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Overview of the Coupled Model Intercomparison Project (CMIP)

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Abstract

The Coupled Model Intercomparison Project (CMIP) is designed to allow study and intercomparison of multi-model simulations of present-day and future climate. The latter are represented by idealized forcing of compounded 1% per year CO_2 increase to the time of CO_2 doubling near year 70 in simulations with global coupled models that contain, typically, components representing atmosphere, ocean, sea ice and land surface. Results from CMIP diagnostic subprojects were presented at the Second CMIP Workshop held at the Max Planck Institute for Meteorology in Hamburg, Germany, in September, 2003. Significant progress in diagnosing and understanding results from global coupled models has been made since the First CMIP Workshop in Melbourne, Australia in 1998. For example, the issue of flux adjustment is slowly fading as more and more models obtain stable multi-century surface climates without them. El Nino variability, usually about half the observed amplitude in the previous generation of coupled models, is now more accurately simulated in the present generation of global coupled models, though there are still biases in simulating the patterns of maximum variability. Typical resolutions of atmospheric component models contained in coupled models is now usually around 2.5 degrees latitude-longitude, with the ocean components often having about twice the atmospheric model resolution, with even higher resolution in the equatorial tropics. Some new-generation coupled models have atmospheric model resolutions of around 1.5 degrees latitude-longitude. Modeling groups now routinely run the CMIP control and 1% CO_2 simulations in addition to 20th and 21st century climate

simulations with a variety of forcings (e.g. volcanoes, solar variability, anthropogenic sulfate aerosols, ozone, and greenhouse gases (GHGs), with the anthropogenic forcings for future climate as well). However, persistent systematic errors noted in previous generations of global coupled models still are present in the present generation (e.g. over-extensive equatorial Pacific cold tongue, double ITCZ). This points to the next challenge for the global coupled climate modeling community. Planning and imminent commencement of the IPCC Fourth Assessment Report (AR4) has prompted rapid coupled model development, which will lead to an expanded CMIP-like activity to collect and analyze results for the control, 1% CO2, 20th, 21st and 22nd century simulations performed for the AR4. The international climate community is encouraged to become involved in this analysis effort, and details are provided below in how to do so.

1. Introduction

Results from the Coupled Model Intercomparison Project (CMIP) diagnostic subprojects were presented at the Second CMIP Workshop held in Hamburg, Germany at the Max Planck Institute for Meteorology in September, 2003. The current status and future plans for CMIP and CMIP-related activities were also reviewed at the workshop, especially with regards to proposed analyses of the upcoming climate model simulations for the IPCC Fourth Assessment Report (AR4).

At a workshop at Scripps Institution of Oceanography in 1994, the CMIP activity was recommended to improve our understanding of processes and simulation capabilities in global coupled models (Meehl, 1995). As a consequence, CMIP was launched in late 1995 by the Climate Variability and Predictability (CLIVAR) Numerical Experimentation Group 2 (NEG2, subsequently reconstituted as the WCRP/CLIVAR Working Group on Coupled Models, WGCM). Since then there have been several phases and activities related to CMIP. The Program for Climate Model Diagnosis and Intercomparison (PCMDI) at the Lawrence Livermore National Laboratory continues to play a central role in the various phases of CMIP. PCMDI has archived and organized all the submitted model data, made the data available to diagnostic subproject investigators, and provided software tools to assist in analysis. PCMDI scientists have collaborated with CMIP scientists in producing analyses of the CMIP multi-model dataset.

For example, Fig. 1 from Covey et al. (2003) shows model responses to idealized 1% per year increasing atmospheric CO_2 for global and annual mean changes in surface air temperature and precipitation as differences between the increasing-CO_2 and control runs. 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. This rather narrow range contrasts with a greater spread of model output for experiments in which the models are run to equilibrium when coupled to a non-dynamic slab ocean in part due to compensating ocean heat uptake in the most sensitive models (e.g. Cubasch et al., 2001). The precipitation responses of the models span a much wider range than the temperature responses. As shown in Figure 1b, the increase in global and annual mean precipitation at the time of CO_2 doubling varies from essentially zero to ~0.2 mm / day. The correlation between precipitation increases and temperature increases is weak.

