ICSU
International Council for Science

WORLD METEOROLOGICAL ORGANIZATION

INTERNATIONAL OCEANOGRAPHIC COMMISSION OF UNESCO

WORLD CLIMATE RESEARCH PROGRAMME

REPORT OF THE NINTH SESSION OF THE JSC/CLIVAR WORKING GROUP ON COUPLED MODELLING

Met Office, Exeter, UK, 3-5 October 2005

AUGUST 2006

ICPO Publications Series No. 106

WCRP Informal Report No. 13/2006

TABLE OF CONTENTS

The ninth session of the JSC/CLIVAR Working Group on Coupled Modelling (WGCM), held jointly with a WGCM/WMP session was kindly hosted by the Met Office, UK, 3-5 October 2005. The session was opened at 0900 hours on 3 October by the Co-Chairs of WGCM, Prof. J. Mitchell and Dr G. Meehl. The list of participants is given in the Appendix A to this report.

The participants were welcomed by the Co-Chairs, Prof. J. Mitchell, Dr G. Meehl and Dr V. Satyan (Joint Planning Staff, WCRP, Geneva).

On behalf of all participants, Dr G. Meehl expressed gratitude to Prof. J. Mitchell for hosting the ninth session of WGCM and the excellent arrangements made. He further expressed his appreciation to Prof. J. Mitchell, ably assisted by staff, Met Office, for the efforts and time they had put into the organization of the session. The Co-Chairs looked forward to the joint WGCM/WMP session scheduled for the afternoon of 25 October.

1. REVIEW OF RELEVANT EVENTS IN THE WCRP AND DEVELOPMENTS IN MODELLING-RELATED ACTIVITIES

WGCM endeavours to maintain a broad overview of modelling activities in the WCRP in its basic task of building up comprehensive climate models. WGCM was informed of the main discussions at and recommendations from the twenty-sixth session of the Joint Scientific Committee (JSC) for the WCRP (March 2005) and the thirteenth session of the CLIVAR Scientific Steering Group (June 2004). In addition, updates of the recent developments within the JSC/CAS Working Group on Numerical Experimentation (WGNE) and the Regional Climate Modelling activities were provided.

1.1 Twenty-sixth session of the JSC

Prof. J. Mitchell briefed the session about the relevant items arising out of the twenty-sixth session of the JSC (Guayaquil, Ecuador, 14-18 March 2005):

- Since most members of the WG were overcommitted with the anthropogenic climate change (ACC) issue and that consequently WGCM had devoted most of its time to this, JSC recommended that a Co-chair of WGCM should be appointed to deal with the issue of natural climate variability in the context of ACC. Also, the membership of WGCM should be expanded to provide additional expertise in this area. JSC reiterated that WGCM should continue as an overarching WCRP group with no change in its dual parentage of the JSC and CLIVAR. It was recognized that attention was needed to improve communications between WGCM and the other activities of WCRP; responsibility for this rested with JSC, WMP, the projects and WGCM.
- JSC also recommended that WGCM should interact closely with THORPEX.
- JSC recognized and encouraged the need for stronger interaction between observational and modelling capabilities, particularly in GEWEX, WGNE and WGCM, for improving understanding and modelling of cloud-radiation feedback processes.
- JSC requested WGNE, WGCM and the wider CLIVAR community to consider how they could collectively accelerate, jointly with CliC, and in close cooperation with the WGOMD, progress in the important areas of sea-ice modelling and related data assimilation.
- JSC noted that SPARC and WGCM (with IPCC in mind) needed to pursue jointly some aspects of solar forcing, including the effect of solar forcing variability on atmospheric composition (e.g. ozone). SPARC should take on the updating of solar forcing at the top of the atmosphere. JSC decided to consider at a later date whether SPARC's Chemistry-Climate Modelling Validation project should lead to another AMIP-like experiment, which would need to involve PCMDI.
- JSC strongly supported the proposal to have a workshop on Model Errors sometime in late 2006 or 2007 organized by WGNE possibly jointly with CLIVAR (WGCM) and GEWEX at least.
- The JSC expressed satisfaction that the topic of climate forcing now had a clear place within the WCRP structure. They encouraged WGCM to increase its consideration of natural climate variability in the context of ACC and to move forward towards comprehensive Earth System Modelling. JSC reiterated that the WGCM should continue to be a pan-WCRP modelling group. The international Workshop on Analyses of Climate Model Simulations for the IPCC AR4, convened by U.S. CLIVAR and hosted by the IPRC, University of Hawaii, 1-4 March 2005, was highly praised.
- JSC stressed the need for strengthening links between Global carbon Project (GCP) and WGCM.

