WCRP REPORT
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WORKSHOP REPORT

IPCC AR5: Lessons Learnt for Climate Change Research and WCRP

International Space Science Institute, Bern, Switzerland 8–10 September 2014

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Group picture taken on 9 September 2014 close by ISSI

(photo by Saliba Saliba, ISSI)

IPCC AR5: Lessons Learnt for Climate Change Research and WCRP

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(Report for the joint WCRP/IPCC Workshop prepared by Gilles Sommeria, under the supervision of the Scientific Steering Committee, and with contributions by the Scientific Steering Committee, Keynote Speakers, Leaders of Break-out Groups and Nicolas Champollion)

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EXECUTIVE SUMMARY (by David Carlson, WCRP Director)

The Joint Scientific Committee (JSC) of World Climate Research Programme (WCRP), working closely with Working Group I of the Intergovernmental Panel on Climate Change (IPCC), organized a meeting on the topic "Lessons Learnt for Climate Change Research" with respect to the recently published IPCC Fifth Assessment Report (AR5). In partnership with the Technical Support Unit of IPCC Working Group I and the International Space Science Institute (ISSI) on the campus of the University of Bern, and with substantial financial support from the Swiss Federal Office for the Environment, WCRP invited more than 75 climate researchers to revisit the AR5 – primarily Working Group I (Climate Change 2013 – The Physical Science Basis), but also Working Group II (Climate Change 2014: Impacts, Adaptation and Vulnerability) and Working Group III (Climate Change 2014: Mitigation of Climate Change) – in light of ongoing climate research and conversely to assess ongoing climate research directions, especially as organized and coordinated by WCRP, in light of AR5. During three days of intense presentations and discussions the participants – a good mixture of lead authors of the IPCC AR5 and WCRP project leaders – evaluated climate science, WCRP directions and plans and future needs for research and assessments.

To the question of research gaps identified in AR5, particularly in the Working Group I report, the participants answered emphatically: almost none. Nearly every researcher could identify progress since AR5 and many advocated expanded discussion of their specific topic in succeeding assessments. However, after the thorough, careful, inclusive and highly professional conduct of the AR5 and Working Group I consultative, compilation and publication processes, the fact that systematic scrutiny, including a pre-meeting survey, turned up no serious omissions or weaknesses represents no surprise. Anticipating this result, the Scientific Steering Committee for the meeting structured the topics and sessions much more around the issue of knowledge gaps. On questions related to these knowledge gaps a much more interesting and useful discussion emerged. The overall approach of AR5 of assigning explicit and calibrated uncertainty language to key findings of the report, either through specifying a qualitative level of confidence (e.g. "medium" or "low" confidence if confidence is limited) or, if the science permits, a quantified likelihood that a certain finding is true, allowed the Scientific Steering Committee to easily extract and expose a series of Key Uncertainties in observations, forcing factors, fundamental understanding and global and regional projections and to then challenge the participants to assess WCRP activities, particularly the WCRP Grand Challenge activities, in light of these uncertainties identified in the IPCC WGI AR5[1]. Perhaps not surprisingly but certainly not inevitably, the group found a good match between goals of the WCRP Grand Challenges – on clouds and atmospheric circulation, sea level rise, climate extremes, water availability, cryosphere and regional climate information – and knowledge gaps identified in the WGI AR5. In many cases this close overlap allowed various break-out groups to focus on details and implementation activities for the Grand Challenges with fresh ideas and new energy.
The cross-analysis of uncertainties versus ongoing activities exposed four areas where uncertainties are still substantial and which were not covered by, but definitely needed for progress within, the WCRP Grand Challenges. These included:
– The issue of ocean (particularly deep ocean) heating and ocean circulation generally (the former certainly identified within the sea level Grand Challenge and prominent within the pre-meeting survey, the latter linked to decadal prediction challenges), which seemed too weakly represented in the meeting agenda and perhaps in the Grand Challenges as well;
– The need for greater emphasis on understanding natural variability and forced change on annual to decadal time scales as relevant and indeed urgent for predictions of climate extremes (particularly those related to water availability) and other climate impacts on regional spatial scales;

[1]Note that this list also formed the basis for the pre-meeting survey of participants.

– The need for better descriptions of and incorporation of aerosols (and other so-called short-lived climate forcers) into understanding and predicting on annual to decadal time scales and on local to regional spatial scales; and
– The growing need to incorporate interactive components of the carbon cycle, including terrestrial and oceanic geochemical and ecological sources and sinks, into analyses and models.

The goal of increased skill on decadal time scales emerged from several sub-groups into a more general theme, indicating a need for WCRP to promote and strengthen its Decadal Climate Prediction Project. Because nearly every speaker and every report emphasized their need for better and more systematic sources of and access to data, substantial interest developed in a proposed earth system reanalysis. Several people suggested that such an effort should build on the enormous impact of meteorological reanalyses through a very broad effort to gather and assimilate data products from across and beyond WCRP activities. Based also on numerous presentations, the assembled group recognized the extreme utility and persistent need for model inter-comparison projects (MIP) applied to many types of models while also raising fundamental concerns about limited computing resources (staff and hardware) available to support those efforts.

Overall, the meeting proved lively and timely for participants and outcomes. Recognizing the enormity and the quality of the AR5 process, the group discussed alternatives, including small topical assessments that might then represent components of a subsequent encompassing assessment. A collective motivation emerged to not simply repeat past steps and past processes, and to not accept CMIP6 outcomes without substantial, collective, perhaps even dramatic improvements over CMIP5 on many fronts and for many features. And, based on explicit reminders of the relentless increase of carbon emissions and anticipation of an abrupt end to the so-called hiatus of global mean surface air temperature increases, a growing and increasingly urgent need for accurate, timely and accessible climate information. For WCRP, and for many participants, the Bern “Lessons Learnt’ ” meeting represented a very necessary step forward.

WORKSHOP REPORT

1. Objectives of the workshop and introductory remarks

The decision to organize this workshop was made in January 2014 by the World Climate Research Programme (WCRP) Joint Scientific Committee (JSC) in consultation with the Working Group I of the Intergovernmental Panel on Climate Change (IPCC WGI), dedicated to the physical science basis of climate change. As WCRP is one of the main contributors to research developments assessed by IPCC (mostly WGI but also to some extent WGII and III), it is natural to expect a feedback from issues raised as part of the IPCC Fifth Assessment Report (AR5) on WCRP strategic directions. A similar approach was conducted after the publication of the Fourth Assessment Report (AR4) with a workshop organized jointly by WCRP, the Global Climate Observing System (GCOS) and the International Geosphere-Biosphere Programme (IGBP) in October 2007 in Sydney. In 2010, GCOS and WCRP jointly expressed the desire to continue to support the IPCC activities and to benefit from a feedback from the IPCC process. In the planning stage for this workshop several options were considered in coordination with GCOS. This meeting was intended to focus on WCRP issues, whereas a second workshop is organized by GCOS in coordination with WGII on 10–12 February 2015, in Bonn.

This workshop was therefore aimed at informal exchanges and brain-storming between scientists involved in climate change research coordination and those who served as authors on the IPCC AR5. Its main purpose was to take stock of key scientific issues identified through the IPCC assessment in WCRP's research plans. It was also intended to help IPCC in its own reflection on future activities and, as appropriate, to feed into the progress report being prepared by GCOS.

IPCC AR5 has identified a number of emerging themes and outstanding issues in climate change research, some of them outlined as key uncertainties by WGI and "research and data gaps" by WGII. IPCC AR5 authors participating in the workshop provided their views on debates held at IPCC on those issues. Additional input from the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) and WGIII report was also considered, as well as new scientific material available since the AR5 cut-off dates. Contributions and discussions focused on issues which are considered as essential for the progress of climate change research and on actions which may facilitate the evaluation of risks and impacts, and the development of adaptation strategies. The agenda was built around scientific themes and types of research activities which are needed for responding to outstanding questions. Outcomes are expected to benefit the planning of major WCRP projects, particularly the "Grand Science Challenges", defined as major areas where efforts in research, modelling, analysis and observations are needed. Among the aspects of WCRP research which should particularly benefit from the workshop are the planning of climate model intercomparison and evaluation activities, and the development of regional climate projections. It is also expected that the input from the authors from the three IPCC working group reports will help to highlight new orientations which may presently be missing in WCRP's remit. From the viewpoint of the participating authors, it is expected that it will provide constructive comments and recommendations for the content of future assessments and that it will contribute to enhancing the quality of research needed to answer the societal challenges addressed by IPCC.

Support for the workshop organization was indicated at an early stage by the International Space Science Institute (ISSI), which offered to host the workshop. Whereas the overall organization was under the responsibility of WCRP Joint Planning Staff and the IPCC WGI Co-Chairs, support in the preparation of the meeting and local organization was provided by the IPCC WGI Technical Support Unit (TSU) and the ISSI staff. The Swiss Federal Office for the Environment financed a large part of the meeting's costs and the IPCC covered the travel costs of participants from developing countries and countries with economies in transition. The Oeschger Centre for Climate Change Research at the University of Bern and the Government of Switzerland sponsored the welcome reception on the first day.

The participants list is attached (Annex A), along with the workshop agenda (Annex B), the guidance document (Annex C) and the survey report (Annex D). The present report covers the preparatory scientific activities, provides brief summaries of keynote presentations, presents the conclusions of the Break-out Groups (BOGs) and finally, the overall recommendations of the meeting.

2. Preparatory scientific activities

2.1. Scientific Steering Committee

The workshop was organized under the supervision of a Scientific Steering Committee (SSC). Its role was to provide scientific guidance in the various stages of the workshop preparation including the invitations, the agenda and the survey, to coordinate the workshop scientific work and to ensure that the workshop outcomes fulfill the objectives set by WCRP and IPCC.

Composition:

- Guy Brasseur (WCRP JSC, SSC Co-Chair)
- Thomas Stocker (IPCC WGI, SSC Co-Chair)
- Sandrine Bony (WCRP WGCM)
- Anny Cazenave (WCRP JSC)
- Vladimir Kattsov (WCRP JSC)
- Katharine Mach (IPCC WGII TSU)
- Gian-Kasper Plattner (IPCC WGI TSU)
- James Renwick (WCRP JSC)

Support: Gilles Sommeria (WCRP consultant) & Nicolas Champollion (ISSI)

2.2. WCRP survey

A WCRP survey was conducted in July 2014 that was circulated to WCRP project leaders and participants and key relevant authors from the recent IPCC reports. Its purpose was to review how IPCC assessment reports impact the climate science community in general and WCRP in particular. The survey focused on research gaps, knowledge gaps and uncertainties, on potential ways forward to make progress (in terms of observing systems, modelling, etc.) and on how all those components are covered in the current existing WCRP programme, including the WCRP Core Projects and Grand Challenges.

The starting point for the survey was the review of outstanding scientific issues identified by IPCC AR5 in WGI report and "research and data gaps" in WGII report, complemented as needed by material from SREX. Views were solicited on how these issues have evolved between AR4 and AR5, how they have been taken up in new studies since AR5 cut-off dates and how they are dealt with in WCRP plans (through the Core Projects or the Grand Challenges). Suggestions on future IPCC/WCRP interface issues as well as on any other aspect of climate research respondents wished to highlight were also welcome.

The results of the survey served as input to the workshop discussions, were made available to WCRP as a resource when refining WCRP work plans, and to IPCC as elements of reflection on future IPCC assessments. The survey report is attached as Annex D, detailed answers being available at:
https://www.dropbox.com/sh/nky1ycy0ww0rj3q/AAC3eI_2RmF0doTqrzAUf6b8a

Main conclusions are as follows**:**

Survey results cover 46 responses, coming mostly from workshop participants; a majority of respondents were from USA and Europe. Contributors made a remarkable effort in offering interesting comments and proposals. The responses may contribute to WCRP and IPCC planning and serve the climate community. The survey is divided into four parts: issues covered by IPCC WGI, the physical science basis; issues covered by IPCC WGII, impacts, adaptation and vulnerability; priorities for research within WCRP, implications for Core Projects and Grand Challenges; and suggestions for future IPCC assessments.

Questions covering WGI issues concern gaps in observations and understanding of climate change, "drivers" of climate change and model projections of global and regional climate change. The main gaps and uncertainties in observations concern precipitation data, changes in large-scale circulation, ice-sheet evolutions and deep ocean. According to the survey, drivers of climate change that deserve most attention are aerosol-cloud interactions followed by cloud feedbacks. The main gap in understanding processes is considered to be the modelling of changes in the water cycle. Main priorities highlighted for projections of climate change are related to yearly to decadal temperature predictions, abrupt non-linear changes and regional prediction. On the evolution since AR4, responses are rather mixed but the main areas of progress concern ice-sheet dynamics and cloud feedback. Survey respondents mainly considered that improvements should be achieved on fundamental processes and observations and data. Indeed, observing technology, temporal and spatial coverage of observations, are the most often mentioned. Most of respondents suggested continuing and maintaining existing observation networks as well as improving data quality. Concerning climate modelling, grid size/resolution, computing power and processes parameterization are the main issues where improvements are recommended, with specific needs for better representation of ice-sheets and better handling of extremes. Further exploitation of CMIP5 data is also recommended.

Questions covering WGII issues concern gaps in impacts, adaptation and vulnerability of climate changes. Main issues identified by respondents with respect to impacts are extreme events, sea-level rise, water availability and resources and food security. . Respondents highlighted the importance of contemplating opportunities to rethink and "co-produce" work on impacts and adaptation. The development of risk management strategies associating the scientific community with regional/local practitioners is one important orientation for progress. Regional aspects are very important, especially for extreme events, and some respondents noticed major data gaps in observations in Africa, South America and Asia, as well as for complex topographies and major river basins. Finally, all respondents agreed on recommendations for making progress which involve temporal and spatial coverage of observations (similar to questions covering WGI issues) and grid size/resolution associated with computing power, in addition to application of climate analyses to societal needs. Responses concerning SREX issues cross over responses for WGI & WGII, highlighting gaps in extreme events, sea level and ice sheets.

Questions covering WCRP research concern priorities for WCRP to fill the most critical gaps for the next IPCC reports, possible additions to Grand Challenges and improvement of the current institutional or technical infrastructure. A number of topics are highlighted within the present WCRP structure but the range of priorities is fairly large. Recommendations for Core Projects include decadal variability, observations of ocean heat content, critical cryospheric processes and surface-atmosphere interactions. The priorities expressed through the Grand Challenges are overall endorsed, with special attention recommended to ocean-ice interactions (in observations and models), risk associated with extreme events, contribution of ice sheets to sea-level rise, uncertainties in water cycle processes, regional downscaling and aerosol effects on clouds and climate. A number of recommendations are related to modelling activities including better parameterizations, advanced supercomputing and data management, higher frequency outputs and better assessment of regional modelling. The benefits of coordinated observation activities are also highlighted, with the need to improve estimates of ocean parameters, fine resolution information and central availability of datasets. The need to create a new Grand Challenge in biogeochemistry was expressed by a number of respondents. Concerning coordination activities and technical aspects, the development of appropriate infrastructures for supporting research and climate services seems essential, with a number of suggestions offered: development of long-term observational networks, better integration between observation and modelling communities, partnership with Copernicus Program (Europe) and the Global Framework for Climate Services (GFCS) and development of interdisciplinarity, especially with the IGBP community and social scientists.

Questions covering future IPCC assessments concern IPCC assessment results and processes that could be taken account in WCRP activities, and suggestions for new climate change research activities that would serve future assessments. Respondents expressed the importance of WCRP focussing on gaps and uncertainties identified and quantified in IPCC assessments, which is precisely the main motivation for the Bern workshop. The need to better take into account WGII approach in the climate science community was mentioned as one important issue. The ever increasing burden from IPCC assessments on the science community was noted as a serious concern. Specific suggestions include decoupling observed climate change assessments (to be done separately on a more frequent basis) from model assessments, more involvement of scientists from countries with economies in transition and more use of references in languages other than English, making the links between WCRP & IPCC activities more clear and transparent. A careful review of the timing of WCRP activities in relation with the IPCC timeline was also recommended. Other proposals include WCRP preparation of a sequence of climate change specific reports as input to a reduced IPCC report, and restructuring IPCC in two WGs. On the question of new research activities that would serve IPCC assessments, a number of respondents highlighted more research on impact issues, better interaction with other disciplines through the international Future Earth initiative (http://www.futureearth.org/) and closer connections with applications.

Overall, the dialogue initiated with the scientific community through this survey was useful even if many of the suggestions are not necessarily innovative. The consideration of how to deal with research gaps assessed by IPCC enables specific issues to be highlighted and may provide additional support to some already agreed upon research orientations. Interaction with the impact and adaptation community and the development of services are two areas where new activities could be developed. The IPCC motivation can probably help support requests from the scientific community for improved observation, data and research infrastructures. This survey also shows that the scientific community represented by WCRP is ready to confirm its commitments to climate change assessments and actively participate in the reflection on future IPCC activities. It is unfortunate that, for a variety of reasons, the participation of respondents from developing countries or countries with economies in transition is very small, and this should be improved in any future survey.

The Science Steering Committee and the survey organizers would like to acknowledge the work of respondents and greatly thank them for their participation.

2.3. Guidance document and Break-out Group organisation

A “guidance document” (attached as Annex C) was prepared ahead of the workshop under SSC supervision to inform participants of the workshop objectives and expected outcomes. One of the main features was the setting up of Break-out Groups (BOGs) aimed at streamlining thematic scientific discussions and preparing recommendations in line with the workshop objectives.

Eight Break-out Groups (BOGs) had been defined and BOG leaders nominated prior to the meeting, and invited to provide a short list of thematic issues that agreed with SSC (cf. guidance document). BOGs 1 to 6 were defined along WCRP Grand Challenge objectives and were organized and lead by the coordinators of the Grand Challenges, with, if possible, the addition of one external expert. BOGs 7 and 8 addressed broad issues covered by IPCC and which could be included in future WCRP activities or addressed in cooperation with WCRP. Each BOG nominated one chair and one or two rapporteurs. Workshop participants were asked prior to the meeting to indicate in which BOG they would take part, with the aim of balancing participation and providing an early indication of “membership” to BOG leaders.

The BOGs’ overall objectives were to come up with ideas or recommendations that would contribute towards addressing key research issues raised by IPCC, observation and modelling needs, from the perspective of WCRP strategic planning. They were expected to make recommendations in their respective domain, using as guidelines a few overarching questions raised by SSC, as follows:

1. What are the major gaps in the domain covered by your BOG (revealed by the IPCC AR5 process) in our understanding of the climate system, and what are the best strategic approaches to address these scientific issues in the next 5–8 years?
2. How could the community focusing on the topics discussed by your BOG contribute to key scientific questions, uncertainties and research issues raised/identified by IPCC?
3. What are the inadequacies/requirements of the current/future observing system in relation with the objectives of your BOG? Similarly, what are the main modelling or modelling infrastructure inadequacies/requirements in relation with the objectives of your BOG?
4. How could WCRP respond to identified gaps and contribute efficiently to the preparation of the next IPCC assessments? Should WCRP produce some specific synthesis papers in preparation to these IPCC assessments and if so, on which topics?

3. Summaries of keynote presentations at the workshop

Welcoming remarks were offered by Mr. José Romero, Swiss Federal Office for the Environment and Swiss Focal Point for the IPCC, on behalf of the Swiss Government; Prof. Thomas Stocker, Co-Chair IPCC WG I, on behalf of the IPCC; Dr. David Carlson, Director WCRP, on behalf of the JSC; Prof. Rudolf Von Steiger, Director ISSI, on behalf of the Institute. Profs. Guy Brasseur and Thomas Stocker, Co-chairs of the workshop SSC provided an outline of the workshop's objectives.

Keynote presentations were prepared generally by two authors and presented by one of them. They were expected to highlight research topics and issues that have been identified in the IPCC process and which fit or potentially fit into WCRP remit, with a long term perspective and updates from recent scientific work. The authors were asked to include specific recommendations on ways to address outstanding issues and encouraged to feed in appropriate break-out groups.

3.1. Session 1: IPCC WGI AR5: Emerging themes and key uncertainties

1. Longstanding uncertainties in IPCC assessments (Thomas Stocker and Gian-Kasper Plattner)

In 2013, Working Group I of the Intergovernmental Panel on Climate Change (IPCC) published its 5th Assessment Report "Climate Change 2013: The Physical Science Basis" (http://www.climatechange2013.org/). The 1535 page report includes a Summary for Policymakers, a Technical Summary, 14 chapters and 6 annexes and was prepared by 259 authors and review editors, with the help by more than 600 contributing authors. The report comprehensively summarizes the current understanding of climate change science, from past and present-day observations to future climate change projections. A key component of all IPCC assessments is the treatment of uncertainties for major findings. However, despite the substantial progress and increased understanding in climate change science over the past 25 years and now five IPCC assessment cycles, areas remain where uncertainties are still large and prevent firmer statements by the IPCC. The presentation reviews such longstanding uncertainties in IPCC assessments emerging from the Working Group I 5th Assessment Report. The discussion focuses on uncertainties relevant to the WCRP Grand Challenges, covering observations, including water cycle and the cryosphere; radiative forcing and physical feedbacks; near-term prediction; sea-level projections; carbon cycle; scenarios and experiment setup for climate model simulations. Based on the current state of these uncertainties, the main question raised is whether the WCRP Grand Challenges are ready to contribute to reducing these longstanding uncertainties in future IPCC assessments.

2. Regional climate change (Krishna Kumar Kanikicharla and Bruce Hewitson)

Emerging points from WGI report are presented: large uncertainties on future changes in regional monsoons, need to improve understanding of how ENSO (El Nino Southern Oscillation) and its connections are changing, critical need for improving knowledge of tropical convection and how it is influenced by a changing climate, need for better understanding of changes in the South Pacific Convergence Zone, need for improved understanding of the sensitivity of Tropical Convection Potential Intensity to changes in SST, need to develop probabilistic projections especially in the extratropic, need to revisit the way percentiles of projections – particularly precipitation – are computed.

The overall perspective from the WGII report is that, producing the required regional climate information for stakeholders is still an ambitious target; until we produce scale-relevant information to usefully inform decisions, science will have minimal immediate value to society. Outstanding questions concerning the producers of regional climate change information are as follows: as resolution increases, there is a need to demonstrate we understand the sources of uncertainty and the regional climate change signal, new extensions of metrics are needed, especially to assess regional information in user-relevant terms, the evolving regional information requires communications so that it is not perceived as being more skillful than it is, nor less skillful than it is, which presumes one can "measure" how skillful it is.

From a "user's point of view", one should take into account these facts:

- "Users" (decision makers) are mostly place-based, meaning that evaluation by means of conventional large scale averages and/or large spatial patterns and/or Taylor diagrams are of limited value.

  "Users" information needs are often attribute based; that is, the issues are often dependent on characteristics of a variable's change, such as rain day frequency, seasonal onset, dry spell duration and threshold exceedences.
- "Users" vulnerabilities are often compound in nature; interactions of multiple climate variables in space and time drive the impacts.
- "Users" mostly operate in a near to medium term decision space under dominant non-climate stressors; climate factors may or may not be important at decision scales.

3. Improving the quality of information on near-term (1–35y) future climate (Scott Power, Rowan Sutton, George Boer, Francisco Doblas-Reyes, Yochanan Kushnir, Sang-Wook Yeh, Tianjun Zhou, Peter Stott, Jerry Meehl and Jochem Marotzke)

Improving the quality of information on near-term (1–35yr) future climate will be underpinned by advances in predictions, projections, the understanding of observed climate variability on decadal and longer time-scales, the understanding of how the information is being used or could be used to benefit society and the presentation of the information available (including associated uncertainty).

Predictions can be improved through e.g. improvements in initialization/data assimilation, ensemble generation and post-processing (including bias-adjustment and calibration of predictions).

Projections can be improved through e.g. improving models (including the realism of internal climate variability in climate models), provision and use of better estimates of future aerosol forcing and research providing greater clarity of the associated uncertainty and additional information to assess the confidence we have in the projections.

Better understanding of observed climate variability is needed because information on near-term future climate, and the associated confidence we assign to the information, is influenced by our ability to simulate and understand past behaviour. This includes the attribution and quantification of the relative importance of internal variability and both anthropogenic and natural external forcing in driving the observed change. Relevant changes include those in atmospheric and oceanic circulation. This also includes progress in our understanding of the mechanisms responsible for internal decadal climate variability, and predictability and apparent skill on annual to decadal time-scales. Progress on the above will be assisted by the emergence of the Decadal Climate Prediction Project (DCPP), a joint project of WGSIP, WGCM and CLIVAR. WCRP aims, in part, to provide useful information for practical applications to assist society. An understanding of what is needed in relation to near-term climate by people developing applications and in possible future IPCC WGII and WGIII assessments is therefore important. This will also assist in improving the presentation of the information available, to facilitate more widespread, prudent use in the broader community.

4. Carbon cycle–climate interactions (Corinne Le Quéré and Fortunat Joos)

This presentation highlights five areas where major gaps persist in our quantitative understanding of carbon-climate interactions, and identifies opportunities for advancing knowledge with the next decade of research.

- Understanding the decadal changes in atmospheric, oceanic and terrestrial fluxes and concentrations of CO_2, N_2O and CH_4 and their drivers. Several interesting decadal changes in biogeochemical cycles have been brought to the fore in recent published work, but have not yet been fully explained. These include: the renewed growth in atmospheric CH_4 concentration after 2006, decadal variability in atmospheric CO_2 growth rate and decadal trends in regional surface ocean pCO_2. Advances in understanding carbon-biogeochemistry-climate interactions could be gained by scrutinizing the decadal changes and relating them to temperature, rainfall, winds and other climatic drivers. Reproducing decadal changes in models would also help to better constrain interactions with the nitrogen cycle (on land), and with changes in ocean currents (in the ocean), particularly in the Southern Ocean. Further insights could be gained by combining physical and biogeochemical observations and making use of isotope data, for example through multiple constraints on detection and attribution of specific signals.

