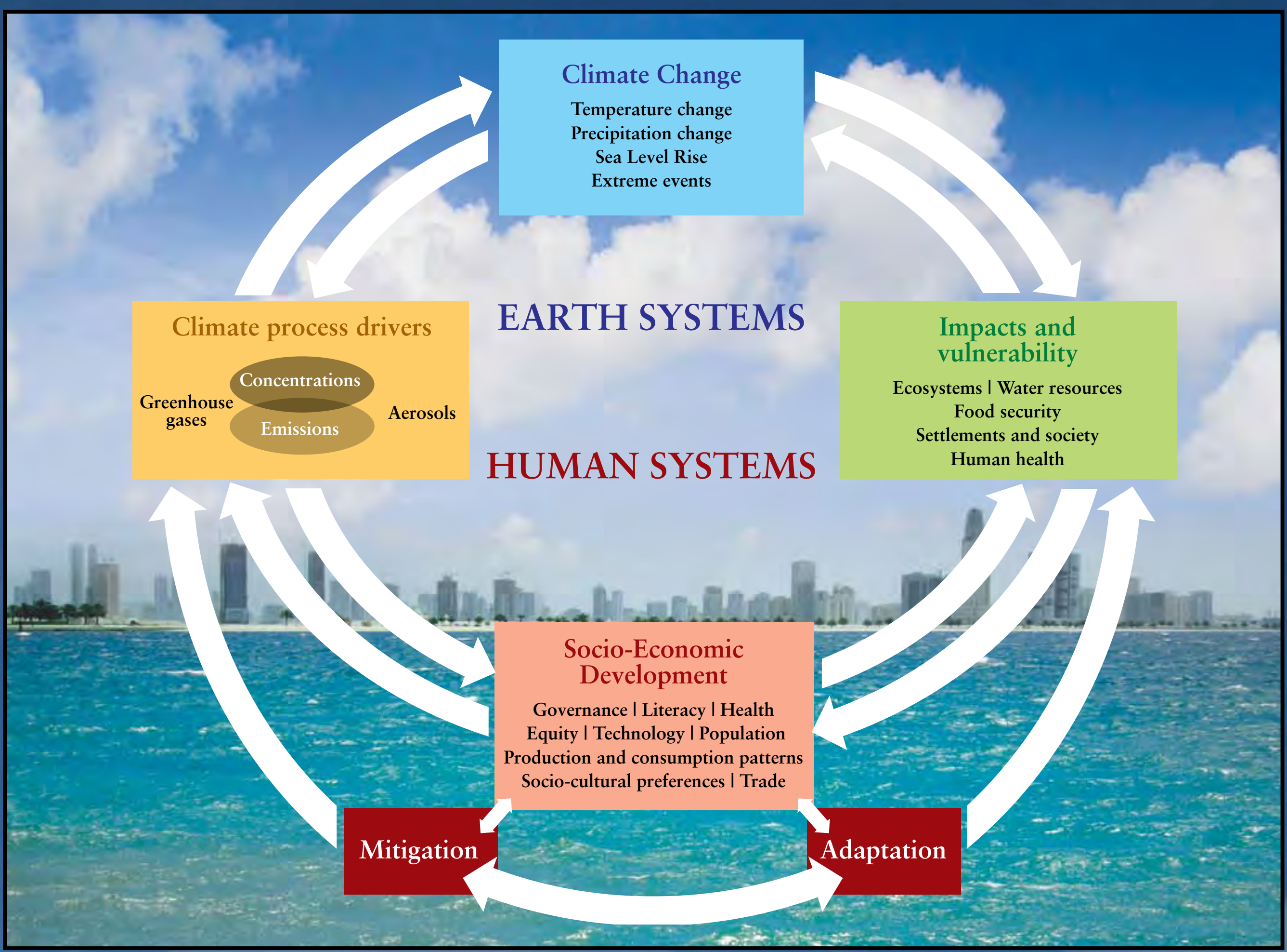
TOWARDS NEW SCENARIOS FOR ANALYSIS OF EMISSIONS, CLIMATE CHANGE, IMPACTS, AND RESPONSE STRATEGIES

TECHNICAL SUMMARY

IPCC EXPERT MEETING REPORT

19–21 September, 2007

Noordwijkerhout, The Netherlands



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This report summarizes supporting material prepared for consideration by the Intergovernmental Panel on Climate Change. The material has not been subjected to formal IPCC review processes. The expert meeting was agreed in advance as part of the IPCC work plan, but this does not imply working group or panel endorsement or approval of this report or any recommendations or conclusions contained herein.

The report has been subjected to an expert peer review process and revised accordingly. The full report is available from the Secretariat and on the IPCC website (http://www.ipcc.ch/ipccreports/supporting-material.htm).

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Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies

IPCC Expert Meeting Report

Technical Summary

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Preface

This report summarizes the findings and recommendations from the Expert Meeting on New Scenarios held in Noordwijkerhout, The Netherlands, 19-21 September 2007. It is the culmination of the combined efforts of the New Scenarios Steering Committee, an author team composed primarily of members of the research community, and numerous other meeting participants and external reviewers who provided extensive comments during the expert review process.

The expert meeting included presentations focused on needs for scenarios as seen from a policymaking perspective, a review of past IPCC scenarios, overviews of evolving plans in the research community, needs and opportunities for scenarios on two different time scales (“near term”—to 2035, and “longterm”—to 2100, extended to 2300 for some applications), and a review of options for the benchmark scenarios, referred to in the report as “Representative Concentration Pathways” (RCPs). Additional presentations addressed institutional issues and options for increasing participation by developing and transition-economy countries. The remainder of the meeting was organized around a series of breakout groups and plenary sessions that provided an opportunity for the research communities to further coordinate their plans, to refine the proposal for the RCPs, and to consider additional cross-cutting issues.

To ensure representation of all major stakeholder groups in the discussion, the Steering Committee selected over 130 participants for the expert meeting from among a much larger number of applicants. These participants represented diverse perspectives from the climate science, impacts, and integrated assessment research communities, scenario user groups, and multilateral and international organizations. More than 30 percent of the meeting participants came from developing countries and countries with an economy in transition.

As requested, through the expert meeting we identified a set of RCPs from the published literature. These pathways provide common starting points from which climate and integrated assessment modelers can begin to work in parallel toward the generation of new integrated scenarios of climate change for a possible AR5. The expert meeting conditionally recommended that the lowest radiative forcing pathway available in the literature from this class of models – IMAGE 2.6 – be used as one of the RCPs because of the strong interest of participating representatives of the policy community. But because this radiative forcing pathway has not been replicated by other models in this class of IAMs, the Steering Committee requested that the Integrated Assessment Modeling Consortium (IAMC) form an evaluation panel to ensure that the scenario is scientifically suitable for use as an RCP. An evaluation process was agreed to by the IAMC and Steering Committee and is described in the report and a series of letters provided in an Appendix. While evaluation panel members may not necessarily agree on all aspects of the robustness of the IMAGE 2.6 scenario, they are asked to provide a single recommendation to the IAMC as the convening body on whether or not it should be considered robust. The IAMC will then transmit the finding to the Steering Committee for expected confirmation of the recommendation.

The steering committee adhered to the catalytic role defined by the IPCC. The report thus describes the current state of planning by the scientific community for preparation of new scenarios. Aspects of the process are still being planned, and thus the report describes a “work in progress”. It is important to note that many of the planned activities encouraging communication and integration across the climate modeling, impacts, adaptation, and integrated assessment communities will require a great deal of effort by the research communities and additional support from governments and funding agencies.

Two additional points made at the time of the meeting should be mentioned:

First, the scientific community had anticipated that, in line with past practice, a decision on the time line and phases of a potential AR5 report would be made by the Panel in 2008. This stems from the fact that, in the absence of a date certain for the completion of AR5, all the major Working Group I modeling groups would have continued active development of their models until the AR5 time line is announced. The details of these developments can affect what types of inputs are needed, particularly with regard to the coupling of atmospheric chemistry and the carbon cycle. Thus increasing this model development period raises the potential for substantive changes that would require detailed reconsideration of the scenario-based inputs to be provided by Working Group III. Collectively, these timing considerations necessitate a period of at least 5 to 6 years for the completion of AR5 following its initial announcement. This recommendation was taken up by the Panel at its 28th Session, when the timing of AR5 was decided along with the two following decisions:

(1) The Panel invites the scientific community developing new scenarios for analysis of emissions, climate change, impacts, and response strategies to move forward actively and with strength, for timely delivery of the scenario results as indicated in timeline presented in the report “Further work on scenarios” presented at the 28th Session of IPCC (Fig.II.1 p.19).

(2) The Panel requests the Bureau to assist timely transfer of the scenarios products outlined in the report “Further work on scenarios” into development of the Fifth Assessment report (AR5), in particular in relation to impacts, adaptation and vulnerability.

Second, the expert meeting and subsequent process of drafting the report has engendered extensive interactions across the research communities and with various user groups. Given their previous roles in the climate modeling and integrated assessment modeling communities, the World Climate Research Programme and the IAMC are poised to play key roles in the proposed plan. However, as yet there is no institutional arrangement to assist the necessary cross-disciplinary communication required—particularly on such a tight timeline. Thus, despite the current willingness and engagement of key individuals, success will be a major challenge and is by no means assured. Given the existing role of the TGICA in facilitating cross-disciplinary communication, the Panel may wish to invite the TGICA to regularly monitor and report to the Panel on progress in the planned activities.

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Co-Chairs, New Scenarios Steering Committee

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We would like to offer our gratitude to those who have made this work possible. We wish to thank the Government of the Netherlands, which provided administrative and logistical support to the Steering Committee and served as a gracious host for the Noordwijkerhout meeting. The Working Group III TSU provided tireless assistance in organizing teleconferences, communications, and the expert meeting itself. Finally, we would like to offer our deepest thanks to the members of the New Scenarios Steering Committee and the report's author team. These individuals showed tremendous dedication without them preparation of the meeting and this report would not have been possible.