1.2 CLIVAR Activities

Dr G. Meehl outlined the key outcomes of the CLIVAR conference and Assessment. The new slogan was to ''Think Globally, Act Regionally''. CLIVAR would continue its activities in Global Observations, synthesis and modeling with key foci on ENSO, Monsoons, THC/Decadal, Anthropogenic climate change and Applications. He also outlined the proposed new ICPO structure.

The key issues of the CLIVAR Conference and Assessment included:

- On an annual basis CLIVAR progress will be assessed against four major global themes: ENSO, Monsoons, THC/Decadal and ACC. Each year a topical workshop will be held for one of the four themes.
- ACC representation to be increased on SSG.
- Global perspective/framework to be provided by Global Observations and Synthesis Panel (GSOP), WGSIP, WGCM, WGOMD, and Climate Change Detection (CCD).
- Global to regional perspective provided by Monsoon Panels for VAMOS, VACS, and AAMP and Ocean Basin Panels for Atlantic, Pacific, Indian and Southern Oceans

Dr Meehl also reported on the US CLIVAR reorganization. The regional panels will be replaced by three topical panels which include:

- Predictability, Prediction and Applications Interface Panel
- Process Studies and Model Improvement Panel
- Phenomena, Observations and Synthesis Panel

1.3 Regional Climate Modelling

Dr F. Giorgi presented a review of the status and recent developments in regional climate modeling. After a review of basic modeling issues, recent developments in the field were highlighted. These included:

- the increase in resolution (10-20 km or even less) and simulation length (multi-decadal) for regional climate modeling experiments.
- the inception of a number of coordinated intercomparison experiments involving multiple RCMs e.g. (PRUDENCE, ENSEMBLES, PIRCS, RMIP-ASIA, RMIP-ARCTIC).
- the increased emphasis towards coupling atmospheric RCMs with models of other components of the climate system, such as regional ocean, biosphere and/or chemistry/aerosol. In other words, the greater emphasis towards the development of regional Earth System models.
- encouraging results have been obtained from preliminary two-way nested GCM-RCM experiments. This approach appears to improve the global model simulation when applied to some key regions, such as the western Pacific warm pool area. More testing for other regions and modeling frameworks is needed to fully evaluate its potential.
- greater application and testing over tropical regions and greater use by scientists in developing countries, mostly because of the development of powerful but inexpensive PC and hard disk technology.

It was also noted that the use of variable resolution atmospheric models and statistical downscaling techniques has considerably increased in the last years. Relative merits of these different regionalization methodologies should be better elucidated. In fact, it was recommended that it would be useful to provide "guidance" material on the use of different techniques.

1.4 Overview of WGNE Activities

Dr A. Lorenc described the work of the Working Group on Numerical Experimentation (WGNE), on behalf of its chairman, Dr M. Miller. WGNE coordinates experiments with atmospheric models, in support of WCRP and CAS. Its work in Numerical Weather Prediction includes data assimilation and (re-) analysis, ensemble systems including monthly and seasonal forecasting, model diagnostics and verification. It considers the development of improved atmospheric models, including dynamical cores and the parameterization of physical processes. WGNE is proposing to hold a conference on Model Systematic Errors early in 2007 - this could be joint with WGCM.

2. NEWS FROM RELEVANT NATIONAL AND MULTINATIONAL PROJECTS

2.1 Earth Simulator, Japan

Dr M. Kimoto reported the current status of the Japanese modeling activities using the Earth Simulator. Several modelling groups, that are supported by the Research Revolution 2002 project (so-called

Kyousei Project) of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT), have successfully finished their runs for the Fourth Assessment Report (AR4) of IPCC.

Other attempts of experimental high-resolution atmosphere/ocean simulations are also progressing. Especially, an attempt of global cloud-resolving simulations has been started with a non-hydrostatic icosahedral atmospheric model, called NICAM, now in an aqua planet configuration with 3.5-km resolution; introduction of realistic land-sea distribution is under way. There is an attempt to carry out fully non-hydrostatic ocean-atmosphere simulation by the Earth Simulator Center.

