The World Climate Research Program Strategy and Priorities: Next Decade

Ghassem R. Asrar, James W. Hurrell, and Antonio J. Busalacchi

Abstract In this chapter an overview of the research planning and priorities of the World Climate Research Program (WCRP) over the next decade is provided. The research, modeling and prediction plans are significantly shaped by the major sponsors of the WCRP, as well as by its international network of scientists and stakeholders. However, major input into the planning process was also derived from sessions and discussions among the more than 1,900 scientists who attended the WCRP Open Science Conference (OSC) in October 2011. This monograph is comprised of position papers emanating from the OSC. They address many of the overall research and intellectual challenges across the WCRP spectrum of activities. A brief overview of these papers is given.

Keywords Climate research • Climate information • Actionable research • Research priorities • Climate services • Future Earth

G.R. Asrar (✉)
World Climate Research Program, World Meteorological Organization,
7 bis Avenue de la Paix, Case Postale No 2300, CH-1211 Geneve 2, Switzerland
e-mail: gasrar@wmo.int

J.W. Hurrell
Earth System Laboratory, National Center for Atmospheric Research,
PO Box 3000, Boulder, CO 80307-3000, USA
e-mail: jhurrell@ucar.edu

A.J. Busalacchi
Earth System Science Interdisciplinary Center (ESSIC),
University of Maryland, Suite 4001, M Square Office Building, #950,
5825 University Research Court, College Park, MD 20740, USA
e-mail: tonyb@essic.umd.edu

G.R. Asrar and J.W. Hurrell (eds.), *Climate Science for Serving Society: Research, Modeling and Prediction Priorities*, DOI 10.1007/978-94-007-6692-1_1,

1 Introduction

The WCRP convened a major Open Science Conference (OSC) on 24–28 October 2011, in Denver, Colorado (Asrar et al. 2012). The purpose of the OSC was to assess the current state of knowledge on climate variability and change, identify the most urgent scientific issues and research challenges, and ascertain how the WCRP can best facilitate research and develop partnerships critical for progress. The OSC also sought to facilitate dialogue and cooperation across the diverse research communities among the WCRP Projects and their network of researchers, as well as with other international research programs, including the International Geosphere-Biosphere Program (IGBP), the World Weather Research Program (WWRP) and the Earth System Science Partnership (ESSP).

The overall theme of conference was "Climate Science in Service to Society" to allow a more effective dialogue between the climate information and knowledge developers (i.e., the research community) and the decision makers faced with difficult adaptation, mitigation and risk management issues. A main goal was to identify key opportunities and challenges in observations, modeling, analysis and process research required to understand and predict Earth system variability and change. The main objectives for the WCRP since its inception have been to determine the predictability of climate and to determine the effect of human activities on climate. The OSC confirmed that these remain valid objectives today, along with the WCRP strategic priority of an enhanced focus on climate research that is of direct value and benefit to society.

More than 1,900 participants, including 541 graduate students and early career scientists from 86 nations and more than 300 scientists from developing nations, made the conference a terrific success. The conference included seven plenary sessions, 15 parallel sessions and more than 2,000 poster presentations organized around daily themes (e.g., societal needs for climate information, the state of the global climate observing system, challenges and opportunities in climate modeling and prediction, and the detection and attribution of climate extremes). The sessions were designed to allow for in-depth plenary presentations informed by a series of community-based scientific position papers, followed by parallel and poster sessions with sufficient time for discussion and one-on-one interactions among presenters and participants.

This monograph is developed around the papers prepared and presented at the Open Science Conference based on contributions by a large number of international climate scientists at the invitation of the WCRP. The conference participants and members of the broader scientific community were invited to provide their comments and feedback to the authors before they were presented and discussed during the conference. Prior to acceptance for inclusion in this book, each paper was revised based on these feedbacks, the outcome of conference deliberations, and at least three independent peer reviews. The scientific challenges and opportunities identified in the following chapters form the basis of climate research priorities for WCRP to pursue through its network of affiliated projects and scientists in the ensuing decade.