Ismail Elgizouli Richard H. Moss

Co-Chairs, New Scenarios Steering Committee

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Technical Summary

I. Background

Scenarios of potential future anthropogenic climate change, underlying driving forces, and response options have always been an important component of the work of the Intergovernmental Panel on Climate Change (IPCC). In the past, the IPCC coordinated the process of developing scenarios for its assessments. During its 25th session (Mauritius, 26–28 April 2006), the IPCC decided that rather than directly coordinating and approving new scenarios itself, the process of scenario development should now be coordinated by the research community. The IPCC would seek to “catalyze” the timely production by others of new scenarios for a possible Fifth Assessment Report (AR5) by convening an expert meeting to consider the scientific community’s plans for developing new scenarios, and to identify a set of “benchmark emissions scenarios” (now referred to in this report as “Representative Concentration Pathways—RCPs” —for reasons discussed in Section I.2). The RCPs will be used to initiate climate model simulations for developing climate scenarios for use in a broad range of climate-change related research and assessment and were requested to be “compatible with the full range of stabilization, mitigation and baseline emissions scenarios available in the current scientific literature.”[1]

The expert meeting was held on 19–21 September 2007 in Noordwijkerhout, The Netherlands. The meeting brought together over 130 participants, including users of scenarios and representatives of the principal research communities involved in scenario development and application. The representatives of the scenario user community included officials from national governments, including many participating in the United Nations Framework Convention on Climate Change (UNFCCC), international organizations, multilateral lending institutions, and nongovernmental organizations (NGOs). The principal research communities represented at the expert meeting were the integrated assessment modeling (IAM) community; the impacts, adaptation, and vulnerability (IAV) community; and the climate modeling (CM) community. Because of this broad participation, the meeting provided an opportunity for the segments of the research community involved in scenario development and application to discuss their respective requirements and coordinate the planning process.

This summary provides an overview of a new parallel process for scenario development and the RCPs discussed and refined at the expert meeting. It briefly reviews recommendations for institutional developments and increased participation of experts and users from developing countries and countries with an economy in transition that would further strengthen the process. Further details are provided in the full report of the expert meeting.

[1] See Box I.1 in the full report of the expert meeting for additional information about the IPCC’s decision on further work on emissions scenarios taken at its 26th Session, Bangkok, Thailand, 30 April–4 May 2007.

I.1 Scenario characteristics and needs from an end-user perspective

During earlier IPCC meetings on scenarios[2] and the planning process for this expert meeting, a variety of user groups participated and provided input about their needs for scenarios of socio-economic, climate, and other environmental conditions. These users could be classified into two broad groups: "end users," policy- and decisionmakers who use scenario outputs and insights in various decision processes; and "intermediate users," researchers who use scenarios from another segment of the research community as inputs into their work.

Based on the interests and needs of end users, the new scenario process will develop global scenarios for two time periods:

- "near-term" scenarios that cover the period to about 2035; and
- "long-term" scenarios that cover the period to 2100 and, in a more stylized way, the period to 2300.

The distinction between near- and long-term scenarios is important because the nature of policy- and decisionmaking, the climate system responses, and capabilities of model projections all change with time scale.

Major motivations for the near-term scenarios are understanding the effect of emissions on air quality, providing information on trends and extreme events, and providing high-resolution output for the IAV community. Near-term adaptation and mitigation analyses can be matched to conventional planning time scales, can explore opportunities and constraints given institutional and technological inertia, and can play an important role in integrating climate change considerations into other areas of management and policy. Key issues on this time scale include identifying immediate risks; developing corresponding adaptive capacity; reducing vulnerability; making efficient investments to cope with climate change; and implementing investments in low-emission technologies, energy conservation, and sink preservation and/or enhancement. This is a new activity for the CM community and as such, is a research issue in progress. Initialization of climate models is a more significant issue for the near term than the longer term. It is anticipated that use of initial conditions that are consistent with the current phase of natural variability of climate system may reduce the spread in ensembles of simulations over the next one or two decades. Thus, the effort to provide high-resolution (0.5°–1°) scenarios for the near-term time scale must still be considered experimental.

The longer term policy focus shifts towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for adaptation, mitigation, and development that are robust over the long term to remaining uncertainties. Scenarios of different rates and magnitudes of climate change provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

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[2] New scenarios for the IPCC process were discussed during several sessions of the Panel and in workshops in Washington, DC, USA (January 2005), Laxenburg, Austria (July 2005), and Seville, Spain (March 2006). For further information on these previous meetings and associated recommendations and decisions,
see: http://www.ipcc.ch/pdf/supporting-material/expert-meeting-2005-01.pdf (Washington),
http://www.mnp.nl/ipcc/pages_media/meeting_report_workshop_new_emission_scenarios.pdf (Laxenburg), and
http://www.ipcc.ch/meetings/session25/doc11.pdf (Seville).

At the expert meeting, representatives of the policy community expressed a strong interest in very low radiative forcing profiles (e.g., radiative forcing that peaks at 3 W/m^2 before 2100 and then declines). It is evident that the policy discussion is moving towards increasingly stringent emissions reductions targets, and that policymakers will need information on the implications of these targets for climate change, unavoidable impacts of even low trajectories, and economic and technological pathways for achieving these targets. How best to reflect this interest in the choice of RCPs, which must be drawn from the existing literature that is only beginning to address this issue, was a major topic of discussion at the meeting.

Another clear interest of scenario users is development of regional- or national-scale socio-economic scenarios that are consistent with global scenarios but that also reflect unique local conditions. This topic seems especially important as increasing attention is focused on regional and national implementation of adaptation and mitigation options, and on how these two response classes can be effectively integrated in climate risk management. The expert meeting addressed this issue in several breakout groups, and preliminary recommendations are included in the full meeting report.

I.2 A parallel process for scenario development

Past scenario development has been conducted in a mainly sequential form, with socioeconomic and emissions scenarios developed first and climate change projections based on those scenarios carried out next. In contrast with the previous linear process, this parallel approach should provide better integration, consistency, and consideration of feedbacks, and more time to assess impacts and responses. The research community developed this process in a series of meetings and workshops.[3] As with all multi-year research plans, this plan is subject to review and revision throughout the process.

The parallel process is initiated with the identification of the RCPs, which will enable the CM community to proceed with new climate change projections at the same time that new work is carried out in the IAM and IAV communities (see Figure 1b). While the RCPs will enable CM scenario development that explores and characterizes future climate change, they do not constrain future work by the IAM community, which, in its portion of the parallel process, will simultaneously develop a range of completely new socioeconomic and emissions scenarios. IAM teams will have complete freedom to develop new scenarios across the full range of possibilities. IAM teams will also explore alternative technological, socioeconomic, and policy futures including both reference (without explicit climate policy intervention) and climate policy scenarios. This approach seems both promising and important given the interest of decisionmakers in exploring how to attain different stabilization levels.

[3] These meetings include a "summer institute" held under the auspices of the Aspen Global Change Institute in July 2006; a joint meeting of the World Climate Research Program's Working Group on Coupled Models (WGCM) and the International Geosphere-Biosphere Programme's Analysis, Integration and Modeling of the Earth System core project in September 2006; an additional summer workshop that was held under the auspices of the Energy Modeling Forum in Snowmass, Colorado in July 2007; and a meeting of the WGCM in Hamburg, Germany from 3–5 September 2007.

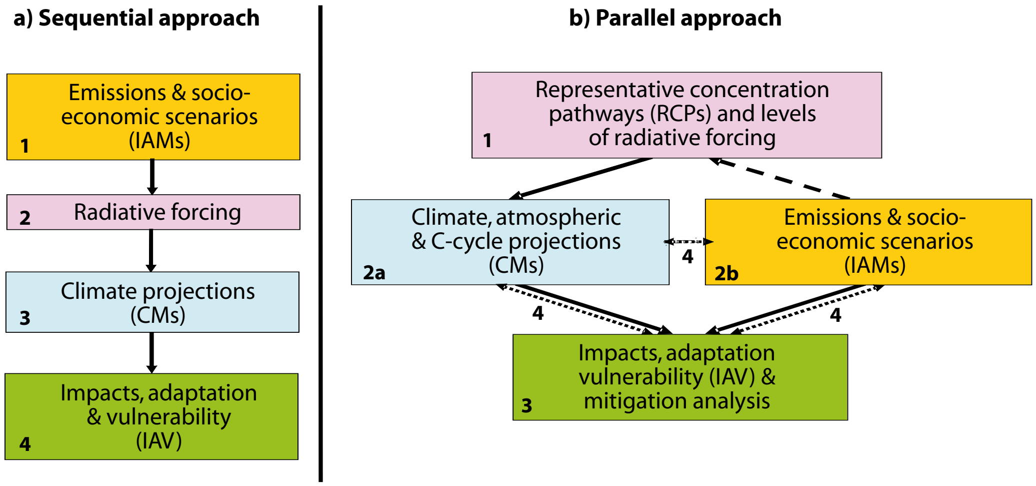

Figure 1. Approaches to the development of global scenarios: (a) previous *sequential* approach; (b) proposed *parallel* approach. Numbers indicate analytical steps (2a and 2b proceed concurrently). Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information and feedbacks (dotted).

The parallel process is an advance from the prior sequential approach for a number of reasons. The approach will allow better use of the expensive and time-consuming simulations carried out by the CM community, as these no longer need to be rerun each time the emissions scenarios are changed. A parallel approach using RCPs partially decouples climate science from the issues of socioeconomic projections because a given concentration trajectory can result from different socioeconomic projections and IAM model outcomes. In the past, when the socioeconomic scenarios were modified, the model simulations had to be run again, even though the changes seldom resulted in meaningful (i.e., detectable) alterations to the modeled future climates. In the future, updated CMs can be run using the same RCPs, allowing modelers to isolate the effects of changes in the CMs themselves. New forcing scenarios can be used to scale the existing CM simulations using simpler models that have been calibrated to give comparable results to the full three-dimensional climate models. There would be no need to rerun models for each new scenario. The saving in computing time could be used to generate larger ensembles at higher resolution, hopefully leading to refined simulations of regional change and extreme events, and a more robust representation of uncertainties and/or probabilities. Of course, the use of pattern scaling always yields an approximation to the output that would have been produced by a state-of-the-art climate model had it been run, and the resulting approximation is better for some variables than for others. The savings in cost and time for climate model set up and runs is therefore purchased at the price of approximation.