A post-Earth Simulator project has been commenced in Japan, aiming at a peta-Flops performance by FYR 2010. Much wider applications to broader scientific disciplines are planned.

A research group, called K-1, that consists of the Center for Climate System Research (CCSR) of the University of Tokyo, the National Institute for Environmental Studies (NIES) and the Frontier Research Center for Global Change (FRCGC), have conducted a twentieth century climate reproduction and future scenario experiment using a coupled model, called MIROC, with relatively high (T106 atmosphere and 1/4 x 1/6 deg Ocean) and medium (T42 + 1 x 1.4 deg) resolutions. The high-resolution simulation enables more reliable discussions on extremes and regional aspects of climate warming, e.g., those associated with the East Asian monsoon front (Baiu front) and Kuroshio.

2.2 Program for Climate Model Diagnosis and Intercomparison (PCMDI), USA

Dr D. Bader presented the relevant PCMDI activities. PCMDI will continue to maintain and improve the IPCC AR4 Model Output Database. Demand for the data averages several hundred Gbytes/day, with peak demands exceeding 500 Gbytes/day. The archive suffered major data losses as a result of computer server hardware failures in May and August, and restoration of the lost data was slow and difficult. PCMDI is working now to build a mirror to the archive (since completed) to increase the archive's resiliency to future equipment failures and data loss. The Earth System Grid project is working on improvements to the interface, including dataset sub-setting and aggregation, and will release those features over the next several months. PCMDI will continue to accept data from modeling groups (currently at 27 Tbytes) until the physical limit of the server is reached. In early 2006, the size of the archive will be expanded from the existing 37 Tbyte limit to accommodate more data from the modeling groups.

Initial preparation for the AR5 database is underway. It is likely that the IPCC AR5 archive will be a hybrid distributed and centralized database sharing a common access portal and catalog. A part of this preparation is a proposal to the WGCM to provide an institutional home for the maintenance and further development of the Climate and Forecasting Convention data format and metadata standards that were essential to the success of the AR4 archive. Additionally, PCMDI is working with the CCSM biogeochemistry working group on a pilot intercomparison of coupled carbon cycle-climate models as a learning exercise for AR5.

PCMDI hosts an Atmospheric Model Parameterization Testbed for the evaluation of cloud and radiation parameterizations using climate models in forecast mode. The project is designed to closely link the DOE ARM Program to US-based model development activities at CCSM and GFDL. Dr S. Klein has taken over leadership of the project subsequent to Dr G. Potter's retirement. Through Dr D. Williamson of NCAR, the project is closely aligned with the WGNE Transpose AMIP experiments. Better connections with the GEWEX Cloud System Study are planned.

3. CONTRIBUTIONS FROM OTHER MODELLING GROUPS

The session was given reports on developments in coupled modelling during the past year at modelling centres in Australia, USA, Japan, France and UK.

3.1 Bureau of Meteorology Research Centre (BMRC) and Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

Dr T. Hirst reported on the current status of the modelling activities at BMRC and CSIRO.

Australian global coupled climate models:

BMRC BCM3
Atmosphere: Spectral T47 (2.4° x 2.4°); 17 levels – σ coordinate
Ocean: MOM 2.2 code; Grid 2° x 2° (0.5°NS over 9°S to 9°N); 25 levels

Applications: Seasonal prediction (POAMA system); interannual variability research; climate feedback research
Reference: Alves et al., 2003, see:
http://www.bom.gov.au/bmrc/ocean/JAFOOS/POAMA/scientific/index.htm

CSIRO Mk3
Version Mk3.0 – IPCC AR4 simulations
Version Mk3.5 – Current standard version
Atmosphere: Spectral T63 (1.9° x 1.9°); 18 levels - hybrid σ,p coordinate
Ocean: MOM 2.2 code; Grid 0.95°NS x 1.9°EW; 31 levels (8 in top 100 m)
Applications: Climate change simulation
Reference: Gordon et al., 2002 http://www.dar.csiro.au/publications/gordon_2002a.pdf

CSIRO Mk3.0 IPCC AR4 simulations:

A complete basic set of IPCC AR4 simulations has been performed with the Mk3.0 model, including an ensemble of three 20th century experiments. Approximately 1.5 Terabytes of monthly and daily model output fields have been processed, checked and sent to PCMDI. The reference is Collier et al., 2006, CSIRO Marine and Atmospheric Research Technical Paper (in final preparation).

