MEETING SUMMARIES

OVERVIEW OF THE COUPLED MODEL INTERCOMPARISON PROJECT

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For the last decade the Coupled Model Intercomparison Project (CMIP) has worked to improve our understanding of processes and simulation capabilities in global coupled models (Meehl 1995). The varying output from the models typifies the problems addressed in CMIP. For example, Fig. 1 from Covey et al. (2003) shows recent results from such simulations for model responses to idealized increases in atmospheric CO_2 of 1% yr^{-1}. The models reach about 2°C global mean surface warming by the time CO_2 doubles (around year 70), and the range of model results stays within roughly ±25% of the average model result throughout the experiments. Experiments in which the models are run to equilibrium when coupled to a nondynamic slab ocean show a greater spread of output, in part due to compensating ocean heat uptake in the most sensitive models (e.g. Cubasch et al. 2001).

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THE SECOND CMIP WORKSHOP

What: 35 members of the modeling community discussed results from CMIP diagnostic subprojects and plans for contributions to the IPCC AR4

When: 24–26 September 2003

Where: Max Planck Institute for Meteorology, Hamburg, Germany

The precipitation responses of the models span a much wider range than the temperature responses. As shown in Fig. 1 (bottom), the increase in global and annual mean precipitation at the time of CO_2 doubling varies from essentially 0 to ~0.2 mm day^{-1}. The correlation between precipitation increases and temperature increases is weak.

CMIP was launched in late 1995 by the Climate Variability and Predictability (CLIVAR) Numerical Experimentation Group 2 [(NEG2) subsequently reconstituted as the World Climate Research Programme (WCRP)/CLIVAR Working Group on Coupled Models (WGCM)]. The planning and commencement of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) has prompted rapid coupled-model development, which is leading to an expanded CMIP-like activity to collect and analyze results for the control, 1% CO_2, and twentieth-, twenty-first-, and twenty-second-century simulations performed for the AR4.

The first phase of CMIP, dubbed CMIP1, was aimed at collection and analysis of present-day control runs from the coupled models. That was followed closely by CMIP2, which additionally collected model data from 1% yr^{-1} CO_2 increase experiments from the coupled models (Meehl et al. 1997). About half the models used some form of flux adjustment defined as nonphysical adjustments of heat and/or water at the ocean surface, used to maintain a stable realistic surface climate. Those two phases of CMIP involved virtually every global coupled model developed for climate change research in the world and amounted to about 25 different models. Results from those phases of CMIP were presented at the First CMIP Workshop, hosted by the Bureau for Meteorology Research Centre (BMRC) in Melbourne, Australia, in 1998 (Meehl et al. 2000).

However, in spite of the significant amount of model data collected, it was recognized that this was still a small fraction of the total output from the models, and this limited the types of analyses that could be performed. For example, most fields were collected as time averages for certain periods, with only monthly mean time series from several fields (surface temperature, precipitation, and sea level pressure).

Thus the next phase of CMIP was called CMIP2+, with the intention being to collect *all* model data generated from control and 1% CO_2 increase experiments for the atmosphere, ocean, sea ice, and land surface. This represented a significant and massive data collection and archival exercise for the U.S. Department of Energy Program for Climate Model Diagnosis and Intercomparison (PCMDI). Due to the extreme logistical issues involved with CMIP2+, only a subset of all of the modeling groups submitted data, but there are currently 12 complete sets of model output available for analysis.

The first CMIP coordinated experiment addresses processes related to possible future changes to the meridional overturning circulation (MOC) in the Atlantic. The experiment is addressing, with coupled-model sensitivity experiments, processes or responses of coupled models that are not adequately addressed with conventional intercomparison techniques with the standard model output. Participants have orchestrated a series of experiments to study the MOC with idealized freshwater flux ("water hosing") experiments and investigate the role of the surface fluxes in weakening the MOC seen in most models when greenhouse gases increase.