I.3 Explanation of RCP terminology, and the role of RCPs in the "parallel process"

The name "representative concentration pathways" was chosen to emphasize the rationale behind their use. RCPs are referred to as *pathways* in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, that is of interest, but also the trajectory that is taken over time to reach that outcome. They are *representative* in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics. The term “benchmark,” used in the IPCC decision, was considered less desirable as it implies that a particular scenario has a special status relative to others in the literature, rather than simply being representative of them. This is a key point because as is explained more completely in Section II of this summary and the full report, the identification and use of the RCPs in climate modeling is only the first step in a new parallel process of scenario development being coordinated by the research community. Consistent with the IPCC’s decision to play a catalytic role in the development of new scenarios, the RCPs are simply intended to expedite the preparation of integrated scenarios by enabling modeling the response of the climate system to human activities to proceed in parallel to development of emissions and other scenarios for use in IAV and mitigation assessments.

I.4 Expected products

To meet the needs of the range of intermediate and end users, the research community is planning to develop five principal products in the lead-up to the publication of a possible AR5:

1. *Representative concentration pathways (RCPs).* Four RCPs will be produced from IAM scenarios available in the published literature: one high pathway for which radiative forcing reaches >8.5 W/m^2 by 2100 and continues to rise for some amount of time; two intermediate “stabilization pathways” in which radiative forcing is stabilized at approximately 6 W/m^2 and 4.5 W/m^2 after 2100; and one pathway where radiative forcing peaks at approximately 3 W/m^2 before 2100 and then declines. These scenarios include time paths for emissions and concentrations of the full suite of GHGs and aerosols and chemically active gases, as well as land use/land cover (see Table A1.1 in the full report). The anticipated completion date is September 2008.

2. *RCP-based climate model ensembles and pattern scaling.* Ensembles of gridded, time-dependent projections of climate change produced by multiple climate models including atmosphere–ocean general circulation models (AOGCMs), Earth system models (ESMs), Earth system models of intermediate complexity, and regional climate models will be prepared for the four long-term RCPs, and high-resolution, near-term projections to 2035 for the 4.5 W/m^2 stabilization RCP only. The long-term scenarios are expected to be run at approximately 2° resolution, while the near-term scenarios may have higher (0.5° to 1°) resolution. These projections can be scaled upward or downward according to the ratio of simulated global mean temperature for the RCP and the temperature change defined in simple CMs forced with different scenarios. The anticipated completion date is fall 2010.

3. *New IAM scenarios.* New scenarios will be developed by the IAM research community in consultation with the IAV community exploring a wide range of dimensions associated with anthropogenic climate forcing. These scenarios are anticipated to be combined with pattern-scaled outputs of the ensemble climate projections (Product 5). Anticipated outputs include alternative socioeconomic driving forces, alternative technology development regimes, alternative realizations of Earth system science research, alternative stabilization scenarios including traditional “not exceeding” scenarios, “overshoot” scenarios, and representations of regionally heterogeneous mitigation policies and measures, as well as local and regional socioeconomic trends and policies. These are anticipated to be available in the third quarter of 2010.

4. *Global narrative storylines.* These are detailed descriptions associated with the four RCPs produced in the preparatory phase and such pathways developed as part of Product 3 by the IAM and IAV communities. These global and large-region storylines should be able to inform IAV and other researchers. New narrative storylines will also be developed as new reference scenarios emerge within Product 3, potentially extending narrative storyline development into the integration phase. Narrative storyline development will be a joint undertaking employing researchers from both the IAM and IAV communities. This product is anticipated to be available in the third quarter of 2010.

5. *Integrated scenarios.* RCP-based climate model ensembles and pattern scaling (Product 2) will be associated with combinations of new IAM scenario pathways (Product 3) to create combinations of ensembles. These scenarios will be available for use in new IAV assessments. In addition, IAM research will begin to incorporate IAV results, models, and feedbacks to produce comprehensively synthesized reference, climate change, and IAM results. These are anticipated to be available in the spring of 2012.

The anticipated time line for the production of these five products is depicted in Figure 2.

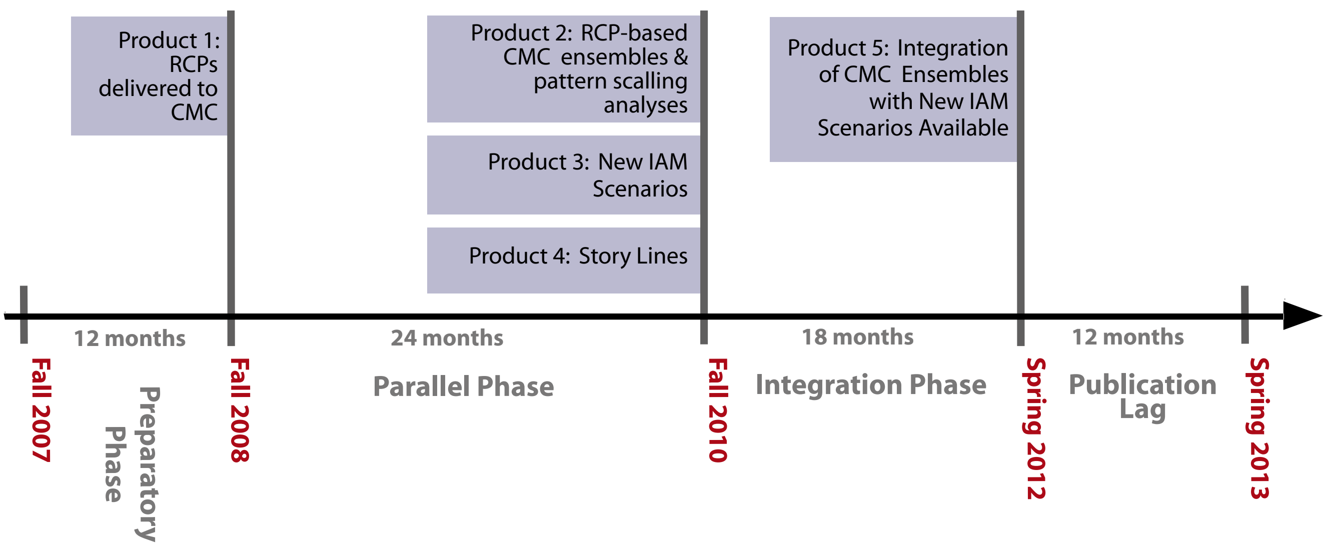

Figure 2. Timeline of key scenario development products (CMC = climate modeling community).

II. Process for Scenario Development

These products will be produced through a new scenario development process that comprises three phases: a preparatory phase and two main phases of scenario development: a parallel phase for modeling and developing new scenarios; and an integration, dissemination, and application phase.

II.1 Preparatory phase

The principal product of the preparatory phase will be four RCPs, produced by IAMs to satisfy the data requirements of the CM community and respond to the IPCC's request for "benchmark" scenarios from the research community. The RCPs are not to be the focus of all subsequent research. They are a device that provides a consistent analytical thread through the research communities and facilitates exploration and characterization of uncertainty—in climate, socioeconomics, emissions, vulnerability, and impacts.

The IAM and CM communities will work together to insure that RCPs reflect the needs of the CM community. Development of the RCPs entails a number of challenges that are the focus of current research across the IAM community. The set of data provided with each RCP will need to be spatially downscaled for short-lived species, gaseous and aerosol emissions, and land use/land cover. Another important challenge is to extend the RCPs from 2100, the typical end point for published results from IAMs, to the year 2300. Given the large socioeconomic uncertainties over such a time scale, a variety of stylized approaches for producing emissions and concentrations data for CMs is under discussion. The planned methods resulting from those discussions will be available for comment. Another important early step in the process will be the development of data reporting standards by the IAM community in conjunction with the CM and IAV communities. The IAM community will produce the required data for CM groups. A careful review and cross-check of the data by participating IAM and CM groups will be included as part of the process. All data associated with the RCPs will be made publicly available to those interested in using them. To help coordinate this work across the IAM teams and between them and other communities involved in global change research, an Integrated Assessment Modeling Consortium (IAMC) has been formed.[4]

II.2 Parallel modeling phase

As illustrated in Figure 1, the parallel phase was developed to expedite the scenario development process. It telescopes work that has traditionally occurred sequentially over a longer period of time. There are advantages and disadvantages to both the traditional sequential approach and the new parallel approach, as discussed in the full report.

The parallel modeling phase will be comprised of extensive, independent work across the research communities that is designed to provide a rich and consistent characterization of the many facets of climate change. In the parallel phase, three activities proceed concurrently. First, CMs employ the RCPs and associated emissions to develop scenarios of changes in the atmosphere, climate, and related conditions (e.g., ocean acidity or sea level rise) over the two time horizons of interest: near term (to 2035) and long term (to 2300). This activity will conclude with pattern scaling analyses designed to characterize a fuller climate space. Second, the IAM research community begins to develop a new suite of scenarios that revisit reference, stabilization, technology, and policy options to create a "library" of new scenarios. Third, the IAM and IAV research communities work to develop "global and regional narrative storylines," downscaling methodologies, and regional/sectoral impact models that can be used by IAV researchers in conjunction with the new scenarios, including the RCPs.

II.3 Integration phase and publication lag

In the integration phase, new ensemble climate scenarios developed during the parallel phase (Product 2) will be integrated with the parallel phase IAM emissions and socioeconomic scenarios (Products 3 and 4) as an input to new IAV studies. To ensure appropriate pairing of CM outputs with

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4 The IAMC was established in November 2006. So far, 37 groups have joined the consortium. See Section IV of the report for further information.

new socioeconomic scenarios, interpolation and pattern scaling of climate model results will also be undertaken. Results will be compiled in a proposed IAV research archive that will facilitate intercomparison and synthesis of results. In the integration phase, IAM researchers will begin the process of integrating IAV research tools directly into IAMs. The goal is to produce internally consistent representations of human activities conducted within the context of changing climate, oceans, and ecosystems. Similarly, climate modelers will also incorporate insights from IAM and IAV research into a new generation of ESMs, to provide a more realistic representation of the effects of human drivers on the physical and biogeochemical systems being modeled. Such integration (by both IAMs and ESMs incorporating results from IAV studies) may also enable new investigation of feedback processes.