CSIRO Mk3.5 – new model version:

A three-year development effort following on from the Mk3.0 has lead to the CSIRO Mk3.5, the current standard model version. There have been numerous changes over the Mk3.0, including an improved river routing scheme, upgraded sea ice numerics, inclusion of ocean surface current velocity in wind stress calculation and incorporation of the Visbeck et al. (1997, J.Phys. Oceanogr., 27, 381-402) scheme to control the strength of oceanic eddy-induced transport in a more physically-based manner. A 500-year control simulation and a 20th century simulation have been performed satisfactorily and a set of climate change simulations are currently underway.

The control solution of the CSIRO Mk3.5 displays several significant improvements over that for the CSIRO Mk3.0. Firstly, the control climate drift is much reduced in the Mk3.5 model, with global mean surface air temperature drifting by less than 0.05°C/century in comparison to a cooling drift of 0.3°C/century in the Mk3.0. Secondly, the circulation and stratification of the Southern Ocean are much improved, with the Antarctic Circumpolar current transport and the depth of winter-time oceanic convective mixed layers much reduced to near observed levels. These improvements in the Southern Ocean simulation primarily resulted from introduction of the Visbeck et al. scheme.

The set of climate change simulations underway with the CSIRO Mk3.5 follow the IPCC AR4 requirements and it is planned to submit these to PCMDI as they complete.

IPCC Model Analysis studies:

A range of IPCC model analysis studies are underway looking at aspects of Australian regional circulation, oceanic behaviour and sea level change. Particular progress has been made in a project to examine anomalously rapid warming (at 1.5 to 2 times the global average ocean surface rate) evident in a range of models in the Tasman Sea. Cai et al. (2005, Geophys. Res. Lett., 32, L23706, doi:10.1029/2005GL024701) showed this warming in the CSIRO Mk3.0 model to be due to enhancement of the East Australian Current, as a result of Sverdrup circulation change (calculated via the Godfrey Island rule) associated with secular change of the Southern Annular Mode. Cai (2005, Geophys. Res. Lett., *in press*) also showed that the model changes for the latter 20th century were broadly consistent with observed changes inferred from reanalysis datasets. Work is in progress to verify the above mechanism in a range of other IPCC models.

Model diagnostic study – Intrinsic coupled variability in the Indian Ocean:

A set of model experiments was conducted using the BMRC BCM3 coupled climate model to investigate whether there is a coupled atmosphere-ocean mode intrinsic to the Indian Ocean and, if so, what is its character in the absence of ENSO (Hendon et al., 2005, in press.). In the observations, an Indian Ocean zonal mode ("IOZM", also referred to as Indian Ocean Dipole – IOD) is evident featuring SST and oceanic heat content perturbations of opposing sign between the eastern and western equatorial Indian

Ocean, associated with equatorial zonal wind anomalies. This pattern is frequently, but apparently not always, associated with (Pacific) ENSO behaviour. The model experiments included a control simulation which featured tropical Indian Ocean variability broadly similar to the observed, including a realistic association between the model's IOZM and ENSO. A second experiment was conducted where the wind stress as seen by the ocean over the tropical Pacific was replaced by the climatological pattern so as to eliminate the model ENSO. The result in the tropical Indian Ocean was a considerable decrease in variability overall, nevertheless the IOZM was still evident as an intrinsic mode with amplitude about two-thirds that in the control, and a tendency for biennial periodicity. The predictability of this intrinsic coupled mode is currently under investigation.

Prospects for next five years:

The Bureau and CSIRO intend to merge their large-scale modelling programs, and develop jointly a modelling system known as the "Australian Community Climate and Earth System Simulator" (ACCESS). This system will provide the modelling capability to support numerical weather prediction, seasonal prediction and climate change impacts assessments, and will include global and regional modelling capability. It will involve extensive collaboration with the Australian university sector. Dr K. Puri has been appointed science leader, and planning is well advanced with the expectation that commencement of coding will begin by mid-2006.

While the new system is being developed, simulations are to be performed with existing models (e.g., CSIRO Mk 3.5) as required to support climate impacts work and to address scientific questions of particular national interest.