Another coordinated CMIP activity is a pilot project called 20th Century Climate in Coupled Models (20C3M). This is an activity that involves collection of a subset of output data from twentieth-century climate simulations with various forcings being performed by global coupled modeling groups. At the present state of knowledge different groups will use different forcings for various logistical or scientific reasons, and participating modeling groups must document the forcing datasets used in their experiments.

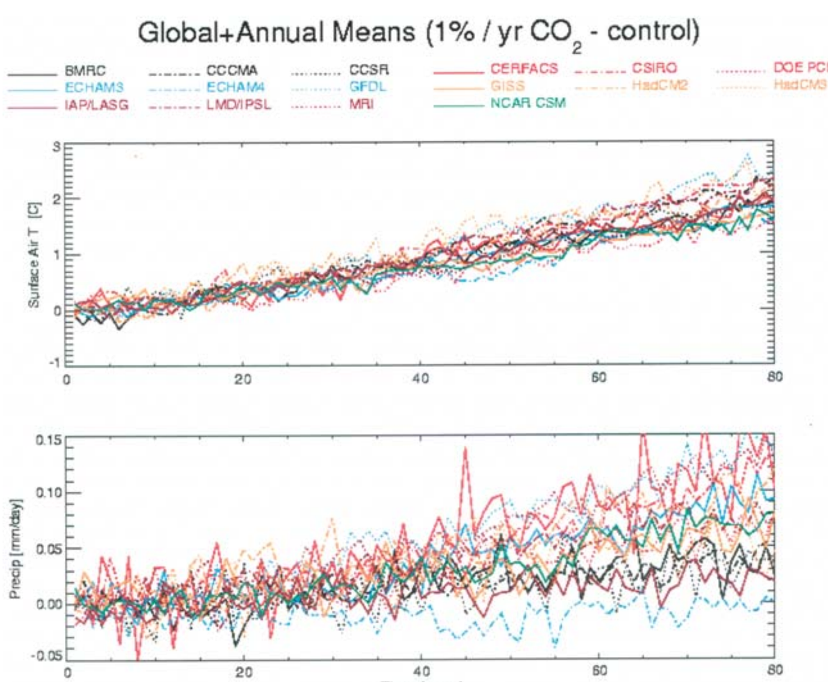

Fig. 1. Globally averaged difference between increasing- CO_2 and control run values of annual mean (top) surface air temperature and (bottom) precipitation for the CMIP2 models (Covey et al. 2003).

The objective of CMIP is for analyses to be performed on the multimodel dataset collected and archived at PCMDI. Following the concept pioneered by the Atmospheric Model Intercomparison Project (AMIP), these analyses are coordinated through so-called diagnostic subprojects. The CMIP Web page (www.pcmdi.llnl.gov/cmip) lists all of the subprojects, CMIP protocols, news, and links. This page also contains a useful reference involving a catalog of all known model intercomparison projects (MIPs) in addition to CMIP.

There were 10 CMIP1 subprojects, with 6 of the 10 producing at least one peer-reviewed publication. There were 22 CMIP2 subprojects, and at the time of the Second CMIP Workshop in September 2003, 12 of 22 had produced at least one peer-reviewed publication. CMIP2+ data were available beginning in 2001, with the final slate of model data available less than a year before the Second CMIP Workshop, but already there were 28 CMIP2+ subprojects, and 4 out of 28 had produced at least one lead-authored paper. Since the workshop, an additional 10 CMIP2+ subprojects have been approved.