- Quantifying the risk of abrupt and/or large biogeochemical-climate feedbacks. Although carbon-climate feedbacks were considered in the temperature projections of AR5, their uncertainty as well as other biogeochemical feedbacks, e.g. related to methane, nitrous oxide, dust, albedo and emissions of GHG precursor substances, were not. This leads to difficulty in interpreting changes in the upper range of projections compared to AR4, and more generally in gauging the risks of large carbon/biogeochemistry feedbacks under potentially large climate change projections. A better understanding of the potentially large feedbacks is needed. These include in particular: the release of carbon and methane from thawing permafrost and peatlands, as current models and observations provide conflicting evidence; how changes in climate extremes will affect the carbon storage on land, which was highlighted by the surprising sensitivity of semi-arid regions and by the widespread tree mortality from drought and temperature extremes in recent studies. A methodology needs to be developed that permits full consideration of biogeochemical-climate feedbacks in addition to the CMIP-type of climate projections.
- Integrating modern observations and paleo proxy information to constrain the biogeochemistry-climate feedbacks in climate projections and to inform climate impacts and adaptation. Recent work has highlighted the potential for emerging properties methodology, data assimilation and probabilistic approaches combining observations and mechanistic understanding, as represented in models to quantify specific aspects of the carbon-climate system. Isotopes of carbon, oxygen, water and other elements permit better quantifying of carbon-water links, constrain GHGs source mix and transport timescales. These methodologies provide an opportunity to constrain models, provide observational-based uncertainties,and to add knowledge to inform adaptation strategies and options, such as the time of emergence of signals. A focus on the constraints between multiple gases in emissions scenarios is also important to better quantify the cumulative carbon-temperature relationship, as non-CO_2 gases account for much of the uncertainty. Of importance is the quantification of cumulative carbon emissions and region-specific climate targets.
- Understanding terrestrial vegetation processes in a managed environment. Interactions are growing between the “natural” and the “managed” vegetation, and they increasingly need to be considered jointly. Terminology differences and processes scope contribute as much as 20% of the differences in published estimates, even more regionally. Some management processes are poorly quantified (e.g. the recovery after agricultural abandonment), and the extent and sensitivity of some carbon pools are poorly quantified (e.g. wetlands, and to a small extent blue carbon in the ocean). New research is needed on the consequences of negative emissions for sink capacity and food production.
- Quantifying the effects of ocean acidification and other less well-known processes. On the known-unknowns, the indirect effect (via ecosystem changes) of ocean acidification on the efficiency of the carbon sink is not quantified, in spite of much new evidence of effects on marine species. Similarly the extent and regional distribution of ocean deoxygenation may affect ecosystem processes and associated N_2O fluxes, but quantitative understanding is poor. New research on river and fresh water systems suggests that anthropogenic perturbations of these fluxes are important, but difficult to track. The ecological impacts of climate change are closely linked to carbon-climate research and would benefit from stronger interactions, especially within the CMIP framework for rigorous quantification and intercomparability across WGs and scenarios.

5. Climate targets beyond temperature (Reto Knutti)

The climate target agreed by governments at Copenhagen in 2009 is to limit global mean warming to less than 2°C relative to pre-industrial times. Other targets like sea level rise, impacts or a combination of targets have received less attention so far. The 2°C temperature target implies a cumulative carbon budget or quota, a limited amount of CO2 that can still be emitted over time. The carbon quota depends on the level of maximum warming to be prevented, the likelihood to actually achieve that goal and the choices made for non-CO2 emissions, but it does not strongly depend on the timing of the emissions. Each ton of carbon therefore leads to about the same amount of warming, no matter when and where it is emitted. While scientifically straightforward, the idea of a global cumulative carbon quota is politically difficult to implement, as it would require a global agreement of how to distribute the remaining carbon quota in a fair way. A more accurate estimate of the carbon quota is unlikely to change the difficulties in agreeing how to share the burden of mitigation. The current discussions largely evolve about synergies and co-benefits of policy measures, which would make mitigation more attractive by linking it to other near term goals.

The scientific community needs to think about ways to integrate the climate (and climate modelling) component into a larger framework of climate, society and the economy, where climate is not just the outcome of prescribed emissions, but where levels of impacts to be avoided can be translated back to emissions and policies, and where climate change feeds back on technology and societal choices for mitigation and adaptation.

6. Aerosols, air quality and climate (Jean-François Lamarque and Piers Forster)

This presentation focuses on highlights from AR5, important science results since AR5, identified gaps in AR5, how air quality fits within the climate system and a proposal to WCRP research themes.

- Highlights from AR5. We have chosen to highlight three main points from AR5: the use of emission-based radiative forcing; the simplification of the discussion of aerosol direct, semi-direct and indirect effects into aerosol-radiation interaction and aerosol-cloud interaction; and the use of effective radiative forcing to capture the importance of fast feedbacks.

- Important science results since AR5. The first paper (Carslaw et al., 2014) identified the importance of natural emissions (such as Dimethylsulfide) as a source of uncertainty to the climate response to anthropogenic aerosols. The second paper (Shindell, 2014) showed that, for many models, the transient climate response is strongly dependent on the inter-hemispheric difference in forcing (i.e. mostly from anthropogenic aerosols) .

- Identified gaps in AR5. These include the limitation of the Representative Concentration Pathways (RCP) emissions for diagnostic of near-term climate impacts. Instead, studies have relied on idealized experiments (e.g. , aerosol emissions fixed at their 2005 RCP4.5 values). Other gaps are specific to the issue of air quality and its link to climate change.

- How air quality fits within the climate system. Air quality fits within the climate system, as it is strongly dependent on meteorological conditions and emissions, including natural emissions (dust, biogenic VOCs). It is also a key element of the Earth system through its impact on people and food security

- Proposal to research themes. We have noted a lack of biogeochemistry-chemistry oriented Grand Challenge in the present WCRP strategy. We have listed two science questions that are of direct relevance to WCRP but highlight the links between biogeochemistry-chemistry and climate science:

  - What is the importance of natural systems when subjected to anthropogenic perturbations?
  - What is the role of near-term climate forcers in the historical climate and future projections? Will it change under climate change? What are the interactions between climate and air quality policies (win-win situations), with links to air quality (health, agriculture, natural vegetation)?

Ref.: Carslaw, K. S. et al., Nature, doi:10.1038/nature12674, 2013
Shindell, D. T., Nature Climate Change, doi:10.1038/nclimate2136, 2014

3.2. Session 2: WCRP Grand Challenges – Strategies to address key uncertainties

Each of the six WCRP Grand Challenges were introduced in a presentation in light of the AR5. The following criteria were adopted by WCRP to define a Grand Challenge:

- A Grand Challenge is both highly specific and highly focused, identifying a specific barrier preventing progress in a critical area of climate science.
- This focus enables the development of targeted research efforts with the likelihood of significant progress over 5–10 years, even if its ultimate success is uncertain.
- It should thus enable the implementation of effective and measurable performance metrics.
- By being transformative, a Grand Challenge should bring the best minds to the table (voluntarily), building and strengthening communities of innovators that are collaborative, perhaps also extending beyond “in-house expertise”.
- It can capture the public’s imagination: teams of world-leading scientists working to solve pressing challenges can offer compelling story lines to capture the interest of media and the public.

1. Clouds, circulation and climate sensitivity (Sandrine Bony, Bjorn Stevens, Dargan M. W. Frierson, Christian Jakob, Masa Kageyama, Robert Pincus, Theodore G. Shepherd, Steven C. Sherwood, A. Pier Siebesma, Adam H. Sobel, Masahiro Watanabe, Mark J. Webb)

Most of the key uncertainties that have been identified through the course of five IPCC assessment reports result from a limited ability to answer two questions: What is our best estimate of climate sensitivity and how does the atmospheric circulation respond to climate change. Climate sensitivity and atmospheric circulation changes condition many aspects of the climate response to anthropogenic forcing, both globally and locally. Better bounds on climate sensitivity and global changes could guide more effective mitigation measures, and a better understanding of how atmospheric circulations respond to warming is essential for guiding adaptation efforts.

Despite decades of model development, the uncertainty in, for instance, regional precipitation projections over the second half of this century is still dominated by model uncertainty. Reducing model uncertainty, and accelerating progress in climate change science in general, requires an improved understanding of the key processes that control climate sensitivity and circulation changes, and a strategy that tailors the development of Earth System Models (ESMs) around those processes. There is strong, and increasing, evidence that these key processes are wrapped up in our understanding of how clouds and moist processes (e.g. convection) more generally couple to circulations.

The ultimate goal of the WCRP Grand Challenge (GC) on “Clouds, Circulation and Climate Sensitivity” is thus to renew the community’s focus on these key processes, and thereby advance our ability to anticipate global and regional climate changes. For this purpose, it proposes to focus research efforts around four key science questions:

- What controls the position, strength and variability of storm tracks?
- What controls the position, strength and variability of tropical rain belts?
- What role does convection play in cloud feedbacks?
- What role does convective aggregation play in climate?

A community focus on these four questions is expected to accelerate progress in climate science by developing tighter bounds on climate sensitivity and by identifying sources of robustness in how large-scale circulations respond to anthropogenic perturbations. It will do so by:

- targeting and energizing the development of Earth System Models
- inspiring and prioritizing new observations
- expanding and exploiting the paleoclimate proxy record
- stimulating new analysis frameworks and experimental methods.

2. Changes in cryosphere (Vladimir Kattsov and Gregory Flato)

The prospect of an ice-free Arctic Ocean; the fate of mountain glaciers providing fresh water to hundreds of millions of people worldwide; the strength of positive feedbacks between the warming climate and natural emissions of greenhouse gases from the thawing permafrost (both terrestrial and sub-sea); the role of ice-sheet dynamics in amplification of Greenland’s contribution to the global sea-level rise; the differences between recent sea-ice extent trends in the Antarctic versus the Arctic – these issues are getting increasing attention in the international scientific research community and relate directly to societal needs for information about climate change and its impacts. These and other processes, in which components of the cryosphere play a central role, remain an important source of uncertainty in projections of future climate change, and so improved understanding of the cryosphere in a changing climate (CCC) clearly is a “Grand Challenge”.

The cryosphere is a multi-facetted component of the climate system and so does not lend itself to a “single-issue” approach. We present above a set of Grand Challenges targeted at components of the cryosphere, with different time scales for the corresponding processes. However, each of these sub-Grand Challenges meets the WCRP Grand Challenge criteria, and so we suggest pursuing a grouping of related and societally relevant themes.

3. Understanding and predicting weather and climate extremes (Xuebin Zhang and Gabi Hegerl)

Understanding changes in the frequency, intensity, spatial extend, duration and timing of extreme weather and climate events are important for the development of climate change adaptation and mitigation. Changes in many weather and extreme events have been observed since about 1950. These include increases in warm extremes and decreases in cold extremes, with many more land regions showing increases than decreases in extreme precipitation. Much of those observed changes has been attributed to human influence, with various degrees of confidence, and has been projected to continue into the future. Yet many challenges in the understanding of past changes and in providing future projections remain. These include uncertainty in extreme precipitation, a large uncertainty in other extremes such as droughts and tropical cyclones, model biases in simulating and a large uncertainty in future projections of various types of extremes. The WCRP Grand Challenge on climate extremes has identified a set of scientific questions to advance research on climate extremes. These include a provision for necessary observational data to characterize and to monitor extremes, and development of proper methods for a comparison between observations and models. It is also vital to determine a strategy to evaluate climate model ability to simulate the right characteristics of extremes for the right reasons and identify for which types of events current models can provide creditable and robust simulations. Advances are only possible if key processes that are involved in extremes are identified and captured into climate models in order to produce creditable simulations of impact relevant events. Model development and observation priorities are important steps to advance this WCRP Grand Challenge.

4. Strategies to address key uncertainties in regional climate information (Lisa Goddard, Francisco Doblas-Reyes and Clare Goodess)

The WCRP Grand Challenge on Regional Climate Information is still refining its activities. In order to bring cross-WCRP expertise together in an integrated way the leadership of this GC has proposed considering regional climate information through the lens of providing information for risk management and decision making, and will prioritize activities under the GC that are relevant to cross-regional and cross-timescale issues. We envision that the initiatives that contribute to the GC will facilitate the creation and use of more scientifically robust climate information at regional-to-local scales. This is important when information is intended for decision-making that concerns risk management, but it does not replace the need for active and two-way involvement with stakeholders.

The IPCC has two main objectives, both of which require regional-to-local climate information. One is adaptation: the IPCC describes the future climate that communities should adapt to. The other is mitigation: energy and land-use policy is activated at a national scale, and countries need to know how bad things might get if they do not reduce emissions. However, the information provided by the IPCC has limitations when it comes to the provision of regional climate information for the present and future.

The limitations take several forms. First, the models may not properly represent observed trends – in spatial pattern or magnitude – even on time-scales of 50 years or more. Second, natural variability at decadal to multidecadal timescales is important for adaptation now and for communicating our present and expected experience of regional climate change. Expectations for decadal variability are not represented in climate change projections, even if provided for the near term. Decadal prediction is a new activity for the IPCC, but skill has not yet been convincingly demonstrated over land areas. Third, downscaling is often advocated as the “cure” to the information limitations of global GCMs. However, while downscaling has value in some cases, neither dynamical nor statistical downscaling will overcome the limitations listed above.

To improve the value of regional climate information from the IPCC, the research community must improve the quality of the models and of the observational datasets used for the validation and verification of the models. We must also improve the accessibility of the data. For the broader community of scientists, practitioners and decision-makers, the climate community can help improve understanding. The IPCC puts considerable effort into this, but there is almost too much information, which makes it difficult for those outside the climate community. WCRP can contribute to better interpretation of IPCC information at regional scales through identification of what models do right and wrong, and why. WCRP can also contribute to information and communication on the sources and quantification of uncertainty across spatial and temporal scales.

5. Regional sea level rise and coastal impacts (Detlef Stammer and Catia Motta Domingues)

Changes in coastal sea level rise (mean and extremes) around the world are among the most severe societal consequences of anthropogenic climate change. Potential coastal zone impacts include shoreline recession, loss of infrastructures, natural resources and biodiversity, displacement of communities, migration of environmental refugees, etc.

Contemporary global mean sea level will continue to rise over many centuries, with the detailed pace and final amount of rise depending substantially on future greenhouse gas emissions. Changes in regional/coastal sea level are expected to substantially deviate from global mean sea level rise over the coming decades. Regional/coastal sea level responses reflect the integration of various climatic processes – involving the ocean, the atmosphere, the geosphere and the cryosphere – in addition to non-climatic factors at the coast (e.g., natural land movement arising from tectonics, volcanism or compaction; land subsidence due to anthropogenic extraction of underground resources; changes in coastal morphology resulting from sediment transport induced by natural and/or anthropogenic factors, etc). Therefore, detailed sea level change along coastlines worldwide can potentially be far more substantial than the global mean rise.

To meet the urgent societal demand for more detailed information on sea level change, WCRP has implemented the theme “Regional Sea Level Rise and Coastal Impacts”, as one of its cross-cutting science questions, or Grand Challenges, involving most core-projects and working groups. The overarching goal of this 10-year WCRP research effort, led by CLIVAR, is to establish a quantitative understanding of the natural and anthropogenic mechanisms of regional to local sea level change, to promote advances in observing systems required for an integrated sea level monitoring and to foster the development of sea level predictions and projections that are of increasing benefit for policy-making (e.g. adaptation/mitigation efforts).

For this purpose an integrated interdisciplinary program on sea level research has been recently developed by a WCRP scoping team, and divided into five main and interconnected working packages (see below). This program aims to promote improved and coordinated physical understanding of all contributions to past, contemporary and future sea level, including the quantification of sources of uncertainty (e.g. from model output and observational data sets, estimation methods, climate system dynamics, etc). The program also aims for close interaction with coastal communities to make sure that results of the proposed scientific research are incorporated into practices of coastal zone management.

Working packages:

1. An integrated approach to historic sea level estimates (paleo time scale)
2. Process understanding of fast ice sheet dynamics (contemporary)
3. Causes for contemporary regional sea level variability and change
4. Predictability of regional sea level
5. Sea level science for coastal zone management

6. Water availability (Sonia Seneviratne, Graeme Stephens, Taikan Oki and Kevin Trenberth)

Water availability is a key issue affecting society in multiple ways. Several past extreme events highlight its importance. Such examples include the 2003 drought and heatwave in Europe, the recent two “100-year droughts” in the Amazon region (in 2005 and 2010), the Pakistan floods in 2010, extensive flooding in 2010–11 in Australia, widespread drought in the United States in 2012, in the Western US in 2013, and California from 2013 into 2014. As well as changes in precipitation, several factors control variations in water availability, not the least also human actions. For instance, changes in land use and rivers (a major water diversion for irrigation of cotton fields) have been invoked as a main driver of the drying of the Aral Sea.
One can thus distinguish two main overall climate drivers of water availability:

- Precipitation and the various processes that controls it (e.g. stable high pressure systems, ENSO, tropical cyclones, convection, land-atmosphere interactions).
- Land surface hydrology (i.e. processes affecting changes in soil moisture, runoff and evapo-transpiration on land), as well as the role of humans in affecting it (land use and land cover changes, including irrigation, agricultural management, etc).

In addition, projected water scarcity is also a major concern. This involves not just changes in water availability due to climate variability and change, but also full considerations of increasing demand.

Several new findings in the area of water availability were obtained shortly before or after the cut-off date of the IPCC AR5 report. Research confirmed that enhanced greenhouse gas concentrations strongly affect several of the processes leading to changes in water availability, through changes in atmospheric moisture, precipitation or land evapo-transpiration. However, changes in other external forcings also play an important part (e.g. land cover and land use changes, changes in aerosol concentrations). In addition, internal climate variability is large and often impairs the attribution of changes. Uncertainties in and lack of adequate observations of both precipitation and land hydrological variables remain a main issue. At present, twentieth century trends in water availability are difficult to detect and attribute in most regions and there are also no clear global change signals in drought. This is because of the large impact of internal climate variability on droughts, and of the dominant regional nature of droughts. On the other hand, increases in intensity of precipitation have become clear in high-latitude regions. Nonetheless, recent results suggest that commonly coined simplifications of the water cycle such as "dry regions getting drier and wet regions getting wetter" do not apply to the records of the last decades. In addition, mean climatologies of the surface energy and water budgets still have large uncertainties, and the role of humans in affecting land hydrology should be considered further. Finally, in spite of the observational shortcomings, there is clear evidence that current climate models display major systematic biases in both precipitation and evapo-transpiration on land, and that model-based uncertainties in projected changes in water availability in key regions (Amazon, North America and the Mediterranean) are so large that they mask most of the uncertainty due to emission scenarios with few exceptions (e.g. projected increased soil moisture drought frequency in the Mediterranean).

The water availability grand challenge is led by GEWEX, which has defined the scientific argumentation to address it. Several activities, both related to the development and analysis of new observational datasets as well as the assessment of model-based uncertainties and related impacts in projection (including CMIP6) have been developed in this context, also in collaboration with other WCRP projects and working groups. These various activities, in particular some more recently refined at the Pan-GEWEX meeting, address many of the identified post-AR5 challenges.

As the part of this presentation six main questions were highlighted with respect to post-AR5 literature:
1. How well can water cycle variables (precipitation, evapo-transpiration, runoff, soil moisture) be described by various observing systems or estimated from observational syntheses, and what basic measurement deficiencies determine the uncertainty estimates at various space and time scales?
2. What processes affect water availability on land, in particular with respect to climate variability (ENSO, decadal variability) and extremes: droughts, floods, heavy precipitation events?
3. What is the role of human water use, land cover and land use changes, and vegetation responses (e.g. CO_2 "anti-transpirant" effect) in affecting water cycle processes and water availability?
4. How do models become better and how much confidence do we have in global and regional climate predictions and projections of water availability?
5. How does anthropogenic climate change affect water cycle characteristics? How can we detect and attribute past trends in soil moisture, snow depth, ground water, and water quality, in addition to those in precipitation and river discharge?
6. How can new observationally-based diagnostic tools and emergent constraints be derived to examine and assess the realism of water cycle processes and reduce uncertainties in projections?

These questions are consistent with on-going plans for the water availability Grand Challenge. In particular, the potential for more synthesis studies (point 6) emerging from the joint consideration of new observational data streams and multi-model experiments has been highlighted. Finally, the presentation emphasized the need for a more focused consideration of water availability in upcoming WG1 assessment reports.

3.3. Session 3: Impacts, risk assessment and scenario development

This session covers two topics which are relevant to WCRP activity and strategy, though not core to WGI and/or WCRP Grand Challenges.

1. The role of risk in the WCRP Grand Challenges: Building from the AR5 (Bruce Hewitson, Tim Carter, William Gutowski, Clare Goodess, Rob Wilby, Linda Mearns)

The title reflects how WCRP is adding new alignment with research foci beyond the fundamental physical questions (as reflected by the newly established Working Group on Regional Climate, WGRC), recognizing that the knowledge priorities are being increasingly shaped by needs to inform risk management.

Risk, as defined in IPCC WG2, is the intersection of hazards, vulnerability and exposure. Risk management touches all aspects of society (including the WCRP itself, for example where models look right for the wrong reason or climate services adopt data inappropriately, thus leading to possible mal-adaptation). The emergent framing of risk is now the dominant shaping force for actions across communities engaged in climate change.

Current climate research is largely a linear delivery process where the fundamental physical climate research is presumed to linearly trickle down through a cascade of "users", yet this approach may deliver products that are poorly aligned with the knowledge needs. A cognizance of risk is reflected in the increasing policy-first approach from the Impact-Adaptation-Vulnerability (IAV) community, which is coming to the fore in climate assessments. For example, an impact model may be used to define key thresholds, and only then is the climate projection data interrogated to inform on how thresholds may be exceeded. Problematically, the existing climate research outputs often have major gaps for meeting these needs.

For WCRP it is thus important to include some alignment of research beyond only fundamental questions, and to include targeted research priorities for informing risk. For example, even though we have a data deluge of climate projections, the internal spread and contradictions (e.g. across multi-model multi-method projections) can confound sensible risk management responses. This major research gap has received little explicit attention within the current formulation of the WCRP grand challenges.

Thus, the leading question is arguably "what gaps in our scientific understanding, if addressed, would maximize the value content of regional climate information for risk management?"

2. Scenario development and integrated assessment model projections (Elmar Kriegler and Brian O'Neill)

Three topics were covered by the presentation – the assessment of mitigation scenarios in the IPCC AR5 of Working Group III, the ongoing development of new emissions scenarios in the context of the new scenario framework and initial thoughts on a set of scenarios that could be run as part of CMIP6 (scenarioMIP).

The AR5 of Working Group 3 collected ca. 900 mitigation scenarios and 300 baseline scenarios without mitigation policies in a database (accessible at https://secure.iiasa.ac.at/web-apps/ene/AR5DB) for its assessment. The large majority of these scenarios came from recent energy-economy and integrated assessment model comparison exercises on the role of technology for climate mitigation, the impact of baseline assumptions on mitigation strategies, the implications of near term policies for the achievability of long term climate targets and implications of the 2°C target for international climate policy negotiations. These scenarios covered the full range of forcing between RCP2.6 and RCP8.5, with only the highest baseline scenarios reaching RCP8.5. On the lower end, the AR5 distinguished between scenarios in the 2.4–2.9, 2.9–3.4 and 3.4–4.0 W/m2 range because the mitigation challenges differ significantly between these forcing levels.

The current work on new socio-economic scenarios to supersede the outdated Special Report on Emission Scenarios (SRES) is based on the new scenario framework that combines the dimension of forcing (as reflected in the RCP levels) and socio-economic development as captured by five so-called shared socio-economic pathways (Sustainability, Middle of the Road, Regional Rivalry, Inequality, Fossil-fueled Development). A set of Integrated Assessment Models (IAMs) are currently producing coupled energy-land use-projections for different combinations of Shared Socio-economic Pathways (SSPs) and RCPs, driven by a set of SSP-based population, economic growth and urbanization pathways for the twenty-first century (accessible at https://secure.iiasa.ac.at/web-apps/ene/SspDbp). The publication of the new scenarios is planned for summer 2015.

The planned new scenario runs as part of CMIP6 (scenarioMIP) would draw on the SSP-based emissions-land use scenarios currently prepared by IAMs. They offer greater possibility to look into important research questions such as the climate implications of overshoot and variations in land use and short-lived forcers, and would provide an improved basis for integrated assessment and climate impact analysis in the 2018–2025 period once the CMIP5 archive has been exploited.

3. Open discussion on risks and scenarios (ClaudiaTebaldi, Bruce Hewitson and Brian O'Neill)

The discussion on the issues of risk offered the idea that WCRP grand challenges should not be user-driven and simply focus on the long term fundamental physical climate research questions. In response, it is noted that recognizing the role of risk doesn't say that fundamental research is not the core focus in WCRP, but that there is an essential responsibility carried by the WCRP producers of knowledge to address how this work contributes (positively or negatively) to risk management. Further, the WCRP stated strategic framework explicitly speaks of translating fundamental understanding into products of high value for a wide range of users, which necessitates explicit engagement with risk framing.

The ensuing discussion focused on the latter topic, with concern voiced by some participants from the climate modelling community about the burden represented by running new scenarios and in general the burden imposed on the community by CMIP phases so tightly scheduled.

The presenter (Elmar Kriegler) and the co-chairs of ScenarioMIP (B. O'Neill, D. van Vuuren and C. Tebaldi) in the room explained the rationale of running updated scenarios on the basis of the newly developed Shared Socio-economic Pathways (SSPs), which would provide the impact and integrated assessment research communities with climate information consistent with SSP assumptions and run by new climate models (after the CMIP5 archive has been exploited for this purpose in the period until 2018). Impact, mitigation and adaptation studies based on this climate information would eventually form the backbone of WG2 and WG3 IPCC reports. The lack of CMIP6 scenario experiments would have the effect of divorcing climate modelling research from the WG2 and WG3 research communities, and therefore breaking the key link between the WG1 assessment and the WG2 and WG3 assessments (in addition, it would make WG1 chapters about future projections either less up-to-date or based on idealized experiments, arguably less policy relevant).

The preliminary ScenarioMIP proposal calls for experiments covering low, medium and high forcing levels in its first tier (including covering the lowest and highest forcing levels RCP2.6 and 8.5, respectively). The RCP8.5 in total radiative forcing pathway may receive highest priority in order to clearly identify the differences in performance between CMIP6 and CMIP5 climate models when running a plausible future scenario. In addition, the proposal includes a Tier 2 of experiments, which would cover the remaining RCP levels and fill gaps in the four RCPs in CMIP5, in a way that provides consistent climate information to the SSP-based analysis of impacts, adaptation and mitigation.