3.2 National Center for Atmospheric Research (NCAR), USA

Dr G. Meehl presented the coupled modelling activites at NCAR. Global coupled climate model efforts at NCAR are coordinated nationally through the Community Climate System Model (CCSM) project. There are now ten working groups coordinating research and model development, and address atmosphere, ocean, polar, land surface, biogeochemistry, climate change, climate variability, software engineering, paleoclimate, and chemistry (the latter is the new working group just added this year).

Currently active climate models at NCAR:

Parallel Climate Model (PCM): atmosphere: CCM3.2, T42, 18L; ocean: POP, 2/3 to 1/2 degree in equatorial Tropics, 32L, biharmonic diffusion, Pacanowski/Philander mixing; sea ice: dynamic (EVP), thermodynamic; and land surface: LSM. (soon to be retired)

Community Climate System Model version 2 (CCSM2): atmosphere: CAM2, T42, 26L; ocean: POP, 1 to 1/2 degree in equatorial Tropics, 40L, GM, KPP; sea ice: dynamic (EVP), thermodynamic; and land: CLM.

CCSM3: atmosphere: CAM3, T85, 26L (also T31 and T42); ocean: POP, 1 to 1/2 degree in eq. Tropics, 40L, GM, KPP; sea ice: dynamic (EVP), thermodynamic, land: CLM. (T42 class models run 8 years per day on IBM SP Power4; T85 is about a factor of two slower).

WACCM: finite volume dynamical core, many more levels in the stratosphere, and coupled chemistry (not coupled to ocean yet).

CSM1 with carbon cycle: CAM1 atmosphere, T31, 3-degree ocean, terrestrial and ocean carbon cycle.

Analysis of models at NCAR has included a study of possible future changes to ENSO (Meehl et al., 2005, Clim. Dyn., accepted). Reduced El Nino amplitude in both PCM and CCSM3 falls outside of natural variability only for high forcing (4X CO_2 or A1B). This is due to warming below the thermocline that reduces the vertical temperature gradient and deepens it. In these models we know that these effects act to reduce the amplitude of El Nino, which is what happens for large forcing from increased CO_2.

With increasing GHGs, there are reduced areas of significant El Nino-related temperature anomalies over North America. This is due to the change in El Nino SLP teleconnections to Pacific-North America, such that with increasing CO_2, the anomalously deepened Aleutian low in the North Pacific shifts east and weakens.

Issues for CCSM:

1. Improving physical biases; Tropical Variability Task Team (TVTT) has been formed.
2. Are the land and biogeochemistry components on track for a CCSM4 that includes an interactive carbon/nitrogen cycle?
3. How should CCSM4 include the indirect effect of sulfate aerosols?
4. How important is the full atmospheric chemistry component for a CCSM4 that addresses an interactive carbon/nitrogen cycle?
5. One estimate for a version of an earth system model run for scenario experiments is that it would require a factor of 25 increase in computing resources
6. What is meant by “seamless” or “unified” modelling?
7. How do we plan for the IPCC AR5? (resource requirements, what are the scenarios/experimental design, what form will the model take, etc.)

3.3 Geophysical Fluid Dynamics Laboratory (GFDL), USA

Dr T. Delworth presented a summary of ongoing model development efforts at GFDL, along with some emerging scientific results using those models. Two versions of the GFDL coupled model were described, CM2.0 and CM2.1, differing in the atmospheric dynamical core and details of model tunings. A full suite of IPCC AR4 model integrations has been performed with each model. Details of the models, as well as model output, are available at http://nomads.gfdl.noaa.gov.

One of the important results to emerge from these models is the simulation of Sahelian drought in the 20th century. These models suggest that part of that drought was a response to anthropogenic climate change, and that the drying will continue in the future. The model has also been used to decompose simulated changes in 20th century ocean heat content into components attributable to various climate change forcing agents. It was found that anthropogenic and natural aerosols have offset a substantial amount of ocean warming that would have occurred solely in response to increasing greenhouse gases. The model has also been used for experiments with paleoclimatic relevance, demonstrating a causal link between a substantial reduction of the thermohaline circulation in the North Atlantic and a pan-tropical suite of climate changes. These tropical changes are extremely similar to changes inferred from proxy reconstructions. Results were also presented from assimilation efforts using a fully coupled model. After conducting an initial control integration, an independent integration is conducted from different initial conditions, but assimilating output from the first (control) integration. In this manner, the second integration is sufficiently constrained to largely reproduce the first integration.