PROGRESS IN GLOBAL COUPLED MODELING. In comparing the state of global coupled modeling from the First to the Second CMIP Workshop, several issues emerged. Flux adjustment is becoming less of a factor now as many current models obtain multicentury stable surface climates without them. El Niño variability was usually about half the observed amplitude in the previous generation of coupled models. El Niño magnitude is now more accurately simulated in the present generation of global coupled models. However, there are still biases in simulating the patterns of maximum variability that are often shifted to the west in the models compared to observations. Typical resolutions of atmospheric component models over the decade from the early 1990s to early 2000s have progressed from about 5° lat–long to around 2.5° lat–long, with the ocean components now often having about twice the atmospheric model resolution, with even higher resolution in the equatorial Tropics. Several modeling groups report new-generation coupled models that have atmospheric model resolutions of around 1.5° lat–long, with one version nearing 1°. Modeling groups routinely run 2xCO_2 simulations with the atmosphere coupled to a nondynamic slab ocean to obtain a measure of equilibrium climate sensitivity. The CMIP control and 1% CO_2 simulations are now standard to evaluate the transient climate response (TCR; see Cubasch et al. 2001). In addition, twentieth- and twenty-first-century climate simulations with a variety of forcings [e.g., volcanoes, solar variability, anthropogenic sulfate aerosols, ozone, and greenhouse gases (GHGs), the latter three for future climate as well] are now standard for global coupled modeling groups.

However, an aspect of global coupled modeling that has changed little with improved model resolution and physics is that there are some systematic errors. Such persistent systematic errors noted in previous generations of global coupled models that still are present in the present generation include an overextensive and too-strong equatorial Pacific cold tongue, a double ITCZ, either weak or little intraseasonal convective activity in the Tropics [e.g., the Madden–Julian oscillation (MJO)], inadequate simulation of stratus clouds in the eastern tropical oceans, and deficient simulation of SST in the equatorial Atlantic, where most models simulate a reversed zonal SST gradient compared to observations.

Workshop attendees pointed to these systematic errors as the next big challenge for the global coupled climate modeling community. With the progression toward even more comprehensive earth system models in the future (e.g., including chemistry, carbon cycle, etc.), even more demands will be placed on correcting these systematic errors and improving the simulations from the physical climate models. Another aspect of global coupled climate models to be addressed is the factors that lead to different climate sensitivities in different models. An IPCC Workshop to discuss this issue occurred in July 2004, in Paris. A separate coordinated activity, the Cloud Feedback Model Intercomparison Project (CFMIP), is concentrating on the contribution of clouds to our understanding of climate sensitivity.

EMERGING THEMES. The following emerging themes were recognized by the 35 attendees and 25 presentations.

1) It is useful to compare coupled and uncoupled components as represented by the various model intercomparison efforts of CMIP, AMIP, and CFMIP. Such comparison of components in the context of the coupled models points to possible sources of model sensitivity and systematic error.
2) The multimodel dataset from CMIP can provide probabilistic estimates of future climate change and quantify the nature of errors with estimates of observed sensitivity.
3) Multimodel output is being used increasingly to force embedded models for regional/local changes of climate that cannot be resolved by the current generation of global coupled models. Such studies have been applied to, for example, hurricanes.
4) Multimodel means give better agreement to observations than single models on regional scales.
5) Ocean heat uptake and ocean dynamical response are important for the coupled climate system response. The previously little-studied role of ocean heat uptake is taking on increasing importance, especially in light of recently available observations with which to compare such estimates.
6) Analyses of extreme events are now being performed from CMIP multimodel data, facilitated by the availability of the CMIP2+ data, which, for the first time, include some daily data.

MULTIMODEL ANALYSES FOR UPCOMING IPCC REPORT

For AR4 studies, the list of runs includes the following.

1) **Twentieth-century simulation to year 2000, then fix all concentrations at year 2000 values and run to 2100 (CO_2 ~ 360 ppm).**
2) **Twenty-first-century simulation with SRES A1B to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 720 ppm).**
3) **Twenty-first-century simulation with SRES B1 to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 550 ppm).**
4) **Twenty-first-century simulation with SRES A2 to 2100.**
5) **1% CO_2 run to year 80 where CO_2 doubles at year 70 with corresponding control run.**
6) **100-yr (minimum) control run including same time period as in 1 above.**
7) **2xCO2 equilibrium with atmosphere–slab ocean (also as input to CFMIP).**
8) **Extend one A1B and B1 simulation to 2300.**
9) **1% CO_2 run to quadrupling with an additional 150 yr with CO_2 fixed at 4xCO_2.**
10) **1% CO_2 run to doubling with an additional 150 yr with CO_2 fixed at 2xCO_2.**
11) **Participate in AMIP, OMIP, and CFMIP.**

