RCP Extension White Paper

Note: This draft white paper was prepared on the basis of a teleconference held Tuesday, June 30, 2009 organized by the Task Group on Data and Scenarios for Impact and Climate Analysis (TGICA) of the IPCC. The aim of the teleconference was to discuss proposals developed by the Integrated Assessment Modelling Consortium (IAMC) working group on the RCP extensions and to get initial feedback from the IAV and climate modeling communities with regards to the preferred options. The participants of the call included representatives from involved research communities and IPCC's three Working Groups and are listed in the appendix. The draft is currently being circulated openly within the climate research community for technical comments. The white paper was drafted by Detlef van Vuuren (PBL), Keywan Riahi (IIASA), Steve Smith (PNL), and Malte Meinshausen (PIK) on behalf of the working group on RCP extensions (IAMC), and Michael Mastrandrea (IPCC TSU-WG2) and Richard Moss (WWF/IPCC-TGICA). Please address comments to Van Vuuren (detlef.vanvuuren@pbl.nl), Mastrandrea (mikemas@ipcc-wg2.gov) and Moss (rmoss@umd.edu).

Introduction

A new set of scenarios to facilitate future assessment of climate change, compatible with the full range of stabilization, mitigation and baseline emission scenarios available in the scientific literature, have been developed by the research community. Four Representative Concentration Pathways (RCPs) have now been agreed upon that specify radiative forcing through the end of the 21st century. The radiative forcing and CO_2 emissions over time for these scenarios are pictured in Figure 1. Information on the RCPs and the process for development of new scenarios can be found in a series of publications, including information can be found in a number of technical papers and reports (Meehl et al. 2007; Hibbard et al., 2007; Moss et al., 2008; van Vuuren et al., 2009).

Note that the philosophy of the RCP scenarios is to provide a single implementation of concentrations and radiative forcing in line with the scenario literature as evaluated for IPCC AR4. It is part of the AR5 process to characterise the uncertainties in a comprehensive manner.

The climate modeling community requested that these scenarios also be extended to 2300 in order to explore the long-term response of the climate system to greenhouse gas forcing. Proposals for extension rules have been made in 2 previous workshops (Washington 2008, Snowmass 2008) – as reflected in the "handshake document" (van Vuuren et al., 2008). Representatives of the IAMC have further explored the impact of these rules and put forward a set of options for discussion. This note presents these proposals and the response to these proposals by the teleconference and is intended to spark additional comments and suggestions, before the recommendations are finalized in August 2009.