4. Reports from Break-out Groups

During day 2 of the meeting BOGs met in four parallel 11/2 hour sessions, thus allowing each participant to be actively involved in one BOG and to attend a second one. BOG leaders were asked to finalize a report of their discussions on day 3 and to make a short presentation to the Plenary for discussion and approval of recommendations. The reports from the BOGs are presented below.

4.1. BOG-1: Clouds, Circulation and Climate Sensitivity *(Chair: Bjorn Stevens; Rapporteurs: Sandrine Bony and Ted Shepherd)*

The challenge

- The climate science community has built a very successful research framework for addressing a key question: namely, whether anthropogenic climate change is a serious concern. This question has long been settled: "warming is unequivocal"
- The questions have now changed: e.g. What will happen to the monsoons? Circulation is the elephant in the room. The framework we have built — the "confidence framework" — is not so suitable for addressing these questions (cf. Krishna's talk)
- Business as usual in our community scientific endeavours is not likely to change the situation; in many ways, we have hit a wall. We need a different approach

Major gaps and needed approach

- We have insufficiently developed theoretical frameworks to guide assessments and provide compelling arguments for robust changes in climate patterns (e.g. dynamical mechanisms). One consequence: Inability to interpret model uncertainty in projections in terms of model errors, and to design relevant strategies for model development (design models that fit the purpose). Another consequence: inability to design discriminating observational tests
- A more strategic approach is needed: namely an end-to-end approach for climate-change assessments of key topics (integrating observations, physical understanding, model evaluation, near/long-term, paleo, etc.)

How could the community contribute?

- Identify a small number of key questions (whose solution would probably unlock other puzzles too), and sustain continuity of community focus on these questions
- Develop the scientific foundation for an end-to-end approach (integrating observations, physical understanding, model evaluation, near/long-term, paleo, etc.)
- Develop multiple story lines and narratives; this can facilitate connection to other Grand Challenges (extremes, regional information, etc.), core projects and working groups, and the wider weather (WWRP) and observational communities
- Organize and support training initiatives: model development, circulation (and moist dynamics)

Observation requirements

- Need to make better use of available observations and reanalyses (nudging, Transpose-AMIP) to facilitate the understanding of the link between processes and climate variations
- Would be helpful to have a twentieth century Earth System reanalysis
- Insufficient temporal information
- Lack of adequate constraints on vertical motion
- Insufficient observations of lower tropospheric water vapour
- Insufficient exploitation of simultaneous multivariate information
- Insufficient exploitation of proxy records for paleo-climates
- Think big, e.g. a field experiment that would be transformative if the resources were available

Modelling requirements

- Use key questions to stimulate and focus model development to accelerate key improvements and to guide further development

- Strengthen the engagement between WCRP activities and modelling centres to change the culture of model development (e.g. allow more room for new ideas rather than "optimization")
- To facilitate the link between science questions and model development (as well as develop the theoretical frameworks), WCRP could support a community hierarchy of models and diagnostic tools, e.g. nudged models, aquaplanets, idealized models
- Encourage better communication across the communities involved in model development (e.g. about integration/tuning procedures; cf. Working Group on Numerical Experimentation, WGNE, surface-drag comparison)

Synthesis

- Three topics for synthesis: storm tracks (Q1), tropical rain belts (Q2), climate sensitivity (Q3,Q4)
- Encourage the development of **compelling story lines** across a series of workshops/meetings focusing on these topics, and set up working groups to facilitate end-to-end assessment (e.g. ISSI international teams)
    - Initial workshops on all three topics are already planned for 2015, with expected review papers as an outcome
    - Next steps will work towards synthesis on the three topics over the subsequent 2–3 years through appropriate community products in the peer-reviewed literature

4.2. BOG-2: Climate Extremes *(Chair: Xuebin Zhang; Rapporteurs: Rowan Sutton and Sun Ying)*

Drafted by Xuebin Zhang, Rowan Sutton, Gabi Hegerl, Ying Sun, with inputs from Kathy Mcinnes and Peter Thorne

The discussion by climate extreme BOG has focused on the aspects of gaps of observation capability for the characterization of extremes and for model validation and of modelling capability for creditable and robust simulation of extremes, and some steps and priorities towards narrowing down these gaps, as summarized below:

A range of phenomena that the Extreme GC should consider

The word *extreme* has been used to describe either a characteristic of a climate variable or that of an impact. The linkage between extreme events and extreme impacts (i.e. natural disasters) is not straightforward because the impacts are affected by not only the weather and climate events but also exposure and vulnerability. As aspects of exposure and vulnerability are not covered by the expertise of the WCRP community, WCRP should therefore consider weather and climate extreme events that may be defined in the statistical sense, i.e., rare (and moderate) events, as well as their physical impacts such as droughts and floods. Additionally, some phenomena (e.g., tropical cyclones) or processes should be considered due to their potential to cause damage due to high wind, rainfall or storm surge flooding. More attention should also be paid to extreme events that cause impacts and that are less studied: for example, sub-daily extreme precipitation and sea levels extremes and extremes in marine environment in general.

Gaps and strategies to address them in observational data and statistical tools

Extremes are by definition rare. *This means it takes longer time periods and perhaps also better resolution in both space and time to properly characterize long-term changes in extreme events. This also means that some extreme values (e.g., amount of short duration rainfall) may be prone to being filtered out by usual data quality control (QC) procedures.* It is important to instigate efforts to undertake new and novel QC / homogenization algorithms and benchmark their performance at daily and sub-daily time-scales, work to create an integrated set of holdings of in situ data over global land areas which combines hourly, daily and monthly series across all elements, including building datasets of parallel measurements for measure changes in observation systems, to digitize data in as cost effective manner as possible and to improve data provision. WCRP should also work with other organizations such as GCOS and WMO to promote free and open access to meteorological and climate data.

There is a general mismatch in the spatial scales between observations (usually taken at point locations) and model simulations (typically interpreted as representing an area of a model grid), making it difficult to conduct a like-with-like comparison between observations and models. Various techniques have been used to grid or to interpolate station data into regulate grid-box to aid in observation and model comparison. There are several inter-twined issues including spatial averaging and the order of operation (i.e., gridding in anomaly, first difference or absolute values etc., uneven number of stations/observations across the space). Work is required to understand these effects and if possible rule out certain approaches to avoid artificial spread. Some data sources may have been under-used such as reanalysis data and various satellite and radar data products, etc.), which may allow better characterization of the spatial footprint of extremes. Work is required to validate those products against observations, especially for extremes.

Statistical tools based on extreme value theory can be very powerful to aid in the analysis and understanding of the long-term changes in extremes that are rare values. These tools that are being further developed include theory of spatial extremes or multi-variate extremes in the statistical sciences. However, the interactions between statistical and climate science communities are not sufficient and the statistical tools are not very accessible to the climate community. It is important to instigate enhanced interactions between the statistical and climate communities through joint meetings and workshops, to provide two-way communication between the communities. It is also important to develop guidance and tools for the analyses of extremes for the wider climate research community.

Gaps and strategies to address them in understanding physical mechanisms involved in extremes and model evaluation

There is a lack of understanding about the types of events for which current models can provide creditable and robust simulations, and in the identification of key processes that climate models must capture in order to produce creditable simulations of weather and climate extreme events. There is not yet enough evaluation of extremes at the process level, where the storylines that lead to extremes are analyzed and the model ability to simulate the conditions leading to extremes can be evaluated. For example, an understanding of the interplay of various processes, including the atmospheric, land, and oceanic processes that lead to prolonged droughts or wet seasons may shed new light to guide model development. Contributions to the changing probability of extremes by anomalous sea surface and ice conditions, and by changing radiative forcing need to be quantified and evaluated in climate models. It is important to select a set of priority events/case for comprehensive comparison, with an aim to understanding interactions of large-scale drivers and local (e.g. land-surface) feedbacks, using various approaches including event attribution. Events that are of large spatial-temporal (continental and seasonal) scales and that involve heavy precipitation or heat waves may provide better opportunities to advance understanding. The selection of such events should consider geographical balance such that events that occurred in the less developed world get selected and studied, although it is recognized that availability of data may be a more challenging issue in less developed world.

Model's capability in simulating extremes can also be scale-dependent. In particular, small scale events such as storms are not explicitly resolved by models and convection related extremes are simulated poorly. There is a need to assess the benefit of high-resolution models in predicting/simulating extremes. Recent studies show promising results: for example, blocking in some seasons is better simulated with high-resolution models. Understanding the causes of observed changes in extremes needs proper characterization of natural variability as well as models' responses to external forcing. This requires long-control simulations, single-forcing sensitivity experiments and other MIPS to save and archive high frequency data. The forced simulations should provide large ensembles to sample variability in extremes, which is a challenge from the relatively short observational record alone. Additionally, it would be ideal if high frequency data were pre-processed to extract information relevant to extremes so that they are more easily accessible to the wider user community. Intra-seasonal to seasonal prediction, near-term prediction of probability of extreme events at impact relevant space/time scales will play increasingly important roles for climate service. This requires the Extremes GC to work and engage with other groups such as WGSIP and CFHP so that high resolution model data are made available and models are also evaluated using new metrics that explicitly take extremes into consideration.

How can WCRP better contribute to future IPCC assessments?

Addressing data gaps should lead to better spatial and temporal coverage, thereby reducing uncertainty in the characterization of past changes in extremes. Addressing modelling gaps will create a firmer basis for the understanding of past changes and projection of future changes. These will be important contributions not only to WGI but also to other WGs.

4.3. BOG-3: Regional Sea Level Rise *(Chair: Anny Cazenave; Rapporteurs: Catia Motta Domingues and Detlef Stammer)*

The breakout group on sea level built its discussion on ongoing planning activities organized and fostered through the WCRP GC on Regional Sea Level Change and Coastal Impacts. That activity is entirely steered by the outcome of the last IPCC assessment and lessons learnt from it with respect to regional sea level. The BOG discussion was steered and oriented along the basic questions posted to all participants.

Main uncertainties and key gaps in sea level research

The following issues were highlighted:

1. Imperfect understanding of causes of observed sea level changes (global and regional): can we (and how to) reduce uncertainties of sea level component estimates at global and regional scales? For example, is it possible to compute glacier mass balance at yearly instead of pendatal intervals? Can we improve the "anthropogenic" land water contribution? How do we reconcile the various Argo-based steric sea level time series? Do we understand the large dispersion of published ice sheet mass balance estimates? With uncertainties in spatial patterns, how good are simulations of climate modes?

2. Imperfect knowledge of deep ocean warming and its contribution to sea level rise**.** Related issues: Earth's energy imbalance and its temporal variations (e.g. hiatus) and ocean heat content. Can we constrain the Earth's energy imbalance and estimate the deep ocean heat content from sea level budget studies and ocean reanalyses? How closed is the system as a function of time-scale?

3. Imperfect knowledge of past regional variability in sea level**:** improve the methods developed to estimate spatial trend patterns in sea level prior to the altimetry era (i.e. past sea level reconstructions and ocean reanalyses: How to reconcile the various products? Improve the use of proxy data prior to 1950.)

4. Still a too poor understanding in detection-attribution: is the regional variability in sea level only due to internal climate variability or can we already detect the fingerprint of anthropogenic forcing? When should the anthropogenic signal emerge out of the natural variability? How good are simulations of climate modes?

5. Large uncertainties in long-term global mean sea level projections**:** how reliable are ice sheet dynamics and land hydrology -both climate-related and human-related- projections for the twenty-first century and beyond?

6. Lack of knowledge about ice sheet abrupt changes**:** thresholds? tipping points?

7. Lack of decadal sea level projections/previsions: how reliable is the natural/internal variability represented in climate models?

8. Large uncertainties in (centennial) regional sea level projections: need to accurately account for all processes (including ocean dynamics) giving rise to regional variability (is it possible to improve Glacial Isostatic Adjustment, GIA, as well as the solid Earth responses to all loading processes: land waters, etc.?). Need for GIA modelling improvements.

9. Lack of understanding of coastal impacts of sea level rise and extreme events: what are the (non linear) interactions between sea level rise and coastal processes (sediment supply, shoreline morphology, river runoff, waves and currents, etc.)?

All issues raised are in agreement with those discussed before by the GC team. The discussion thus confirmed the GC planning. However, the discussion also emphasized the need for the study of long-term sea level change, including respective future changes. The existence of tipping points and irreversible processes of the polar ice sheets is essential in this context. The discussion also highlighted the need to think about the impact of the use of terrestrial water resources on sea level.

Best strategic approaches to address key gaps and uncertainties

The roadmap for approaches and community involvement in the sea level topic was largely drafted through the GC science plan. The workshop outcome confirmed plans (as did the pan-CLIVAR meeting) helped to sharpen the program by prioritizing first steps in its implementation. Among those steps will be the following activities, performed in collaboration with other efforts within WCRP and outside, such as ocean heat content, cryospheric paleo studies, water availability, model development, etc. Activities suggested include:

1. Set up an "Observations Intercomparison Projects" for sea level-related parameters (Argo, ocean reanalyses, GRACE-based ocean mass, hydrological model outputs, past sea level reconstructions, etc.), surface forcing components, etc. Identify the causes of differences in terms of global mean and regional variability. Such an activity would specifically address topics 1, 2 and 3.

2. More research is needed on downscaling of long-term regional projections towards coastal areas (from regional to local). This activity would address topic 8 above.

3. Develop integrated multidisciplinary local studies on coastal impacts of sea level rise accounting for all processes at work in coastal areas (sediment supply, changes in shoreline morphology and bathymetry due to changes in winds, waves and currents, river runoff, urbanization, etc.). Develop cases studies in developing countries and small island developing states. This activity refers to topic 9.

4. Expand climate model/observations intercomparisons for sea level and its components (land ice, steric effects, land hydrology, etc.) (twentieth century and last few decades; global and regional). Discuss model sensitivity and address the question: do models perform as well for all variables (thermal expansion, salinity, glaciers, ice sheets, land hydrology) or only for some of them; implications on future projections. Investigate how well models reproduce the internal variability. This activity refers to topics 4, 5 and 7 above.

5. Perform model/observations intercomparisons on paleo time scale to investigate tipping points of the polar ice sheets (in collaboration with the Cryosphere BOG). This activity would address topics 4 and 6.

Requirements for current/future observing systems

1. Insure continuity and global coverage (including the Arctic) of various observing systems (satellite altimetry, Argo, GRACE, tide gauges with GNSS, etc.) of required accuracy for climate studies.

2. Develop (expand) a deep Argo program.

3. Improve the land ice observational network (for mass balance studies) in ice sheet marginal areas.

4. Provide traceable reference quality measurements from in situ and satellite missions to build long, well calibrated climate records.

5. Provide users with guidance about most suitable data/model outputs to be used.

6. Develop a global coastal observational network and data base, including data on waves, currents, extreme events, river runoff, shoreline movements, etc. (data rescue).

7. Work at climate model improvement (one or two-way coupling of AOGCMs and dynamic ice sheet models, ocean mixing, account of land hydrology - natural and anthropogenic, GIA, etc.).

8. Projections of wave climate change (COWCLIP). Still required: Projections in storm surge change with quantified uncertainties for particular coastal regions.

9. Targeted studies in selected locations using state of the art coastal models to better understand governing processes. Such efforts may assist in developing techniques to infer coastal change from larger scale metrics.

Requirements for modelling

1. Work at climate model improvement (one or two-way coupling of AOGCMs and dynamic ice sheet models, ocean mixing, account of land hydrology -natural and anthropogenic-, GIA, etc.).

2. Projections of wave climate change (COWCLIP). Still required: Projections in storm surge change with quantified uncertainties for particular coastal regions.

3. Targeted studies in selected locations using state of the art coastal models to better understand governing processes. Such efforts may assist in developing techniques to infer coastal change from larger scale metrics.

How can WCRP handle identified gaps and uncertainties, and contribute to future IPCC assessments?

Addressing the gaps in our knowledge identified through the IPCC process to be addressed in the GC effort will substantially advance the field. Providing answers to the identified questions will create a firm basis for addressing regional to coastal sea level aspects in the next IPCC assessment not only in WG 1 but also in other WGs. It should be recalled that efforts are ongoing related to sea level in other sectors and communities as well.

4.4. BOG-4: Changes in Cryosphere *(Chair: Vladimir Kattsov; Rapporteur: Gregory Flato)*

The Cryosphere Grand Challenge covers a broad range of topics and involves processes that are often poorly understood and rely on small-scale physical quantities that are difficult to observe. These processes are often crudely (if at all) represented in Earth System models. The Grand Challenge white paper outlines a number of broad issues and it was agreed that they covered important issues related to the cryosphere and its role in climate. It was also noted that the WCRP Climate and Cryosphere (CliC) core project has already organized a meeting to initiate specific activities addressing some of the Grand Challenge issues, and progress is being made. In the area of polar climate prediction, an international effort, the Polar Climate Predictability Initiative (PCPI), has a number of sub-themes aimed at understanding polar predictability and improving modelling capability to make quantitative predictions at seasonal to decadal time-scales.

The discussion highlighted the lack of climate change detection and attribution applied to cryospheric quantities (for some components there was little or no literature available for the AR5). This gap is expanded on below.

More specific near term gaps/priorities were identified:

- An overarching WCRP priority should be the promotion of research connecting model performance to the reliability of models for various applications (detection and attribution, prediction, projection). This is connected to the issue of performance metrics (and therefore to observations), but requires research to identify those metrics that are indicative of model reliability. The issue arises in the context of the Cryo GC because the only instance in AR5 in which a subset of model results were used (based on historical performance) was for sea ice.

- There is a quantitative discrepancy between observed and simulated trend in Antarctic sea-ice extent (increase observed; decline simulated). This was noted in the AR5, but available literature did not allow assessment of underlying causes. Subsequent work has suggested possible physical mechanisms, but what remains is a systematic examination of these via targeted experiments.

- No literature was available at the time of the AR5 to assess the detection and attribution of the anthropogenic effect on global glacier mass balance (although there has been a paper published recently on this subject). There are some relevant global observational data, and some global glacier mass balance models. What is missing is a coordinated attempt to evaluate these models and to apply them in a detection and attribution context. Such models would also provide direct input to GCs on sea level and water availability (particularly via the seasonality of glacier melt).

- Rapid mass loss of the Antarctic ice sheet has been observed, but detection/attribution has not been possible so far. Targeted efforts on application of ice sheet models to historical climate change, along with long simulations to estimate natural variability, would address this gap. The application of such models to future climate scenarios would feed directly into GC on sea level.

In some cases, CliC is already coordinating activity that is directly aligned with these priorities and the WCRP Cryosphere Grand Challenge. For example, an ice sheet model intercomparison activity is being developed that is aimed at evaluating and applying large ice sheet models to historical and future climate forcing. Similarly, a new activity is starting up on the evaluation and application of global glacier mass balance models – it was noted that extending this to include detection and attribution analysis would be very valuable.
It was suggested that a workshop targeted at planning coordinated experiments to address the physical mechanisms for Antarctic sea-ice extent changes would allow progress on understanding historical change and model shortcomings. It is also important to ensure that suitable experiments be included in CMIP6 to support detection and attribution analyses related to sea ice.

Finally, the broader issue of connecting model performance measures (based on historical or paleo simulations) and the reliability for future predictions/projections is a topic that should be pursued by the WMAC. A WCRP strategy to tackle this problem needs to be developed, and will undoubtedly take several years.

In terms of observations, new coordination mechanisms like the WMO's Global Cryosphere Watch program are expected to enhance the observational database. On the other hand, there is an ongoing decline in many in situ observing networks (e.g. glaciers), and in some cases severe gaps in observing networks (e.g. permafrost), that will impact on some of the activities listed above. The WCRP data advisory council provides a mechanism for identifying observational gaps and promoting observational programs, and cryospheric observations must remain part of this. It is also important to note that data sets have associated publications so that they can be used and cited in IPCC and other assessments.

The cryosphere BOG participants were generally supportive of WCRP efforts to develop synthesis or review papers.

4.5. BOG-5: Regional Climate Information *(Chair: Clare Goodess /Rapporteurs: Francisco Doblas-Reyes, Lisa Goddard and Bruce Hewitson)*

The Regional Climate Information (RCI) Grand Challenge was initially established as three time-scaled frontiers (intra-seasonal and seasonal predictability and prediction; decadal variability, predictability and prediction; reliability and value of long-term regional climate change projections) with a fourth frontier on how to transform this knowledge into decision relevant information. In order to bring cross-WCRP expertise together in an integrated way, it has been agreed to instead consider the issues in the time-scaled frontiers through the "lens" of informing risk management and decision making. This means adopting a cross-regional and cross-timescale focus.

Thus, the first part of BOG5 was devoted to discussing some of the questions relating to Frontier 4, focusing on those perceived to be most relevant to the workshop audience. BOG5 also discussed some of the issues recently identified by members of the CLIVAR and GEWEX communities (during a session of the Working Group on Regional Climate, WGRC, in The Hague in July 2014). The perspectives of these questions come through strongly in the BOG5 responses to the workshops' overarching questions, which are summarized below.

Major gaps in the domain covered by the BOG

- Lack of good observational data in developing countries
- Lack of clear understanding of changes in regional phenomena and drivers of variability (and of how to prioritize efforts to increase understanding)
- Lack of understanding of the role of and mechanisms behind teleconnections in the spatial disaggregation of uncertainty
- Lack of a framework to translate climate data and output into regional climate information and guidance
- From the perspective of the Regional Climate Information Grand Challenge (GC), this question can be rephrased as: what gaps in our scientific understanding and information, if addressed, would maximize the value content of regional climate information at all time scales of interest to a wide range of stakeholders?

Best strategic approaches to address these scientific issues in the next 5–8 years

- Design a mechanism for the Regional Climate Information GC to work with the other GCs, the WCRP core projects and the IAV community to identify information relevant to regional scale climate
- Provide "regional laboratories" for facilitating capacity building and the use of data and modelling resources, integrated with other capacity building initiatives

How could the community focusing on the topics discussed above contribute to key scientific questions, uncertainties and research issues raised/identified by IPCC?

- Enhance communication channels to achieve mutual benefit from regional expert knowledge (e.g. involving RCOFs, regional climate scientists)
- Enhance the understanding of the contribution of local and regional processes to the regional climate response (e.g. land-surface feedbacks under the influence of large-scale forcings)
- Foster the transferability of methodologies (e.g. to explore and understand intraseasonal variability, development of coupled regional modelling) between regional communities and programmes to enhance cross-regional understanding and synergies
- Understand sources of model uncertainty from a regional perspective, including feedback from users (recognizing that there is a large range of users)

Inadequacies/requirements of the current/future observing system in relation to the objectives of the BOG

- The system needs to provide error estimates and to go beyond temperature and precipitation.
- The system needs to deliver high-quality observations and "high quality" should be user determined/defined.
- Evaluating models, especially high resolution, is a challenge; there is also a need to improve understanding of processes to include in ESMs, which has implications for observational needs; such needs provide a motivation for building and improving reanalyses.
- Observations should be used to provide information on local climate changes/early warning signs of climate changes/impacts and to characterize past and current climate variability.
- Need to increase the use of observations in the development of evaluation metrics, and in bias correction and statistical downscaling; this will help in communicating and convincing about the accuracy/reliability of products.

How could WCRP contribute efficiently to the preparation of the next IPCC assessments? Should WCRP produce some specific synthesis papers in preparation for these IPCC assessments and if so, on which topics?

- By expanding the scope of assessments of both regional phenomena and regional climate
- By bridging the gap between global and regional activities to increase the visibility of the regional activities in the IPCC process, including a better assessment of regional modelling, observations and downscaling in the context of the much-needed enhanced dialogue between WGI and WGII
- By identifying literature gaps, preparing review/synthesis papers and commissioning expert meetings on:

- partitioning variability and change in models and observations
- separation of the local and remote contributions to regional variability
- the contribution from downscaling
- distillation of multi-model multi-method predictions and projections
- advancing knowledge by taking advantage of climate research targeting different time-scales

Given the reframing of the RCI Grand Challenge, the current steering group (which brings together people from WGRC, CLIVAR, GEWEX and WGSIP) is undertaking a series of consultations within the WCRP, IPCC and the wider community (also bringing in the Vulnerability, Impacts and Adaptation [VIA] perspective). BOG5 forms an important part of this consultation process, which will result in a shorter, more focused implementation plan for the RCI Grand Challenge. This was going to be drafted following the WCRP Expert Meeting on Climate Information "Distillation" hosted by WGRC at the end of October 2014. The Distillation workshop was intended to foster innovation in the analysis and interpretation of multi-model, multi-method, multi-scale, regional climate information, in the context of often uncertain observational histories and a perplexing range of future human climate influences. The workshop developed a research agenda to address distillation challenges for climate information at regional scales. It thus played a major role in taking forward specific and concrete actions on the RCI Grand Challenge. The participants included members of the WCRP and IPCC communities, and a number of participants of this Bern workshop.

In addition to actions emerging from the Distillation workshop, promotion and development of the "regional laboratory" idea identified by BOG5 will play an important role in implementing the RCI Grand Challenge and in bringing different communities together (e.g., CORDEX, GEWEX and CLIVAR).

In summary, and with respect to input to the next IPCC report (considering both WG1 and WG2 perspectives), the following major theme emerging from the RCI Grand Challenge is proposed:
provision of reliable regional climate information from climate predictions and projections: an essential component of this theme is the development of a framework to translate climate data and output into **information** and guidance for risk management and decision making

4.6. BOG-6: Water Availability *(Chair: Sonia Seneviratne; Rapporteurs: Taikan Oki and Kevin Trenberth)*

Drafted by Sonia I. Seneviratne, Graeme Stephen, Taikan Oki and Kevin E. Trenberth, with input from Sandrine Bony, David Carlson, Jean-Louis Dufresne, Christian Jakob, Valerie Masson-Delmotte, Fortunat Joos, Cath Senior, Adrian Simmons and Peter van Oevelen

Water availability constitutes one of the key challenges in the context of climate change, and is associated with large impacts to human society through changes in droughts, floods and long-term water resources. The BOG discussions built upon new literature published after the cut-off date of the IPCC AR5 (see also summary of plenary presentation), including the activities and assessments currently on-going for the WCRP Water Availability Grand Challenge, in particular as part of GEWEX activities.