2 Evolution of WCRP Research Mandate

The WCRP was established at the conclusion of the first World Climate Conference in 1980, in Geneva, Switzerland. Under the sponsorship of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, and the International Council for Science (ICSU), the aim of WCRP is to facilitate the 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 (Asrar 2009). This primary objective was reaffirmed in 2005 with a new strategic framework for WCRP referred to as COPES (Coordinated Observation and Prediction of the Earth System). COPES was designed to 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. Through this framework WCRP strives to 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 (WCRP 2005).

In 2008, the sponsors of the World Climate Research Program (WCRP) initiated an independent review of the Program to evaluate the extent to which WCRP adds value to national efforts in climate research. The international panel of experts also identified and recommended major future research priorities for WCRP (ICSU-IGFA 2009). The Review Panel took a prospective view with the aim of maximizing the future added value of WCRP while learning from a retrospective assessment of the current program and its recent evolution. The Review focused on interactions within WCRP and also its external connections. The Review Panel considered not just science relevance, but also the policy and development relevance of WCRP. Questions considered by the review panel included: "What is the role of natural versus social science? Does the Program engage the younger generation of scientists? What is the relationship of WCRP to the Earth System Science Partnership? Is the increasing collaboration between IGBP and WCRP an impetus for even tighter working relationships? What do end-users serviced by members of the sponsoring international organizations expect from WCRP?"

Upon completion of their review and deliberations, the panel recognized the many important achievements of WCRP, and it concluded that WCRP plays a significant role in helping society meet the challenges of global climate change. The panel cited numerous examples of unique contributions by the program and pointed out that, without WCRP leadership, such contributions would not have been possible. The panel concluded, however, that WCRP lacked the focus, planning, and funding to meet the scientific challenges identified in the COPES document. A recommendation was "WCRP must focus its Projects and connect with partners and users in strategic ways, and it will need new resources to do so". The panel indicated that WCRP should continue to stay in the forefront of climate research, modeling and prediction, in order to attract international research leaders to volunteer their time and efforts to support the Program. The panel also concluded excellence in

research alone is not sufficient: WCRP also needs to facilitate the use of the scientific knowledge it develops by decision makers to demonstrate the benefits to be accrued by its sponsors, stakeholders and the society at large. In this regard, the panel offered several specific recommendations aimed at building the necessary focus and connections into WCRP and its partnerships (ICSU-IGFA 2009).

In parallel with the independent review of WCRP, the Joint Scientific Committee (JSC), who has the scientific oversight for the Program, began to engage in a dialogue with the WCRP International Projects and other partner programs (e.g., IGBP, WWRP, ESSP) to develop a strategy and implementation plan for the future. The WCRP International Projects are: Global Energy and Water Experiment (GEWEX), CLImate VARiability and Change (CLIVAR), Climate and Cryosphere (CliC) and Stratospheric Processes And their Role in Climate (SPARC). The JSC and the leaders of these Projects reached agreement in short order to adopt the WCRP COPES strategic framework as a blueprint for the near-term (2008–2012) and worked to develop an accompanying implementation plan (WCRP 2009b). This approach offered sufficient time for developing a longer-term (post 2012) strategy through consultation with the international scientific community at large, and for transitioning the functions and structure of the four core Projects to support future research directions and emerging priorities. The logic behind this two-phase approach was to foster active community engagement in setting the new research directions and priorities through a "bottoms up" and participatory approach, a necessity given the voluntary nature of the Program.

3 Future Plans and Priorities of WCRP Major Sponsors

To set the stage for its deliberations, the JSC also sought guidance from the three major WCRP sponsors. This was especially important because the three sponsors had also initiated their own future planning through separate processes.

The WMO convened the World Climate Conference-3 (WCC-3) in September 2009, in Geneva, Switzerland, about 30 years after the first conference (WCC-1) that established the WCRP. More than 2,500 scientists, policymakers, Non-Governmental Organizations (NGOs) and a wide range of regional and national experts from 150 countries participated. The scientific and technical part of the conference, "the Expert Segment," identified an urgent need for establishing the Global Framework for Climate Services (GFCS) as a complement to the research, observations and assessment initiatives that resulted from the WCC-1 and WCC-2. The Expert Segment called for major strengthening and implementation of the essential elements of a global framework for climate services; however, they stated that for a GFCS to be successful it must function as an integrated and end-to-end system, with the main focus on delivery of climate information and services to the end users and stakeholders of such information. The five essential elements of the GFCS were identified as:

- The Global Climate Observing System and all its components and associated activities; and provision of free and unrestricted exchange and access to climate data;

- The World Climate Research Program, underpinned by adequate computing resources and increased interaction with other global climate relevant research initiatives;
- Climate services information systems taking advantage of enhanced existing national and international climate service arrangements in the delivery of products, including sector oriented information to support adaptation activities;
- Climate user interface mechanisms that are focused on building links and integrating information, at all levels, between the providers and users of climate services, and that are aimed at the development and efficient use of climate information products including the support of adaptation activities; and
- Efficient and enduring capacity building through education, training, and strengthened outreach and communication.

In 2011, the WMO Congress endorsed the GFCS initiative as a UN system-wide effort and requested that WMO establish a secretariat to facilitate the development of an implementation plan and a governance strategy to be presented for further deliberation and approval at an extra ordinary session of its member states in October 2012 in Geneva, Switzerland. In this process, WCRP was identified as a major contributor to the development of the Research, Modeling and Prediction pillar of the GFCS (Fig. 1), in coordination and with active engagement of other major international research programs (WMO 2011). The GFCS Implementation Plan that was recently approved by the WMO Congress includes an annex chapter that highlights research priorities and WCRP expected contributions for the GFCS during next decade (WMO 2012).

In September 2009, the ICSU General Assembly decided to develop a future strategy for ICSU environmental research. Subsequently, ICSU established an international planning panel to initiate this process through a combination of web-based consultation and several planning workshops during 2010–2011. The ICSU visioning process concluded that there is a need to expand Earth System Science research towards sustainability science that explicitly covers development and equity in relation to other global change issues. The visioning process led to the identification of five Grand Challenges for the international global change research communities (Table 1, ICSU-ISSC 2010; Reid et al. 2010). Simultaneously, the international funding agencies developed the Belmont Challenges (ICSU-ISSC 2010) with a strong regional and sectoral emphasis and user orientation.

The ICSU strategy calls for trans-disciplinary research towards the goal of global sustainability by recognizing a need for end-to-end and solution oriented approaches to Earth system research through more effective partnerships between natural, socioeconomic sciences, and engineering disciplines (ICSU-ISSC 2010). In 2011, ICSU appointed a Transition Team consisting of international scientists and experts to develop further its research strategy and a governance mechanism for its oversight. The ICSU initiative is entitled “Future Earth: Research for Global Sustainability”. It is envisioned Future Earth will succeed ESSP (Leemans et al. 2009). A subset of the International Group of Funding Agencies (IGFA), called the Belmont Forum, together with some UN system organizations and ICSU, have established an Alliance to oversee the governance and implementation of the Future Earth initiative.