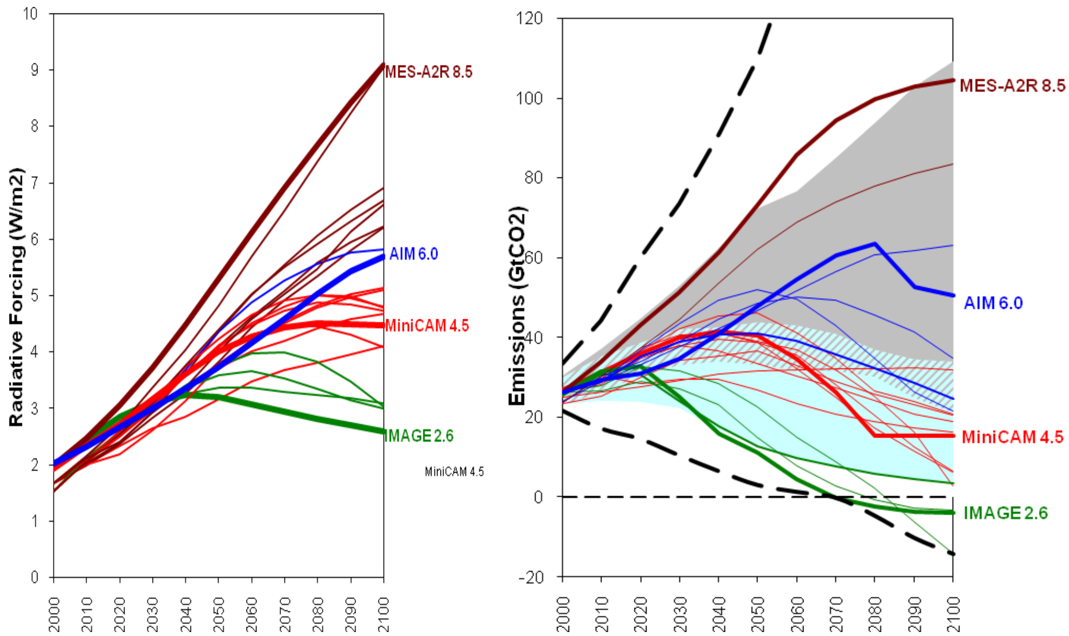

Figure 1. Radiative forcing relative to pre-industrial conditions (left panel) and energy and industry CO2 emissions (right panel) for selected RCPs (colored lines), and for the maximum and minimum (dashed lines) and 10th to 90th percentile (shaded area) in the post-SRES literature Blue shaded area indicates mitigation scenarios; gray shaded area indicates reference scenarios (Figure from Moss et al., 2008).

Rationale

The primary purpose of these extensions is to investigate long-term climate dynamics and changes important for impacts assessment, such as sea level rise. A common set of extended pathways allows comparison among climate models. As discussed in the RCP handshake document (van Vuuren et al., 2008), the IAM community views post-2100 to be beyond the range of reasonable projection of socioeconomic development, given the deep uncertainty inherent in projecting socioeconomic trends. Thus, these extensions were agreed to be specified as extrapolations based on simple rules, to avoid possible interpretation as true "scenarios."

While it is possible to apply one simple rule for extrapolation to all RCPs, this may miss important opportunities for model experiments to study long-term climate dynamics. Therefore, a balance must be struck between simplicity and capacity to achieve the goal of the extensions.

Based on the purpose of the extension, criteria that we have used in evaluating extension options include:

- Relevance for exploring long-term dynamics of the climate system;
- Relevance for exploring ranges of possible impacts;

- Inclusion of long-term features not previously included in model comparison exercises, such as peak-and-decline behavior;
- Facilitation of comparison across the different extensions;
- Use of simple rules to avoid interpretation as scenarios.

Extension Options

To produce extended pathways for radiative forcing, assumptions must be made regarding fossil CO_2 emissions, non-CO_2 emissions, and land use emissions. The discussion that follows focuses initially on fossil CO_2 emissions, as these represent by far the largest contribution to radiative forcing in the long-run (see also Strassman, 2008). Other emissions are discussed subsequently.

Simple rules that can be used to produce pathways beyond 2100 include:

(i) Constant emissions (emissions are held fixed at their 2100 level)

(ii) Constant forcing (radiative forcing is held fixed at its 2100 level)

(iii) Adapted emissions (changing emissions/forcing subject to a simple rule, e.g., constant percentage annual change)

Clearly, the first two rules are somewhat simpler than the third. The third rule could, however, add attractive attributes to the set of scenarios. However it was noted that the use of adapted emissions introduces complexity and may be difficult to communicate compared to the inherently simpler (i) and (ii).

Figure 2 depicts the approximate radiative forcing trajectories resulting from application of a selected set of extension options (as explained further below). Figure 3 depicts fossil energy and industrial CO_2 emissions for RCP 8.5 and 3-PD under different extension options.