Time Line & Critical Path of Scenario Development

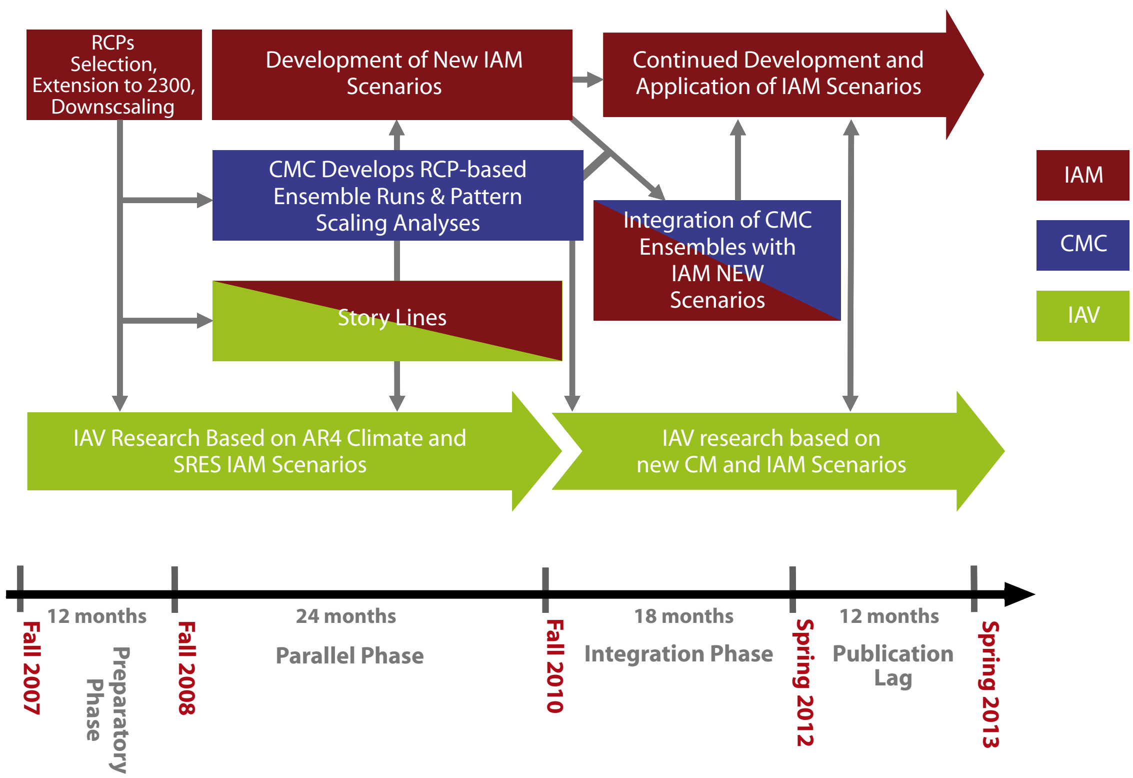

Figure 3: Some of the major scenario-related activities across the IAV, IAM, and CM research communities and relationships among them. The boundaries between these phases are not precisely defined, although near-term deadlines, such as the fall 2008 deadline for availability of RCPs, can be taken as relatively more precise.

There is a time lag between the completion of research and its documentation and publication. Thus, while publication will proceed throughout the years leading up to a potential AR5, some time needs to be budgeted at the end of the process to accommodate those research products that emerge at the latest date. That time lag is about one year. The lag is presently unavoidable and should be incorporated in planning.

The interactions among research communities during the three phases of scenario development are depicted in Figure 3.

III. “Representative Concentration Pathways”

The early identification of a set of “Representative Concentration Pathways” (RCPs) will facilitate coordination of new integrated socioeconomic, emissions, and climate scenarios. The main rationale for beginning with RCPs is to expedite the development of a broad literature of new and integrated scenarios by allowing the modeling of climate system responses to human activities to proceed in parallel to emissions scenario development (see Figure 2).

The IPCC requested that the RCPs should be “compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the current scientific literature,” and that they should include information on a range of factors beyond concentrations and emissions of long-lived GHGs, including emissions of other radiatively active gases and aerosols (and their precursors), land use, and socioeconomic conditions (see Appendix 1 of the full report for a detailed description of the data requirements). This information should be sufficient to meet user needs, in particular the data needs for climate modeling. In order to take into account the effects of emissions of all GHGs and aerosols, the RCPs have been selected based primarily on their emissions, associated concentration outcomes, and net radiative forcing. Each of the selected RCPs will come from a different IAM and include the concentration pathway and corresponding emissions and land use pathways.

III.1 Uses and limits

The core uses of RCPs and the CM outcomes associated with them are:

- *Input to CMs.* As discussed in Section II, RCPs are mainly intended to facilitate the development of integrated scenarios by jump-starting the CM process through the provision of data on emissions, concentrations, and land use/land cover needed by CMs. Results from these CM simulations will then be used to recalibrate the climate system components of IAMs, to inform IAV studies, and to incorporate feedbacks from climate impacts back into the socioeconomic drivers during later phases of the scenario development process.
- *To facilitate pattern scaling of climate model outcomes.* Climate change projections based on RCPs will cover a wide range of outcomes. These outcomes, together with control runs with no anthropogenic radiative forcing, will be used to investigate the extent to which they can be scaled to provide climate change outcomes for intermediate forcing levels without re-running the CMs (see Section II.4 of the full report). For this purpose, it is important to analyze the nonlinearity of the climate change response to different levels and time paths of forcing (including peak and decline pathways), using comparable CM simulations forced with multiple RCPs.
- *To explore the range of socioeconomic conditions consistent with a given concentration pathway.* It is an open research question as to how wide a range of socioeconomic conditions could be consistent with a given pathway of forcing, including its ultimate level, its pathway over time, and its spatial pattern. The RCPs will facilitate exploration of alternative development futures that may be consistent with each of the four RCPs.
- *To explore the climate implications of spatial forcing patterns.* Each RCP will have a particular spatial pattern of forcing due to differences in both spatial emissions and land use. The RCPs will provide a new focus for work on the open research question of how wide a range of spatial patterns of forcing could be consistent with a given climate change outcome.

There are a number of limitations to the use of RCPs that must be kept in mind in order to avoid inappropriate applications. These include:

- *They should not be considered forecasts or absolute bounds.* RCPs are representative of plausible alternative scenarios for the future but are not predictions or forecasts of future outcomes. No RCP is intended as a "best guess," most likely, or most plausible projection.
- *They should not be considered policy-prescriptive.* The RCPs are meant to support scientific research to examine various climate change futures and their implications for adaptation and mitigation without making any judgment as to their desirability.
- *The socioeconomic scenarios underlying each RCP should not be considered unique.* Each RCP is based on a scenario in the literature that includes a socioeconomic development pathway. However, the socioeconomic scenario underlying each RCP is just one of many possible scenarios that could be consistent with the concentration pathway.
- *The socioeconomic scenarios underlying the RCPs cannot be treated as a set with an overarching internal logic.* While each individual RCP was developed from its own internally consistent socioeconomic foundation, the four RCPs as a group were selected on the basis of their concentration and forcing outcomes to be compatible with the full range of emissions scenarios available in the literature. Therefore, there is no overarching logic or consistency to the set of socioeconomic assumptions or storylines associated with the set of RCPs. In particular, the socioeconomic scenario underlying one RCP should not be used in conjunction with that of another RCP, and cannot be freely used interchangeably with the assumptions underlying other RCPs. Furthermore, the set of underlying socioeconomic scenarios is not intended to span the range of plausible assumptions for any particular socioeconomic element (population, gross domestic product growth, rates of technological change, land use, etc.).
- *There are uncertainties in the translation of emissions profiles to concentrations and radiative forcing.* This is particularly true for the carbon cycle and atmospheric chemistry. Each RCP represents one possible set of assumptions with regard to this translation. Both the development of new techniques and tools for translating emissions to concentrations and uncertainty analyses should be coordinated in subsequent phases by the CM community and IAMC. See Section II of the full report for discussion of research plans in this area.

The remainder of this section of the Summary describes the process by which RCPs were identified from the literature.

III.2 Desirable characteristics

The preferences of end- and intermediate-user communities regarding the general features of the RCPs are reflected in the following "desirable characteristics" for the scenarios, which include range, number, separation and shape, robustness, comprehensiveness, and near-term resolution.

- *Range:* The IPCC, reflecting the interests of policy users, requested that the RCPs "should be compatible with the full range of stabilization, mitigation, and baseline emission scenarios available in the current scientific literature." The research and user communities have also expressed a clear interest in a set of concentration and radiative forcing pathways that spans from a high pathway to a low pathway and facilitates research on and insights into potential futures between the high and low pathways, as well as the uncertainties in the high and low pathways themselves. The lowest radiative forcing pathways available in the literature peak and then decline. Participants at the expert meeting expressed an interest in the peak and decline shape of these pathways, as well as their low radiative forcing levels.

- *Number:* The research and user communities concluded that four RCPs should be produced, although it is not expected that all CM groups will carry out simulations based on all four RCPs. Four RCPs were deemed appropriate in that the number of scenarios was even (which avoids the natural inclination to select the intermediate case as the "best estimate"), more than two scenarios would be available (to allow for intermediate pathways in addition to a high and low), and the number of scenarios was small (reflecting resource constraints within the CM community due to the high cost of model simulations).
- *Separation and shape*: The interpretation of AOGCM runs is most effective when the climate change signal to be detected is large compared to the noise of inherent climate variability. For climate change outcomes to be statistically distinguishable by models, the radiative forcing pathways should be well separated by the end of the 21st century and/or have distinctive shapes. Clearly distinguishable climate change outcomes will facilitate research associating impacts with particular ranges of climate change and assessments of the costs and benefits of avoided impacts.
- *Robustness:* Given the substantial resource requirements associated with running CMs, it is prudent that the RCPs and the scenarios on which they are based be considered robust by the scientific community. In this context, robustness means that a scenario is technically sound in that it employs sound assumptions, logic, and associated calculations; and its level of radiative forcing over time could be independently replicated by other models, which represent other sets of assumptions,[5] with scenarios that are considered to be technically sound. In general, scientifically peer-reviewed publication is considered to be an implicit judgment of technical soundness.[6]
- *Comprehensiveness*: Anthropogenic climate change is driven by a number of factors, all of which contribute to radiative forcing of the climate system. The RCPs need to model all of these factors so that they are internally consistent. The radiative forcing factors include the full suite of GHGs, aerosols, chemically active gases, and land use. The CM community will require gridded emissions for aerosols, chemically active gases, and methane, as well as land use/land cover data.
- *Near-term high-resolution scenarios*: One of the RCPs will be used to produce climate change projections at an increased spatial resolution (e.g., 0.5° latitude x longitude) for the first 30 years (to 2035). Using one of the RCPs, rather than a separate scenario, provides near- and long-term continuity.