On the outlined basis, four main research questions were identified and discussed in the BOG:
1. Which characteristics of precipitation affect water availability, and how are they changing?
2. What are the roles of land surface processes and human water use in affecting water availability?
3. How can new observational data streams be used to detect and attribute changes in water availability, and constrain climate change projections?
4. How predictable are the key drivers of water availability on sub-seasonal to decadal time scales?

Substantial new literature and datasets have become available since AR5 in these four areas, and a number of WCRP activities are contributing to these outlined questions. In particular, a great deal of relevant planning has occurred within GEWEX. A reorganization of GEWEX has taken place around the WCRP Water Availability and Extremes Grand Challenges (GC) and is coordinated under the GEWEX Science Questions. Two relevant workshops were organized on this topic in 2013. In addition, discussions on several new topics of relevance to the Water Availability GC were initiated at the 2014 Pan-GEWEX meeting. Finally, discussions with other parts of the WCRP community are starting to be established.

Main topics of discussions and related activities were the following:

1. Which characteristics of precipitation affect water availability, and how are they changing?
   - Close global energy and water budgets and provide reduced uncertainty estimates.
   - Determine regional sources of precipitation uncertainties, in particular in high-latitudes and high-altitudes.
   - Provide global maps of main drivers for meteorological droughts (i.e. lack of precipitation).
   - Relevance of high-resolution modelling for precipitation representation

2. What are the roles of land surface processes, land use and human water use, in affecting water availability?
   - Dedicated CMIP6 multi-model experiments addressing land surface forcings and feedbacks, in particular with respect to the simulation of land water availability ("LandMIPs")
   - Observations (jointly with activities under point 3.)
   - Land modelling developments (land use and land cover changes, representation of human water use, subsurface hydrology)

3. How can new observational data streams be used to detect and attribute changes in water availability and constrain climate change projections?
   - GPM (Global Precipitation Measurement mission): assessment and evaluation with ground observations, validation of models
   - Land surface observations: Multi-datasets syntheses for single variables or global energy and water balances, new diagnostic products for evapotranspiration mostly based on remote sensing retrievals, remote sensing estimates of surface soil moisture and terrestrial water storage, possible consideration of paleo-climate data and water/carbon isotopes (as tracers and for model validation)

4. How predictable are the key drivers of water availability on sub-seasonal to decadal time scales?
   - Early warning and monitoring of droughts in selected key regions: Global Drought Information System (GDIS)
   - GLASS (Global Land/Atmosphere System Study) and GASS (GEWEX Atmosphere System Study) activities
   - Contributions from WGSIP, WGCM and CLIVAR

The BOG has also highlighted the potential for more interactions with other communities within WCRP, which should help integrate research on water availability across a larger community. Interactions have already been initiated with CliC in the context of the Land, Snow and Soil moisture Model Intercomparison Project (LS3MIP). Potential interactions with CLIVAR on relevant topics (e.g. monsoons) were also initiated at the joint PanGEWEX/PanCLIVAR meeting. In addition, the WCRP GDIS activities are highly relevant for the outlined questions 1 and 4. Furthermore, interactions with the clouds, circulation and climate sensitivity grand challenge also were discussed in the context of new high-resolution modelling activities planned within GEWEX.

Finally, a recommendation of the BOG for future IPCC reports, in particular the AR6, was to better address the overarching water availability topic under upcoming WG1 contributions, in particular in the view of recent new research developments (e.g. new observational data, new model developments and multi-model experiments, as well as upcoming new synthesis studies combining models and observations).

4.7. BOG-7: Biogeochemical, Aerosols, Atmospheric Chemistry Aspects

(Chairs: Venkatachalam Ramaswamy and Sybil Seitzinger; Rapporteurs: Fortunat Joos and Drew Shindell)

Central Challenge #1: To what extent does climate change affect air pollution and vice versa?

- Identify and quantify the relevant processes.
- Take into consideration the effects of environmental change on air pollution, and the effects of emissions on atmospheric composition and climate.
- Provide scientific foundations for optimal strategies that combine air pollution and climate change mitigation, taking into consideration both near- and long-term horizons.

Major questions and gaps

- How do aerosols and other short-lived climate forcers affect circulation, weather and climate across spatial scales? How do the effects compare to those of long-lived GHGs?
- How do we improve the understanding and effect better quantification of aerosol-cloud interactions using observations, process understanding and models?
- How will meteorology under climate change affect air quality?
- What is the importance of natural aerosol and its dependence on anthropogenic loading and climate evolution?
- There is a lack of adequate observational data on air pollution and environmental degradation in most regions.
- Which climate mitigation measures have air quality co-benefits and/or penalties, and *vice versa*?

Strategies to address the questions/ gaps (observational)

- Bring together the existing diverse data sets on short-lived forcing agents to establish an easily accessible, unified data set for purposes of understanding and improved predictability (emissions, concentrations, deposition, transport, fluxes, etc.).
- Plan and implement new high frequency and resolution satellite observations related to short-lived forcings that can be combined with key climate variables.
- Initiate targeted field campaigns and studies to improve understanding of processes such as rates of aerosol transformation, aerosol scavenging or chemical loss rates and the integrated effects of multiple processes to compare with model budgets.

Strategies to address the questions/ gaps (modelling)

- Increase horizontal and vertical resolution of models to capture finer spatial scales typical of short-lived climate forcers.
- Capture the realism of the key processes using improved parameterizations based upon fundamental knowledge and observations (e.g. aerosol microphysics and optics, heterogeneous processes, photochemistry and related physical climate processes).
- Improve the accuracy of natural and anthropogenic emissions of short-lived species and their sensitivity to climate change (links to ocean and land biogeochemical cycles).
- Improve representation of the transformation process from emissions to concentrations to radiative effects to climate responses.
- Develop and plan MIPs that help define current best practices, model deficiencies and biases and sensitivities to key processes.
- Ensure that models simulate the necessary processes and generate the required information for health impacts analysis.

Central Challenge #2: To what extent is the climate sensitive to biogeochemical processes and feedbacks?

- Identify and quantify the relevant processes.
- Take into consideration the whole chain from emissions to impacts to information for decision making.
- Consider implications for vulnerability, adaptation and mitigation.

Major questions and gaps

<u>Identification and quantification of the relevant processes</u>

- What is the risk of amplification of climate change via biogeochemical processes and feedbacks including biophysical feedbacks (albedo, evapotranspiration)?
- How much do carbon-nutrient-water interactions and changes in atmospheric composition, influence land and ocean sources and sinks of climate relevant agents?

- How do changes in climate, e.g. ocean circulation, affect the exchange of heat, carbon and trace gases between the atmosphere and ocean?
- How do changes in climate, e.g. precipitation, affect the exchange of carbon and trace gases between the atmosphere and the terrestrial biosphere?
- How do GHG fluxes from highly vulnerable carbon pools (e.g., large/ high-latitude carbon pools, permafrost) respond to changing climate, including climate extremes and abrupt changes?
- Where and when do trends in the biogeochemical cycles and ecosystems emerge from natural variability?

<u>Considering the whole chain from emissions to impacts to information for decision making</u>

- How do natural emissions and sinks of climate relevant agents respond to the anthropogenic perturbations (changes in atmospheric composition, land-use, climate)?
- How can we better quantify the cumulative carbon emissions consistent with specific climate-change targets?
- How does land management influence emission, atmospheric composition and climate?

<u>Implications for impacts, adaptation and vulnerability (IAV)</u>

- To what extent is the accumulation of GHGs irreversible?
- How sensitive are marine and terrestrial ecosystems and biogeochemical processes to multiple stressors including climate change, acidification and atmospheric composition?
- Evolution of marine and terrestrial resources, including considerations of tipping points, in a changing climate (e.g., crops, fisheries)?

Strategies to address the questions/gaps (combined observational, modellin, and analyses)

- Advance monitoring and analyses of space-time variations in biogeochemical and ecosystem variables to quantify trends and natural variability, particularly *in situ* observations.
- Develop methodologies (paleo and modern observations, model, process understanding) to address inadequate or missing representations of carbon, methane, nitrous oxide, atmospheric chemistry in Earth System Models (ESMs), considering extreme events.
- Develop methodologies to address the cycling of isotopes of carbon, water, oxygen and geotracers to better quantify biogeochemical and water cycles and to constrain GHG source mix and transport time-scales.
- Improve and better use historical and paleo information to constrain climate-GHG sensitivities and responses.
- Utilize the added value of combined physical and biogeochemical observations in the ocean to diagnose and understand change, including Southern Ocean processes and heat and tracer fluxes.
- Combine expertise from the observational, land managment and DGVM communties to improve quantitative understanding of vegetation-soil processes in managed environment.
- Develop methodologies to understand and quantify the effects of multiple stressors on biogeochemistry and ecosystems.
- Improve interactions between ESMs and IAV communities and models.
- Initiate an integrated earth system reanalysis for the last decades.

Recommendations to WCRP (for both Central Challenges)

- Identify and engage the relevant partners, e.g. GCP, IGBP, Future Earth and WCRP project leaders, to further develop, prioritize and implement the strategies to address the issues, particularly those that bear on societal concerns.
- Form a (or several) joint-working group(s) to develop and implement strategies to make progress in the research on the different topics, with an emphasis on identifying the source of and characterizing the major uncertainties.
- Several of the major questions have strong connections to the WCRP Grand Challenges that have been framed as well as the Core Projects, particularly as they pertain to the understanding and prediction of the physical climate system including anthropogenic change. Thus, progress on the twin Central Challenges will be significantly advanced through sustained collaborations over the course of the contemplated MIP, IPCC (WGI,II,III) and other major international activities.
- Link with other groups (such as WHO, FAO) to quantify the impacts of atmospheric chemistry, aerosols and biogeochemical cycles on ecosystems, agriculture, health, etc.

4.8. BOG 8 – Decadal Timescale Quantification: Attribution and Prediction *(Chair: Jochem Marotzke; Rapporteurs: George Boer and Peter Stott)*

High-priority gaps in our current understanding:

Surface-warming hiatus:
Despite a flurry of publications on the hiatus, no comprehensive synthesis has occurred since AR5. But such synthesis is required, because almost all individual papers still offer single-cause explanations. The AR5 assessment still stands but needs to be updated urgently.

Decadal prediction:
Best practice in initialization and ensemble creation needs to be developed; the same holds for best practice for bias adjustment, calibration and forecast assessment.

Forcing for use in climate models:
Forcing information is not annually resolved for all contributions. Updates post-2005 are missing for some contributions (e.g., solar, volcanic in CMIP5), and forcing information is missing in part for the pre-satellite period. There is substantial uncertainty around volcanic forcing for historical and millennium simulations, and substantial uncertainty in tropospheric aerosol forcing over the entire period.

Projections:
The possible influence of volcanoes is missing from current-generation projections. Furthermore, a methodology is missing for integrating different information streams for near-term prognoses. For example, the assessment of expected near-term global surface temperature change had to be developed on the fly in IPCC WGI AR5, Chapter 11.

Attribution of events/Case studies:
An important gap concerns the understanding of Atlantic Multi-decadal Variability (AMV). The question is still open as to what extent the AMV can be attributed to internal variability or to regional tropospheric aerosol forcing. Because it is unclear whether robust attribution can be achieved, an alternative strategy would test the hypothesis that the shift in aerosol burden from Europe to Asia, from the middle to the end of the twentieth century, was responsible for climate changes over the Atlantic. This alternative approach focuses less on attribution than on exploring the effects of the shifting aerosol burden.

Earth system predictability:
Understanding and predicting interannual to decadal variations in the carbon cycle, among them variations in carbon uptake by the ocean or the land biosphere, is important scientifically and might support global carbon-emissions accounting.

Proposals on what to do:

The surface-warming hiatus requires a three-pronged approach, addressing (1) the current hiatus, focusing on the forcing contributions as well as the spatial and seasonal footprint including mechanisms leading to the footprint, (2) mechanisms of model hiatuses, which may or may not differ among instances, and (3) case studies of past hiatuses such as the mid-century hiatus, but also of related phenomena such as accelerated warming periods (related because they show the opposite yet similar-in-magnitude deviation from the multi-decadal trend). Strategy: This task could be tackled by an ISSI working group. For a start, the IPCC WG1 AR5 Box 9.2 Team (plus potential additions) should be re-convened, to provide a comprehensive review.

The Decadal Climate Prediction Project (DCPP) is strongly endorsed and is seen as the right strategy for tackling the decadal-prediction issues. DCPP is encouraged to engage with MAC (Modelling Advisory Council), WGSIP (Working Group on Seasonal to Interannual Prediction) and WGCM (Working Group of Coupled Modelling) concerning possible inclusion of carbon-cycle components in decadal prediction experiments. This should be possible with little extra effort (assuming initialization of carbon reservoirs is not intended).

Connection with the Radiative Forcing Model Intercomparison Project (RFMIP) is likely to be crucial for addressing the forcing uncertainty and its role for both decadal and multi-decadal variability.

Connection with the International Detection and Attribution Group (IDAG) is crucial for strategically addressing the attribution of climate events to either external forcing or internal variability. The latter is intended to explain mechanisms and to point to an “origin” in a past climate state; identification of such an origin is closely related to the event being predictable.

Prognosis of near-term climate change requires the use of all relevant sources of knowledge, using not only the CMIP model ensemble as in long-term projections, but also knowledge gained from decadal prediction experiments, seasonal-to-interannual prediction (e.g., methods of bias correction) and results from detection and attribution studies.

Summary: The strategy dealing with Decadal Timescale Quantification: Attribution and Prediction involves interaction with a sufficiently large number of different communities – implying sufficiently complex coordination effort – that, if developed today, would be a strong contender for one of the Grand Challenges.

Observational requirements:

Sustained observations:

It is crucial to sustain Argo (Array for Real-Time Geostrophic Oceanography), because Argo is indispensable for the climate energy budget. Furthermore, it is necessary to extend the network to “deep Argo” (below 2000 m depth) to close the current observational “leak”. Maintaining the RAPID AMOC (Atlantic Meridional Overturning Circulation) observational array at 26.5°N is crucial because the AMOC exerts a central dynamical influence on the mean climate and climate variability.

Strategic aims:

- Still-existing gaps in surface temperature must be filled. Although surface temperature is the best-observed climate quantity, data coverage is not fully global.
- Information for annually resolved forcing must be provided. The technical strategy for accomplishing this aim remains to be determined.
- The capability to diagnose changes in ocean heat uptake rates, including their vertical distribution, must be developed. The technical strategy for accomplishing this aim remains to be determined.

Implications for an IPCC AR6:

All activities described here will contribute to our increase in knowledge, to be assessed in an AR6. The most immediate qualitative difference will be in linking the recent past to near-term future climate variation and change. This link will have a more solid foundation than in AR5.

5. Main workshop outcomes and concluding remarks

The workshop was a unique occasion for an informal dialogue between project leaders in climate change research and those who served as authors on the IPCC reports. The workshop was organized shortly after the release of the IPCC AR5 WGI report and during the final phase of the preparation of WGII and WGIII reports. Of the 79 participants, about two thirds were authors of the AR5, a majority from the WGI but also some from the WGII and WGIII reports. JSC, WCRP core projects, councils and modelling groups were all represented and most WCRP Grand Challenge coordinators attended the workshop. The overall scientific organization was overseen by a Scientific Steering Committee consisting of both WCRP and IPCC representatives, and co-chaired by one member of JSC and a co-chair of IPCC WGI. Preliminary input to the workshop stemmed from a WCRP survey among the climate change research community in July 2014. A "guidance document" for the participants prepared ahead of the workshop served as an introduction to the workshop objectives, structure and intended outcome. The principle was to have one day dedicated to Plenary presentations and discussions, one day of BOG discussions and a final day dedicated to the presentation of conclusions and recommendations by the BOGs and their discussion and approval by the Plenary.

Presentations

On day 1 of the workshop, a first set of presentations by scientists who served as authors on the IPCC AR5 provided an overview on key scientific uncertainties, research and/or knowledge gaps, and new research topics emerging from the IPCC assessment. The workshop then provided an opportunity for ample discussions on how the issues are, and will be, addressed in WCRP activities, and in consequence, for recommendations on how to tackle them in the future. Topics covered included a general introduction on longstanding uncertainties in IPCC assessments by the co-chair and TSU Head of IPCC WGI, and presentations made jointly by one author from IPCC WGI and one author from IPCC WGs II or III on the following topics: regional climate change, decadal predictions and projections, carbon cycle-climate interactions, climate targets, aerosols and aerosol-climate interactions, as well as air quality and climate. In a second set of keynote presentations, the WCRP Grand Challenge coordinators then presented the status of the Grand Challenges in the light of the latest IPCC findings. In addition, two more keynote presentations were made on important topics covered by the IPCC assessment that are not at the core of current WCRP activities: one on the role of risk of climate change and how it is covered in the Grand Challenges by an author from IPCC WGII, and the second on climate change scenario development by an author from IPCC WGIII. Plenary discussions were engaged and will help to revisit the objectives of the WCRP Grand Challenges in light of the most recent IPCC assessment.

Break-out Groups

On day 2, the meeting of BOGs in successive parallel sessions enabled productive discussions among participants. It also allowed those participants who served as authors on the IPCC reports to offer their expertise in Grand Challenge discussions and provide useful input to their planning. BOGs1 to 6 were defined along Grand Challenge objectives and led by Grand Challenge coordinators in association with usually one author from the IPCC AR5 not directly involved in the "challenge". BOG7 on biogeochemical, aerosols, atmospheric chemistry aspects and BOG8 on decadal timescale attribution and prediction, lead by authors of the AR5, addressed broad climate change related issues which either fall in WCRP remit but are not dealt with by present Grand Challenges, or are not currently at the core of WCRP activities. It was agreed that WCRP would benefit from their inclusion in future activities and from increased cooperation with organizations currently covering or intending to cover these topics (e.g. IGBP and Future Earth).

Conclusions and recommendations from BOGs are summarized in section 4 of this report. Each BOG had identified priority thematic issues and was invited to answer, in its respective domain, four overarching questions in relation to major research gaps and ways to address them, contributions expected from the research community, requirements for observing systems and modelling techniques and infrastructure, and proposals for future WCRP contribution to IPCC.

Research needs identified by BOGs

A selection of research needs or orientations identified by BOGs is as follows:

- the development of a proper framework to forecast the evolution of large-scale climate features such as storm tracks, tropical rain belts and monsoons
- an accurate evaluation of climate sensitivity to radiative forcing
- the development of a proper framework to assess changes in the statistics of climate extremes, including statistical tools to analyse long term changes in extremes
- the need to improve the evaluation of causes and the forecast of regional sea level changes, making use, for example, of model/observations inter-comparisons for sea level change and its components
- specific studies on anthropogenic attribution for cryospheric quantities, one proposal being the planning of coordinated experiments on Antarctic sea ice
- specific efforts in understanding changes and variability in regional phenomena and in their translation into information and guidance, accompanied with the development of "regional laboratories" for facilitating capacity building
- a close coordination of WCRP components for the prediction of the key drivers of water availability on sub-seasonal to decadal time scales
- the need to better quantify the relationship between air pollution and climate change
- the need to better assess the risk of amplification of climate change via biogeochemical processes
- the development of joint strategies and working groups between WCRP and partner programmes to address biogeochemical issues that bear on societal concerns
- further studies on decadal timescale attribution and prediction (including better understanding of the recent "warming hiatus") as part of the development of strategies for inter-annual to decadal prediction

Requirements for observing systems

Requirements for observing systems include:

- improvements in the observation of lower tropospheric water vapour
- the development of appropriate data sets and statistical tools for extreme events
- the development of a global coastal observation network and data base,
- further development of the Global Cryosphere Watch,
- the development of regional data sets as a basis for model evaluation and statistical downscaling
- assessment and evaluation of new water cycle related products from recent and new space observation missions
- the development of a unified data set on short-lived biogeochemical forcing agents
- progress in monitoring and analysis of space-time variations for biogeochemical and ecosystem variables
- continuity and global coverage of oceanic parameters, especially in the deep ocean

Modelling requirements

Modelling requirements call for advances in modelling techniques, including:

- parameterization of land-surfaces
- sea-ice and ocean mixing processes
- atmospheric chemistry and aerosol processes
- coupling of AOGCM with dynamic ice-sheet models
- development of idealized models to address changes in climate patterns
- development of high resolution modelling for extreme events,
- developments in precipitation modelling
- development of improved diagnostic and validation tools adapted in particular to extreme events and regional climate information
- re-analyses and simulation of case studies for better understanding of specific features such as changes in climate patterns or surface-warming hiatus

Coordination role of WCRP and possible new "Grand Challenges"

Proposals were made to improve the coordination role of WCRP in a number of areas, such as communication across the communities involved in model development, supporting community access to a hierarchy of models and diagnostic tools, setting up working groups and workshops focusing on identified gaps, development of MIP type projects, promotion of observational programmes or campaigns. Working with ISSI was considered as a very positive experience. Several BOGs mentioned capacity building in their priorities and opportunities offered by ISSI for "international teams" and workshops will certainly be considered as part of future WCRP activities.

The workshop reaffirmed the role of the six existing Grand Challenges as priority research areas for the WCRP community and, as described above, a number of proposals were made for each of these in response to uncertainties or gaps identified in the IPCC AR5. The topic of biogeochemical, aerosols and atmospheric chemistry aspects was considered by the workshop participants as an important area for enhanced cooperation between WCRP and IGBP (and later on with Future Earth), with the involvement of relevant partners to deal among others with issues of societal concern. It was recommended to form one (or several) joint working groups to propose topic specific initiatives. Finally, on the topic of decadal attribution and prediction, the workshop participants informally endorsed the strategy of the Decadal Prediction Panel, and recommended the possible establishment of a new Grand Challenge.

Three specific "cross-cutting" proposals endorsed by the workshop

In addition to BOG recommendations, three specific proposals from the whole group were endorsed in Plenary:

- Several of the BOGs identified a general need for cross-validation of climate products from space and in situ observations which could take the form of an **"Observations Inter-comparison Project".**

- A specific effort carried out by the "Regional Climate Information" Grand Challenge but of interest to several of the other Grand Challenges calls for the development of a framework to translate climate data and output into information and guidance for risk management and decision making, with the aim of providing reliable **regional climate information** from climate predictions and projections. **Integrated regional studies** could serve as test-beds for the approach, with a coordinated use of data and modelling resources associated with a capacity building aspect.

- **Earth System reanalysis for twentieth century:** As a result of BOG recommendations and informal discussions, the workshop proposed to initiate a feasibility study of a reanalysis of the Earth System covering the entire twentieth century. Global re-analyses have served since the 1980s as "virtual laboratories" for model developments and observation assessments, starting with meteorological re-analyses but recently extended to the global oceans, with however, strong limitations with respect to cryospheric or biogeochemistry processes. Periods covered have also progressively extended throughout the twentieth century, in spite of severe inbalances and limitations in data extent and coverage. This endeavour would be an incentive for a number of communities to work together and learn from each other. This also would have the advantage of being highly visible with the results understandable and usable by a large number of potential users. WCRP could facilitate the planning of such an effort through substantial partnerships, particularly from biogeochemistry and ocean ecology communities, and would seek important commitments from major modelling centres. This workshop indicated a significant motivation within the research community for this undertaking.

WCRP's contribution to IPCC

The workshop participants recognized the importance for the research community and particularly for WCRP to carefully consider the IPCC assessments after completion and to reflect upon the knowledge and research gaps identified by the IPCC. There was clear interest from WCRP project leaders to respond to needs identified through the assessments and to actively take part in future IPCC assessments.

Two orientations which would benefit WCRP's input to IPCC assessments would be to better take into account the needs expressed by WGII and WGIII communities in the terms of reference of climate model inter-comparison projects and to bridge the existing gap between global and regional activities. The first orientation is taken up as part of the next phase of the Climate Model Intercomparison Project. As a contribution to the second one, the strategy being developed for regional climate research aims at an integrated approach optimizing the use of observations, modelling and physical understanding from the definition of scenarios to the preparation of useable information.

With respect to the assessment activity itself, the growing quantity of model outputs and publications is an issue for the continuation of high quality climate change assessments. As a response, it was suggested that the WCRP Grand Challenges could encourage the writing of peer-reviewed community "synthesis" papers on a few topics. It was recognized that these papers could provide useful input to future IPCC assessments.

Proposed article

V. Ramaswamy, former JSC member and experienced contributor to the IPCC process, has been approached to lead the preparation of an article encompassing a review of WCRP Grand Challenges and research priorities in a broad IPCC perspective, making use of discussions and recommendations from this workshop, including input from the survey. Several journals have been mentioned as possible support for this, but some preference has emerged for the Bulletin of the American Meteorological Society.