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% per year CO2 increase experiments from the coupled models (Meehl et al., 1997). About half the models used some form of flux adjustment defined as non-physical 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 a significant amount of model data collected, it was recognized that that 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 monthly mean time series only available for select 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% CO2 increase experiments for atmosphere, ocean, sea ice and land surface. This represented a significant and massive data collection and archival exercise for PCMDI. Due to the extreme logistical issues involved with CMIP2+, only a subset of all the modeling groups submitted data, but there are currently 12 complete sets of model output available for analysis.

Two more CMIP activities were noted at the 2003 Hamburg workshop. The first is CMIP Coordinated Experiments . Participation in is elective for the modeling groups, with these experiments arising from a group of scientists interested in addressing, with coupled model sensitivity experiments, certain processes or responses of coupled models that are not adequately addressed with conventional intercomparison techniques with the standard model output. The first CMIP Coordinated Experiment is being performed to address processes related to possible future changes to the meridional overturning circulation (MOC) in the Atlantic. Experiments have been formulated to study the MOC with idealized fresh-water flux ("water-hosing") experiments, and investigate the role of the surface fluxes in weakening the MOC seen in most models when greenhouse gases increase. Preliminary results show a substantial sensitivity across models to the recovery of the MOC after the water-hosing has been applied and then shut off after 100 years.

A second coordinated CMIP activity is a pilot project called "20th Century Climate in Coupled Models" (20C3M). A subset of output data is being collected from 20th century climate simulations with various forcings (e.g. solar, volcanoes, sulfate aerosols, greenhouse gases, ozone) being performed by global coupled modeling groups. It is recognized that 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. This activity is of interest to the climate change detection/attribution community to be able to compare simulations of 20th century climate across the models, and is currently underway.

These various phases of CMIP are managed by the CMIP Panel (Gerald Meehl, chair, Bryant McAvaney (who took the place of previous panel member George Boer), Curt Covey, Mojib Latif, and Ron Stouffer). The objective of CMIP is for analyses to be performed on the multi-model dataset collected and archived at PCMDI. Following the concept pioneered by the Atmospheric Model Intercomparison Project (AMIP), these analyses are coordinated through "diagnostic subprojects". The process involves submitting a short (one page) project summary listing objectives and data required to the CMIP Panel chairman. The proposal is then circulated via email to the CMIP Panel members for review. Comments are received on the order of weeks, and the subproject investigator is then contacted with the outcome. The process is not designed to be exclusionary, but to be more of a value-added registration procedure to avoid overlap with other subprojects, suggest research avenues to investigators, and coordinate use of the model data. PCMDI maintains a CMIP web page listing all the subprojects, CMIP protocols, news and links (www-pcmdi.llnl.gov/cmip). This page also contains a useful reference involving a catalogue of all known model intercomparison projects ("MIPs") in addition to CMIP. New subprojects can be initiated at any time, and the process is open to everyone.

CMIP1 is now completed, and 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, 12 of 22 had produced at least one peer-reviewed publication. CMIP2+ data began to be available 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.