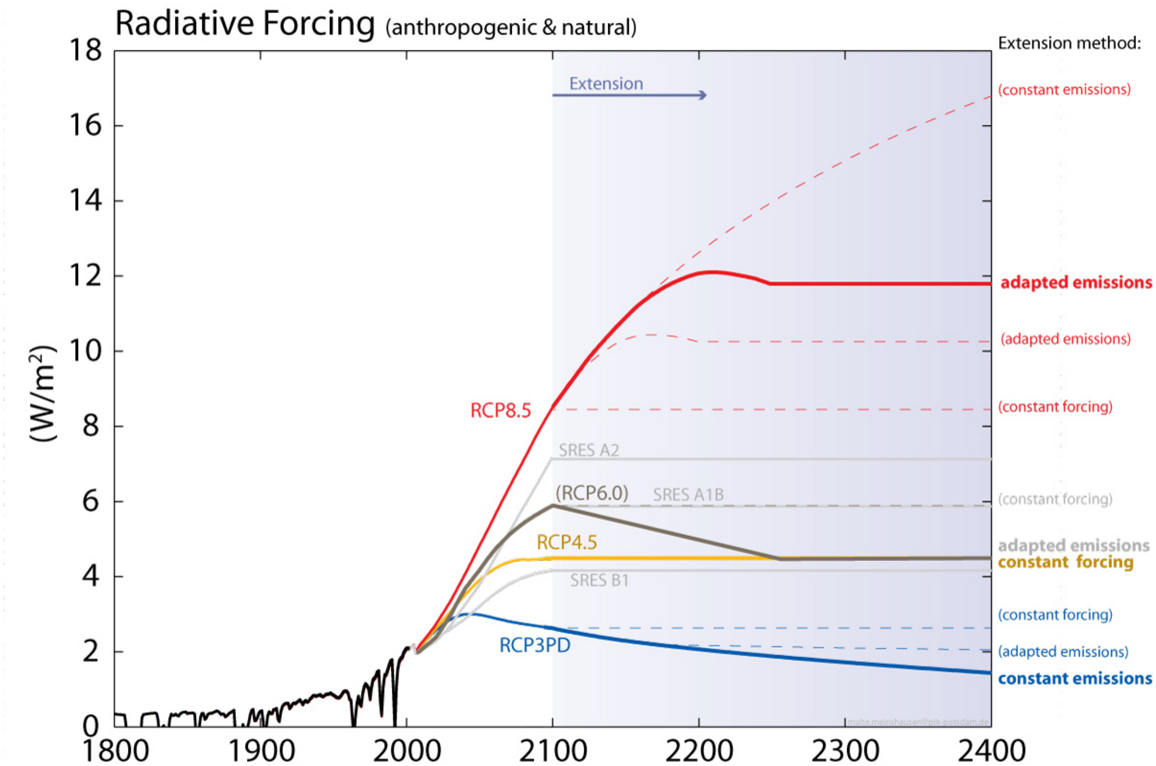

Figure 2: Schematic illustration of radiative forcing in line with a set of extension proposals developed by Detlef van Vuuren, Malte Meinshausen, Steve Smith, and Keywan Riahi. Solid bold lines post-2100 indicate the proposed recommendations by the teleconference participants with dashed lines indicating additional extension possibilities under alternative extension rules. Note that the final RCP6.0 pathway is not yet available and has been approximated here for illustrative purposes.

Proposals

We briefly discuss the options and the proposal for the various RCPs.

RCP3-PD

Under RCP3-PD, forcing peaks by 2050 at ~3 W/m^2, and decreases to 2.6 W/m^2 by 2100. Thus, emissions are negative in 2100, and radiative forcing is declining. Options include holding radiative forcing constant, holding emissions constant or developing an intermediate pathway in which radiative forcing continues to decline for some time beyond 2100 but eventually stabilizes further in the future. This additional option was proposed to reflect the possibility of limits on negative emissions. Figure 2 displays radiative forcing, and Figure 3 fossil fuel and industrial CO_2 emissions for three extension options.