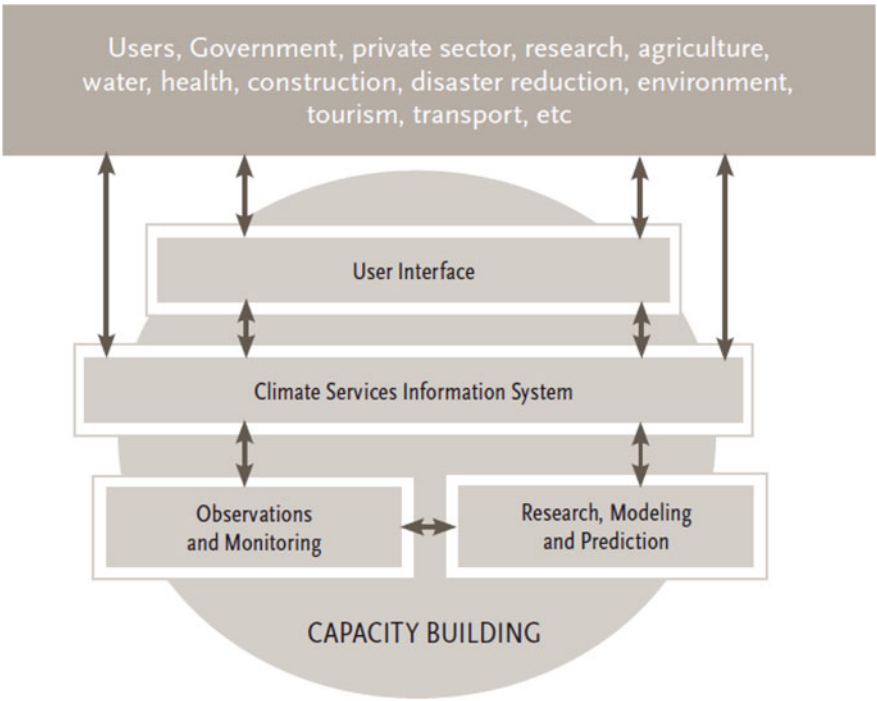

Fig. 1 A conceptual illustration of how the five major pillars of the Global Framework for Climate Services (GFCS) must function in a coordinated and integrated manner to realize the GFCS grand vision in near-, mid- and long-term (Adapted from WMO 2011)

Table 1 The five Grand Challenges according to the International Council of Science (ICSU 2010)

Challenge 1	Forecasting: improve the usefulness of forecasts of future environmental conditions and their consequences for people
Challenge 2	Observing: develop, enhance and integrate the observation systems needed to manage global and regional environmental change
Challenge 3	Confining: determine how to anticipate, avoid and manage disruptive global environmental change
Challenge 4	Responding: determine what institutional, economic and behavioral changes can enable effective steps toward global sustainability
Challenge 5	Innovating: encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy, and social responses to achieve global sustainability

The Future Earth initiative has the strategic goal "to develop knowledge for solutions to move toward a future of integrated environmental, social, and economic well-being *[or…provide new knowledge to face risks and seize opportunities posed by global environmental change and to support transitions of societies in the world to global sustainability]*". The intent is to deliver at global and regional scales the knowledge required for sustained human development in an era of rapidly escalating global environmental risks and new opportunities. The Future Earth will include major foci in synthesis and

assessment of research knowledge, communication, bridging science with policy and practice, and capacity development such as training and development of the next generation of early career scientists, especially those from developing countries. These exciting goals and objectives will require a "step change" in required funding, both flexible institutional funding and competitive research funding (ICSU-ISSC 2010).

The IOC/UNESCO, a third sponsor of WCRP, organized its second OceanObs09 Conference in 2009, in Venice, Italy to define its strategy for ocean observations and research in the ensuing decades (Hall et al. 2009). The conference objective was to take stock of progress made since the first OceanObs Conference in 1999 to identify future observations and research priorities in support of the IOC mission. More than 800 participants from 36 countries confirmed significant progress on the goals and priorities identified in the first conference. These included the establishment of global in situ observing networks in the oceans, development and operation of space-based ocean observing satellites through international cooperation, and test-beds for near real-time ocean information activities such as GODAE. The participants recognized the seminal contributions of the WCRP to the ocean observing systems through major research projects such as World Oceans Climate Experiment (WOCE), Tropical Oceans Global Atmosphere (TOGA), and the regional observing systems through the CLIVAR project. The conference identified the following priorities through a conference statement (Hall et al. 2009);

> Provision of routine and sustained global information on the marine environment sufficient to meet society's needs for describing, understanding and forecasting marine variability (including physical, biogeochemical, ecosystems and living marine resources), weather, seasonal to decadal climate variability, climate change, sustainable management of living marine resources, and assessment of longer term trends. The ocean observing system must be sustained and enhanced because; 1) systematic observation of the properties of the ocean and the information derived are changing what we know about the ocean and its implications for society; 2) the real-time flow of these observations underpin the development, production, and delivery of many ocean services and support coastal zone management; 3) global oceans information is critical to support forecasting of climate, weather and natural hazards from daily to centennial time scales; 4) the development of an increasing range of ocean assessments and climate services for planning, early warning, adaptation and mitigation, depend upon availability of accurate observations and models of the world ocean; 5) the ocean is an important sink of anthropogenic CO2, and ocean acidification potentially has significant impacts on marine ecosystems; 6) sustainable management of marine living resources depends on timely and accurate monitoring of and information on biogeochemical cycles and ecosystem function; 7) biodiversity is understood to be a key factor in ensuring sustainable ecosystem function; 8) healthy coastal environments and their interactions with the open ocean are important to society; and 9) the oceans remain seriously under-sampled, and no single nation can perform all necessary ocean observations.