2. Issues and topics from the workshop

In comparing the state of global coupled modeling from the first to the second CMIP workshops, several issues emerged. Flux adjustment is becoming less of a factor now as many current models obtain multi-century stable surface climates without them. El Nino variability was usually about half the observed amplitude in the previous generation of coupled models. El Nino 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 degrees latitude-longitude to around 2.5 degrees latitude-longitude, with the ocean components now often having about twice the atmospheric model resolution, with even higher resolution in the equatorial tropics. Several modeling groups reported at the workshop on new-generation coupled models that have atmospheric model resolutions of around 1.5 degrees latitude-longitude, with one version nearing 1 degree. Modeling groups routinely run 2XCO2 simulations with the atmosphere coupled to a nondynamic slab ocean to obtain a measure of equilibrium climate sensitivity. The CMIP control and 1% CO2 simulations are now standard to evaluate the transient climate response (TCR, see Cubasch et al., 2001). In addition, 20^{th} and 21^{st} 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 less with improved model resolution and physics are some systematic errors. These were noted to occur in previous global coupled models and are still present in the current generation of models. Examples of these systematic errors include an over-extensive 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 towards 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 is understanding factors that lead to different climate sensitivities in different models. An IPCC workshop to discuss this issue is scheduled for 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.

3. Emerging themes from the workshop

A number of 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 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 multi-model dataset from CMIP can provide probabilistic estimates of future climate change and quantify the nature of errors with estimates of observed sensitivity.
3. Multi-model 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 (e.g. Levitus et al., 2001).
6. Analyses of extreme events are now being performed from CMIP multi-model data, facilitated by the availability of the CMIP2+ data which, for the first time, includes some daily data.

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 greater importance of heat relative to fresh water flux in affecting MOC strength. Earth System Models of Intermediate Complexity (EMICs) can show roughly comparable responses on the global scale but are not designed to resolve regional scales.

9. The nature of regional responses to increasing CO_2 can cause quite different patterns of temperature change e.g. El Nino-like, or Arctic Oscillation (AO)-like.

10. Climate sensitivity and response should be compared among models for 20th century as well as the last 1000 years, and cloud feedback (even the sign) is a major uncertainty.

11. PCMDI will continue to play a major role in CMIP and other model intercomparison activities, with promotion of netCDF, CF metadata standard and PCMDI-supplied software library to provide uniform data structure.

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 upcoming IPCC AR4. Preliminary indications are that sensitivities of new model versions may be converging near 2°C – 3°C, and the reasons for this need to be understood. The IPCC Workshop on Climate Sensitivity mentioned above will be held in Paris in July, 2004, to discuss this issue specifically. The recent CFMIP Workshop in April, 2004, has collected more information on the climate sensitivity of current models.

4. Future directions and opportunity to participate in IPCC AR4

It was noted at the workshop that the immediate future of CMIP is tied directly to 20th century and future climate simulations being performed for the IPCC AR4. Part of the requirement for modeling groups to participate in the scenario simulations for the AR4 is the standard control and 1% per year CO2 increase experiment. 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. The analysis of scenario simulations for 20th and 21st century climate will also provide useful information since the multi-model dataset will provide a better estimate of uncertainty of projected changes of climate.

Modeling groups around the world have agreed to perform an unprecedented set of coordinated 20th and 21st Century climate change experiments, in addition to commitment experiments extending to the 22nd Century, for the IPCC AR4. There will be a considerable expenditure of human and computer resources to complete these experiments. The resulting multi-model dataset will be a unique resource that will enable international scientists to assess model performance, model sensitivity, and model response to various forcings for 20th and 21st Century climate and beyond.

The list of runs includes:

1. 20th century simulation to year 2000, then fix all concentrations of greenhouse gases and sulfate aerosols at year 2000 values and run to 2100 (CO_2 ~ 360ppm)

2. 21st century simulation with SRES A1B to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 720ppm)

3. 21st century simulation with SRES B1 to 2100, then fix all concentrations at year 2100 values to 2200 (CO_2 ~ 550ppm)

4. 21st 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 year (minimum) control run including same time period as in 1 above

7. $2XCO_2$ 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 years with CO_2 fixed at $4XCO_2$

10. 1% CO_2 run to doubling with an additional 150 years with CO_2 fixed at $2XCO_2$

11. participate in AMIP, the Ocean Model Intercomparison Project (OMIP), and CFMIP

Some groups will be running multi-member ensembles for at least some of these simulations. The number of ensemble members is up to the modeling groups to decide based on available computer resources, but may range from three to five members, with a number of groups running single realizations.