III.3 Scenarios in the literature and types of RCPs

In the IPCC Fourth Assessment Report (AR4), Working Group III assessed the literature on baseline and stabilization scenarios published since the Special Report on Emissions Scenarios (SRES) and the Third Assessment Report (TAR). More than 300 scenarios were identified in AR4, 147 and 177 of which were baseline and stabilization scenarios, respectively. A significant development since the TAR is the extension of many IAMs beyond carbon dioxide (CO_2) to other GHGs. This innovation has permitted the assessment of multigas mitigation strategies. About half of the scenarios assessed in AR4 were multigas scenarios, including 71 multigas baseline scenarios and 76 stabilization scenarios. While many IAMs

[5] Assumptions can vary across models in terms of, among other things, socioeconomics, technologies, economic structure, atmospheric chemistry, climate modeling, and the carbon cycle.

[6] There are several definitions of robustness in both common and scientific usage. In the context of the RCPs, we use it to mean "well supported," consistent with one of its definitions as "strong or sturdy." The criteria used to establish whether a scenario is well supported are technical soundness and replicability. Earlier in the Technical Summary, robustness is used in a different sense in the context of describing policies that perform well under a variety of assumptions. This usage is based on an alternative definition of robustness as relatively invariant under a wide range of conditions.

have been extended to other gases, to date only a few comprehensively account for the major components of radiative forcing. For the purpose of this report, the radiative forcing trajectories of more than 30 of these comprehensive scenarios were collected to facilitate the identification of candidates for the RCPs.[7] The left panel of Figure 4 shows the range of global average radiative forcing across these scenarios, while the right panel provides a comparison of the CO_2 emissions pathways associated with the comprehensive scenarios in the left panel to the full range of CO_2 emissions pathways in the literature. The right panel therefore provides perspective on the compatibility of the published comprehensive radiative forcing scenarios with the entire published emissions scenarios literature. In general, the CO_2 pathways associated with scenarios providing comprehensive radiative forcing pathways effectively represent more than the 10th to 90th percentile range of CO_2 emissions pathways across the post-SRES literature.[8] This percentile range is not used as a criterion for scenario selection, but provides a useful descriptive measure of the overlap between the ranges of the two sets of scenarios.

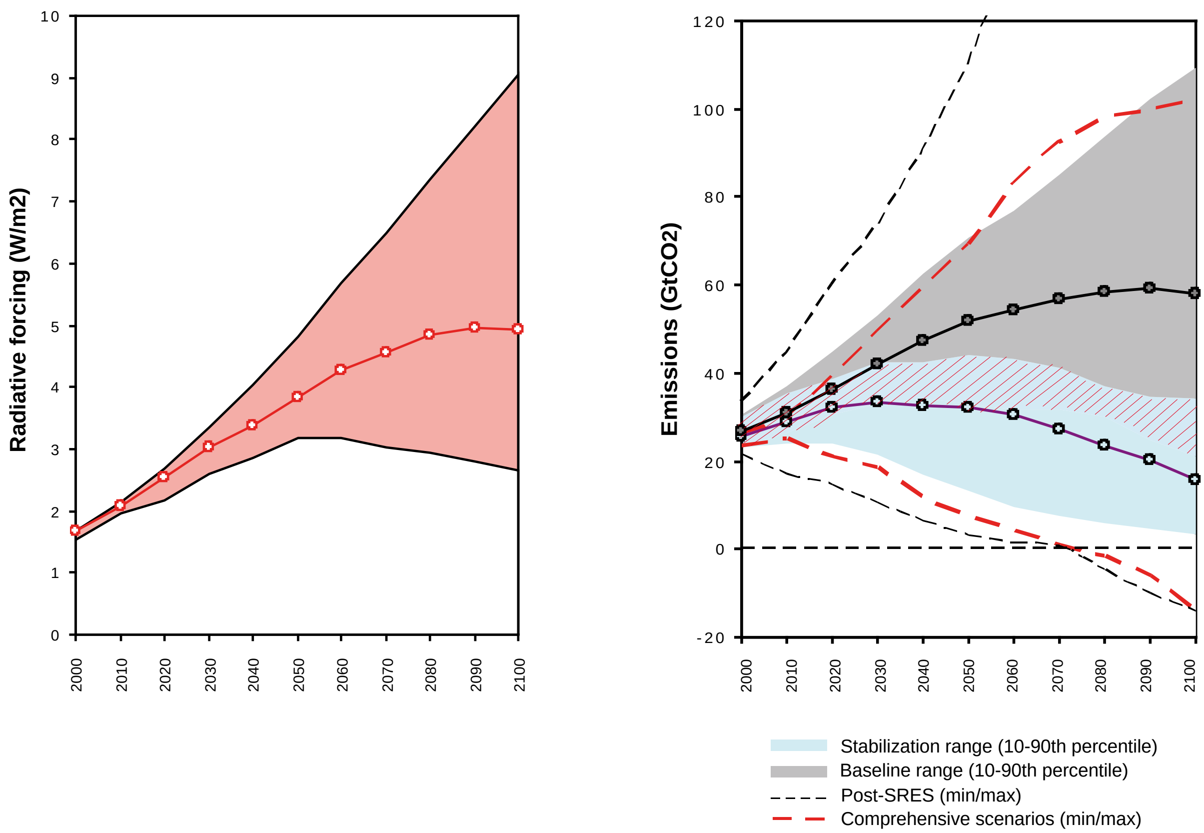

Figure 4. Full range and median of the comprehensive radiative forcing pathways (left panel) and CO_2 emissions pathways for various ranges and medians (right panel). In the right panel, the lines connecting the filled and open circles are medians of the range of baseline and stabilization scenarios, respectively. The red dashed lines denote the full range of energy and industry CO_2 emissions pathways associated with the comprehensive scenarios from the left panel. Data published for these scenarios extend only to 2100; RCPs will need to extend data to 2300.[9]

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7 IAMs in this class compute internally consistent projections of radiative forcing and its major components—the full suite of GHG and non-GHG emissions and concentrations, land use/land cover, and climate, as well as the terrestrial and oceanic carbon cycle (see Table A1.1 in Appendix 1 of the full report). Note that radiative forcing was not available in a comparable format for all 37 scenarios in the literature. Hence, Figure 4 includes forcing for 32 of these scenarios only.

8 "Post-SRES" scenarios are those published in the literature after publication of the SRES in 2000.

9 Note that it was not possible to clearly distinguish between energy/industry and land use emissions for all scenarios in the literature. Therefore, the CO_2 emissions ranges in Figure 4 (denoted by the blue and gray shaded areas in the right panel) include scenarios with both energy/industry and land use CO_2 emissions.

The scenario literature was reviewed with respect to the desirable characteristics of range, number, separation and shape, robustness, and comprehensiveness in order to define types of RCPs. Four RCP types were defined in terms of a radiative forcing level and pathway shape to match the desirable characteristics given the available literature (Table 1).

The set of pathways in Table 1 are representative of the range of baseline and stabilization radiative forcing, concentration, and emissions pathways in the literature, with the full range of available radiative forcing and concentration pathways covered and from the 90th percentile down to below the 10th percentile of GHG emissions covered.[10]

Table 1. *Types of representative concentration pathways.*

Name	**Radiative Forcing**[1]	**Concentration**[2]	**Pathway shape**
RCP8.5	>8.5 W/m^2 in 2100	> ~1370 CO_2-eq in 2100	Rising
RCP6	~6 W/m^2 at stabilization after 2100	~850 CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
RCP4.5	~4.5 W/m^2 at stabilization after 2100	~650 CO_2-eq (at stabilization after 2100)	Stabilization without overshoot
RCP3-PD[3]	peak at ~3W/m^2 before 2100 and then decline	peak at ~490 CO_2-eq before 2100 and then decline	Peak and decline

Notes:
[1] Approximate radiative forcing levels were defined as ±5% of the stated level in W/m^2. Radiative forcing values include the net effect of all anthropogenic GHGs and other forcing agents.
[2] Approximate CO_2 equivalent (CO_2-eq) concentrations. The CO_2-eq concentrations were calculated with the simple formula Conc = 278 * exp(forcing/5.325). Note that the best estimate of CO_2-eq concentration in 2005 for long-lived GHGs only is about 455 ppm, while the corresponding value including the net effect of all anthropogenic forcing agents (consistent with the table) would be 375 ppm CO_2-eq.
[3] PD = peak and decline.

III.4 Climate modeling community prioritization

Given the scientific and computing limitations, and different resource constraints across CM teams, some CM teams may only be able to run a subset of the proposed RCPs. Therefore, the CM community has assigned a preferred order to RCP runs. The priority order for CM RCP simulations is:

1. Both the high and low RCPs at a minimum (RCP8.5 and RCP3-PD);
2. The intermediate-range RCP with near-term resolution (RCP4.5); and
3. RCP6.

[10] The set of scenarios in this literature has been strongly influenced by specifications of intercomparison exercises and continuity with earlier experiments, so it should not be considered a frequency distribution of independent analyses from which relative robustness, likelihood, or feasibility can be deduced.

III.5 Criteria

Based on the identified RCP pathway types and required data, a set of criteria was defined to identify candidate scenarios from the literature. Box 1 summarizes the criteria for selecting candidate scenarios in the peer-reviewed literature that could serve as RCPs. These criteria reflect the desirable characteristics, identified types of RCPs, and data requirements discussed in this report.

III.6 Candidates

Based on the criteria in Box 1, the IAM community identified 20 RCP candidates from the literature, which are listed in Table 2. Note that each asterisk in Table 2 can represent more than one scenario, and some modeling teams produced more than one scenario over time that would satisfy an RCP type definition. Each model and institution listed in Table 2 has scenarios that satisfy all of the criteria for at least one of the RCP levels requested, which was confirmed via consultation with the modeling teams.

