A Strategy for Climate Change Stabilization Experiments with AOGCMs and Earth System Models

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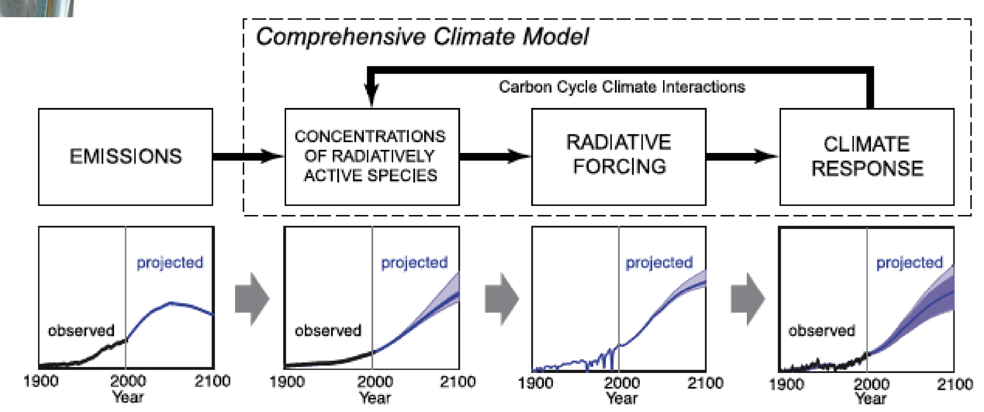

Figure 1. Several steps from emissions to climate response contribute to the overall uncertainty of a climate model projection (Meehl et al. 2007).

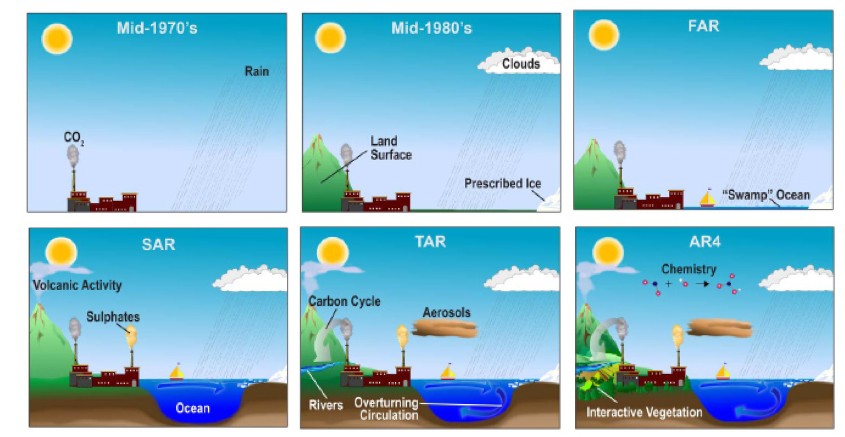

Figure 2. Evolution of Atmospheric General Circulation Models to Earth System Models through the IPCC process.

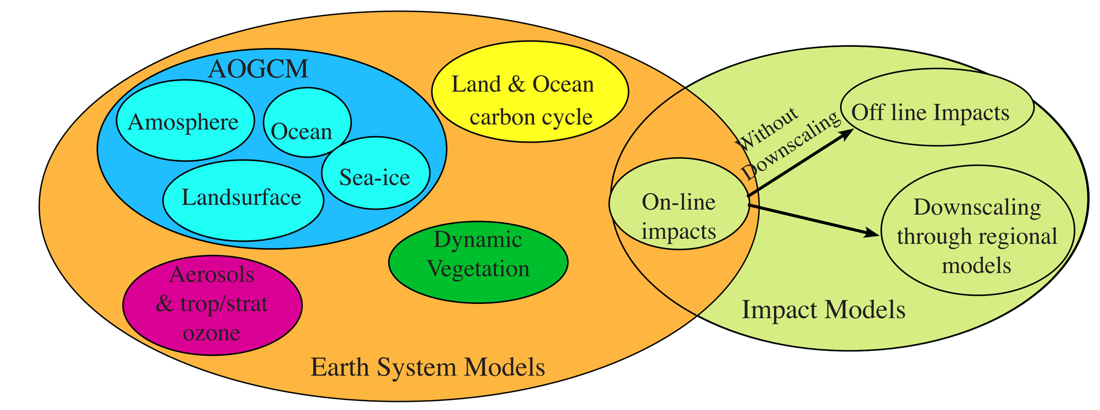

Figure 3. Major components of AOGCMs (blue) and ESMs (orange) and relationship to impact models and downscaling analyses.