There will be an international effort to collect, compile, and analyze output from this multi-model dataset for direct input to the IPCC AR4 in 2004-2005. Under the auspices of the IPCC and WGCM, this effort will be coordinated by Gerald Meehl (chairman, NCAR, USA), with WGCM chair John Mitchell (Hadley Centre, U.K.), and WGCM members Bryant McAvaney (BMRC, Australia), Curt Covey (PCMDI, USA), Mojib Latif (MPI, Germany), and Ron Stouffer (GFDL, USA), in conjunction with PCMDI where the data will be archived. The initial deadline for submission of model data is September 1, 2004.

Having collected and archived the multi-model data, there will also be an emphasis on an analysis effort to produce results for the AR4. To do this, the panel listed above will lead an effort to enlist volunteers from around the world to analyze the model data. **Individuals and groups who wish to register with the WGCM Climate Simulation Panel to analyze certain aspects of the IPCC climate model simulations can contact Gerald Meehl (meehl@ncar.ucar.edu) starting now and continuing to September 1, 2004.** Any interested party can have access to the model data. Therefore, this will not be a screening process but a registration. The Panel will compile a list of scientists and topics that will be given to the appropriate lead authors at the IPCC First Lead Authors Meeting in September, 2004. This material will serve as a place holder for results that can be incorporated into the first draft that will be prepared for the Second Lead Authors Meeting in May, 2005. The model data will be available in early September, 2004, and the analyses will continue into the first part of 2005.

Results from the analysis of the IPCC simulations will be communicated to the lead authors of the appropriate chapters of the AR4 through a workshop convened under the auspices of the U.S. CLIVAR Program. The workshop will be hosted by the International Pacific Research Center at the University of Hawaii March 1-4, 2005. Members of the US CLIVAR Scientific Steering Committee who will lead the organization of this effort include Gerald Meehl (NCAR), James Hurrell (NCAR), Lisa Goddard (IRI), and Dave Gutzler (Univ. New Mexico). In order for results to be assessed for the AR4, scientific papers describing the findings must be submitted to peer-reviewed journals prior to the Second Lead Authors Meeting in May, 2005.

Thus the traditional CMIP idealized forcing 1% CO2 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 (http://www-pcmdi.llnl.gov/cmip).

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References

Covey, C., K.M. AchutaRao, U. Cubasch, P. Jones, S.J. Lambert, M.E. Mann, T.J. Phillips and K.E. Taylor, 2003: An overview of results from the Coupled Model Intercomparison Project. *Global and Planetary Change*, **37**, 103-133.

Cubasch, U., G. A. Meehl, G. J. Boer, R. J. Stouffer, M. Dix, A. Noda, C. A. Senior, S. Raper and K. S. Yap, 2001: Projections of future climate change. In: Climate Change

2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. van der Linden, X. Dai, K. Maskell, C. I. Johnson (eds.)]. Cambridge University Press, 525--582.

Levitus, S., J.I. Antonov, J. Wang, T.L. Delworth, K.W. Dixon, and A.J. Broccoli, 2001: Anthropogenic warming of earth's climate system. *Science*, **292**, 267--270.

Meehl, G.A., 1995: Global coupled general circulation models. *Bull. Amer. Meteorol. Soc.*, **76**, 951--957.

Meehl, G.A., G.J. Boer, C. Covey, M. Latif, and R.J. Stouffer, 1997: Intercomparison makes for a better climate model. *Eos,* 78, 445--446, 451.

Meehl, G.A., G.J. Boer, C. Covey, M. Latif, and R.J. Stouffer, 2000: The Coupled Model Intercomparison Project (CMIP). *Bull. Amer. Meteorol. Soc.*, **81**, 313--318.