Box 1: Criteria for consideration as an RCP candidate

1) Peer-reviewed and published: the pathway must be reported in the current peer-reviewed literature.
2) Types of RCPs: the pathway must correspond to one of the four RCP types that satisfy the desirable characteristics:
   a) RCP8.5 (>8.5 W/m^2 in 2100, rising)
   b) RCP6 (~6 W/m^2 at stabilization after 2100, stabilization without overshoot)
   c) RCP4.5 (~4.5 W/m^2 at stabilization after 2100, stabilization without overshoot)
   d) RCP3-PD (peak at ~3W/m^2 before 2100 and then decline)
3) Data requirements:
   a) Variables: The IAM scenario must project pathways for all of the required variables through 2100—the full suite of GHGs, aerosols, chemically active gases, and land use/land cover.
   b) Long-term/near-term resolution: the existing data and the modeling team must be amenable to finalizing the data as needed for the required resolution using the methods defined from the technical consultations between the IAM and CM communities. These include harmonization of output and base year data, downscaling, and extending published data to 2300 (see Appendix 1 of the full report).
4) Modeling requirement: for reliability, radiative forcing results must have been generated with an IAM that contained carbon cycle and atmospheric chemistry representations.
5) Timeline: the modeling team must be able to deliver the data in a timely manner. Dates will be coordinated with the CM community with the expectation that:
   a) Initial data will be available by the summer of 2008, including (i) a draft full resolution of the data, and (ii) a fully documented scenario.
   b) Final data will be delivered to the CM community no later than the fall of 2008.

It must be stressed that the requirement that scenarios meet the criteria only applies to the selection of RCPs in the preparatory phase. In subsequent phases of the open scenario development process, these criteria will not apply—all models will have full opportunity to participate in all subsequent research phases.

Table 2. *RCP candidates. Asterisks indicate that at least one scenario is available, although there may be more than one.*

IAM (affiliation)[1]	RCP8.5	RCP6	RCP4.5	RCP3-PD	Reference(s)
AIM (NIES)		*[2]	*	*[2]	Fujino et al. (2006), Hijioka et al. (2008)
GRAPE (IAE)			*		Kurosawa (2006)
IGSM (MIT)	*	*	*		Reilly et al. (2006), Clarke et al. (2007)
IMAGE (MNP)	*	*	*	*	van Vuuren et al. (2006, 2007)
IPAC (ERI)		*[2]	*		Jiang et al. (2006)
MESSAGE (IIASA)	*	*	*	*	Rao and Riahi (2006), Riahi et al. (2007)
MiniCAM (PNNL)		*	*		Smith and Wigley (2006), Clarke et al. (2007)

Notes:
[1] AIM = Asia-Pacific Integrated Model, NIES = National Institute for Environmental Studies, GRAPE = Global Relationship to Protect the Environment, IAE = Institute of Applied Energy, IGSM = Integrated Global System Model, MIT = Massachusetts Institute of Technology, IMAGE = Integrated Model to Assess the Global Environment, MNP = Netherlands Environmental Assessment Agency, IPAC = Integrated Policy Assessment Model for China, ERI = Energy Resource Institute, MESSAGE = Model for Energy Supply Strategy Alternatives and their General Environmental Impact, MiniCAM = Mini-Climate Assessment Model, PNNL = Pacific Northwest National Laboratory.
[2] These scenarios are available, but would require revisions to meet the RCP forcing criteria.

III.7 The RCPs

Based on an assessment of the candidates to meet the identified data requirements, the initial proposed RCPs presented to the expert meeting, and input from the research and user communities at the meeting, the Steering Committee has identified the following sources and models for the RCPs:[11]

RCP	Publication – IAM
RCP8.5:	Riahi et al. (2007) – MESSAGE
RCP6:	Fujino et al. (2006) – AIM[12]
RCP4.5:	Clarke et al. (2007) – MiniCAM[13]
RCP3-PD:	van Vuuren et al. (2006, 2007) – IMAGE

The four specific RCPs are based on several considerations:

- All of the candidates have been peer reviewed and published and can provide the required consistent set of data;
- Not all modeling groups whose scenarios were identified as candidates (Table 2) confirmed their willingness to participate in this activity;

[11] See Table 2 notes for definition of model acronyms.
[12] The AIM modeling team revised this scenario slightly to comply with the 6 W/m^2 stabilization criterion. The revised stabilization scenario is published in Hijioka et al. (2008).
[13] The ERI IPAC team is collaborating with the PNNL MiniCAM team on data finalization as it relates to Asia.

- The selected set of models are those capable of satisfying the data requirements and the modeling teams have substantial experience relevant to developing the required data sets;
- The forcing profiles of these models have been analyzed thoroughly, using simple CMs with updated IPCC AR4 parameterization;
- Among the modeling teams represented in Table 2 who are willing to participate, the MESSAGE and IMAGE models can produce scenarios on the high and low end (RCP3-PD and RCP8.5). The IMAGE model was selected for the low pathway, due to the larger number of low stabilization scenarios available from the model. The MESSAGE model was selected for the high scenario, since it can provide an updated and revised A2-like scenario, which would allow comparisons with earlier climate assessments and thus continuity from the perspective of the CM community. This scenario includes features requested by the IAV community, namely a high magnitude of climate change and factors related to higher vulnerability (e.g., higher population growth and lower levels of economic development);
- Both the AIM and the MiniCAM models could provide the required data for the intermediate levels. The MiniCAM model was chosen for RCP4.5, while AIM was chosen for RCP6.

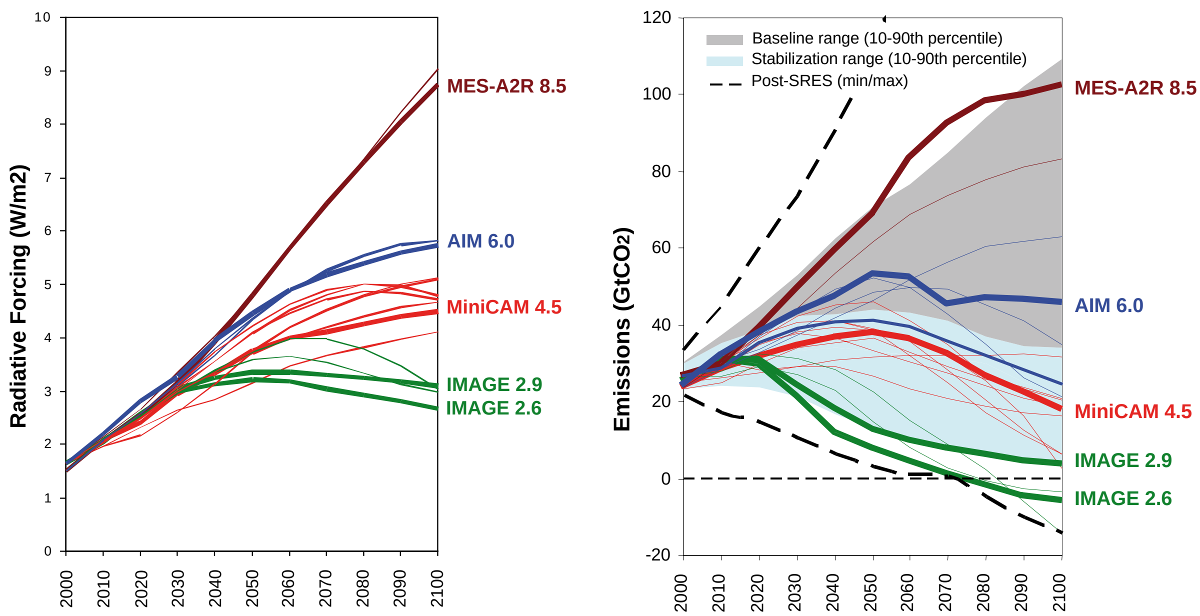

Figure 5. Radiative forcing compared to pre-industrial (left panel) and energy and industry CO_2 emissions (right panel) for the RCP candidates (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature. These percentiles reflect the frequency distribution of existing scenarios and should not be considered probabilities. Blue shaded area indicates mitigation scenarios; gray shaded area indicates baseline scenarios.[14]

[14] Note that it was not possible to clearly distinguish between energy/industry and land-use emissions for all scenarios in the literature. Therefore, the CO_2 emissions ranges in Figure 5 (denoted by the blue and gray shaded areas in the left panel) include scenarios with both energy/industry and land-use CO_2 emissions.

Figure 5 provides an illustrative overview of how the identified RCPs represent the literature—in terms of radiative forcing pathways (left panel) and energy and industry CO_2 emissions pathways (right panel). The four selected RCPs are highlighted as thick colored lines. Thin colored lines represent the 20 candidate RCP scenarios from Table 2. The different colors correspond to the different RCP forcing levels in 2100 (green <3 W/m^2; red ~4.5 W/m^2; blue ~6 W/m^2; brown ~8.5 W/m^2). RCP8.5 (MES-A2R8.5) and RCP3-PD (either IMAGE2.6 or IMAGE 2.9) are at the upper and lower boundaries of the radiative forcing pathways available. However, they are not at the absolute boundaries of emissions pathways published since the TAR. The RCP8.5 is representative of the 90th percentile of the baseline CO_2 emissions range. The RCP3-PD, on the other hand, is representative of CO_2 emissions pathways at or below the 10th percentile. See the main report for the non-CO_2 emissions pathway figures. The two IMAGE model pathways in Figure 5 are discussed next.

III.8 IMAGE 2.6 or IMAGE 2.9 for the low pathway

Based on the expert meeting discussions, the IMAGE 2.6 scenario (van Vuuren et al., 2006, 2007) is conditionally identified as the selection for the RCP3-PD pathway, but its robustness needs to be assessed. If the robustness of the scenario is established by the process outlined below and discussed further in the full report, the IMAGE 2.6 scenario will be used for the low pathway. Otherwise, the IMAGE 2.9 pathway (van Vuuren et al., 2006, 2007) will be chosen. The robustness evaluation will ensure delivery of one of the two pathways via a scientifically rigorous process. Agreement on the nature of the robustness evaluation was reached through consultations between the Steering Committee and the IAMC following the expert meeting (see Appendix 2 of the full report).