Acknowledgements

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ANNEX A: LIST OF PARTICIPANTS

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ANNEX B: WORKSHOP PROGRAMME

Day 1: Monday, 8 September 2014

08:30–09:00	**Registration**
09:00–09:20	***Opening and Welcome Remarks (Chair: Vladimir Kattsov)*** ◆ ***Mr José Romero, Swiss Federal Office for the Environment and Swiss Focal Point for the IPCC*** ◆ ***Mr Thomas Stocker, Co-Chair, IPCC Working Group I*** ◆ ***Mr David Carlson, Director, World Climate Research Programme*** ◆ ***Mr Rudolf von Steiger, Director, International Space Sciences Institute***
09:20–09:50	***Introduction (Guy Brasseur and Thomas Stocker)***
09:50–10:20	**Break**
PLENARY SESSION 1: IPCC WGI AR5: EMERGING THEMES AND KEY UNCERTAINTIES ***(Chair: Guy Brasseur)*** [12 minute keynote presentations followed by 5 minutes Q&A]	
10:20–10:37	***Longstanding Uncertainties in IPCC Assessments (Thomas Stocker and Gian-Kasper Plattner)***
10:37–10:54	***Regional Climate Change (Krishna Kumar Kanikicharla and Bruce Hewitson)***
10:54–11:11	***Decadal Prediction and Projections (Scott Power and Rowan Sutton)***
11:11–11:28	***Carbon Cycle–Climate Interactions (Corinne Le Queré and Fortunat Joos)***
11:28–11:45	***Climate Targets Beyond Temperature (Reto Knutti and Elmar Kriegler)***
11:45–12:02	***Aerosols, Air Quality and Climate (Jean-Francois Lamarque and Piers Forster)***
12:02–12:30	**Open Discussion**
12:30–14:00	**Lunch**
PLENARY SESSION 2: WCRP GRAND CHALLENGES: STRATEGIES TO ADDRESS KEY UNCERTAINTIES ***(Chair: Thomas Stocker)*** [12 minute keynote presentations followed by 5 minutes Q&A]	
14:00–14:17	***Clouds, Circulation and Climate Sensitivity (Sandrine Bony and Bjorn Stevens)***
14:17–14:34	***Changes in Cryosphere (Vladimir Kattsov and Gregory Flato)***
14:34–14:51	***Climate Extremes (Xuebin Zhang and Gabi Hegerl)***

14:51–15:08	***Regional Climate Information (Lisa Goddard, Francisco Doblas-Reyes and Clare Goodess)***
15:08–15:25	***Regional Sea Level Rise (Detlef Stammer and Catia Motta Domingues)***
15:25–15:42	***Water Availability (Sonia Seneviratne and Graeme Stephens)***
15:42–16:15	**Open Discussion**
16:15–16:45	**Break**
PLENARY SESSION 3: IMPACTS, RISK ASSESSMENT AND SCENARIO DEVELOPMENT *(Chair: Claudia Tebaldi)* [15 minute keynote presentations followed by 5 minutes Q&A]	
16:45–17:05	***The Role of Risk in the WCRP Grand Challenges: Building from the AR5 (Bruce Hewitson)***
17:05–17:25	***Scenario Development and Integrated Assessment Model Projections (Elmar Kriegler and Brian O'Neill)***
17:25–17:55	**Open Discussion**
17:55–18:10	**Tasking the Breakout Groups**
18:10–18:30	***International Space Science Institute: Current Activities Relevant to Climate Research (Rudolf von Steiger)***
18:30	**Adjourn**
18:45–20:15	**Welcome Reception at the University of Bern on the Terrace at Sidlerstrasse 5 *(Sponsored by the Oeschger Centre, University of Bern and the Government of Switzerland)***

Day 2: Tuesday, 9 September 2014

BREAKOUT GROUP SESSION 1	
09:00–10:30	**Meet in Plenary before BOG splitting** **BOG-1: Clouds, Circulation and Climate Sensitivity** ***(Chair Bjorn Stevens; Rapporteurs: Sandrine Bony and Ted Shepherd)*** **BOG-2: Climate Extremes** ***(Chair: Xuebin Zhang; Rapporteurs: Rowan Sutton and Sun Ying)*** **BOG-4: Changes in Cryosphere** ***(Chair: Vladimir Kattsov; Rapporteur: Gregory Flato)*** **BOG-7: Biogeochemical, Aerosols, Atmospheric Chemistry Aspects** ***(Chair: Venkatachalam Ramaswamy and Sybil Seitzinger; Rapporteurs: Fortunat Joos and Drew Shindell)***
10:30–11:00	**Break**
BREAKOUT GROUP SESSION 2	
11:00–12:30	**BOG-3: Regional Sea Level Rise** ***(Chair: Anny Cazenave; Rapporteurs: Catia Motta Domingues and Detlef Stammer)*** **BOG-5: Regional Climate Information** ***(Chair: Clare Goodess; Rapporteurs: Francisco Doblas-Reyes and Lisa Goddard)*** **BOG-6: Water Availability** ***(Chair: Sonia Seneviratne; Rapporteurs: Taikan Oki and Kevin Trenberth)*** **BOG-8: Decadal Timescale Quantification: Attribution and Prediction** ***(Chair: Jochem Marotzke; Rapporteurs: George Boer and Peter Stott)***
12:30–14:00	**Lunch**
PLENARY SESSION 4	
14.00–14.30	**Coordination and Stocktaking** ***(Chair: Guy Brasseur and Thomas Stocker)***
BREAKOUT GROUP SESSION 3	
14:30–16:00	**BOG-1: Clouds, Circulation and Climate Sensitivity** **BOG-2: Climate Extremes** **BOG-4: Changes in Cryosphere** **BOG-7: Biogeochemical, Aerosols, Atmospheric Chemistry Aspects**
16:00–16:30	**Break**
BREAKOUT GROUP SESSION 4	
16:30–18.00	**BOG-3: Regional Sea Level Rise** **BOG-5: Regional Climate Information** **BOG-6: Water Availability** **BOG-8: Decadal Timescale Quantification: Attribution and Prediction**
18:00	**Adjourn**

Day 3: Wednesday, 10 September 2014

09:00–10:30	**BOG Report Writing Time**
10:30–11:00	**Break**
PLENARY SESSION 5: REPORTS FROM BREAKOUT GROUPS ***(Chair: Gian-Kasper Plattner)*** [15 minute reports followed by 5 minutes Q&A]	
11:00–11:20	**BOG-1: Clouds, Circulation and Climate Sensitivity**
11:20–11:40	**BOG-7: Biogeochemical, Aerosols, Atmospheric Chemistry Aspects**
11:40–12:00	**BOG-3: Regional Sea Level Rise**
12:00–12:20	**BOG-4: Changes in Cryosphere**
12:20–13:50	**Lunch**
PLENARY SESSION 6: REPORTS FROM BREAKOUT GROUPS ***(Chair: Anny Cazenave)*** [15 minute reports followed by 5 minutes Q&A]	
13:50–14:10	**BOG-5: Regional Climate Information**
14:10–14:30	**BOG-6: Water Availability**
14:30–14:50	**BOG-2: Climate Extremes**
14:50–15:10	**BOG-8: Decadal Timescale Quantification: Attribution and Prediction**
15:10–15:40	**Break**
PLENARY SESSION 7: CLOSING PLENARY ***(Chair: Guy Brasseur and David Carlson)***	
15:40–16:10	**Open Discussion**
16:10–16:20	**Next Steps: Deliverables, Timetable, Thanks**
16:20–16:30	***Closing Remarks (Guy Brasseur, Gian-Kasper Plattner, David Carlson, Rudolf von Steiger)***
16:30	**Adjourn**

ANNEX C: WORKSHOP GUIDANCE DOCUMENT

1. Objectives of the workshop

The aim of the workshop is informal exchanges and brain-storming between scientists involved in climate change research coordination and IPCC authors. Its main purpose is to take stock of key scientific issues identified through the IPCC assessment in WCRP's research plans. This has the potential to help IPCC in its own reflection on future activities.

IPCC Fifth Assessment Report (AR5) has identified a number of emerging themes and outstanding issues in climate change research, some of them outlined as key uncertainties by Working Group I (WGI) and "research and data gaps" by WGII. IPCC authors participating in the workshop will provide their views on debates on those issues held at IPCC. Additional input from the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) and WGIII report will also be considered, as well as new scientific material available since the AR5 cut-off dates. Contributions and discussions will focus on issues which are considered as essential for the progress of climate change research and on actions which may facilitate the evaluation of risks and impacts, and the development of adaptation strategies. The agenda is built around scientific themes and types of research activities which are needed for responding to outstanding questions. Outcomes are expected to benefit the planning of major WCRP projects, particularly the "Grand Science Challenges", defined as major areas where efforts in research, modelling, analysis and observations are needed. The planning of climate model intercomparison and evaluation activities and the development of regional climate projections are aspects of WCRP research which should particularly benefit from the workshop. It is also expected that the input from IPCC authors from the three working groups will help to highlight new orientations which may presently be missing in WCRP remit. In addition, the workshop will feed into the progress report being prepared by the Global Climate Observing System (GCOS). From IPCC viewpoint, it is expected that it will provide constructive comments and recommendations for the content of future assessments and that it will contribute to enhancing the quality of research needed to answer the societal challenges addressed by IPCC.

2. Preparatory scientific activities

2.1 Scientific Steering Committee

The role of the Scientific Steering Committee (SSC) is to provide scientific guidance in the various stages of the workshop preparation, including the invitations, agenda and survey, to coordinate the workshop scientific work, and to ensure that the workshop outcomes fulfill the objectives set by WCRP and IPCC.

Composition:
- Guy Brasseur (WCRP JSC member, SSC Co-Chair)
- Thomas Stocker (IPCC WGI Co-Chair, SSC Co-Chair)
- Sandrine Bony (WGCM Co-Chair)
- Anny Cazenave (WCRP JSC member)
- Vladimir Kattsov (WCRP JSC Vice-Chair)
- Katharine Mach (IPCC WGII, TSU Science Director)
- Gian-Kasper Plattner (IPCC WGI TSU Head)
- James Renwick (WCRP JSC member)

Support: Gilles Sommeria (WCRP consultant) & Nicolas Champollion (ISSI)

2.2 Survey

A survey has been conducted with IPCC authors, WCRP project leaders and participants. Its purpose was to review how IPCC assessment reports impact the climate science community in general and WCRP in particular. The survey focused on research gaps, knowledge gaps and uncertainties, on potential ways forward to make progress (in terms of observing systems, modelling, etc.) and on how all those components are covered in the current existing WCRP programme, including the WCRP Core Projects and Grand Challenges.

The survey began with the review of outstanding scientific issues identified by IPCC AR5 in WGI report and "research and data gaps" in WGII report, complemented as needed by material from SREX. Views were solicited on how these issues have evolved between AR4 and AR5, how they have been taken up in new studies since AR5 cut-off dates and how they are dealt with in WCRP plans (through the Core Projects or the Grand Challenges). Suggestions on future IPCC/WCRP interface issues as well as on any other aspect of climate research respondents wished to highlight were also welcomed.

The results of the survey will serve as input to the workshop discussions and will be made available to WCRP as a resource when refining WCRP workplans and to IPCC to inform the on-going reflection on future IPCC assessments. A survey report is part of the workshop package, with detailed answers available at:

https://www.dropbox.com/sh/nky1ycy0ww0rj3q/AAC3eI_2RmF0doTqrzAUf6b8a.

3. Keynote presentations

Keynote presentations will be prepared by two authors and be presented by one of them. The presentations are expected to highlight research topics and issues that have been identified in the IPCC process and which fit or potentially fit in WCRP remit, with a long term perspective and updates from recent scientific work. They would ideally include specific recommendations on ways to address outstanding issues. Material from the presentations will be made available to SSC and Breakout Group (BOG) chairs, and early contacts between keynote speakers and appropriate BOG chairs are encouraged.

4. Break-out Groups

Break-out Groups (BOGs) 1 to 6 are defined along Grand Challenge objectives and are organized and led by the coordinators of the WCRP Grand Challenges. BOGs 7 and 8 address issues which might be included in future WCRP activities. Each BOG will be co-led by a chair and one or two rapporteurs. The SSC, in collaboration with the BOG chairs, will tentatively pre-assign participants to the eight BOGs in order to ensure transition from the Plenaries into the BOGs during the meeting. Participants are free to move in and out of BOGs, but room size will limit participation in BOGs to some extent.

The object of BOGs is to come up with ideas that contribute towards addressing IPCC "Key Uncertainties" and WCRP Grand Challenges. Any other recommendations regarding IPCC, WCRP, GCOS, etc., will be welcomed.

All BOGs are expected to address (1) a few overarching (general) questions as well as (2) more specific questions specific to the focus of each BOG. The overarching questions are:

5. What are the major gaps in the domain covered by your BOG (revealed by the IPCC AR5 process) in our understanding of the climate system, and what are the best strategic approaches to address these scientific issues in the next 5–8 years?
6. How could the community focusing on the topics discussed by your BOG contribute to key scientific questions, uncertainties and research issues raised/identified by IPCC?

7. What are the inadequacies/requirements of the current/future observing system in relation with the objectives of your BOG? Similarly what are the main modelling or modelling infrastructure inadequacies/requirements in relation with the objectives of your BOG?
8. How could WCRP contribute efficiently to the preparation of the next IPCC assessments? Should WCRP produce some specific synthesis papers in preparation to these IPCC assessments and if so, on which topics?

Role of BOG Chair:

- be the main contact person for the SSC
- guide and keep the discussions focused, avoid large distractions
- address different views and maintain balance
- steer the group towards a set of conclusions/key points (a bullet list), which will be presented to the Plenary
- provide input to the workshop report and potentially to a scientific publication to come out of the workshop

Role of BOG Rapporteur(s):

- take notes of the discussions
- prepare with the BOG Chair the bullet list to be presented to the Plenary
- prepare a one to two page summary of the discussions together with the BOG Chair
- take part in the workshop report and publication

During the workshop, members of the organizing team will keep track of and collect products (notes, bullet lists, summaries) from all the BOG sessions and the Plenary discussion. Material will be distributed electronically to all meeting participants every day after the meeting adjourns. All meeting material will be made available to the SSC and participants within a few days after the meeting's end.

5. Definition and composition of individual break-out groups and questions that will help guide the discussions

BOG-1: Clouds, circulation and climate sensitivity *(Chair Bjorn Stevens; Rapporteurs: Sandrine Bony and Ted Shepherd)*

1. The importance of climate sensitivity
2. Why understanding circulation is critical
3. How clouds mediate forcing
4. The role of cloud processes in natural variability
5. Linking tropospheric circulation to changing patterns of SSTs, land-surface properties and the middle/upper atmosphere
6. How to reconcile bottom-up (or process-oriented) and top-down (or global) constraints on climate sensitivity
7. Extent and limits of our understanding of changes in large-scale precipitation patterns
8. The role of assessments within WCRP
9. How to focus and support model development
10. Directing ideas towards data
11. The importance of better integrating paleo-indicators into all of our work
12. The importance of hierarchies of models to develop robust understanding

BOG-2: Climate extremes *(Chair: Xuebin Zhang; Rapporteurs: Rowan Sutton and Sun Ying)*

1. How can we improve the collation, dissemination and quality of observations needed to assess extremes and what new observations do we need?
2. Can models be further improved to better simulate, predict and project extremes?
3. What do we understand about the interactions between large-scale drivers and regional-scale land-surface feedbacks that affect extremes, and how can these processes be improved in models?
4. To what extent can detected changes in extremes be attributed to forcing external to the climate system and/or to internal factors such as modes of variability?
5. What factors have contributed to the changes in probability of a particular observed event?
6. How has drought changed in the past, what were the causes and how will it change in the future?
7. Are changes in the frequency and intensity of extremes predictable at seasonal to decadal scale and if so, how can we best realize that potential, and how can society best use such forecasts?
8. How will large-scale phenomena such as monsoons and modes of variability change in the future, and how will this affect extremes?

BOG-3: Regional sea level rise *(Chair: Anny Cazenave; Rapporteurs: Catia Motta Domingues and Detlef Stammer)*

1. How to reduce uncertainties on observations of sea level components (global and regional)
2. Can the sea level closure budget approach help to estimate the deep ocean heat content? What is the implication for Earth's energy imbalance?
3. How to improve past sea level reconstructions and ocean reanalyses
4. Detection/Attribution applied to regional sea level patterns
5. Need for an intercomparison project of all data sets used in sea level studies; Expand model-data intercomparisons (sea level and components)
6. How to improve the ice sheet and land hydrology components of long-term sea level projections
7. Importance of decadal and centennial regional sea level projections, accounting for all climate- and non climate-related processes; Downscaling to the coast.
8. Need for integrative studies of coastal impacts of sea level rise

BOG-4: Changes in cryosphere *(Chair Vladimir Kattsov; Rapporteur: Gregory Flato)*

1. Better quantification of uncertainty in historical observations/reconstructions of cryosphere variability and change (needed both for model evaluation and detection and attribution studies)
2. Reduce uncertainty in contribution of ice sheets and mountain glaciers to future sea-level rise
3. Improve modeling and reduce uncertainty in permafrost change and associated changes in carbon sources/sinks.
4. Reconcile modeling and observations of variations in Antarctic sea-ice extent
5. Improve quantification of impacts of cryosphere changes on water availability
6. Consequences and risks associated with declining sea ice in the Arctic

BOG-5: Regional climate information *(Chair Lisa Goddard /Rapporteurs: Francisco Doblas-Reyes, Clare Goodess and Bruce Hewitson)*

1. What gaps in our scientific understanding and information, if addressed, would maximize the value content of regional climate information at all time scales of interest to a wide range of stakeholders?
2. How can we define the best ways to post-process climate data to provide the targeted regional information required for IAV applications within the context of risk management? This implies that climate data is not climate information and includes how to best use information from ensembles of simulations to provide trustworthy uncertainty estimates.
3. How to best convey credibility and uncertainty in its multiple forms to users of regional climate information?

4. What new approaches are needed to understand the sources of uncertainty at the regional level as a function of methods, scales and processes? Is it possible to disaggregate the contributions from local, regional and remote processes, including the co-behavior of processes?
5. Can we define the role(s) of high-quality regional observations, including historical and proxy observations?
6. How to draw on and bring added value to initiatives and work undertaken in other grand challenges without duplicating them?

BOG-6: Water availability *(Chair: Sonia Seneviratne; Rapporteurs: Taikan Oki and Kevin Trenberth)*

1. How can we better understand and predict precipitation variability and changes, and how do changes in land surface and hydrology influence past and future changes in water availability and security?
2. How well can precipitation be described by various observing systems, and what basic measurement deficiencies and model assumptions determine the uncertainty estimates at various space and time scales?
3. How do changes in climate affect the characteristics (distribution, amount, intensity, frequency, duration, type) of precipitation – with particular emphasis on extremes of droughts and floods?
4. How do models become better and how much confidence do we have in global and regional climate predictions and projections of precipitation?
5. How do changes in the land surface and hydrology influence past and future changes in water availability and security?
6. How do changes in climate affect terrestrial ecosystems, hydrological processes, water resources and water quality, especially water temperature?
7. How can new observations lead to improvements in water management?
8. How can better climate models lead to improvements in water management?

BOG-7: Biogeochemical, aerosols, atmospheric chemistry aspects *(Chairs: Venkatachalam Ramaswamy and Sybil Seitzinger; Rapporteurs: Fortunat Joos and Drew Shindell)*

Biogeochemistry, including atmospheric chemistry: Issues post-CMIP5 (selecting a few "important" subjects).

For all the points below, key questions that arise are: how many of these processes are relevant for seasonal, decadal or centennial time scales, relevant for regional or global climate change/sensitivity, occurring on natural and/or anthropogenic forcing, what are the relevant metrics, what are the sources of uncertainties:

1. Strength of the feedbacks in the interactions between climate and the carbon and nitrogen cycles. These encompass land and ocean areas, including coastal zones.
   - On the carbon side, the two main feedbacks at play are CO_2 concentration–carbon cycle and climate-carbon cycle. Both have large uncertainties and are poorly constrained by observations. Uncertainty is larger for land than for the ocean carbon cycle.
   - On the role of nitrogen: It regulates the carbon cycle (main limiting nutrient on land), hence controls the strength of the two feedbacks above. N_2O emissions are also directly dependent on nitrogen cycling (both on land and ocean). (Note: CMIP5 had only one N-enabled model).
2. Methane emissions and feedback with the climate system. Not covered in CMIP5. This would come from wetlands but potentially more important from permafrost. Methane hydrate from ocean shelves are not considered as yet in ESMs.
3. Chemistry-climate: Tropospheric and stratospheric ozone linkages with climate evolution, including interactions with atmospheric circulation. Ozone-methane connections and regional air quality and climate.

4. Aerosol-climate: aerosol radiative interactions involving the different species, especially black carbon. Emissions, transport and transformation. Influences on variables beyond surface temperature. Role of dust: how much is human-induced and how does it modify climate? Scenarios of space-time aerosol emissions beyond ~2000.
5. Aerosol-cloud-climate interactions: nature of changes in tropics, extratropics and polar regions. Influences on circulation and precipitation. Fast feedbacks and cloud changes. Aerosol-induced feedback processes versus other cloud feedback processes.

BOG-8: Decadal time-scale quantification: Attribution and prediction *(Chair: Jochem Marotzke; Rapporteurs: George Boer and Peter Stott)*

1. Is it possible to attribute individual weather and climate events, including their impacts, and if so how?
2. Is it possible to reliably quantify the contributions of internal variability as well as external forcings to observed decadal scale climate variability at regional scales?
3. To what extent can the probability of extremes be linked to inter-decadal climate variability, including large scale modes of variability such as PDO, AMO, etc.?
4. Can we develop a seamless way of presenting observations, decadal predictions and multi-decadal projections and their uncertainties? [ref. to continuing difficulties with presenting projections in terms of earlier reference periods, see Note a to Table SPM.2 on page 23 of the AR5 SPM, and also difficulties in assessing future warming in 2016–2035 relative to 1986–2005, see the discussion at 11.3.6.3.]
5. How do we verify initialized climate predictions and unitialized climate projections? [ref. to the global warming hiatus and the issue of whether or not the CMIP5 models were consistent with the observed warming hiatus.]
6. Are changes in the frequency and intensity of extremes predictable at the decadal scale?

6. Expected outcomes and follow up activities

The workshop report will be prepared under SSC supervision with input from keynote speakers and taking into account the BOG reports prepared by the BOG Chairs/Rapporteurs. It will serve as input material for WCRP planning and IPCC reflection, and as a basis for a potential scientific publication. GCOS will make use of some of the workshop output for its on-going progress report.

ANNEX D: SURVEY REPORT

Report of the survey organized in July 2014 on
" Lessons learnt from IPCC AR5 for climate change research and WCRP "

Report outline

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Acronyms used in this report

AR4/5:	Fourth/Fifth Assessment Report
CMIP:	Couple Model Intercomparison Project
ENSO:	El Niño Southern Oscillation
GCM:	General Circulation Model
IPCC:	Intergovernmental Panel of Climate Change
ISSI:	International Space Science Institute
SREX:	Special Report on Extreme Events
WCRP:	World Climate Research Program
WGI/II:	Working Group I/II

Link to the survey results

A survey was launched by World Climate Research Program (WCRP) from 27 May until 7 July to the WCRP community and Intergovernmental Panel of Climate Change (IPCC) Working Group I (WGI) and II authors. 46 responses have been collected, the major part from scientists involved in the workshop organized on 8-10 September by WCRP with IPCC co-sponsorship and hosted by International Space Science Institute (ISSI). Survey results have been interpreted by Scientific Steering Committee members (Sandrine Bony, Guy Brasseur, Anny Cazenave, Katharine Mach, Kasper Plattner, Vladimir Kattsov, James Renwick) and edited by Gilles Sommeria (WCRP consultant) & Nicolas Champollion (ISSI post doc).

A link to detailed survey results is available at:
https://www.dropbox.com/sh/nky1ycy0ww0rj3q/AAC3eI_2RmF0doTqrzAUf6b8a?dl=0

I. *Purpose of the survey*

WCRP is one of the main contributors to climate research assessed by “Working Group I - The Physical Science Basis” of IPCC and for certain aspects by “Working Group II - Impacts, Adaptation and vulnerability”. It is therefore essential for WCRP to take stock of key scientific issues identified in the course of the IPCC's Fifth Assessment Report (AR5) and to review WCRP's future research plans in this context.

The WCRP jointly with IPCC is organising a workshop entitled “IPCC AR5: Lessons Learnt for Climate Change Research and WCRP” in order to learn from the relevant authors of the IPCC AR5 and its findings to help guide future strategies for effective and exciting climate change research. The workshop takes place from 8-10 September 2014 at ISSI, Bern, Switzerland.

WCRP & ISSI conducted the survey in preparation for the above workshop. Its purpose was to review how IPCC assessment reports impact on the climate science community in general and WCRP in particular. The survey focused on research gaps, knowledge gaps, and uncertainties, on potential ways forward to make progress (in terms of observing systems, modeling, etc.), and on how all those components are covered in the current existing WCRP programme, including the WCRP Core Projects and Grand Challenges. It also included some questions related to the way IPCC assessments are reflected in WCRP activities.

II. *Structure of the survey*

The starting point for the survey was the review of outstanding scientific issues identified by IPCC AR5 in WGI report (referred to as “key uncertainties” in Technical Summary, see Annex I) and “research and data gaps” in WGII report, complemented as needed by material from IPCC Special Report on Extreme Events (SREX). Respondents were also invited to mention other outstanding research issues highlighted within the reports. In order to facilitate interpretation of responses, a classification of research and observation issues was proposed (see Annex II). Views were solicited on how these issues have evolved between AR4 and AR5, how they have been taken up in new studies since AR5 cut-off dates, and how they are dealt with in WCRP plans (through the Core Projects or the Grand Challenges). In addition suggestions on future IPCC/WCRP interface issues were welcome as well as on any other aspect of climate research which participants wished to highlight.

The survey results are available to WCRP as a resource when refining WCRP work plans and to IPCC in order to inform the on-going reflection on future IPCC assessments. Comments received as part of the survey are not attributed, but we acknowledge with thanks all respondents (see the list of respondents in Annex III). The questions of the survey are presented in Annex IV.

III. Overview of the survey

The survey was sent to around 500 persons (IPCC WGI & II authors and WCRP community). We received 46 responses, e.g. around 10%. The short delay to answer, in addition to a relatively long and detailed survey, partly explains the low rate of responses. The 46 responses mostly originate from participants to the coming IPCC/WCRP workshop (where 80 persons will participate). Some of the responses are fairly exhaustive and many contain constructive proposals.

The following figures provide overall statistics on responses. A large majority of respondents (about 75%) are IPCC authors (see Fig. 1), with a ratio of about two to one for WGI versus WGII representation. A little more than a quarter of respondents are part of WCRP coordination bodies (see Fig. 2), another quarter being in the category "user of results from WCRP process". We also noticed that half of respondents are not formally related to WCRP.

With respect to geographic distribution, United States of America (USA) and Europe represent most of the responses (see Fig. 3), with, in Europe, a good participation of people from United Kingdom (UK) and Switzerland. This matches the workshop participation but indeed does not represent a balanced geographic distribution. However, 15 countries around the world and the 6 continents (see Fig. 4) are represented although Europe and USA dominate.

The areas of expertise of the respondents cover all broad climate domains of IPCC WGI and some key areas of IPCC WGII, even if the percent of responses is low. The main themes of the respondents are atmospheric and ocean circulation & interaction, water and carbon cycle, sea level, cryosphere, paleoclimate, hydrology, climate modeling & observation as well as climate prediction, remote sensing of the Earth, land cover, climate variability in space & time and sensibility, extreme events, climate attribution & adaptation, human dimensions of climate change & public policy, economics of climate change, …

Finally, the representativeness of the survey is somewhat weakened by the low rate of responses. However, because of the large cover of expertise areas of the respondents, as well as the detailed responses, survey results may still be considered as useful for WCRP & IPCC communities.

