the ocean, and related information to build long-term global datasets, recognizing that such datasets are a basis for diagnostic studies and particularly for study of long-term trends, detection and attribution of causes of climate variability and change, and the development and evaluation of climate models. In 2014, WCRP, in partnership with the Committee on Earth Observation Satellites (CEOS) and the Coordinating Group of Meteorological Satellites (CGMS), is co-convening in Darmstadt, Germany, a conference to discuss the current and future state of space-based climate observations in order to evaluate recent achievements, ascertain critical challenges ahead, and to identify gaps in the space-based climate observing system and the risk to the continuity of climate observational records. The international space agencies intend to use the outcome of this conference in developing their plans and priorities for the development of these observing systems.

Regional Capacity Development

WCRP is promoting active engagement of early career scientists in all its activities, with particular emphasis on scientists from least-developed and developing countries, so as to build up

the diverse future workforce needed to meet the increasingly complex scientific challenges of climate research. Through strategic partnerships with WCRP sponsors (WMO, ICSU, and IOC) and sister organizations such as the START (Global Change System for Analysis, Research and Training), APN (Asia-Pacific Network for Global Change Research), and IAI (Inter-American Institute for Global Change Research), WCRP is currently undertaking a wide range of education, training and capacity development activities. For example, 71 students and early career scientists participated in WCRP meetings in 2012 including 25 early career scientists who participated in 13 regional WCRP workshops held in all the WMO regions, such as the:

- CORDEX regional training workshop in Asia, Pune, India, 17-20 October;
- Summer School on Climate and Ecosystem Interaction, Ankara, Turkey, 23-28 July; and
- Energy, Water and Climate Change young scholars forum, Nicosia, Cyprus 10-12 December.

CORDEX, in partnership with a large number of regional organizations including START, APN, IAI, development banks and non-governmental organizations, is developing regional research capacity for, among others, Africa, Asia and Latin America and Caribbean. CORDEX presents an unprecedented opportunity to advance knowledge of regional climate responses to global climate change and for these insights to benefit on-going climate-adaptation and risk-assessment research, policy planning and development investments in these regions. For example, a consortium of organizations, consisting of WCRP, the University of Cape Town's Climate Systems Analysis Group, START, the International Centre for Theoretical Physics, the Swedish Meteorological and Hydrological Institute-Rossby Center, and the Climate and Development Knowledge Network, initiated an analysis and training programme to provide an initial assessment of CORDEX results for Africa that is regionally focused and prioritized to the continent's information needs. The training programme focuses on skill development in working with climate model results, analysis of CORDEX datasets and compilation and writing-up of the results for broad dissemination to users. Participants in the training programme are grouped into teams according to the sub regions they represent and their respective areas of expertise. This approach, initially focused on Africa, is now being replicated for South Asia, Latin America and Caribbean, and other geographic regions worldwide.

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