What is the current status of climate and earth system models?

In 2006, the Analysis Integration and Modeling of the Earth System (AIMES) core project of the International Geosphere-Biosphere Programme (IGBP) and the Working Group on Coupled Models (WGCM) of the World Climate Research Programme (WCRP) led a series of workshops towards the use of Earth System Models (ESMs) and Atmosphere-Ocean General Circulation Models (AOGCMs) in climate change assessments (Hibbard et al. 2007). Today, standard climate models evolved from atmospheric, to coupled atmosphere-ocean models, or AOGCMs, including components that simulate the coupled atmosphere, ocean, land, and sea ice (Figure 2). Some modeling centers are now incorporating carbon cycle models into AOGCMs in a move towards an Earth System Model (ESM) capability. Additional candidate components to include in ESMs are aerosols, chemistry, ice sheets, and dynamic vegetation (e.g., Cox et al. 2000, Friedlingstein et al. 2006). The scenario approach used in all Intergovernmental Panel on Climate Change (IPCC) Assessment Reports to date developed atmospheric concentrations and their derived emissions based on story lines (Figure 1). We discuss a new strategy for using climate system models as part of a biophysical-climate and integrated assessment approach. The motivation is to develop a next-generation experimental design that follows on prior strategies, with increased coordination and collaboration between climate, integrated assessment, mitigation and adaptation communities. We present a two-phase strategy for near-term and longer-term climate change simulations for AOGCM and ESMs (Figure 3).

Near-term experimental design (2005-2030)

A major goal for 25-year model projections is to provide better guidance about the likelihood of changes in climate extremes at regional scales. Meeting this challenge will require understanding the processes that produce extremes related to the hydrological cycle, and on understanding relevant atmospheric and oceanic processes that operate on appropriate timescales. Regional-scale predictions will require finer-resolution spatial models that incorporate simple chemistry, aerosols, and dynamic vegetation. On this short timescale, carbon cycle feedbacks would be small and a carbon cycle component would not be included.

Determining the significance of regional changes, and especially those of climate extremes, will require numerous simulations in an ensemble approach. Given that scenarios of long-lived greenhouse gases do not differ substantially prior to 2030, a single, midrange scenario will be used here for model predictions. On this short timescale, additional experiments are possible with higher resolution models. For example, several scenarios for pollutants (aerosols and short-lived gases) to study their effects on weather could be provided for low, medium, and high emissions projections as perturbations around the standard scenario, and testing hypotheses (e.g., targeted emissions reduction or overshoot strategies, injecting sulfur into either the stratosphere or troposphere) with model experiments to mitigate climate change.

Interactions and feedbacks to the climate system will nevertheless need to be explored with ESMs to try and ascertain unintended consequences on other Earth system model components such as ecosystems and atmospheric chemistry. These near-term simulations could use a coupled initialized state close to the present day state of the climate system, though the utility of this approach is still being explored by the modeling communities as a research question. This strategy will incorporate past climate forcings to account for (1) radiative imbalances that produce shortterm committed climate change, (2) the facilitation of model verification; and (3) the logistics involved with the coupled assimilation/initialization process.