3.4 Global Modelling Groups, Japan

Dr M. Kimoto reported recent activities of the Japanese global modeling groups:

- The CCSR/NIES/FRCGC group has conducted climate projection experiments with relatively high (T106 atmosphere and 1/4 x 1/6 deg Ocean) and medium (T42 + 1 x 1.4 deg) resolution coupled models. The high-resolution simulation enables more reliable discussions on extremes and regional aspects of the warming, associated with more realistic simulations e.g., of East Asian monsoon front (Baius front) and of the Kuroshio. Increases in frequencies of heavy precipitation as well as non-precipitating days, i.e., increasing extremity in the hydrological cycle, are expected in East Asia.

- The MRI/JMA group has made high-resolution time-slice climate projection experiments, which enable more realistic simulations of Typhoons and other heavy precipitation events. 20-km AGCM and cloud-resolving regional simulations have been conducted. More active and prolonged Baiu frontal activity, general decrease in number of typhoons, and increase in stronger typhoons are predicted.

- The Central Research Institute of the Electric Power Industry (CRIEPI), in collaboration with NCAR, conducted an “overshoot” Scenario experiment for future projection. Global temperature and the strength of thermohaline circulation tend to follow leveled and decreased emission scenarios over the next century, but a considerable temporal delay exists in the response of global sea level.

- The FRCGC/CCSR group is also developing an integrated earth system model. A pilot, interactive carbon cycle experiment has indicated positive feedback of the climate-carbon cycle interaction.

3.5 Institut Pierre Simon Laplace (IPSL), France

Dr P. Braconnot presented the modelling activities at IPSL, France. Until March 2005, the activity was mainly devoted to the IPCC simulations and the transfer of the data to PCMDI. The timing was similar for the CNRM group.

Several projects were proposed as part of the analysis of IPCC scenarios. Also a French project (ESCRIME) aims at the analysis of the two French models. At the moment 15 sub-projects have been proposed.

The carbon cycle is now implemented in the model version used for AR4 and new simulations with interactive carbon are on the way and the results will contribute to the C4MIP project.

The coupling with the aerosol and atmospheric chemistry INCA is being introduced in a parallel version of the IPSL_CM4 model. This requires coupling the aerosols properties to the radiative code following what was done for sulfates for AR4.

A parallel version of the coupled model will be available soon, and a subset of IPCC scenarios will be run at higher resolution in the coming year.

IPSL_CM4 is also used to run paleoclimate experiments as part of the PMIP2 project. To illustrate the last results obtained at IPSL, three subjects were highlighted. The first one considered the analysis of the sensitivity of cloud radiative forcing to SST in the tropics performed by Bony and Dufresne (2005), using CMIP simulations run for AR4. By sorting the sensitivity of the cloud forcing as a function of convection regimes they found that there was a link between climate sensitivity and the low level clouds in regimes of low subsidence. A second part of the work consisted of using the satellite and reanalysis data to evaluate how the cloud forcing evolves as a function of SST for interannual variability. The rationale is that this provides information on model performance for future climate in the regimes that have similar sensitivity for interannual variability and long-term climate change. The second one illustrated how different convection and cloud schemes affect the simulated seasonal cycle and interannual variability in the tropics. When the coupled model is run with the Tiedke convection scheme instead of the Emanual one, the ITCZ is systematically located further south, and the seasonal cycle of the equatorial upwelling is damped. The last example concerned new interactive carbon cycle model development and the first results of this new version of the model. In the present version carbon is not transported in the atmosphere.

3.6 Met Office, Hadley Centre, UK

Dr O. Boucher presented the progress on physical climate modelling in the Met Office on behalf of Dr V. Pope. The HadGEM1 model has a resolution of 1.875° in longitude and 1.25° in latitude with 38 vertical layers. Coastal tiling in the ocean model improves the resolution of islands and coasts. Version 2 of the MOSES land surface exchange model has been used. The model includes sulphate, fossil-fuel black carbon and biomass burning aerosols and diagnostic sea-salt aerosols but not mineral dust. The performances of the HadGEM1 model have been presented and discussed. They are superior to those of its predecessor HadCM3 in many respects, including sea-ice extent, cloud distribution, and tracer transport to the stratosphere. At 4.4K for a doubling CO_2, HadGEM1 has a larger climate sensitivity than HadCM3 but a similar transient climate sensitivity. The HadGEM1a project will focus on improving the ENSO performance of HadGEM1.