4 Overview of Following Chapters

The following chapters consist of the key position papers that were prepared and presented at the OSC. Each paper addresses the overall research and intellectual challenges of the topic it covers. Together, the papers present an excellent assessment of the current state of knowledge on climate variability and change, identify the

scientific challenges and most urgent research issues, and ascertain how the WCRP can best facilitate research and develop partnerships critical for progress during the next decade. Each paper benefited from comments and feedback from at least three independent reviewers. The following chapters are organized according to the major scientific themes of the OSC.

The Climate System Components and Their Interactions: The presentations in this part of the conference focused on the need for WCRP to remain focused on facilitating the discovery of key processes in each component of the Earth's climate system and the interactions among them. They also referred to the need to represent these processes in models and thereby provide the basis for improved predictions of climate variability and change. Talks emphasized, for instance, significant shortcomings in our understanding of cloud and convection-related processes, as well as uncertainties in aerosol radiative effects (Sherwood et al. and Rosenfeld et al., this volume). Gaps in our understanding of the complexity of the hydrological cycle and human influences on the character and dynamics of it were discussed, as well as the fact that these are central to our understanding of many other atmospheric, chemical, and physical processes (Gleick et al., this volume). The many research achievements, yet remaining challenges, around land-atmosphere coupling were also presented and discussed (Oki et al., this volume).

Observation and Analysis of the Climate System: Presentations in these sessions outlined significant progress over the past three decades in observations of all of the major Earth system domains (i.e., atmosphere, oceans, land and polar region). These observations are increasingly needed for planning and informed decision making related to climate services in the broadest sense. However, data gaps and other major challenges still exist, such as how best to deal with the continually changing observing system, especially from satellites, in order to provide a continuous climate record (Trenberth et al., this volume). Since most observing systems were not developed with a climate objective in mind, tremendous efforts have gone into assessing and reprocessing data records. Recent progress in reprocessing and reanalyzing observations, as well as existing challenges and next steps in these efforts, were described and discussed by OSC participants (e.g., Bosilovich et al., this volume).

Assessing and Improving Models and Predictive Capabilities: Climate and Earth System models are getting more realistic, comprehensive and capable to deliver short-, medium- and long-term predictions and projections to users. The scientific basis for prediction from weeks to decades, current capabilities and outstanding challenges were highlighted in these sessions (e.g., Kirtman et al., this volume), as were the reliability of models used for longer-term climate projections and the power of multi-model ensembles (van den Hurk et al., this volume). The presentations also emphasized, however, the need for WCRP to continue to facilitate comprehensive and coordinated model evaluation, especially in light of the long list of systematic errors that plague all models, and the importance of continued development of the "foundations" of Earth System models, namely the atmospheric, oceanic, and land components. Overall, the sessions re-confirmed the major outcomes and recommendations of the WCRP Modeling Summit (WCRP 2009a).

Climate Assessments and Future Challenges: The speakers in these sessions focused both on science-based climate and environment assessments and strengthening the policy relevance of such assessments by highlighting the need for research on anthropogenic climate change (Bony et al., this volume; Solomon et al. this volume). Priority should be given to understanding the processes and mechanisms responsible for climate variability and predictability at regional scales (Vera et al., this volume; Rosenlof et al., this volume). Promoting research on detection and attribution of extreme events and research on heat waves, tornadoes, extreme precipitation and tropical cyclones will provide a solid scientific foundation to improve their prediction (Stott et al., this volume; Zwiers et al., this volume). It was also stated that cryospheric research is rich with grand challenges and recommended that WCRP continue to promote research, modeling and analysis for addressing large uncertainties in knowledge of ice sheet mass balance for sea-level change and variability, sea-ice dynamics, and changes in solid precipitation in a changing climate, with a major regional focus.