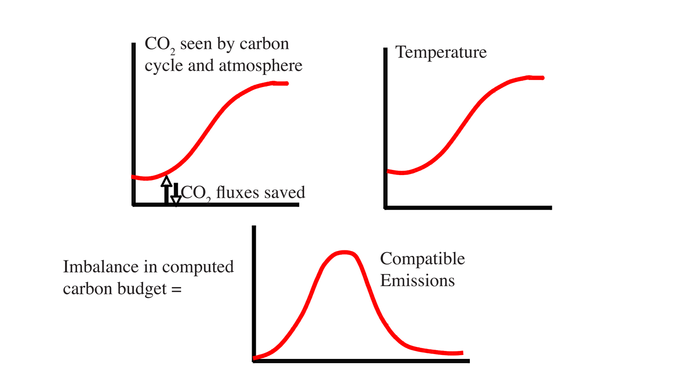

Figure 4. Schematic of experiment 1. The carbon cycle responds to (left) increasing CO_2 concentrations and (right) changes in temperature. The land and ocean CO_2 fluxes are saved to derive emissions for IPCC WG III. The land and ocean fluxes are not radiatively active with the atmosphere.

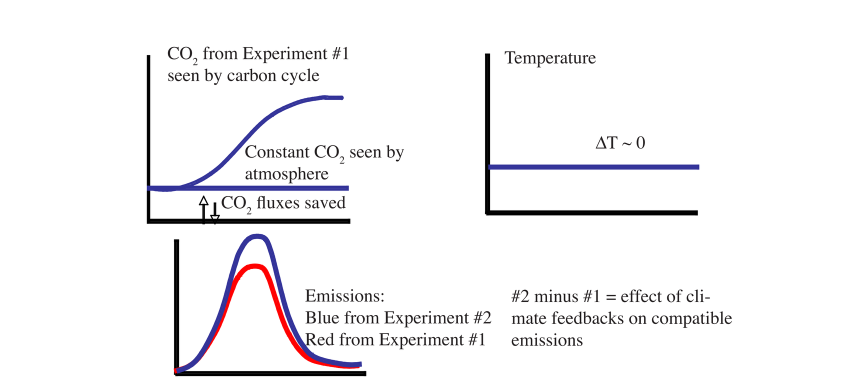

Figure 5. Schematic of experiment 2. The carbon cycle (land and ocean) responds to (upper left) CO_2 concentrations from experiment #1. Atmospheric CO_2 is constant for the radiation calculation so there is (upper right) little temperature change. Land and ocean CO_2 fluxes are saved to derive emissions for IPCC WG III. The land and ocean fluxes are not radiatively active with the atmosphere. This experiment allows carbon cycle and compatible emissions calculations by an ESM or offline carbon cycle model.

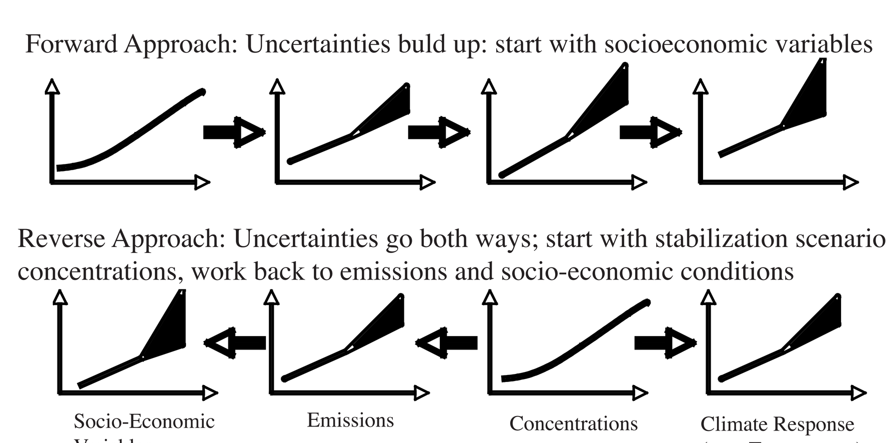

Figure 6. (top) Traditional progression of derived emissions to climate system response. (bottom) New strategy starts with benchmark concentration scenarios from IPCC WG III to modeling groups. The climate system response is still generated from concentrations (arrow from concentrations to temperature)

Long-term experimental design (2005-2100 and beyond)