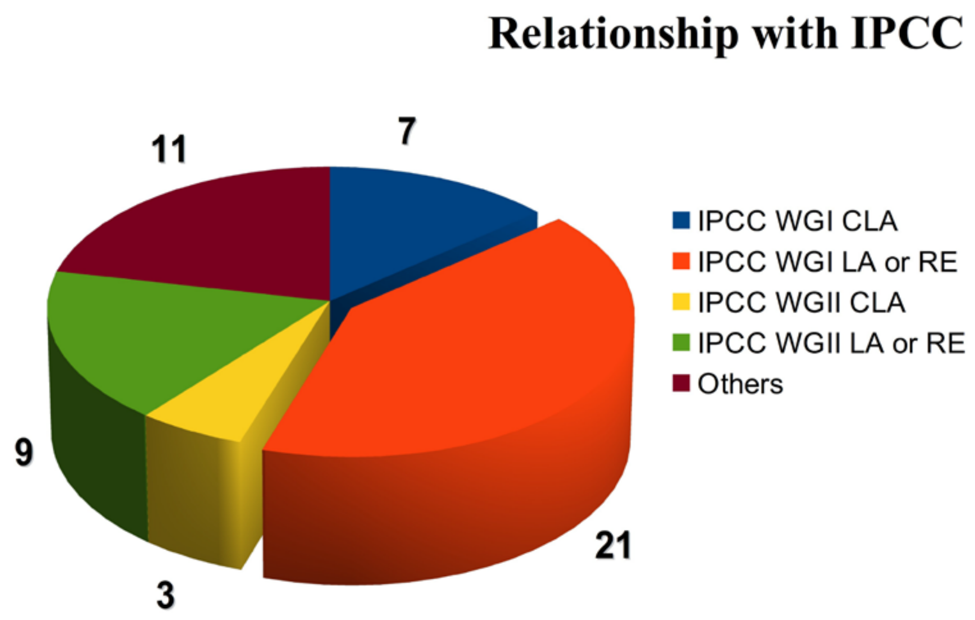


Fig. 1: Relationship with IPCC of the survey respondents. The total number of the graph respondents is higher than the number of survey respondents due to multiple relationships. (CLA: Coordinating Lead Authors – RE: Review Editors– LA: Lead Authors)

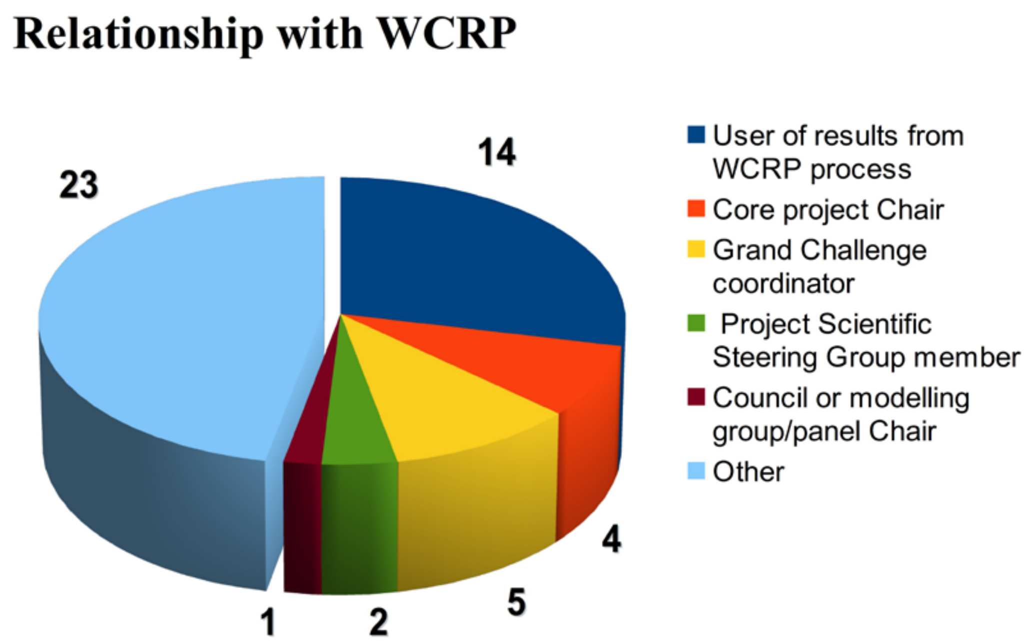


Fig. 2: Relationship with WCRP of the survey respondents, The total number of the graph respondents is higher than the number of survey respondents due to multiple relationships.

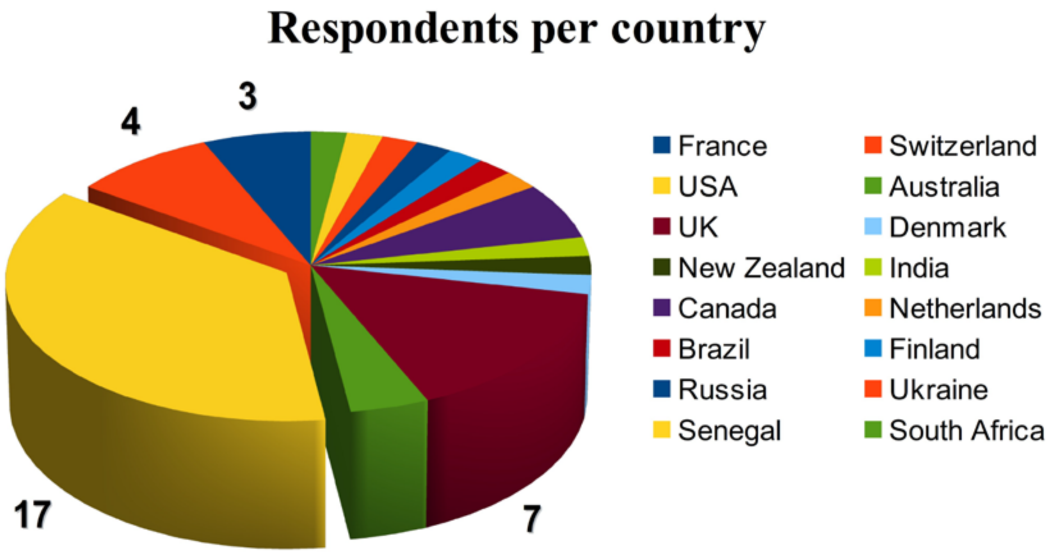


Fig. 3: Origin per country of the survey respondents (46 persons).

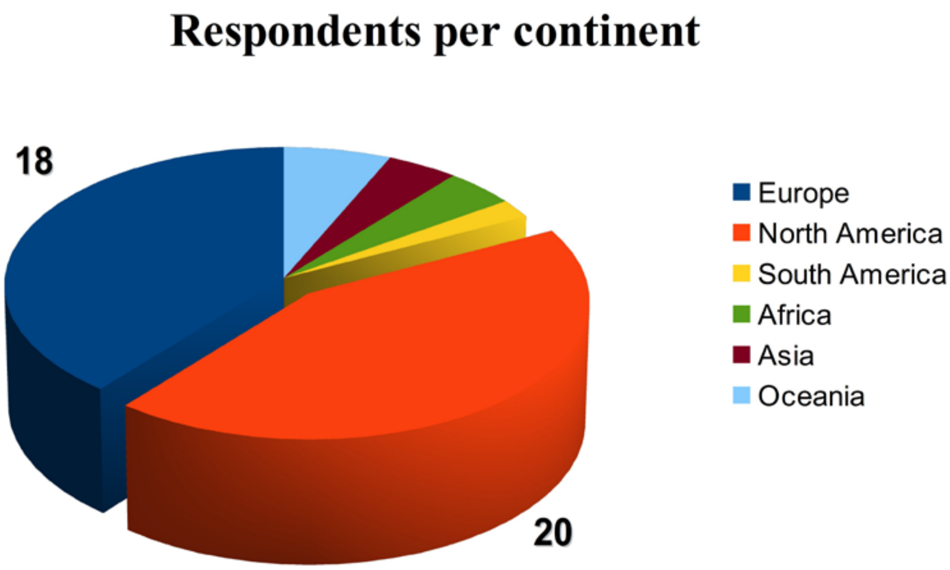


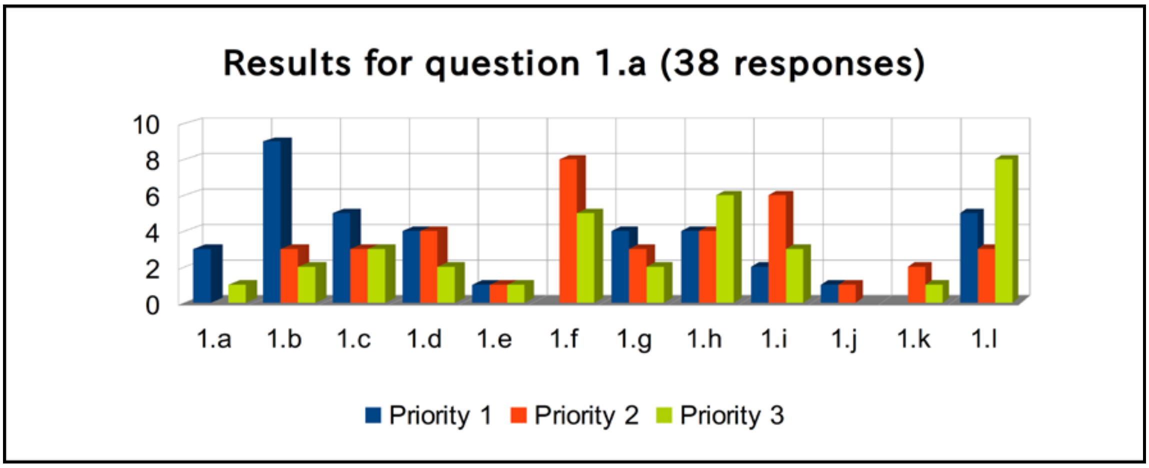
Fig. 4: Origin per continent of the survey respondents (46 persons).

IV. Detailed analysis of the survey results

Issues covered by WGI: the physical science basis

1. Key gaps in observations of changes in the climate system

1.1. Priority issues identified by IPCC: the first question is on prioritizing the key issues by listing the top 3 among the 12 "gaps" identified in IPCC AR5 by WGI. The statistics of the 38 responses is summarized in Fig. 5 below.



1.a	Troposheric & stratospheric warming	1.g	Sub-surface ocean temperature
1.b	Global precipitation change over land	1.h	Annual & global deep ocean temperature
1.c	Observation of global cloud variability	1.i	Observation of ocean deeper than 2000 m
1.d	Observation of global dryness	1.j	Observation of ocean circulation features
1.e	Long-term change in tropical cyclones	1.k	Sea ice change in Antarctica
1.f	Long-term change in large-scale atmospheric circulation	1.l	Antarctica mass loss

Fig. 5:The top 3 main issues among the 12 "gaps" identified in IPCC AR5 by WGI (see Annex I).

Fig. 5 shows that the top priority is about improving precipitation data (key variable to understand the global water cycle; high societal impacts). The next two issues are about ice sheet dynamics & ice-ocean interactions, especially Antarctica mass loss (key for future sea level rise), and observation of clouds variability & change (largest uncertainty in climate modeling). The following issues are about ocean temperature measurements, including the deep ocean, and observation of global dryness. If issues g, h and i are grouped together (all about 3-D ocean temperatures), then better observations of the ocean heat content (critical to understand energy uptake in the climate system and close the Earth's energy budget) becomes the top priority (10 responses), followed by precipitations and ice sheet dynamics.

The top 2nd choice is about the atmospheric circulation and variability of large scale atmospheric patterns. It is followed by the issue about deep ocean heat content (2nd choice for those who did not rank it first).

The top issue of the 3rd choice is ice sheet dynamics & ice-ocean interactions. It is followed by ocean temperatures and ocean heat content. The 2nd and 3rd choices are coherent with the top priority list. While responses are in general agreement with the key uncertainties identified by IPCC WGI in AR5, they highlight 4 key issues: (i) ocean heat content, (ii) precipitation, (iii) ice sheet dynamics and (iv) large-scale circulation patterns for which improved observations are critically needed.

1.2. Important issues in addition to the identified list by IPCC: on the important issues to highlight in addition to the identified list, there are two categories of responses: observations of additional climate variables & processes, and improvements in data processing.

Observations of additional climate variables & processes:

- all components of the Earth's energy budget not listed in the survey annex: radiation at the top-of-atmosphere and surface, land fluxes, sea fluxes
- extremes
- soil moisture, evapotranspiration, runoff
- aerosols-clouds interactions
- coastal processes
- land carbon budget and permafrost

Improvements in data processing:

- data rescue (especially on extremes and coastal processes)
- systematic estimate of observational uncertainties
- validation and intercomparison of gridded data sets (develop a Climate Model Intercomparison Project (CMIP) -type program for observations and gridded data sets)
- analyses in synergy of several climate variables

Others: more research is needed on adaptation planning and on closing the gap between model results and coastal management

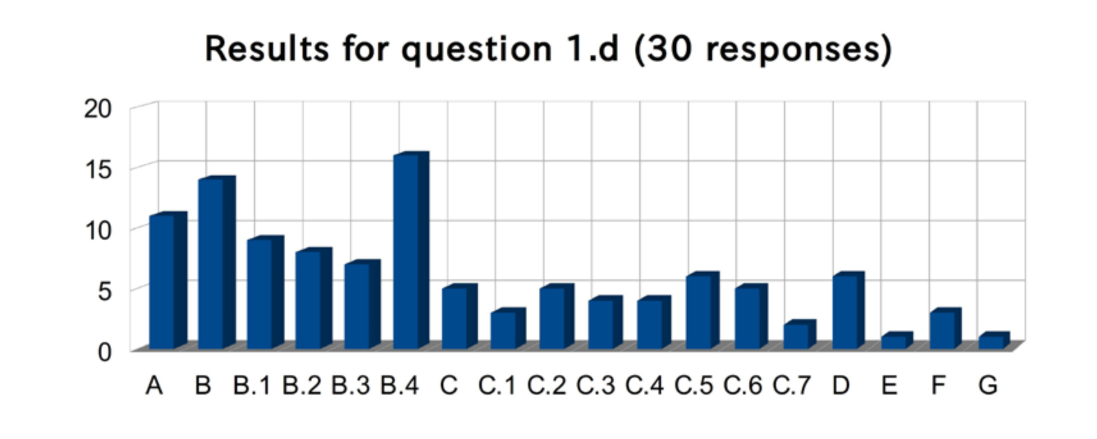
1.3. Proposals for making progress: on proposals for making progress, responses are numerous and broad range (see Fig. 6). Observation & data, followed by fundamental processes, are highlighted by comparison of modeling. Especially, making progress in temporal and spatial coverage of observations is essential for the majority of respondents.

The main recommendations about observations are:

- insure continuity of the various observing systems (space-based and in situ)
- provide traceable reference quality measurements from in situ networks and satellite missions in order to build long, well calibrated climate records
- insure regular upgrades of satellite observations and reprocessing of climate records
- develop an intercomparison project for gridded data sets
- improve atmospheric and ocean reanalysis
- develop (expand) a deep Argo program
- expand in situ networks for soil moisture and evapotranspiration
- make freely available in situ data on precipitation and runoff
- improve data access and metadata information; more generally provide users with some guidance about the most suitable data sets to be used at regional scale

A few recommendations deal with climate modeling:

- need for more research on downscaling (for adaptation planning)
- improve sub-grid processes parameterization
- develop model evaluation at the scale and variables relevant for socio-economic needs



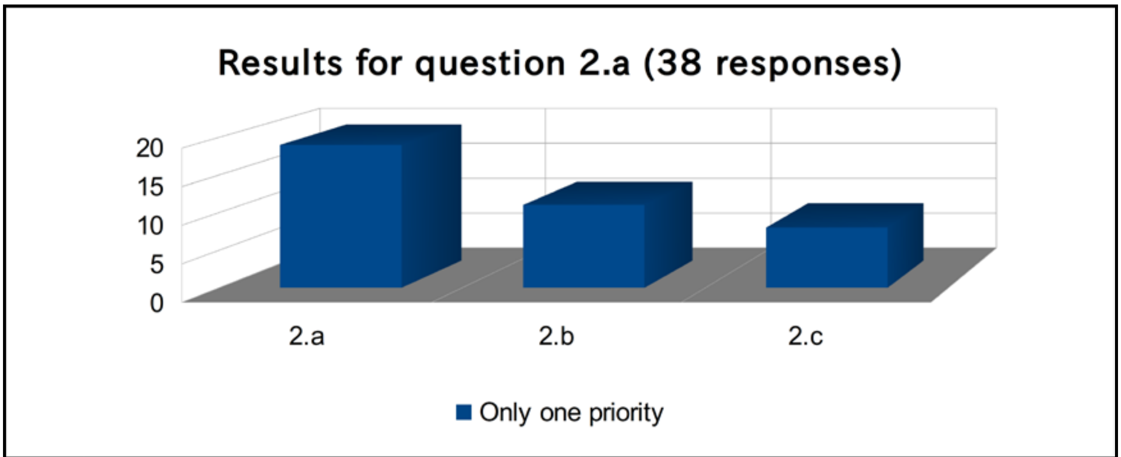
A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
B.2.	Data & metadata quality	C.6.	GCM issues
B.3.	Data access & stewardship	C.7.	Downscaling issues
B.4.	Temporal and/or spatial coverage of observations	D.	Application of climate analyses to societal needs
C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 6: Proposals for making progress in the top 3 issues selected in the 12 “gaps” identified in IPCC AR5 by WGI using Annex II. Multiple choice for the respondents was available.

1.4. Evolution since AR4: on the evolution between AR4 and AR5, responses are rather contrasted. A few indicate minimal evolution. Other refer to some specific publications to highlight some progress (e.g., on ice sheet dynamics and cloud feedback). Most responses acknowledge improvement in data monitoring over the recent years but also stress the need for better data coverage in some regions and complain about still too short and inhomogeneous climate records. A few responses mention progress in process understanding.

2. Key gaps in drivers of climate change

2.1. Priority issues identified by IPCC: only three sources of uncertainty were listed in the IPCC AR5 by WGI regarding drivers of climate change. People who responded to question 2 prioritized them, but many respondents noticed that (i) items 2a and 2b were not independent from each other, and (ii) other important uncertainties were not listed (see Fig. 7). Fig. 7 also shows that uncertainty in cloud-aerosol interactions and the associated radiative forcing is considered 47% of times the most important, following by uncertainty in cloud feedbacks, e.g. 31%, and at last uncertainty in carbon-climate feedbacks, e.g. 22%.



2.a	Radiative forcing associated to aerosol-cloud interactions	2.c	Positive feedback between climate & carbon cycle
2.b	Quantification of positive cloud feedback		

Fig. 7:The main issue among the 3 "gaps" identified in IPCC AR5 by WGI (see Annex I).

Cloud-aerosol interactions are considered as a priority uncertainty because:

- they prevent reliable estimates of the past radiative forcing, and therefore hinder the interpretation of recent climate trends, and the estimate of the observed response to greenhouse gas forcing
- uncertainties in past radiative forcing is key for many areas of climate science (e.g. D&A, estimates of climate sensitivity, interpretation of past regional responses, climate modeling)
- aerosols and clouds impact circulation through their effect on heating profiles, and then affect teleconnections

Cloud feedbacks are considered as a priority uncertainty because:

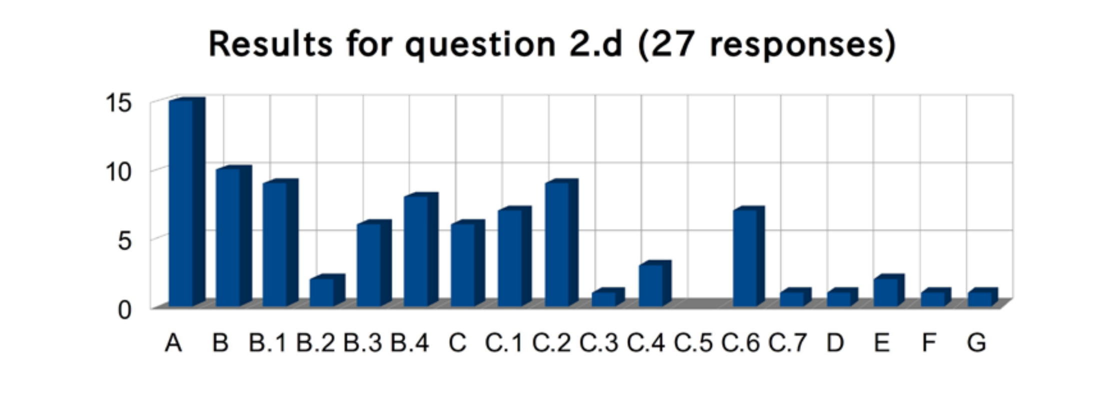
- they impact climate on all timescales (while aerosols impact climate mostly on short timescale and carbon cycle feedbacks on long timescales)
- they are key for the long-standing uncertainty in climate sensitivity
- uncertainty in cloud feedbacks impacts all areas of climate change science

Carbon-climate feedbacks are considered as a priority uncertainty because:

- they can be pervasive and abrupt
- they constitute a major challenge for understanding and simulating paleo-climatic changes
- they are critical for understanding the effectiveness of land-use changes in mitigation policies

2.2. Important issues in addition to the identified list by IPCC:

- projections of future drivers, particularly emissions of CH4 and N2O
- deforestation, land-use and terrestrial carbon feedbacks (e.g. vegetation feedbacks associated with droughts)
- volcanic aerosol forcing (small volcanoes entirely missing, big eruptions too idealized)
- solar forcing (e.g. its amplitude for last millennium and last glacial maximum)
- ocean heat uptake
- ozone interaction with climate



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
B.2.	Data & metadata quality	C.6.	GCM issues
B.3.	Data access & stewardship	C.7.	Downscaling issues
B.4.	Temporal and/or spatial coverage of observations	D.	Application of climate analyses to societal needs
C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 8: Proposals for making progress in the main issue selected in the 3 "gaps" identified in IPCC AR5 by WGI using Annex II. Multiple choice for the respondents was available.

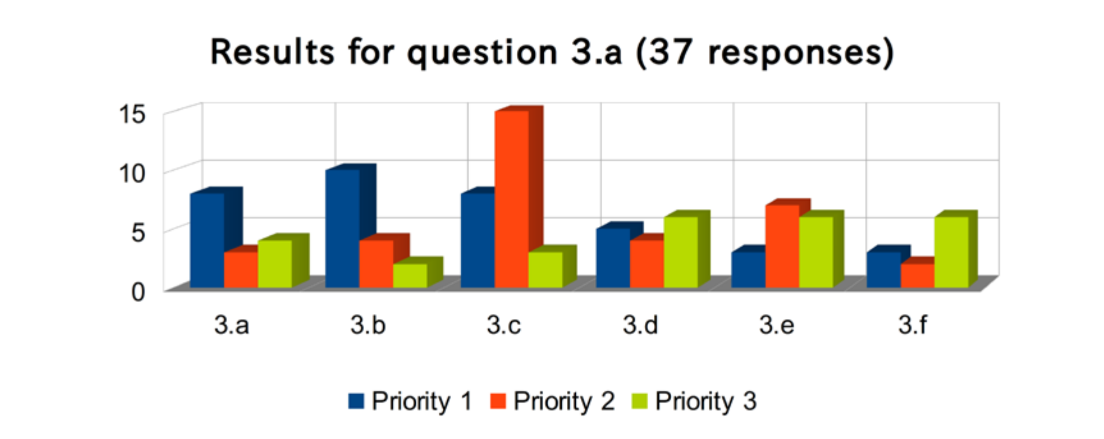
2.3. Proposals for making progress: most important proposal for making progress is about fundamental processes (see Fig. 8), following by observation & data, especially observing technology and spatial and temporal coverage of observations. Modeling is not on the top priority for making progress on drivers of climate change, however computer processing is an important issue as grid resolution, computer power, processes parameterization and Global Circulation Model (GCM) issues. Proposals for making progress include:

- the provision of annually updated historical forcing
- putting more emphasis on the validation of past drivers
- organize coordinated assessments of regional drivers
- paying more attention to the relative roles of natural variability vs forced climate changes

2.4. Evolution since AR4: progress in taking into account bio-geochemical feedbacks between AR4 and AR5 is noted. Significant progress has taken place on radiative forcing and cloud feedback, with an improved definition of radiative forcing, a better understanding of cloud feedback, and the identification of the role of convection in controlling low cloud layers. The prioritization of this topic within the WCRP Grand Challenge on clouds, circulation and climate sensitivity should help support future progress.

3. *Key gaps in understanding the climate system and its recent changes*

3.1. Priority issues identified by IPCC:



3.a	Simulation of clouds	3.d	Regional scale & uncertainties due to model resolution
3.b	Observational uncertainties for climate variables	3.e	Simulation of extreme events
3.c	Modeling the changes in the water cycle	3.f	Human influence on drought, tropical cyclone & Antarctic warming, sea ice and mass balance

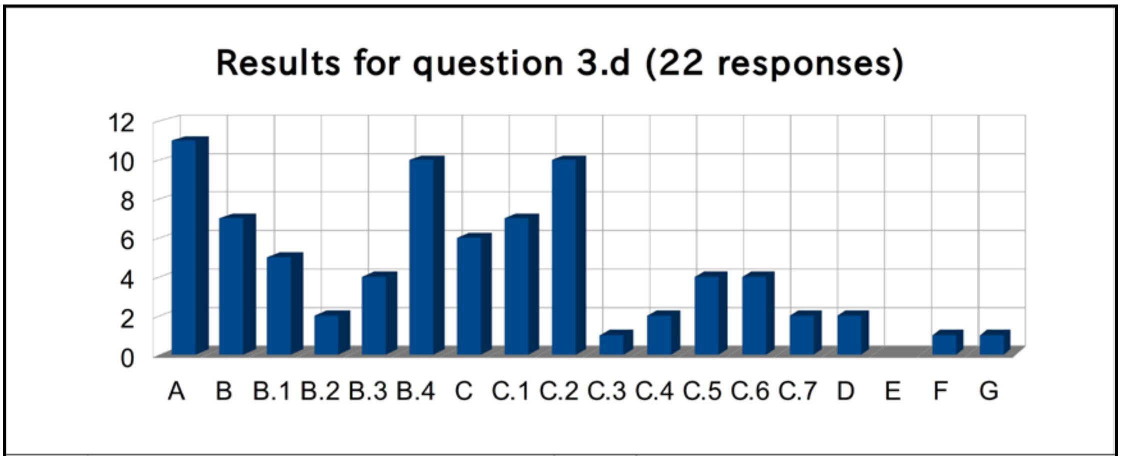
Fig. 9:The top 3 main issues among the 6 "gaps" identified in IPCC AR5 by WGI (see Annex I).