Translating Scientific Understanding of Climate System into Climate Information for Decision Makers: The speakers in the final plenary session of the Conference focused on the development and use of climate knowledge and information for socio-economic development and societal services. They stated that, in less developed countries, there is a direct relationship between building adaptive capacity and development (Lemos et al., this volume). Many of the causes of vulnerability are connected to development deficits, which calls for a new paradigm of adaptive development and the requirement for countries to solve some of their development problems in a context of climate and environmental change. The ICSU vision for "Future Earth" initiative and associated Grand Challenges (Reid et al. 2010), for example, states that the global sustainability is a prerequisite for poverty alleviation. The concept of "planetary boundary thresholds" (Rockstrom et al. 2009) calls for innovative pathways for societal transformations to ensure global sustainability, and science-based planetary stewardship for human prosperity.

Climate services are a necessary element of this transformation, and they have the potential to bridge communities, language and value systems. The language of uncertainty employed in the climate information provision, however, casts doubts among users, and there is a merit for informing them based on the concept of probabilities and likelihood. Providing climate information that meet or exceed in time, space, and frequency the user-defined needs is powerful. The issues of responsibility, accountability, credibility, and values are largely missing from the climate services dialogue. To put them in place, producers and users of climate information need to collectively develop the language that leads to plausible, defendable and actionable messages. For example, in the area of climate and health, projects like Meningitis Environmental Risk Information Technologies (MERIT) (Thompson et al. 2006) is showing significant achievements in implementing health–climate alliance. The basis for joint action is the agreement among the stakeholders on the corresponding evidence, stemming from a strategic approach to the creation of the evidence, together with the development of a cumulative knowledge base, effective

dissemination of knowledge, with development of effective means of access to knowledge, and resulting in initiatives to increase the uptake of evidence in both policy and practice.

Meeting the Climate Information Needs of Decision Makers: A clear and emerging priority from the OSC was the need for "actionable" science. The consensus that emerged at the conference was that the number one service to society provided by WCRP is the encouragement and enabling of the climate-related research that will provide the scientific basis for sound decision making over the next decades. WCRP should also help in developing an interface between climate information and its use for a particular application. The main challenge in the discussion of science support to climate services is the optimal balance of fundamental and applied research, and interface between climate research and climate information and users. Given the still existing gap between science and decision-making, the need to understand and use deliverables of climate research outcomes become even more important than in the past.

The reality is that decision-makers – including water providers, farmers, insurance companies, oil exploration companies and many more – need climate and other scientific information to guide decisions more than ever before. Future water availability in a region, for example, may guide crop selection for the ensuing year, or siting decisions for a new water treatment plant that will be operational for decades. But there is often a mismatch between the scientific data available and the information needed, so there is a need for "symbiotic" relationships between providers and users of climate information to ensure that 'actionable' (timely, accessible, and easy to understand) climate information is developed and used effectively.

The need for actionable science was also explored during an evening session with a panel of experts from the private sector. Sponsored by the University of Maryland's Earth System Science Interdisciplinary Center, the panelists were senior executives of several major companies – BP, Northrup Grumman, Zurich Financial Services, Computer Sciences Corporation and the Weather Channel. The discussion focused on the need for scientists and the private enterprise to work better together toward actionable information. They shared the perspective that conversations during scientific conferences such as the OSC were a start, in that awareness of the richness of the scientific data and information available is gained by users while scientists begin to understand what kind of data and information is required to guide business and policy decisions. Participants agreed that while gaps exist today between data and information needs and availability, those gaps are rich with opportunity. In particular, there is the chance for private companies to use the data created by the research community to deliver more detailed, relevant information to decision-makers. The participants stated the need now is to go beyond understanding natural systems alone into understanding how natural systems connect with human systems, and that requires understanding the kinds of information the users need to make decisions. A major point made repeatedly by the users of climate information throughout the conference was the importance of their early and

continued engagement with scientists to define the needs from science, the type of information required, and the most effective way to convey the results to inform actionable decisions. The "symbiotic" relationship between producers and users of climate information was identified as the best model to ensure such effective partnership.