Longer-term projections quantify feedbacks in the Earth system related to climate outcomes that could be affected by various socioeconomic and policy considerations. Carbon cycle feedbacks are important on this timescale and would be included for these experiments, though atmospheric chemistry and aerosols would be calculated simply or prescribed. Three experiments are proposed:

1. Long-Term Benchmark Stabilization: in this experiment, both AOGCMs and ESMs are run with a scenario of prescribed CO_2 concentrations leading to stabilization (Figure 4).
2. Carbon Cycle Response to Increasing Concentrations: This experiment is similar to Experiment 1, with the exception that the atmospheric CO_2 concentrations are held constant at pre-industrial levels for radiative calculations in the atmosphere, but other ESM components respond to the increasing CO_2 concentrations from Experiment 1 (Figure 5). The derived emissions from Experiment 2 represent the carbon cycle feedback reacting only to the prescribed increasing atmospheric CO_2 concentrations. Comparing the derived emissions from Experiments 1 and 2 provides an indicator of the magnitude of the carbon cycle/climate feedback in terms of those different emissions.
3. Emissions-Driven Carbon Cycle/Climate: This experiment is driven by emissions rather than by concentrations. Each ESM calculates the concentrations resulting from an idealized prescribed standard emissions time series (e.g., 1% per year for CO_2) with a fully interactive carbon cycle.

Previously, scenarios have started with socio-economic considerations evolving to emission scenarios, then concentrations were derived and the models were run to produce climate changes that were used by IPCC Working Group II (WGII) scientists for climate impact studies (Figure 6). The proposed strategy for climate change stabilization experiments instead begins with concentrations and goes back to socioeconomics

Overall recommendations for future climate change experiments

An integrated and synergistic effort is needed to produce past, current, and future emissions scenarios that would ensure the use of consistent and documented data relevant to the global change communities. In addition, Earth System Models of Intermediate Complexity (EMICs) capture essential feedbacks while using far less computer resources than a typical AOGCM or ESM. For impacts reported by WGII scientists, up-to-date model projections need to be made available to impacts modelers several years before the production of the WGII report. This could be done by staggering the WGI and WGII reports or by producing new climate change simulations as soon as possible. There is a need for a PCMDI-equivalent for WGII and WGIII communities where relevant climate model output can be collected, archived, and tailored for use by these scientists. This could include an expanded role for the IPCC Data Distribution Center. An international community organization mechanism is also needed for the WGII and WGIII communities. Finally, an assessment of regional climate change effects will require gridded emission data for aerosols and short-lived trace gases.

Our proposed strategy involves a number of unresolved science questions that need to be addressed including, but not limited to: (1) how to initialize short-term model experiments, (2) how to archive time-evolving chemistry/aerosols for regional climate change, (3) how to resolve the number of ensembles versus resolution with regards to signal-to-noise in detecting projected near term climate changes, (4) how to develop and implement land use change datasets and information, (5) how/if to specify stratospheric ozone, (6) what additional methods might be useful for quantifying carbon cycle feedbacks, and (7) when and/or how to incorporate ice sheet components in ESMs.

Future activities

- Integrated Assessment Model Scenarios meeting early August, 2007 to coordinate land-use datasets with WG1.
- IPCC Expert Scenarios Meeting: 'Towards New Scenarios for Analysis of Emissions, Climate Change and Response Strategies'. The meeting will be held in Noordwijkerhout, The Netherlands, 19 -21 September 2007, and will be hosted by the Dutch Government. The objective of this meeting is to identify requirements and plans for the development of new scenarios of emissions, climate change, and adaptation and mitigation (including underlying socio-economic conditions that shape emissions and vulnerability). The scenarios will be of interest to the research and user communities, and will assist in the coordination of research assessed in a possible IPCC Fifth Assessment Report (AR5). The meeting will provide a unique forum for various for various groups and scientific communities to meet and discuss plans and coordination requirements for new scenario development.
- The internagional global change programmes' "Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report" , Sydney, Australia, 4-6 October 2007.
- A coordinated WGCM/AIMES white paper to be published as a special WCRP report for IPCC (from Hibbard et al. 2007)

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