Of the key uncertainties in understanding the climate system and its recent changes – observational uncertainties (3b), clouds (3a), and water cycle (3c) are leading as the 1st priority. Changes in the water cycle (3c) is the absolute leader as a second priority, which makes it also the total champion in the "all-three-priorities list". In the latter list, the other two "prize-winners" are extremes (3e) and observations (3b), but with significantly lower scores.

3.2. Important issues in addition to the identified list by IPCC and further suggestions for making progress: according to respondents, additional issues missed in the suggested list of uncertainties include: monsoons, El Niño Southern Oscillation (ENSO), circulation and precipitation together, circulation alone, vegetation productivity and ocean carbon cycle, Earth energy imbalance, small-scale disasters, wind speed, long scale variability in the ocean in mid to deep levels, Arctic and mountains. But there is no agreement at all between respondents on the missed issues.

Identify solutions for making progress in understanding the climate system and its recent changes are in first priority to better understand fundamental processes and with significantly lower scores to improve observation & data and modeling (see Fig. 10). However, two more specific points are highlighted: temporal and spatial coverage of observations (B.4) and processes parameterization (C.2). Noteworthy comments from respondents are as follows:

"This list is mixing issues related to process understanding and climate change attribution. For example the points listed under 3.f are important in a wider context than just climate change attribution. Similarly as for point 3.a, the uncertainties are related to fundamental issues with process understanding, in addition to issues with data availability (quality of observations, number of considered events, etc.)."



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
B.2.	Data & metadata quality	C.6.	GCM issues
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B.4.	Temporal and/or spatial coverage of observations	D.	Application of climate analyses to societal needs
C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 10: Proposals for making progress in the top 3 issues selected in the 6 "gaps" identified in IPCC AR5 by WGI using Annex II. Multiple choice for the respondents was available.

"These issues (and issues raised on previous pages of this survey) are all identified in the WCRP Grand Challenges (Sea Level, Cryosphere, Clouds and Climate Sensitivity, etc.), and well identified also by the different core projects of WCRP."

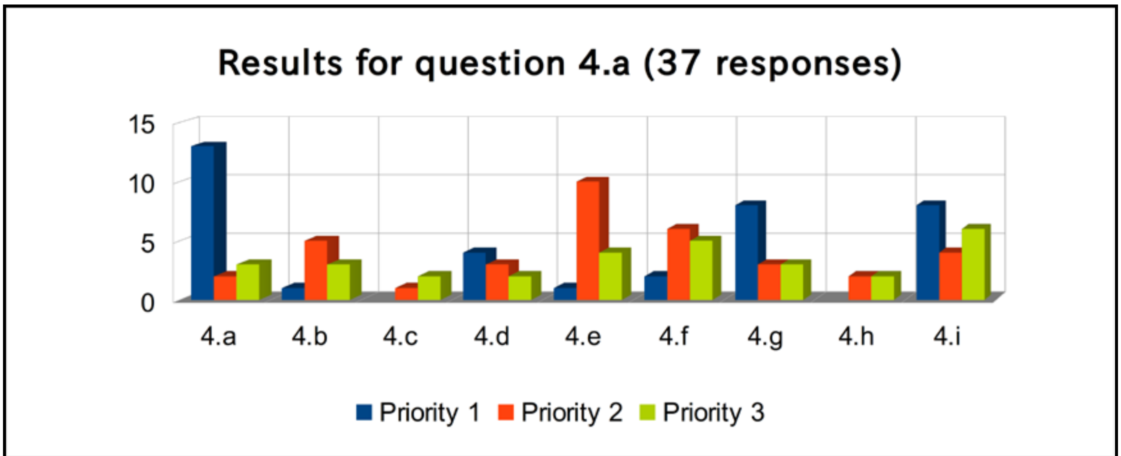
"This section reflects the end-to-end problem of observing, modeling and understanding the climate system. All aspects are important and there seems no clear path to making progress in a systematic way. Pouring additional long-term resources into 3 major climate centers (North America, Europe, Asia), say, could provide focus but seems unlikely to happen. Otherwise, it is business as usual with funding agencies, international agencies, and researchers focusing on parts of the problem on a short term basis."

4. Projections of global and regional climate change

4.1. Priority issues identified by IPCC:

Issue 4.a, limited skill for short-term projections and for precipitation projections, is clearly the biggest issue for most respondents. Comments suggest that advances on decadal scales will lead to improvements in longer-term projections, and public uptake of climate change information would increase if credible short-term predictions can be provided.

Issue 4.e, low confidence about abrupt changes, doesn't rate as the most important isnce, when the frequency of selection is summed across all three choices, issues 4.i and 4.a are the two most commonly selected. Issue 4.g, ice-sheet contributions to sea level rise, also came in as relatively important overall. The least important issues overall were deemed to be 4.c, tropical cyclones, and 4.h, semi-empirical models of sea level rise.



4.a	Yearly to decadal averages of temperature prediction	4.f	Carbon losses from thawing permafrost
4.b	Changes in Northern storm position and strength	4.g	Ice sheet dynamics contribution to sea level rise
4.c	Basin-scale tropical cyclone frequency and intensity	4.h	Semi-empirical model for sea level rise projections
4.d	Changes in soil moisture and surface run off	4.i	Regional climate changes
4.e	Abrupt or nonlinear changes		

Fig. 11: The top 3 main issues among the 9 "gaps" identified in IPCC AR5 by WGI (see Annex I).

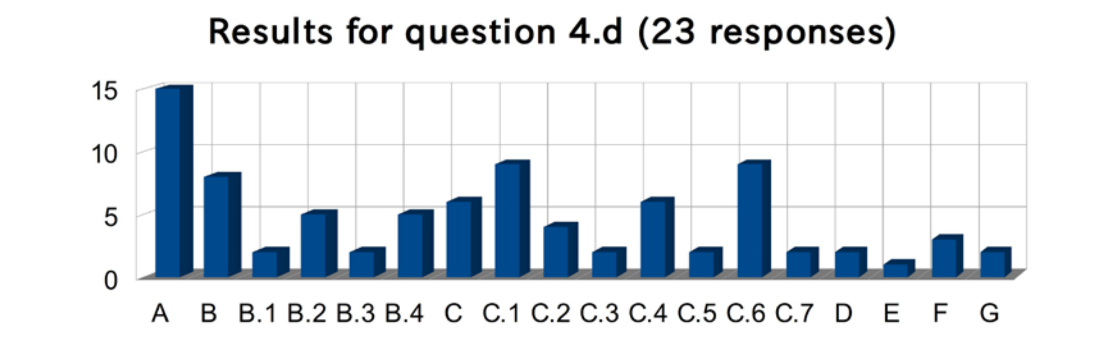
Issue 4.e, low confidence about abrupt changes, doesn't rate as the most important isnce, when the frequency of selection is summed across all three choices, issues 4.i and 4.a are the two most commonly selected. Issue 4.g, ice-sheet contributions to sea level rise, also came in as relatively important overall. The least important issues overall were deemed to be 4.c, tropical cyclones, and 4.h, semi-empirical models of sea level rise.

4.2. Important issues in addition to the identified list by IPCC: issues considered to be missing were quite an eclectic mix, including changes to ENSO, teleconnections, regional precipitation projections and uncertainties, regional extremes, parameterisations, ocean model initialisation. Most of these come back to better regional and better decadal-scale climate change projections/predictions.

4.3. Proposals for making progress: suggested ways forward include improved observing systems and process studies, smarter use of GCM output (taking account of model error), and improved GCMs-higher resolution, better ice sheet modelling, improved air-sea coupling etc (see Fig. 12). The first proposal for making progress in global and regional climate change still stays to impove observation and data with specific improvement needed in modeling as ust expained above.

4.4. Evolution since AR4: several respondents felt there had been little progress between AR4 and AR5. It was noted that we now have a clearer picture of changes in tropical cyclones, and larger ensembles of model output. Regional uncertainty is more explicitly recognised in at least some papers now.

4.5. Specific proposals for CMIP: regarding CMIP, several respondents expressed concern that the CMIP5 archive has not been fully exploited and that we need more data-model intercomparison work, rather than just more model runs. "*Less model runs but more thought and coordination*". Better representation of ice sheets (and other cryosphere components), to improve sea level projections, and "better" handling of extremes were also identified.



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
B.2.	Data & metadata quality	C.6.	GCM issues
B.3.	Data access & stewardship	C.7.	Downscaling issues
B.4.	Temporal and/or spatial coverage of observations	D.	Application of climate analyses to societal needs
C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

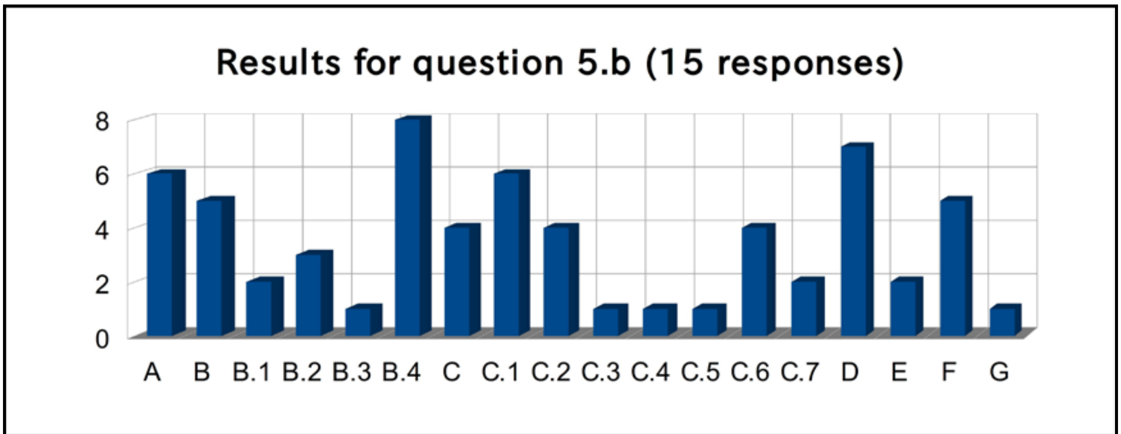
Fig. 12: Proposals for making progress in the top 3 issues selected in the 9 "gaps" identified in IPCC AR5 by WGI using Annex II. Multiple choice for the respondents was available.

Issues covered by WG II: impacts, adaptation and

5. Impacts

Across responses, the following impact categories were identified as especially relevant to future WCRP work: extreme events, sea level rise and ice sheets, water availability and resources, consequences of high-magnitude warming, and food security. While attribution of impacts to climate change creates important understanding of the sensitivity of human and natural systems, challenges in attributing impacts to anthropogenic climate change were noted, especially for human systems.

Using only Annex II to identify key issues, the temporal and spatial coverage of observations is the first issue identified as a gap in impact, following by application of climate analyses to societal needs, grid resolution & computing power and fundamental processes (see Fig. 13).



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
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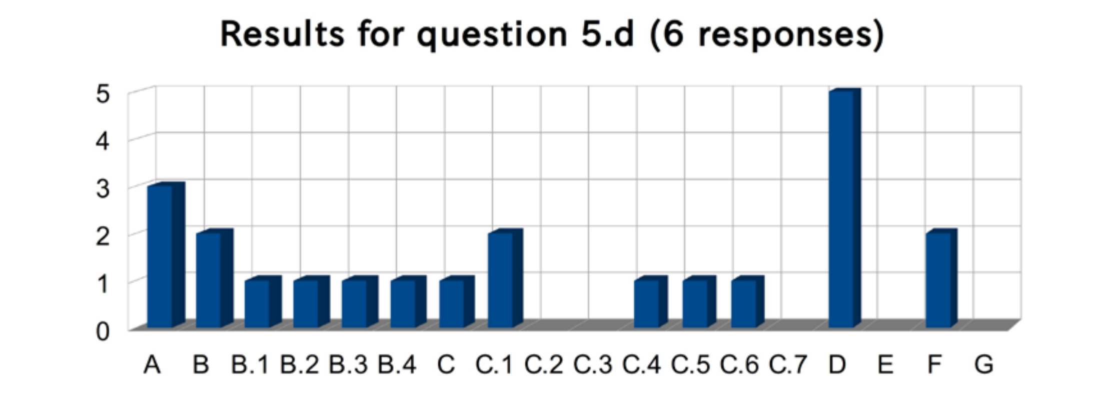
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 13: Key issues in impacts of climate change, selected using Annex II. Multiple choice for the respondents was available.

Key issues (from above graph and all comments) underpinning current data gaps were identified as follows: (i) limitations in available high-quality observational data (historical and present, ground-based and remote) with which to evaluate the sensitivity of human and natural systems to climate variability and calibrate and test impact models; (ii) needs for improved guidance on how to best select observations, modeling outputs, and downscaling methods in analyzing impacts; (iii) challenges in incorporating societal, economic, technological, and environmental factors that strongly affect sensitivity (as well as vulnerability and exposure) of human and natural systems to climate change; (iv) the importance of prioritizing impact model development, which has lagged behind climate model development but is central to understanding the risks of climate change; (v) the need to expand impact modeling intercomparisons and improve them, to understand responses of human and natural systems across more impact sectors (from agriculture, water, and vegetation, to human health, biodiversity, infrastructure, and coasts).



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
B.2.	Data & metadata quality	C.6.	GCM issues
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B.4.	Temporal and/or spatial coverage of observations	D.	Application of climate analyses to societal needs
C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 14: Proposals for making progress in impacts of climate change, selected using Annex II. Multiple choice for the respondents was available.

Finally, proposals for making progress in gaps of impact understanding of climate change is essentially in application of climate analyses to societal needs (see Fig. 14).

6. Adaptation

Responses emphasized that adaptation is about people making decisions under uncertainty in a changing world. The tight link between impacts and adaptation was underscored, with lessons on how to effectively grapple with available information and persistent complexities starting to emerge. Responses highlighted the importance of contemplating opportunities to rethink and “co- produce” work on impacts and adaptation, with user input into problem definition, the range of options explored, and the presentation of results.

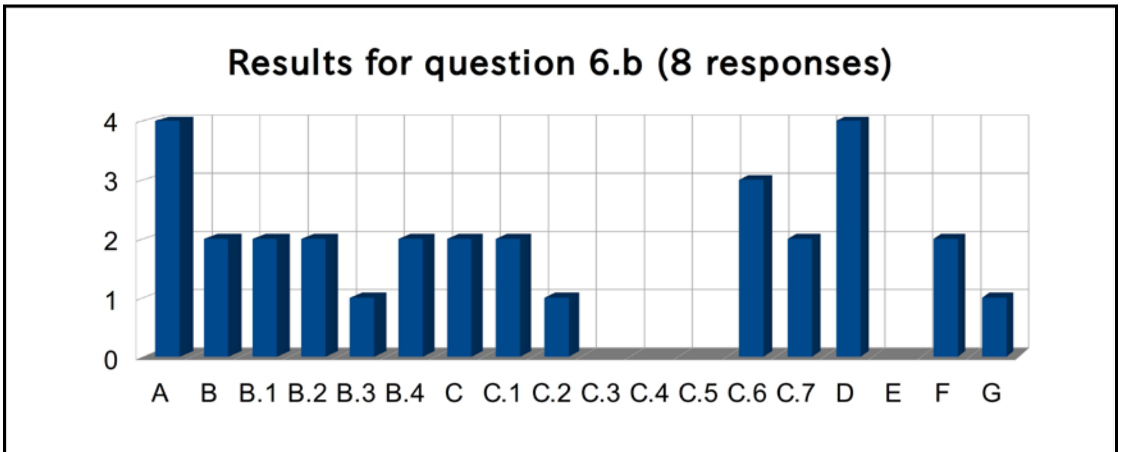
Diverse responses speaking to these themes include the following:

"*More data does not mean better adaptation. What is needed are opportunities for learning under uncertainty, to assess options… and implications of certain decisions for human and natural systems. This implies a shift from quantification and prediction to ethical decision-making.*"

"*Progress on adaptation has been slow, despite advances in climate science. This suggests the need for a more concerted effort at knowledge exchange and knowledge brokering with regional/local practitioners (engineers, foresters, water managers, urban planners, etc.). This would occur within a planning process oriented towards risk management that enables learning in an iterative manner. Climate services could be part of this effort…*"

3 priorities are highlighted: *"i) how to enhance adaptive capacities, including ways to embrace change and uncertainties; ii) understanding limits to adaptation (e.g. by considering risks at different levels of warming); iii) supporting adaptation as a process"*.

The following graphs, e.g. Fig. 15 & 16, were used in the paragraph above to analyze the comments on key issues, gaps and how to make progress in adaptation to climate change. Especially, they highlight two main issues in order to make up for the gaps in adaptation: (i) fundamental processes and (ii) application of climate analyses to societal needs. However, respondents mainly emphasize progress needed in fundamental processes.



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
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C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 15: Key issues in adaptation of climate change, selected using Annex II. Multiple choice for the respondents was available.

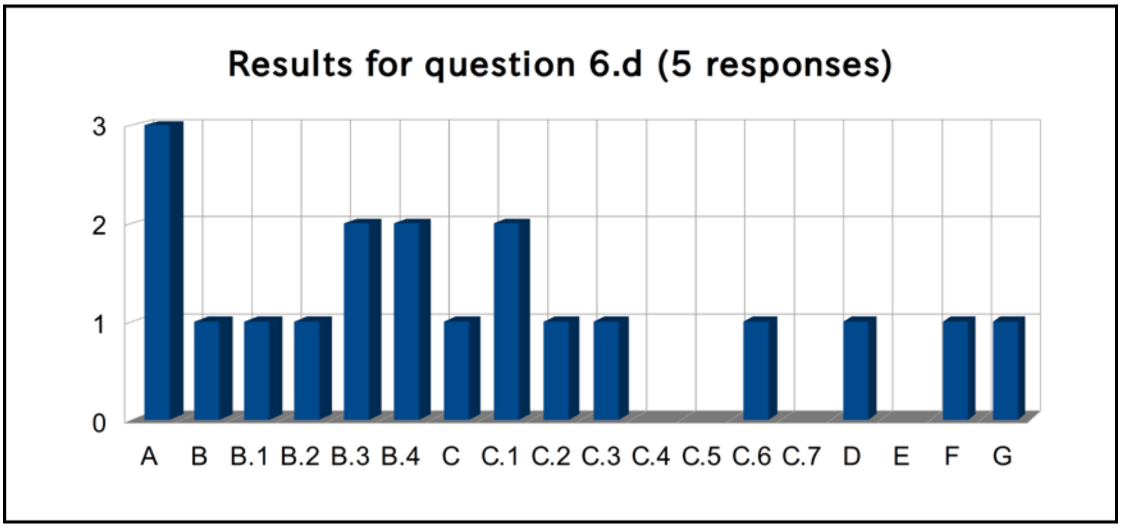


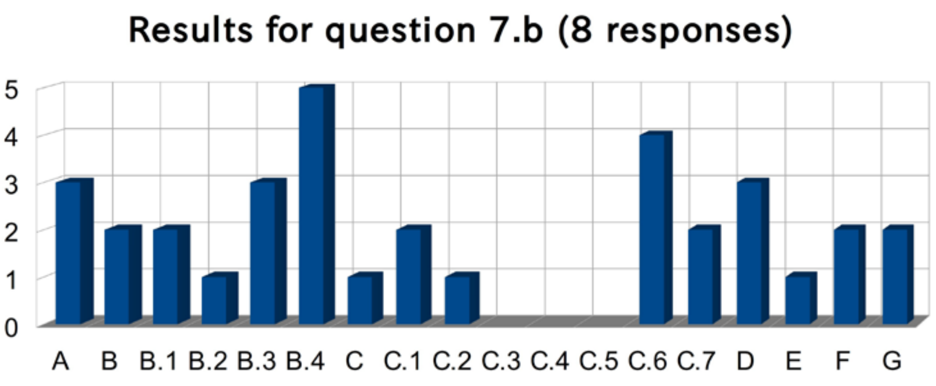
Fig. 16: Proposals for making progress in adaptation of climate change, selected using Annex II. Multiple choice for the respondents was available.

7. Regional aspects

The following research issues and data gaps emerged across responses:

- given that different processes can be active at regional scales, understanding of regional climate change needs to consider regional drivers and feedbacks, especially for extremes
- major data gaps still exist in Africa, South America, and Asia in particular. These gaps limit current understanding of impacts at regional scales. The data gaps can be accompanied, in addition, by fewer available scientists to investigate climate processes in given regions
- at the same time, research on impacts for people and human systems even in high-income countries has lagged, especially in terms of the distribution of impacts
- uncertainties persist for complex topographies such as in the Himalayas, foothills, and major river basins

As often responded, the temporal and spatial coverage of observations & data is the key issue regarding the uncertainties and gaps in our understanding of regional aspects of climate change (see Fig. 17). Regarding this result, respondent proposals for making progress in regional aspects relate to fundamental processes, GCM issues and application of climate analyses to societal needs (see Fig.18).



A.	Fundamental processes	C.3.	Data assimilation
B.	Observations & data	C.4.	Validation
B.1.	Observing technology	C.5.	Reanalysis capabilities
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C.	Modeling	E.	Present and future emission scenarios
C.1.	Grid size/resolution; Computing power	F.	Linkage of climate applications to socio-economic data
C.2.	Processes parametrization	G.	Other

Fig. 17: Key issues in regional aspects of climate change, selected using Annex II. Multiple choice for the respondents was available.

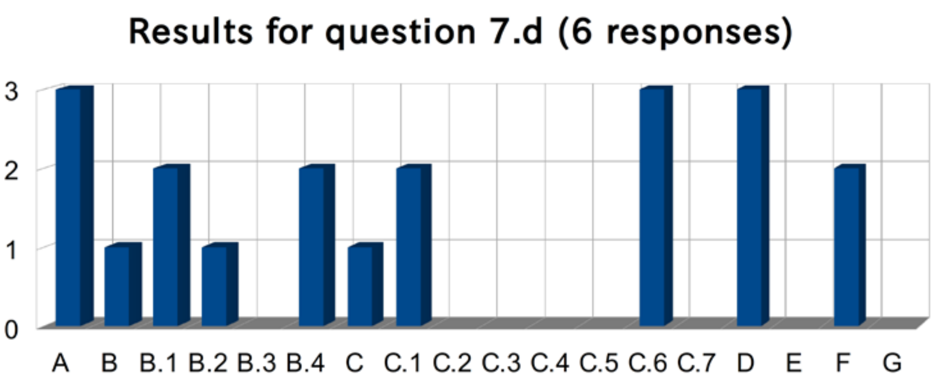

Fig. 18: Proposals for making progress in regional aspects of climate change, selected using Annex II. Multiple choice for the respondents was available.

8. Material from SREX report

There were only 14 respondents for parts (a) and (b) of question 8, and only 5 for parts (c), (d), and (e). The most commonly selected issues were: uncertainties around tropical cyclones, storm tracks and extreme precipitation (including drought). Other issues mentioned were: sea level extremes, improved modelling of extremes, Arctic and high-elevation extremes, making information more user-relevant (WGII focus), using better risk assessment frameworks, and better methods of comparing point and gridded information. There was little justification given, apart from recognising the inadequacy of existing observing networks, and the high social relevance of advancing our understanding of and ability to predict changes in extreme events.

In terms of the list of research and observation needs, the most commonly selected were:

- level of understanding of fundamental processes (e.g., aerosol-cloud interaction)
- temporal and/or spatial coverage of observations (e.g., length of time series, global/regional networks, satellites)
- grid size/resolution; computing power
- GCM issues

Regarding proposals for making progress (5 responses), similar responses were forthcoming – a need for better observing networks, especially for extremes, and better process understanding and modelling. This was reflected in the "needs" selected from Annex II (mostly observations & data). Comments on advances from AR4 to AR5 were a mixed bag, with no clear message.