5 Summary

As a result of the week's deliberations at the OSC, several major scientific themes and priorities emerged from the conference presentations and discussions. They include: (1) the need for prediction of the Earth System bridging the physical climate system with biogeochemistry, the social sciences, and human dimensions, a problem that transcends the WCRP and one that should benefit from the proposed Earth System Science alliance; (2) the opportunity, provided by new satellite observations, to make a quantum leap in understanding of clouds and aerosols and their contributions to climate sensitivity; (3) the necessity of skilful climate information on regional scales, embodying the so-called "seamless prediction" paradigm; (4) the importance of quantifying "true" uncertainty in climate predictions; (5) the challenges and opportunities of predicting how natural modes of climate variability will modify the "forced" anthropogenic component of climate change over the coming years to decades; (6) the increasing importance of establishing the predictability of polar climate, perhaps especially with the opening of the Arctic and international negotiations regarding increased commercial traffic for shipping and extraction of natural resources; (7) the need to better understand the causes of extreme events and performing attribution studies in near real-time; (8) the challenges of improved predictions of future sea-level rise on regional scales, which will require knowledge of not only cryospheric and thermosteric contributions but also how gyre circulations, storm tracks, and tidal amplitudes will change; and (9) the requirement to train and empower the next generation of climate scientists across all corners of the globe, a priority of the future WCRP as it seeks opportunities for capacity development with its partners in the human and social sciences.

The general consensus among the OSC participants was that the WCRP and its affiliate network of international scientists and Projects must continue to provide the scientific foundation for understanding and predicting the Earth's climate system. However, they also must play a major role in providing the resulting knowledge and information in ways that yield practical solutions to the complex and interrelated challenges required to ensure a sustainable Earth for future generations. The World Climate Research Program, its leaders, and network of projects stand ready to support the research community in pursuing the challenges and opportunities identified during the conference and captured in the following chapters of this book in the spirit of pursuing Climate Science in Service to Society in the ensuing decades.

References

Asrar GR (2009) The World Climate Research Programme. Public Serv Rev Sci Technol 3:115–120
Asrar GR, Busalacchi A, Hurrell J (2012) WCRP Open Science Conference. American Geophysical Union, Eos Transactions 93(12), 20 Mar 2012
Hall J, Harrison DE, Stammer D (eds) (2009) "Conference Statement" in Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society, vol 1. Venice, 21–25 Sept 2009, Publication ESA WPP-306, doi:10.5270/OceanObs09
ICSU-IGFA (2009) Review of the World Climate Research Programme (WCRP). International Council for Science, Paris. Available at www.icsu.org, ISBN: 978-0-930357-70-2, 57 pp
ICSU-ISSC (2010) Earth system science for global sustainability: the grand challenges. International Council for Science, Paris. Available at www.icsu.org, ISBN: 978-0-930357-73-3, 20 pp
Leemans R, Asrar G, Busalacchi A, Canadell J, Ingram J, Larigauderie A, Mooney H, Nobre C, Patwardhan A, Rice M, Schmidt F, Seitzinger S, Virji H, Vorosmarty C, Young O (2009) Developing a common strategy for integrative global environmental research and outreach: the Earth System Science Partnership (ESSP). Curr Opin Env Sust 1:4–13
Reid W, Chen D, Goldfarb L, Hackmann H, Lee YT, Mokhele K, Ostrom E, Raivio K, Rockström J, Schellnhuber HJ, Whyte A (2010) Earth system science for global sustainability: grand challenges. Science 330:916–917
Rockstrom J, Steffen W, Noone K, Persson K, Chapin F III, Lambin E, Lenton M, Scheffer M, Folke C et al (2009) Planetary boundaries: exploring a safe operating space for humanity. Nature 461:472–475
Thompson M, Molesworth A, Djingarey M, Yameogo K, Belanger F, Cuevas L (2006) Potential of environmental models to predict meningitis epidemics in Africa. Trop Med Int Health 11:1–9
World Climate Research Programme (WCRP) (2005) Strategic framework 2005–2015, "Coordinated Observation and Prediction of the Earth System", WCRP-123, WMO/TD-No. 1291, 65 pp
World Climate Research Programme (2009a) World Modelling Summit for Climate Prediction, Reading, UK, 6–9 May 2008, WCRP-No. 131, WMO/TD-No. 1468, 29 pp
World Climate Research Programme (2009b) WCRP Implementation Plan 2010–2015, Geneva, WMO/TD-No. 1503, 43 pp
World Meteorological Organization (2011) Climate knowledge for action: a global framework for climate services (GFCS). The report of high level task force for GFCS, WMO-No. 1065, 240 pp
World Meteorological Organization (2012) Implementation plan for the Global Framework for Climate Services, WMO-No. (in print), 90 pp