7) The source of uncertainty from parameterizations in climate models can be evaluated through parameter-varying experiments.
8) Preliminary results from the first CMIP coordinated experiment for MOC show the importance of heat relative to freshwater flux in affecting MOC strength, that earth system models of intermediate complexity (EMICs) can show roughly comparable responses on a global scale but cannot resolve regional scales, and that partial coupling is useful for diagnosing model differences.
9) The nature of regional responses to increasing CO_2 can cause quite different patterns of temperature change, for example, El Niño–like, or Arctic Oscillation (AO)–like.
10) PCMDI will continue to play a major role in CMIP and other model intercomparison activities, with promotion of netCDF, CF metadata standard, and a PCMDI-supplied software library to provide uniform data structure.
11) Climate sensitivity and response should be compared among models for the twentieth century as well as the last 1000 yr, and cloud feedback (even the sign) is a major uncertainty.
12) Most modeling groups have either just recently completed or are in the final stages of completing development of new model versions, with a strong awareness of timing new model versions for the upcoming IPCC AR4. Preliminary indications are that sensitivities of new model versions may be converging near 2°–3°C, and the reasons for this need to be understood. This issue was specifically discussed at the IPCC Workshop in Paris in July 2004. More information on the climate sensitivity of current models was collected at the CFMIP Workshop in April 2004.

FUTURE DIRECTIONS AND OPPORTUNITY TO PARTICIPATE IN IPCC AR4. The immediate future of CMIP is tied directly to twentieth-century and future climate simulations being performed for the IPCC AR4. It was recognized at the workshop that the idealized forcing experiments that historically have been central to CMIP are likely to yield the most relevant scientific insight into the workings of the coupled climate system. Analysis of scenario simulations for twentieth- and twenty-first-century climate will also provide useful information in terms of a multimodel datasets.

Modeling groups around the world have agreed to perform an unprecedented set of coordinated twentieth- and twenty-first-century climate change experiments, in addition to commitment experiments extending to the twenty-second century, for the IPCC AR4. There will be a considerable expenditure of human and computer resources to complete these experiments. The resulting multimodel dataset will be a unique resource that will enable international scientists to assess model performance, model sensitivity, and model response to various forcings for twentieth- and twenty-first-century climate and beyond.

There will be an international effort to collect, compile, and analyze output from this multimodel dataset for direct input to the IPCC AR4 in 2004–05. Under the auspices of IPCC, the Working Group on Coupled Modelling (WGCM) has set up a panel to coordinate the collection and archival of the multimodel output at PCMDI. The initial deadline for submission of model data was 1 September 2004. The panel is leading an effort to enlist volunteers from around the world to analyze the model data for AR4. Any interested party can have access to the model data (e-mail: IPCC_analysis@ucar.edu and check the CMIP Web page for further details). The model data is now available for analysis, and the analysis work will continue into 2005.

The analysis results will feed directly to the lead authors of the appropriate chapters of the AR4. A workshop, presenting results from the multimodel analyses, will be convened under the auspices of U.S. CLIVAR and will be hosted by the International Pacific Research Center at the University of Hawaii, 1–4 March 2005. To be eligible for AR4 consideration, scientific papers need to be submitted to peer-reviewed journals by May 2005.

Thus the traditional CMIP-idealized forcing 1% CO_2 increase experiments will be fundamental to these intercomparisons for the AR4, and, as in past IPCC assessments, CMIP-related activities will once again play an important role in the IPCC process. For further information and updates on all CMIP and CMIP-related activities, please see the CMIP Web site (www.pcmdi.llnl.gov/cmip).

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