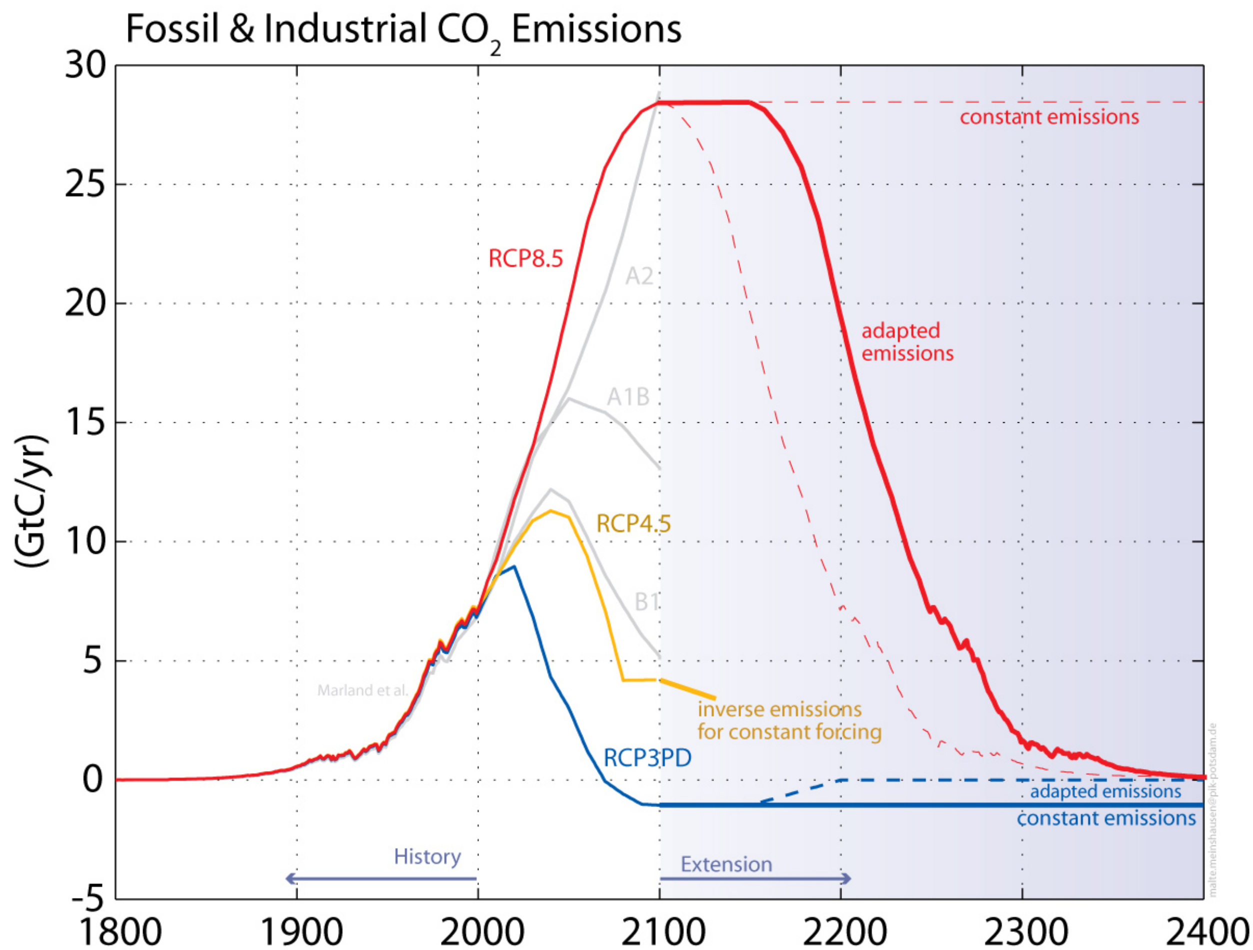

Figure 3: Illustration of fossil energy and industrial CO_2 emissions beyond 2100 following the various extension proposals. Solid extended lines indicate the consensus of the participants.

Recommendation: Constant Emissions

There was tentative agreement among the participants that a pathway involving declining radiative forcing beyond 2100 was preferable for consistency with the pre-2100 pathway and the peak & decline ("PD") design specification. Further, the participants agreed that the capacity to sustain negative emissions after 2100 could not be ruled out. Therefore, the participants tentatively agreed on a pathway assuming constant emissions. Such a pathway is lower than has been run to date by complex earth system models and allows investigation of climate dynamics and long-term impacts under a slow decline in radiative forcing.