Priorities for research within WCRP,
implications for core projects and Grand

9. *Top priorities to be considered by WCRP in order to fill the most critical gaps in possible future IPCC assessments reports*

9.1. Core Projects:

- better understanding of decadal to multi-decadal variability; predictions from seasons to multi-decades
- field observations of ocean heat content, ice shelf-ocean interactions and air-sea exchanges
- critical cryospheric processes, Greenland, Antarctica, ice sheet mass
- surface tropospheric interactions with sea ice, ocean, land (including water), stratosphere
- climate variation and food security
- storm tracks, extreme events and their attribution
- better estimate of climate sensitivity
- rephrase activities in terms of society relevant questions
- bio-geochemical cycles (release of CO2,, CH4 from permafrost)
- synergy view of the hydrological cycles including aerosols and chemistry aspects

9.2. Grand Challenges:

- estimates of heat content, improved ocean-ice interactions, coupled climate-ice sheet GCMs
- simulation of the last millennium including the role of internal variability
- new grand challenge in biogeochemistry
- emphasis on extreme events and on risks associated with climate change
- more focus on sea level rise and contribution of ice sheets
- more on regional downscaling projections including clouds and extreme events
- better marry physical and process understanding with statistical and model based attribution
- more focus on aerosol effects on climate (clouds and precipitation)

9.3. Modeling Activities:

- ice sheet-climate interactions
- land-climate interactions
- extreme events
- develop an “European ReAnalysis (ERA)” international supercomputing infrastructure
- develop Earth system grid
- provide results at higher frequency
- assess what is really gained through regional modeling
- CMIP should recognize the service aspect of some coordinated experiments

9.4. Observation Coordination Activities & other suggestions:

- improve estimate of ocean heat and salinity changes
- need central storage of WCRP datasets
- better integration between observational and modeling communities
- Obs4MIP should support metadata and include observational uncertainties
- need fine resolution information to improve understanding and simulation of intense precipitation

10. Topics to be addressed by WCRP in addition to Grand Challenges

Here are some topics that are being proposed:

- ocean heat content and decadal variability
- patterns of climate change
- biogeochemistry/ecosystems: carbon and nitrogen cycles; interactions between carbon and water cycles
- improvement in climate modeling
- development of climate services: climate communication, climate research, shaping climate services, societal impacts of climate change, climate change and poverty, partnership with the Copernicus Program in Europe; partnership with the Global Framework for Climate Services (GFCS)

11. Improvement of current institutional and technical infrastructure

Here are some improvements that are being proposed:

- more sustained funding. Infrastructure should be recognized as an operational requirement
- maintain a fair number of models, but only the best ones; develop a number of well funded multi-national climate prediction centers
- develop seamlessness between climate modeling and dissemination of information, particularly on extremes; make stand against pseudo-science
- add a grand challenge on biogeochemistry
- become more interdisciplinary: climate scientists should work with other scientists, include more social scientists, link with International Geosphere-Biosphere Programme (IGBP), more cooperation between climate-related organizations
- develop training activities
- IPCC activities need to be improved (avoid duplications between chapters). IPCC effort should not relay on voluntary efforts; scientists are burned out
- support sustained, long-term observation networks. Improve links between observation and modeling

Suggestions for future IPCC assessments

12. *Specific aspects of the IPCC AR5 assessment results to be better taken account in WCRP activities*

19 responses have been received, 16 with substantive input. One theme highlighted by several of the respondents was the need for WCRP to consider the gaps identified and the uncertainty assessment in the IPCC AR5 in its activities. One respondent mentioned in this context the need to focus more on understanding projections, another one the poor definition of high-end scenario for sea level rise. Other topics mentioned for WCRP to focus more on include:

- extremes (e.g., tropical storms), extreme impacts, vulnerability globally
- paleo-climate
- land biosphere representation in climate models (e.g., nutrient controls)
- climate risks related to abrupt or nonlinear changes
- improve understanding of WGII-type frameworks used in IPCC (e.g. risk, transformation) in the climate science community

A few more fundamental process related comments were received, including:

- reporting on (observed) changes should be more routine work and operational, no longer be done by the IPCC; Modeling activities should then be covered independently
- may need to find alternatives to constantly improving models in order to keep advancing understanding
- links between WCRP activities and IPCC should be made clearer and more transparent
- more involvement in WCRP of scientists from countries with economies in transition; more use of references in languages other than English

13. *Specific aspects of the IPCC AR5 assessment process to be better taken account in WCRP activities*

15 responses have been received, 12 with substantive input. Several respondents mentioned (i) the ever-increasing burden from IPCC assessments on the science community and the need to carefully review the timing of WCRP activities with the IPCC time-line in mind, and (ii) the need for WCRP to focus on gaps and uncertainties identified and quantified in IPCC assessments.

One respondent summarized the contribution with "*maybe we need to completely decouple the Model Inter-comparison Project (MIP) and IPCC time-lines, and avoid a new MIP coming in shortly before an IPCC report is released.*" Another respondent proposed an alternative process where WCRP would prepare "a *sequence of scientific reports*". Instead, that would provide input to a possible, "*much reduced*" IPCC report. Finally, one respondent proposed to restructure the IPCC WGs to have only two WGs: (i) Physical science basis plus impacts and vulnerability to climate changes; (ii) Adaptation and mitigation of climate change.

Other topics mentioned for WCRP to focus more on include:

- more regional scale assessments needed in order to most efficiently inform decision making on decision-relevant scales
- more focus on adaptive capacity due to changes in extremes; more on hydrological extremes; hurricanes projections; variability vs forced changes

- need to better involve the WCRP members in the expert review of WGI drafts
- improve regional balance of members/contributors/authors in WCRP/IPCC

14. Specific suggestions for new climate change research activities (within or outside WCRP) that would serve future IPCC assessments

17 responses have been received, 16 with substantive input. A wide range of specific suggestions have been received. A number of respondents highlighted the need to focus more on climate change impacts and to better integrate approaches across disciplines.

A listing of research topics suggested by respondents is provided below:

- hiatus
- land climate engineering as an adaptation option
- modeling of heavy precipitation events and links to flooding and related impacts
- social, institutional, and technological innovation processes, and their role in adaptation
- regional focus: regional modeling, downscaling, regional monitoring in developing coun- tries to improve science basis for future WGII assessments
- value transformation in solving the climate change challenge
- understanding impacts and risk in the context of intersecting inequalities
- increased focus on impacts of climate change on key resource sectors. Reduction in uncer- tainties in modeling impacts, costs and possible adaptation responses. Closer linking/collab- oration across communities (climate, impacts, costs, etc.)
- end-to-end attribution of impacts

In terms of process and institutions, suggestions include:

- 2-3 year WCRP assessments on certain WCRP relevant topics in between successive IPCC assessment reports
- proposal for a new CLImate VARiability and predictability (CLIVAR) “Climate Dynamics Panel”
- WCRP to foster interactions with other disciplines through Future Earth project
- closer connection of research to applications

And finally, one submission calls for an end of the comprehensive IPCC assessments (in particular for WGI) and a focus on cross WG Special Reports, plus perhaps more frequent updates on the state of climate, possibly done by WCRP for WGI physical science basis topics.

V. *Summary & concluding remarks*

Survey results cover 46 responses, coming mostly from workshop participants and with a majority of USA and European respondents. Contributors made a remarkable effort for interesting comments and proposals. The responses, analyzed and summarized in this report, may contribute to WCRP & IPCC planning and serve the climate community. The survey is divided into 4 parts: issues covered by IPCC WGI, the physical science basis; issues covered by IPCC WGII, impacts, adaptation and vulnerability; priorities for research within WCRP, implications for Core Projects & Grand Challenges; suggestions for future IPCC assessments.

Questions covering WGI issues concern gaps in observations and understanding of climate change, "drivers" of climate change and model projections of global and regional climate change. The main gaps & uncertainties in observations concern precipitation data, changes in large-scale circulation, ice-sheet evolutions and deep ocean. According to the survey, drivers of climate change that deserve most attention are aerosol-cloud interactions followed by cloud feedbacks. The main gap in understanding processes is considered to be the modeling of changes in the water cycle. At last, main priorities highlighted for projections of climate change are related to yearly to decadal temperature predictions, abrupt non-linear changes and regional prediction. On the evolution since AR4, responses are rather contrasted but the main areas of progress concern ice-sheet dynamics and cloud feedback. Survey respondents mainly consider that improvements should be achieved on fundamental processes and observations & data. Indeed, observing technology, temporal and spatial coverage of observations are the most often mentioned. Most of respondents suggest to continue and maintain existing observation networks as well as improving data quality. Concerning climate modeling, grid size/resolution, computing power and processes parametrization are the main issues where improvements are recommended, with specific needs for better representation of ice-sheets and better handling of extremes. Further exploitation of CMIP5 data is also recommended.

Questions covering WGII issues concern gaps in impacts, adaptation and vulnerability of climate changes. Main issues identified by respondents with respect to impacts are extreme events, sea level rise, ice-sheets, water availability and resources, food security ... Respondents highlighted the importance of contemplating opportunities to rethink and "co-produce" work on impacts and adaptation. The development of risk management strategies associating the scientific community and regional/local practitioners is one important orientation for progress. Regional aspects are very important, especially for extreme events, and some respondents noticed major data gaps in observations in Africa, South America and Asia, as well as for complex topographies and major river basins. Finally, all respondents agreed on recommendations for making progress which are temporal and spatial coverage of observations (similar to questions covering WGI issues) and grid size/resolution associated with computing power, in addition to application of climate analyses to societal needs. Responses concerning SREX issues cross over responses for WGI & WGII, highlighting gaps in extreme events, sea level and ice sheets.

Questions covering WCRP research concern priorities for WCRP to fill the most critical gaps for next IPCC reports, possible additions to Grand Challenges and improvement of institution and infrastructure. A number of topics are highlighted within the present WCRP structure but the range of priorities is fairly large. Recommendations for Core Projects include decadal variability, observations of ocean heat content, critical cryospheric processes and surface-atmosphere interactions. The priorities expressed through the Grand Challenges are overall endorsed, with special attention recommended to ocean-ice interactions (in observations and models), risk associated to extreme events, contribution of ice-sheets to sea level rise, uncertainties in water cycle processes, regional downscaling and aerosol effects on clouds and climate. A number of recommendations are related to modeling activities including better parameterizations, advanced supercomputing and data management, higher frequency outputs, better assessment of regional modeling. The benefits of coordinated observation activities are also highlighted, with the need to improve estimate of ocean parameters, fine resolution information and central availability of datasets. The need to create a new Grand Challenge in biogeochemistry is expressed by a number of respondents. Concerning coordination activities & technical aspects, the development of appropriate infrastructures for supporting research and climate services seems essential with a number of suggestions: development of long-term observational networks, better integration between observation & modeling communities, partnership with Copernicus Program (Europe) & the Global Framework for Climate Services (GFCS), development of interdisciplinarity, especially with the IGBP community and social scientists.

Questions covering future IPCC assessments concern IPCC assessment results and processes that could be taken account in WCRP activities and suggestions for new climate change research activities that would serve future assessments. Respondents expressed the importance for WCRP to focus on gaps & uncertainties identified and quantified in IPCC assessments, which is precisely the main motivation for the Bern workshop. The need to better take into account WGII approach in the climate science community is mentioned as one important issue. The ever increasing burden from IPCC assessments on the science community is mentioned as a serious concern. Specific suggestions include decoupling observed climate change assessments (to be done separately on a more frequent basis) from model assessments, more involvement of scientists from countries with economies in transition and more use of references in languages other than English, making clearer and more transparent the links between WCRP & IPCC activities. It is also recommended to carefully review the timing of WCRP activities in relation with the IPCC time-line. Other proposals include the preparation of a sequence of climate change specific reports by WCRP as input to a reduced IPCC report, and restructuring IPCC in two WGs. On the question of new research activities that would serve IPCC assessments, a number of respondents highlighted more research on impact issues, better interaction with other disciplines through Future Earth, and closer connection with applications.

Overall, the dialogue initiated with the scientific community through this survey was useful even if many of the suggestions are not necessarily innovative. The reflection on how to deal with research gaps assessed by IPCC enables to highlight specific issues and may provide additional support to some already agreed research orientations. Interaction with the impact and adaptation community and the development of services are two areas where new activities could be developed. The IPCC motivation can probably help support requests from the scientific community for improved observation, data and research infrastructures. This survey also shows that the scientific community represented by WCRP is ready to confirm its commitments to climate change assessments and actively participate in the reflection on future IPCC activities. It is unfortunate that, for a variety of reasons, the participation of respondents from developing countries or countries with economies in transition is very small, and this should be improved in any future survey.

The Science Steering Committee and the survey organizers would like to acknowledge the work of respondents and greatly thank them for their participation.

Annex I

KEY UNCERTAINTIES IDENTIFIED IN IPCC AR5, WGI REPORT

The following paragraph and list is extracted from the Technical Summary of WGI I report (TS.6 Key uncertainties). More details on specific research needs can be found in the respective chapters of the reports.

This final section of the Technical Summary provides the reader with a short overview of key uncertainties in the understanding of the climate system and the ability to project changes in response to anthropogenic influences. The overview is not comprehensive and does not describe in detail the basis of for these findings. These are found in the main body of this Technical Summary and in the underlying chapters to which each bullet points in the curly brackets.

1. Key Uncertainties in Observation of Changes in the Climate System

a/ There is only medium to low confidence in the rate of change of tropospheric warming and its vertical structure. Estimates of tropospheric warming rates encompass surface temperature warming rate estimates. There is low confidence in the rate and vertical structure of the stratospheric cooling. {2.4.4}

b/ Confidence in global precipitation change over land is low prior to 1950 and medium afterwards because of data incompleteness. {2.5.1}

c/ Substantial ambiguity and therefore low confidence remains in the observations of global- scale cloud variability and trends. {2.5.7}

d/ There is low confidence in an observed global-scale trend in drought or dryness (lack of rainfall), due to lack of direct observations, methodological uncertainties and choice and geographical inconsistencies in the trends. {2.6.2}

e/ There is low confidence that any reported long-term (centennial) changes in tropical cyclone characteristics are robust, after accounting for past changes in observing capabilities. {2.6.3}

f/ Robust conclusions on long-term changes in large-scale atmospheric circulation are presently not possible because of large variability on interannual to decadal time scales and remaining differences between data sets. {2.7}

g/ Different global estimates of sub-surface ocean temperatures have variations at different times and for different periods, suggesting that sub-decadal variability in the temperature and upper heat content (0–700 m) is still poorly characterized in the historical record. {3.2}

h/ Below ocean depths of 700 m the sampling in space and time is too sparse to produce annual global ocean temperature and heat content estimates prior to 2005. {3.2.4} i/ Observational coverage of the ocean deeper than 2000 m is still limited and hampers more robust estimates of changes in global ocean heat content and carbon content. This also limits the quantification of the contribution of deep ocean warming to sea level rise. {3.2, 3.7, 3.8; Box 3.1}Final Draft (7 June 2013) Technical Summary IPCC WGI Fifth Assessment Report

j/ The number of continuous observational time series measuring the strength of climate relevant ocean circulation features (e.g., the meridional overturning circulation) is limited and the existing time series are still too short to assess decadal and longer trends. {3.6}.

k/ In Antarctica, available data are inadequate to assess the status of change of many characteristics of sea ice (e.g., thickness and volume). {4.2.3}

l/ On a global scale the mass loss from melting at calving fronts and iceberg calving are not yet comprehensively assessed. The largest uncertainty in estimated mass loss from glaciers comes from the Antarctic, and the observational record of ice-ocean interactions around both ice sheets remains poor.{4.3.3, 4.4}

2. Key Uncertainties in Drivers of Climate Change

a/ Uncertainties in aerosol-cloud interactions and the associated radiative forcing remain large. As a result, uncertainties in aerosol forcing remain the dominant contributor to the overall uncertainty in net anthropogenic forcing, despite a better understanding of some of the relevant atmospheric processes and the availability of global satellite monitoring. {2.2, 7.4, 7.5, 8.5}

b/ The cloud feedback is likely positive but its quantification remains difficult. {7.2}

c/ Paleoclimate reconstructions and Earth System Models indicate that there is a positive feedback between climate and the carbon cycle, but confidence remains low in the strength of this feedback, particularly for the land. {6.4}

3. Key Uncertainties in Understanding the Climate System and its Recent Changes

a/ The simulation of clouds has shown modest improvement since AR4, however it remains challenging.{7.2, 9.2.1, 9.4.1, 9.7.2}

b/ Observational uncertainties for climate variables other than temperature, uncertainties in forcings such as aerosols, and limits in process understanding continue to hamper attribution of changes in many aspects of the climate system. {10.1, 10.3, 10.7}

c/ Changes in the water cycle remain less reliably modelled in both their changes and their internal variability, limiting confidence in attribution assessments. Observational uncertainties and the large effect of internal variability on observed precipitation also precludes a more confident assessment of the causes of precipitation changes. {2.5.1, 2.5.4, 10.3.2}

d/ Modelling uncertainties related to model resolution and incorporation of relevant processes become more important at regional scales, and the effects of internal variability become more significant. Therefore, challenges persist in attributing observed change to external forcing at regional scales. {2.4.1, 10.3.1} e/ The ability to simulate changes in frequency and intensity of extreme events is limited by the ability of models to reliably simulate mean changes in key features. {10.6.1}

f/ In some aspects of the climate system, including changes in drought, changes in tropical cyclone activity, Antarctic warming, Antarctic sea ice extent, and Antarctic mass balance confidence in attribution to human influence remains low due to modelling uncertainties and low agreement between scientific studies. {10.3.1, 10.5.2, 10.6.1}

4. Key Uncertainties in Projections of Global and Regional Climate Change

a/ Based on model results there is medium confidence in the predictability of yearly to decadal averages of temperature both for the global average and for some geographical regions. Multi-model results for precipitation indicate a generally low predictability. Short-term climate projection is also limited by the low confidence in projections of natural forcing. {11.1, 11.2.2, 11.3.1; Box 11.1}

b/ There is low confidence in projections for a poleward shift of the position and strength of Northern Hemisphere storm tracks. {11.3.2, 12.4.4}

c/ There is generally low confidence in basin-scale projections of significant trends in tropical cyclone frequency and intensity in the 21st century. {11.3.2, 14.6.1}

d/ Projected changes in soil moisture and surface run off are not robust in many regions. {11.3.2, 12.4.5}

e/ Several components or phenomena in the climate system could potentially exhibit abrupt or nonlinear changes, but for many phenomena there is low confidence and little consensus on the likelihood of such events over the 21st century. {12.5.5}

f/ There is low confidence on magnitude of carbon losses through CO2 or CH4 emissions to the atmosphere from thawing permafrost. There is limited confidence in projected future methane emissions from natural sources due to changes in wetlands and gas hydrate release from the sea floor. {6.4.3}

g/ There is medium confidence in the projected contributions to sea level rise by models of ice sheet dynamics for the 21stcentury, and low confidence in their projections beyond 2100. {13.3.3}

h/ There is low confidence in semi-empirical model projections of global mean sea level rise, and no consensus in the scientific community about their reliability. {13.5.2, 13.5.3}

i/ There is low confidence in projections of many aspects of climate phenomena that influence regional climate change, including changes in amplitude and spatial pattern of modes of climate variability.

Annex II

REFERENCE TO RESEARCH AND OBSERVATION NEEDS

Whenever possible, please structure your answers using the following list of research and observation needs (A-G), in order to facilitate processing of the survey. In addition, where appropriate, please reference the WCRP Grand Challenges or Core Projects (as presented on WCRP website http://www.wcrp-climate.org/).

List of research and observation needs

A. Level of understanding of fundamental processes (e.g., aerosol-cloud interaction)

B. Observations and data

B.1. Observing technology (e.g., instrument capability and quality)

B.2. Data and metadata quality (e.g., homogeneity of long time series)

B.3. Data access and stewardship

B.4. Temporal and/or spatial coverage of observations (e.g., length of time series, global/regional networks, satellites)

C. Modelling

C.1. Grid size/resolution; Computing power

C.2. Parameterization of physical, chemical and biogeophysical processes

C.3. Data assimilation

C.4. Validation

C.5. Reanalysis capabilities

C.6. GCM issues

C.6. Downscaling issues into geographical regions (e.g., in relation to risk assessments)

D. Application of climate analyses to societal needs (e.g., impacts on and feedback from biodiversity, human health, water management, agriculture)

E. Development of present and future emission scenarios

F. Linkage of climate applications to socio-economic data (e.g., for attributing economic and social value to climate analyses)

G. Other (do not fit in the above categories)

Annex III

LIST OF SURVEY RESPONDENTS

Ananicheva Maria Institute of Geography RAS
Bala Govindasamy Indian Institute of Science
Boer George CCCma
Brown Otis NC State University
Carter Timothy SYKE
Cazenave Anny LEGOS /CNES
Church John CSIRO
Cohen Stewart Environment Canada
Collins Matthew University of Exeter
Forest Chris Pennsylvania State University
Hegerl Gabi University of Edinburgh Gille
Sarah UC San Diego
Gleckler Peter PCMDI/LLNL
Gutowski William Iowa State University
Joos Fortunat University of Bern
Marengo José CCST/INPE
Joussaume Sylvie LMD/CNRS
Karl Tom NOAA
Knutti Reto ETH Zurich
Krinner Gerhard LGGE/CNRS
Nicholls Robert University of Southampton
Ly Omar INGE SAHEL SA
Otto-Bliesner Bette NCAR
Overpeck Jonathan University of Arizona
Patt Anthony ETH Zurich
Thorne Peter NERSC
Polonsky Alexander Marine Hydrophysical Institute
Porter John Uinversity of Copenhagen
Power Scott Bureau of meteorology
Ramaswamy Venkatachalam GFDL /NOAA
Renwick James Victoria University of Wellington
Rignot Eric UC Irvine
Sabine Christopher NOAA/PMEL
Scaife Adam Met Office
Seneviratne Sonia ETH Zurich
Stott Peter Met Office
Stouffer Ronald GFDL/NOAA
Sutton Rowan NCAS
Taylor Karl PCMDI
Shepherd Ted University of Reading
Tol Richard University of Sussex
Trenberth Kevin NCAR
Tschakert Petra Pennsylvania State University
Urquhart Penny Independent consultant
van de Wal Roderik IMAU
Zhang Xuebin Environment Canada

Annex IV

WCRP SURVEY: LESSONS LEARNT FROM IPCC AR5 FOR CLIMATE CHANGE RESEARCH AND WCRP

KEY GAPS, UNCERTAINTIES AND DEFICIENCIES IN CLIMATE RESEARCH

Issues covered in Working Group I: The Physical Science Basis

1. Observations of changes in the climate system (refer to the IPCC-identified key uncertainties in **Annex I**).

1.a. Prioritize issues by listing the top three ones in your views from Annex I (e.g. : 1e, 1g, 1a)
1.b. Provide reasons for those you selected
1.c. Are there any important issues you would like to highlight in addition to the identified list? Please be as specific as possible
1.d. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
1.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGI report (15. March 2013)

2. Drivers of climate change (refer to the IPCC-identified key uncertainties in **Annex I**).

2.a. Prioritize issues by listing the main one in your view from Annex I (e.g. : 2c)
2.b. Provide reasons for your selection
2.c. Are there any important issues you would like to highlight in addition to the identified list? Please be as specific as possible
2.d. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
2.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGI report (15 March 2013):

3. Understanding the climate system and its recent changes (refer to the IPCC-identified key uncertainties in **Annex I**).

3.a. Prioritize issues by listing the top three ones in your views from Annex I (e.g. : 3b, 3c, 3a)
3.b. Provide reasons for those you selected
3.c. Are there any important issues you would like to highlight in addition to the identified list? Please be as specific as possible
3.d. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
3.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGI report (15. March 2013)

4. Projections of global and regional climate change (refer to the IPCC-identified key uncertainties in **Annex I**).

4.a. Prioritize issues by listing the top three ones in your views from Annex I (e.g. : 4a, 4b, 4d)
4.b. Provide reasons for those you selected
4.c. Are there any important issues you would like to highlight in addition to the identified list? Please be as specific as possible
4.d. Identify solutions for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
4.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGI report (15. March 2013)
4.f. Make here any specific proposal related to the Climate Model Intercomparison Project

Working Group II: Impacts, Adaptation and Vulnerability

In WGII report, research and data gaps, key uncertainties or research needs and priorities are identified at the end of most chapters in a special paragraph. You are therefore invited to focus on the chapters which correspond to your specific expertise or experience and make use of the information contained generally at the end of each chapter, restricting as much as possible your comments to domains related to WCRP activities . For convenience we have separated impact and adaptation issues.

5. Impacts

5.a. Select up to three "impact" domains where research and data gaps can be addressed by WCRP
5.b. Identify key issues and provide reasons for this (indicate where your proposals fit, using A-G categories as in Annex II)
5.c. Is there any important issue missing in your view from the report or not sufficiently highlighted ? Please be as specific as possible
5.d. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
5.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGII report (31 August 2013)

6. Adaptation

6.a. Select up to 3 "impact" domains where research and data gaps can be addressed by WCRP
6.b. Identify key issues and provide reasons for this (indicate where your proposals fit, using A-G categories as in Annex II)
6.c. Is there any important issue missing in your view from the report or not sufficiently highlighted ? Please be as specific as possible
6.d. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
6.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGII report (31 August 2013)

7. Regional aspects (chapters 21-30)

7.a. Select up to three major issues identified under research and data gaps, key uncertainties or research needs and priorities (valid for any region or related to specific regions)
7.b. Provide reasons for the issues you selected (indicate where your proposals fit, using A-G categories as in Annex II)
7.c. Is there any important issue missing in your view from the report or not sufficiently highlighted ? Please be as specific as possible
7.d. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
7.e. How have the above mentioned issues evolved between AR4 and AR5, how have they been taken up in studies post the AR5 cut-off dates for published literature to be covered in the WGII report (31 August 2013)

8. Material from SREX report

8.a. Select up to three major issues identified in SREX in the domain of competence of WCRP
8.b. Provide reasons for the issues you selected (indicate where your proposals fit, using A-G categories as in Annex II)
8.c. Identify proposals for making progress (indicate where your proposals fit, using A-G categories as in Annex II)
8.d. Is there any important issue missing in your view from the report or not sufficiently highlighted ? Please be as specific as possible
8.e. How the above issues have evolved between AR4 and AR5, how they have been taken up in new studies since AR5 publication cut-off dates?

PRIORITIES FOR RESEARCH WITHIN WCRP, IMPLICATIONS FOR CORE PROJECTS AND GRAND CHALLENGES

9. What should the top priorities be within present WCRP structure in order to fill the most critical gaps in possible future IPCC assessment reports? Please provide not more than one for each core project or activity within your domain of expertise(this may repeat some suggestions made earlier).

9.a. Recommendations related to Core Projects (CliC, CLIVAR, GEWEX , SPARC)
9.b. Recommendations related to Grand Challenges (Regional climate information, Clouds, circulation and climate sensitivity, Changes in water availability, Cryosphere in a changing climate, Sea level rise and regional impacts, Science underpinning the prediction and attribution of extreme events)
9.c. Recommendations related to modeling activities (WGCM, WGNE, WGSIP, WGRC, Model development activities under WMAC, Model-data archiving and dissemination: obs4MIPs, ana4MIPs, Earth System Grid Federation). Identify specific recommendations for CMIP.
9.d. Recommendations related to observation coordination activities (under WDAC)
9.e. Recommendations related to capacity building activities
9.f. Do you have suggestions on improving the communication of climate research results to the public and decision makers

10. Which scientific issues of relevance to climate change research you believe should be addressed by WCRP in addition to the present Grand Challenges, and how they should be addressed.

11. How can the current institutional or technical infrastructure for climate research be improved? Please select your top two improvements.

SUGGESTIONS FOR FUTURE IPCC ASSESSMENTS

12. Are they any specific aspects of the IPCC AR5 assessment results that you believe should be better taken into account in WCRP activities or that you would like to highlight in relation with WCRP activities?

13. Are they any specific aspects of the IPCC AR5 assessment process that you believe should be better taken into account in WCRP activities or that you would like to highlight in relation with WCRP activities?

14. Do you have specific suggestions for new climate change research activities (within or outside WCRP) that would serve future IPCC assessments?