The background paper to the expert meeting proposed the IMAGE 2.9 scenario. However, meeting participants expressed an interest in the lowest radiative forcing scenario in the available literature from this class of IAMs.[7,15] The lowest radiative forcing scenario is the IMAGE 2.6 scenario.

The IMAGE 2.6 scenario has radiative forcing that peaks rapidly near 3 W/m^2 and declines to a radiative forcing of 2.6 W/m^2 in 2100. The IMAGE 2.9 scenario peaks at over 3 W/m^2 and declines to a radiative forcing level of 2.9 W/m^2 in 2100.[16] The emissions, concentration, and radiative forcing pathways to 2100 for both scenarios are presented in Figures III.2 to III.6 in the full report. Data finalization requires extension of these scenarios to the year 2300. There is significant policy and scientific interest in radiative forcing pathways that continue to decline. The IAM and CM communities recognize this interest, and have already begun coordinating in order to develop data finalization methods, including methods for extension to 2300. Discussions on how to carry out the extension are ongoing. The planned methods resulting from those discussions are expected to be available for comment through the IAMC.

Meeting participants expressed an interest in scenarios that show a clear peak in radiative forcing and explore the lowest stabilization scenarios published in the literature, as they offer unique scientific and policy insights. A variety of points were made in support of the IMAGE 2.6 scenario for use as the RCP3-PD. First, the IMAGE 2.6 CO_2 emissions pathway, which reaches 7.6 $GtCO_2$ in 2050 as

[15] See Appendix 4 of the full report for some position papers that were distributed at the meeting discussing this point.

[16] Both of the van Vuuren et al. (2006, 2007) scenarios are stabilization scenarios that stabilize by the middle of the 22nd century at radiative forcing levels below 2100 levels. This information was not available in the scenario publications but was obtained through consultation with the IMAGE modeling team. The post-2100 radiative forcing and emissions characteristics of these scenarios may change with the extension to 2300.

compared to 12.8 $GtCO_2$ for IMAGE 2.9, was argued to be more consistent with political discussions regarding particular 2050 emissions reduction objectives and long-run objectives for limiting increases in global mean surface temperature. Second, combined with RCP8.5, the IMAGE 2.6 scenario would span a broader range of radiative forcing and more fully encompass the scenarios literature from all classes of models.[17] Finally, the research communities as a whole found the IMAGE 2.6 peak-and-decline shape, very low radiative forcing pathway, and negative CO_2 emissions scientifically interesting.

However, there was concern about the IMAGE 2.6 scenario because, as presented in the literature, it was exploratory in nature. Like some other very low scenarios, the scenario requires rapid investment in mitigation early in the century and deployment of negative emissions technologies later in the century;[18] however, there were technical concerns about the IMAGE 2.6 characterization of the negative emissions technology. Moreover, recent focus on the diverse consequences of widespread use of bioenergy (including associated nitrous oxide emissions), a requirement in the IMAGE 2.6 scenario, may have important implications. Finally, the IAM community has not yet evaluated the technical feasibility of reaching such low radiative forcing levels. Specifically, the radiative forcing scenario has not yet been reproduced by other models in this class of IAMs (i.e., those that model radiative forcing and its components). In contrast, the IMAGE 2.9 pathway is considered robust in that other models in this class of IAMs published similar peer reviewed results. In this context, recall that robustness means that a scenario is technically sound in that it employs sound assumptions, logic, and associated calculations; and its level of radiative forcing over time could be independently replicated by other models, which represent other sets of assumptions, with scenarios that are considered to be technically sound.

During the meeting discussion, the IAM community noted that the IMAGE 2.9 scenario also satisfies many of the various interests. Both IMAGE 2.6 and 2.9 are overshoot scenarios with peaking and declining radiative forcing, where the peak and decline of IMAGE 2.6 is more pronounced. Both scenarios are included in the lowest class of stabilization scenarios assessed by the IPCC in the AR4 in terms of total radiative forcing (this class contains only three multigas scenarios). Both the IMAGE 2.6 and 2.9 pathways could achieve the target of limiting the global mean temperature increase to 2°C. Based on different probability density functions for climate sensitivity, Meinshausen et al. (2006) estimate the probability of not exceeding 2°C global average temperature increase as 30 to 80% for the 2.9 scenario and 50 to 90% for the 2.6 scenario.

Given the level of interest in the IMAGE 2.6 scenario, the IAMC offered to organize a scientific IAM community exercise and assessment panel for evaluating the robustness of the IMAGE 2.6 scenario for selection as the RCP3-PD. Given the scientific and technical questions raised, the IAMC believes that it is vital to evaluate the scientific question of whether the IMAGE 2.6 scenario is robust before substantial CM community resources are applied in evaluating its climate and atmospheric chemistry implications.[19] The intent of the evaluation is to provide the IMAGE 2.6 scenario if found to be robust.

[17] An additional point was made that IMAGE 2.6 was preferable for climate pattern scaling. However, pattern scaling techniques allow for scaling up or down (see the discussion in Section II.4 of the full report). The full validity of pattern scaling requires further research.

[18] The negative emissions technology is bioenergy combined with CO_2 capture and storage (CCS) that *ceteris paribus* has a net negative effect on atmospheric concentrations of GHGs. While bioenergy-based mitigation strategies are assumed in both the IMAGE 2.6 and 2.9 scenarios, it is the combination of bioenergy with CCS that is novel in IMAGE 2.6.

[19] Technical concerns were not raised about the other proposed RCPs, and each has been replicated.

Should the exercise be unable to establish the robustness of the IMAGE 2.6 scenario, the published (and replicated) IMAGE 2.9 overshoot scenario will be provided to the CM community instead to serve as the low RCP. So as not to delay the hand-off of data to the CM community, the IMAGE modeling team will be preparing the required CM input data from both the published IMAGE 2.6 and 2.9 scenarios.

Agreement on the nature of the robustness evaluation was reached through consultations between the Steering Committee and the IAMC following the expert meeting through a series of four letters (see Appendix 2 of the full report). To ensure the scientific credibility and transparency of the evaluation, the IAMC will appoint a panel that will be responsible for providing a consensus recommendation on the robustness of the IMAGE 2.6 scenario. Based on its robustness assessment, the panel will provide a single recommendation on whether the IMAGE 2.6 or IMAGE 2.9 scenario should be used for the lowest RCP. While panel members may not necessarily agree on all aspects of the robustness of the IMAGE 2.6 scenario, they are asked to provide a single recommendation on whether or not it should be considered robust to the IAMC as the convening body, which will then transmit the finding to the Steering Committee for expected confirmation of the recommendation. The conclusions of the evaluation panel will be provided to the IPCC in a letter report that will provide a detailed description of the full evaluation process and results.

The assessment process will be based on two general criteria, both of which must be met by the IMAGE 2.6 scenario: technical soundness and replicability. For the former, the IAMC will ask the modeling teams to (a) review the published IMAGE 2.6 scenario for technical soundness (i.e., assumptions, logic, and associated calculations), and (b) address any technical issues that arise from that review. The IMAGE modeling team will lead an evaluation of the technical components of the IMAGE 2.6 scenario, particularly those that distinguish the scenario from the IMAGE 2.9 scenario, namely the representation of bioenergy combined with CO_2 capture and storage (CCS). If the team review reveals fundamental problems with the IMAGE 2.6 scenario that have significant bearing on the scenario and cannot be addressed with minor revisions, it will not be selected as an RCP. The findings from this assessment will be made available to the review panel for consideration.

For replicability, the IAMC will ask all the IAM teams working with this class of models to participate in the design and development of low stabilization scenarios that replicate key radiative forcing features of the IMAGE 2.6 pathway shape (i.e., peaking rapidly near 3 W/m^2 and declining to around 2.6 W/m^2 in 2100). The modeling teams will be asked to employ their standard assumptions and include bioenergy and CCS, but avoid non-traditional assumptions like geo-engineering, dramatic dietary changes, or severe economic collapse. This term of reference provides some structure for the modeling that is broadly consistent with the IMAGE 2.6 scenario. Replication will be deemed successful if both of the following occur: (a) the IMAGE team, after addressing any modest technical issues identified in their assessment of the IMAGE 2.6 scenario, is able to generate the scenario using the latest version of the IMAGE model; and (b) at least two of the other IAM models in this class are able to generate a scenario with a similar radiative forcing pathway that is considered to be technically sound.

The panel will ensure that the evaluation is conducted in a careful, scientific, and unbiased manner, and will develop and apply a set of broad criteria to be considered in the evaluation of the technical soundness of the replication scenarios. The panel is invited to consider, among other things, technical soundness of the representation of key technologies, internal plausibility and consistency of the technology portfolio, GHG and carbon cycle accounting, land use implications, and economic considerations relative to the 2.9 W/m^2 pathway. In addition, scenario analysis by the modeling teams might identify important new criteria, in which case these would be clearly communicated by the panel in its letter report.

III.9 Further research on scenarios with very low radiative forcing levels

Given the growing interest of the international community in scenarios with a clear peak and decline in radiative forcing and very low stabilization levels, it is strongly recommended that governments and funding agencies support further research on scenarios that peak and then decline to very low stabilization levels.

IV. Institutional and Coordination Issues

Because the new scenario development and implementation process outlined in this report is innovative in so many ways—including its approaches to scenario development and elaboration, its linkages among a range of contributors to climate change research, and its linkages between them and users of the scenarios and other interested stakeholders—it raises a number of issues for coordination, data management and exchange, and institutional development. Resolving these issues will require the active involvement of existing research coordination mechanisms such as the Earth System Science Partnership, the World Climate Research Programme, the International Geosphere-Biosphere Programme, the International Human Dimensions Programme, and the IAMC. It may also be necessary to create new mechanisms where institutions are lacking, for example, to improve coordination and problem solving within the IAV community (see Section IV.4 of the full report).

IV.1 Coordinating with end users

Many national and international organizations think about the future from their own perspectives, and this necessarily entails considering the potential implications of climate change for a diverse range of activities such as development planning, food production and distribution, provision of water resources, conservation of protected environments, and management of other environmental issues as diverse as reducing local air pollution and slowing desertification of soils.