RCP4.5

RCP4.5 is already close to stabilization of radiative forcing at 4.5 W/m^2 in 2100. CO2 concentrations and radiative forcing are held constant after 2100. Figure 2 displays radiative forcing for this extension option.

Recommendation: Constant Forcing

The consensus among participants was that the simplest and most appropriate assumption for this pathway is constant forcing beyond 2100. Such a pathway allows investigation of climate dynamics and long-term impacts under constant radiative forcing—a straightforward stabilization pathway.

RCP6

RCP6 exhibits increasing radiative forcing, slowing over time and reaching approximately 6 W/m^2 by 2100[1]. Similar as in RCP4.5, CO2 concentrations are close to stabilizing. Therefore, a similar assumption of constant forcing could be made, in which radiative forcing is stabilized at 6 W/m^2. Alternatively, this RCP could be used to explore in more detail the irreversibility of climate change and its impacts, a topic relevant to research and policy making. Therefore, an alternative pathway for RCP6 is one that peaks at 6 W/m^2 in 2100 and declines thereafter, stabilizing at 4.5 W/m^2. Such a pathway allows direct comparison of the climate response with that under the RCP4.5 stabilization scenario, to examine differences between an overshoot and non-overshoot scenario stabilizing at the same level. Figure 2 displays a schematic radiative forcing illustration for these extension options, although a later convergence towards 4.5 W/m2 is possible.

Recommendation: Adapted Emissions

A majority of the group thought that the extension for RCP6 where emissions would return to 4.5 W/m2 (peak) would provide a unique opportunity by which to investigate the issue of irreversibility and the projected impacts under such a large overshoot pathway. Such pathways have not been run by complex earth system models comparisons in the past. The design of the extension will deliberately be simple still – to make sure that it is not misinterpreted as a scenario based on socio-economic modeling. A minority favored the stabilization at 6 W/m^2.

RCP8.5

Under RCP8.5, radiative forcing is still increasing in 2100, and emissions are still high. An assumption of constant emissions would result in very high radiative forcing (above approximately 16 W/m^2 under default assumptions), with indefinite increase (and concentrations in 2300 of ~3000ppm CO_2). There was some concern that such high concentrations might be outside the range to which climate and carbon cycle models have been calibrated, and questions were raised regarding the consistency of such a pathway with fossil fuel reserves. Constant forcing would hold radiative forcing fixed at 8.5 W/m^2, but would introduce a discontinuity with very rapid decline of emissions, which would not be consistent with the rising emissions pathway of the RCP to 2100 (and would also not explore part of the range of possible outcomes). An intermediate pathway, would allow emissions to decrease more smoothly over time, leading to stabilization of radiative forcing at a level higher than 8.5 W/m^2 and dependent on the rate of emissions decline. Two proposals were presented that reflected a decrease in emissions symmetrical to the increase prior to 2100, one reaching close to 12 W/m^2 at stabilization, one reaching just above 10 W/m^2. Figures 2 and 3 display radiative forcing and annual emissions for these extension options.

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[11] The RCP6.0 pathway is not yet available, and has been approximated for illustrative purposes.

Recommendation: Adapted Emissions

Most participants favored to use an intermediate pathway in which post-2100 emissions decline over time, leading to stabilization of radiative forcing at either about 10 or 12 W/m2. Such a stabilization scenario at this high level of radiative forcing has not been run in complex earth system models. Based on further discussions, the drafters of this document recommend the higher stabilization pathway, which would provide a wider range of radiative forcing across the RCP extensions.

Land use, non-CO_2 gases and other Emissions

Extension of CO_2 emissions from land use and of non-CO_2 forcing agents were also discussed. For the sake of simplicity (and in particular to allow easy interpretation of the results), the following proposals are made:

- Land use pattern is frozen at 2100 for all extensions.
- Land use related CO_2 emissions would be equilibrated to zero after, e.g., 2125. The resulting emissions are depicted in Figure 4.
- Non-CO_2 gas forcing is frozen after 2100; most of the emissions originate from agriculture so this assumption can be seen as consistent with the land use assumption.
- The radiative forcing of all air pollutants is frozen after 2100. For nearly all gases, radiative forcing is low in 2100 and has been declining.