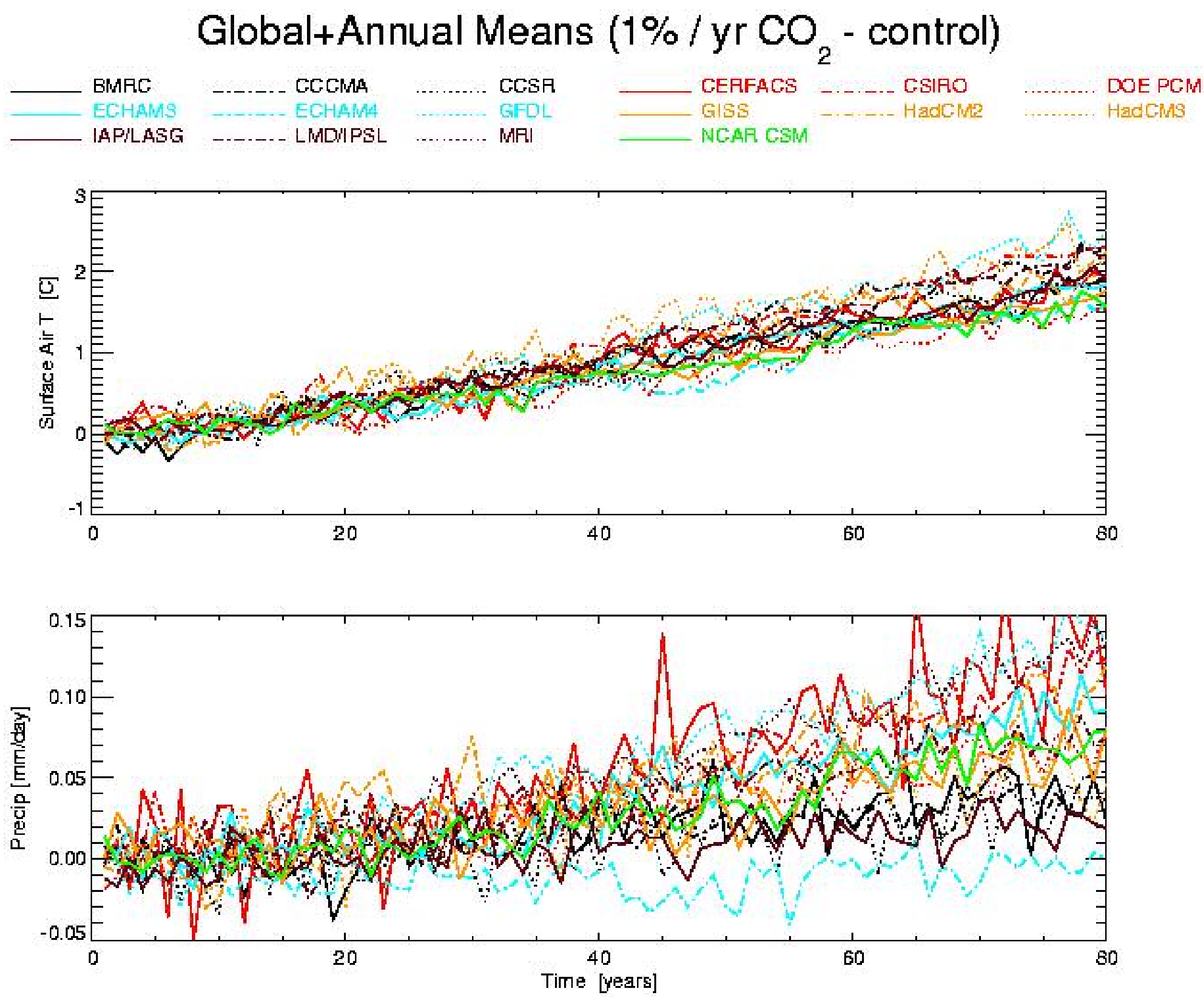

Figure caption

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