A further issue to explore is whether there is value in bringing together like-minded international organizations to contribute to climate-change related scenario development, and to consider a common core of assumed futures around which individual organizations can develop more detailed assumptions for their own specific purposes. The IPCC could convene a group on global change scenarios among organizations such as the UNFCCC, the United Nations Food and Agriculture Organization, the World Bank, the United Nations Environment Programme, the World Health Organization, the United Nations Development Program, and major NGOs and private sector organizations that require climate change and associated socioeconomic scenarios for their own planning purposes.

Other possible ways of organizing the end user–scenario developer dialogue can also be envisioned. These include, for example, having a set of meetings with selected stakeholder groups (rather than organized user groups) over the course of the scenario development process. Another option would be for the IPCC bureau to undertake facilitation of the dialogue during IPCC plenaries and other meetings of interested parties. Designing a scenario process website in an open and interactive way could also encourage feedback from potential users. A final option that has proved useful in other environmental science and policy subject areas is to identify technically proficient members of user groups to be linked individually with scenario development and implementation as "bridges" between the core scenario science and potential uses of the scenarios. Outlining the resources that will be required for these coordination efforts is a critical component for successfully integrating other potential users into the process. It is also important to consider these coordination issues in the context of progress towards a possible AR5.

IV.2 Coordinating across the research communities

Developing a new international climate change scenario infrastructure, built on full collaboration among the CM, IAM, and IAV scientific communities, is clearly essential for supporting climate change response decisions in the future. It requires, however, connecting three research communities that in most regards lack a tradition of working together and in some cases may not automatically see such close coordination as a high priority for their time and resources. An example that highlights a community priority for coordination is recent developments in the evolution of the physical climate models to new ESMs that include, for instance, dynamic vegetation and biochemistry. These new, coupled biophysical-climate models may produce conflicting land cover and emissions estimates relative to the IAM scenario projections. It will be important for these communities to develop a consistent strategy with regard to land use and emissions for a possible AR5. The parallel process described in this document provides a strategy for explicit engagement between the communities. Overcoming obstacles to inter-group coordination is therefore key.

In support of the new international climate change scenario infrastructure, several steps are needed and under consideration by the research community that will require communication with, between, and across sector experts for action by the middle of calendar year 2008:

(1) An IAM/IAV meeting to develop a joint strategy for storyline development, including plans for regional participation, encouraging especially more participation of developing country/economies in transition (DC/EIT) researchers;
(2) An IAV expert workshop to propose steps to build structure and add coherence to the work of that community, especially as it relates to new scenario development, and facilitating in particular the participation of DC/EIT researchers;
(3) An IAM/IAV meeting to develop plans for the scenario library; and
(4) A joint IAM/IAV/CM discussion that provides shared insights into model assumptions and requirements within and across modeling groups.

Several other steps are also needed over the coming two years in order to address a variety of challenges in moving toward new integrated scenarios of broad value to the climate change research, policy, and stakeholder communities:

(1) A CM/IAM/IAV community expert workshop to pursue a collaborative approach to climate change downscaling and its relationships with bottom-up regional and local storyline development, with the participation of DC/EIT researchers encouraged. In addition, challenges regarding nonlinearities and lags related to pattern scaling will need to be addressed.
(2) An IAM/IAV community meeting to develop strategies for improving the integration of mitigation into IAV analyses;

(3) A joint CM/IAM/IAV community meeting with selected stakeholder groups to assure sensitivity to stakeholder concerns and information needs, with a special focus on DC/EIT countries particularly prone to severe climate change impacts in the near term;
(4) A CM/IAM/IAV community meeting to exchange information about current data management assets and practices and to identify steps that would improve prospects for data integration, with active participation of DC/EIT country experts; and
(5) A CM/IAM/IAV community expert workshop on a topic of interest to all three communities, using that topic both to advance understanding of the subject and to enhance communication among the communities (e.g., sea ice/sea level rise/coastal impacts and adaptation).

V. Increasing Developing Country Participation

Many policymakers and stakeholders in developing countries are now considering their own climate change response strategies and assessing their particular vulnerabilities and potential impacts. Since the IPCC AR4 indicated that developing countries are likely to bear a disproportionate share of climate change impacts, the development of more representative models, scenarios, land use/land cover monitoring, and other planning tools has taken on special urgency there. Intensified efforts to involve scientists from developing countries in the scenario creation process will be needed to ensure that the representation of developing regions in key models and scenarios has sufficient resolution and accuracy to support sound climate change responses in these areas.

Through its decision on further work on emissions scenarios at its 25th Session (April 2006, Mauritius) the IPCC requested that the expert meeting consider the ongoing problem of identifying and involving sufficient expertise from Africa, Asia, Latin America, island states, and from countries with economies in transition, principally in Central Europe and the former Soviet Union.

Future efforts to increase and sustain DC/EIT participation in climate change assessments must address a series of challenges that have contributed to their under-representation to date. Among these is the need for the expansion of expert and institutional scientific capacity in developing regions. There is significant variance in current levels of scientific capacity within and among developing regions, resulting in a corresponding variance in capacity for participation in international scenario development efforts and climate change assessments. Likewise, there is an ongoing need for more funding and for new funding mechanisms to support the continued participation of DC/EIT representatives in international scientific activities related to climate change. Addressing capacity and funding limitations to enhanced DC/EIT participation will demand concerted outreach and integration initiatives on the part of the broader international research and policy communities.

V.1 Recommended Actions

The following proposed actions constitute the elements of a plan to promote the accelerated development of DC/EIT capacity and enhance the participation of these regions in future scenario development and climate change assessment. The recommendations are grouped according to their relevance to each of the specific challenges mentioned above, although there is inevitably and necessarily overlap among recommendations in each area.

A principal recommendation is that the IPCC sponsor a workshop in 2008 dedicated to addressing the manifold challenges associated with efforts to expand DC/EIT scientific capacity and participation in international scenario development and climate assessment activities. Such a workshop would provide an opportunity for key members of the research community to begin discussing and prioritizing the actions listed below, to identify additional or alternative recommendations, and to initiate the development of new inter-/intra-regional networks for sustained DC/EIT capacity building and deeper participation in the international research community.

Additional specific recommendations include:

1. Modeling and Scenario Development

- Inventory and assess current intraregional modeling representation in DC/EIT countries and identify data and institutional needs, capacity limitations, and opportunities for/barriers to intraregional coordination and linkage among IAM and ESM teams.
- Inventory and assess current DC/EIT representation in key global IAMs and ESMs. Key issues to address include key variables, data sources and availability, scalability, and questions of intraregional aggregation.
- Foster collaboration among DC/EIT modelers for intraregional model integration and for collaborative efforts with global modelers for the improvement of DC/EIT representation, the development of new regional storylines and scenarios, and for scenario downscaling/upscaling and pattern scaling in preparation for a possible AR5.

2. Expert and Institutional Capacity Development

- Establish and sustain DC/EIT scientific peer groups to identify key areas for capacity development and expansion, and for the nomination of peers as potential participants in future modeling and scenario development institutions.
- Promote intra- and trans-regional DC/EIT modeling and scenario development initiatives, modeled on existing programs such as those managed by the System for Research, Analysis, and Training and other institutions with training and capacity-building missions, to develop deeper and broader scientific capacity in DC/EIT regions and to expand data development and availability, as described in the 2005 Task Group on Data and Scenario Support for Impact and Climate Analysis framework proposal. Capacity building for downscaling and upscaling of model results should be a key area of emphasis.
- Establish an online network/clearinghouse of DC experts and institutions to familiarize the international scientific community with existing capacities, foster communication among individual researchers and modeling groups, and call attention to geographic and disciplinary areas in which additional capacity building is needed.

3. Funding DC/EIT participation and capacity development

- Identify potential donor institutions for sustained financial sponsorship of capacity building efforts. These might include multilateral institutions (e.g., World Bank, regional development banks), international organizations such as the United Nations Development Programme, national governments, and private scientific and educational foundations such as the Gates Foundation.
- Identify potential collaborating centers and institutions to serve as lead agencies for the management of funding for future efforts to build DC/EIT capacity and participation and to serve as grantmaking and networking institutions.

- Establish a trust dedicated to funding fellowships for young scientists from DC/EIT regions to study and work abroad with leading modelers and scientific research groups.

4. Coordination and Outreach

- Identify key areas for capacity building, research, and storyline and scenario development; existing DC/EIT data limitations and needs; IAV assessment capacity needs; and potential avenues of inter-regional coordination and financial support for sustained efforts to address these problems.
- Promote stronger coordination between DC/EIT researchers and user community members beginning with new outreach efforts on the part of key data and research institutions. For example, the Program for Climate Model Diagnosis and Intercomparison and the IAMC could be primary vehicles for outreach to DC/EIT by the CM and IAM communities, respectively.
- Promote exchanges and collaborative efforts between DC/EIT regions and modeling groups in industrialized countries to develop capacity in regions and in areas currently receiving less attention in DC/EIT areas and to establish institutional relationships among younger modelers and emerging groups in key DC/EIT countries and established groups in industrialized countries.

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This report summarizes the findings and recommendations from the Expert Meeting on New Scenarios held in Noordwijkerhout, The Netherlands, 19-21 September 2007. It is the culmination of the combined efforts of the New Scenarios Steering Committee, an author team composed primarily of members of the research community, and numerous other meeting participants and external reviewers who provided extensive comments during the expert review process.

The expert meeting included presentations focused on needs for scenarios as seen from a policymaking perspective, a review of past IPCC scenarios, overviews of evolving plans in the research community, needs and opportunities for scenarios on two different time scales ("near term"—to 2035, and "longterm"—to 2100, extended to 2300 for some applications), and a review of options for the benchmark scenarios, referred to in the report as "Representative Concentration Pathways" (RCPs). Additional presentations addressed institutional issues and options for increasing participation by developing and transition-economy countries. The remainder of the meeting was organized around a series of breakout groups and plenary sessions that provided an opportunity for the research communities to further coordinate their plans, to refine the proposal for the RCPs, and to consider additional cross-cutting issues.

This material has not been subjected to formal IPCC review processes. The expert meeting was agreed in advance as part of the IPCC work plan, but this does not imply working group or panel endorsement or approval of this report or any recommendations or conclusions contained herein. The full report is available from the IPCC Secretariat.