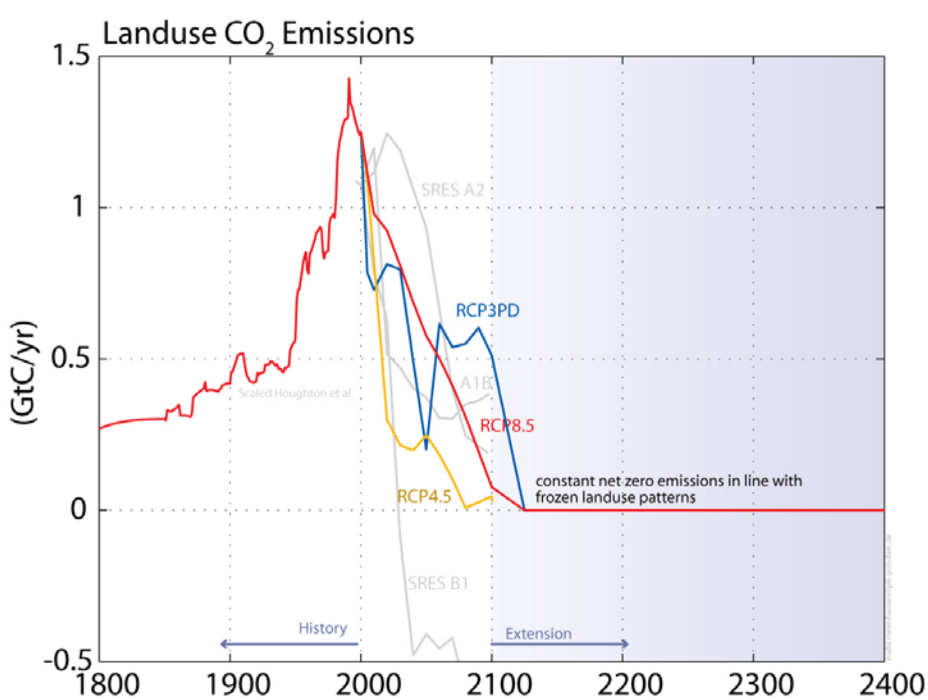

Figure 4: Extended CO_2 emissions from land use patterns approximately corresponding to the frozen land use patterns at 2100. For comparison, land use CO_2 emissions from several SRES scenarios are shown (grey lines).

Summary and Conclusion

A large amount of work has gone into preparing the RCP data for transfer to climate modelers. As discussed in the IPCC Expert Meeting on New Scenarios report, an additional step in setting the stage for climate modeling was to suggest RCP extensions to facilitate coordinated modeling and intercomparison of model experiments to explore slow climate processes. In summary, the proposed recommendations for the extensions are:

RCP3-PD: Constant Emissions (declining radiative forcing after 2100)

RCP4.5: Constant Forcing (stabilized at 4.5 W/m^2)

RCP6: Adapted Emissions (overshoot pathway peaking at 6 W/m^2 and stabilizing at 4.5 W/m^2)

RCP8.5: Adapted Emissions (stabilizing near 12 W/m^2)

References

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Strassman, K., Plattner, G-K, and Joos, F. (2008). CO2 and non-CO2 radiative forcings in climate projections for twenty-first century mitigation scenarios. Clim Dyn. DOI 10.1007/s00382-008-0505-4 van Vuuren, D.P., Feddema J., Lamarque J-F, Riahi K., Rose, S., Smith, S. Hibbard, K. (2008). "Work plan for data exchange between the Integrated Assessment and Climate Modeling community in support of Phase-0 of scenario analysis for climate change assessment (Representative Community Pathways)." See http://www.aimes.ucar.edu/docs/RCP_handshake.pdf.

Appendix: Call Participants

IAMC workgroup on RCP extension: Malte Meinshausen (PIK), Keywan Riahi (IIASA), Steve Smith (PNNL), Detlef van Vuuren (PBL)

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