Dr H. Banks presented an overview of recent work in ocean and sea ice modelling in the Met Office. The ocean component of HadGEM1 has an ocean resolution of 1° x 1° increasing to 1/3° in the meridional direction on the Equator. Ocean transports in the HadGEM1 model agree well with those in the HadCM3 model. The sea ice component of HadGEM1 includes a number of new features; in particular, a sea ice rheology and multiple ice thickness categories. Sea ice distributions in the HadGEM1 model are significantly improved over the HadCM3 model. Current work in ocean and sea ice modelling is focussed on moving to use the NEMO ocean model and CICE sea ice model. Dr Banks also described work being undertaken at the Hadley Centre to attribute observed ocean changes in the Indian Ocean and Labrador Sea. Developing our understanding of processes associated with the thermohaline circulation (THC) is also enabling the development of a THC risk assessment.

Dr O. Boucher presented the latest Hadley Centre results on Earth System modelling. A number of potential feedback loops and interactions have been identified that need to be included in Earth System models. These include the carbon-climate feedback, the DMS-sulphate-cloud feedback, the ozone impact on plant productivity and carbon uptake, the physiological impact of CO_2 on plant and runoff, the vegetation-soildust-ocean biology chain, climate impacts on atmospheric chemistry, climate impacts on emissions of chemicals from vegetation, interactions between the aerosol and carbon cycles. The HadGEM2 project aims at building an Earth System model to address the most important of these feedbacks and couplings.

4. REVIEW OF WGCM INITIATIVES

4.1 *Coupled Model Intercomparison Project (CMIP) (Dr G. Meehl)*

The IPCC model analysis project was approved by WGCM in October 2003. The WGCM Climate Simulation Panel (Drs G. Meehl (Chair), J. Mitchell, B. McAvaney, M. Latif, C. Covey, R. Stouffer) has overseen and coordinated collection, archival and analysis of model data for the IPCC AR4. 2005 marked the 10th anniversary of CMIP. During the year, significant accomplishments related to CMIP included: PCMDI has collected, archived and distributed the model data (and will do so for next few years); a successful international IPCC model analysis workshop was held in March 2005 and overseen by the WGCM Climate Simulation Panel (see below for details); all CMIP2+ data are available for analysis from PCMDI

The Catalogue of MIPs is maintained with cooperation of WGCM and IGBP/AIMES, and is maintained on the WCRP web page with a link from the CMIP web page (http://www-pcmdi.llnl.gov/projects/cmip/index.php). Publications issued include: Report of the CMIP Workshop, September 2003 by Meehl, G.A., C. Covey, B. McAvaney, M. Latif, and R.J. Stouffer, 2005, and Overview of the coupled model intercomparison project. *Bulletin of American Meteorological Society, 86, pp 89-93.* CMIP subprojects have produced 47 peer-reviewed publications, 6 other publications, 4 PCMDI publications and produced significant contributions to IPCC AR4; there are 43 CMIP2+ subprojects currently active, in addition to 10 completed subprojects from CMIP1 and 22 from CMIP2.

Though the IPCC deadlines have passed, sign-up for access to the multi-model dataset and data download rate remain almost constant. This indicates that the multi-model dataset is continuing to be used and will have ongoing utility over the next few years.

Dr D. Karoly proposed a CMIP coordinated experiment for detection/attribution purposes that would involve 3-4 member ensembles of 20th century climate with GHG-only and natural-only forcing experiments. This met with general approval. Dr Karoly will write up a proposal for vetting by the CMIP Panel, and then this will be sent to the modelling groups. PCMDI has agreed to collect these additional data.

4.2 *CMIP and IPCC (Dr G. Meehl)*

The IPCC AR4 motivated the formulation of the largest international global coupled climate model experiment and multi-model analysis effort ever attempted, and is being coordinated by the WGCM Climate Simulation Panel (see above). Fourteen modelling groups from around the world are participating with 21 models. Considerable resources have been devoted to this project. PCMDI has archived >30 TeraBytes of model data so far.

Results from analyses of the multi-model dataset were presented by 125 scientists at a workshop convened by US CLIVAR and hosted by IPRC (Univ. of Hawaii) March 1-4, 2005, and are feeding directly into the AR4 assessment process. Due to the large number of participants, the format of the workshop was "short presentation/poster". Feedback from participants indicated this was a successful workshop. 125 scientists participated in the workshop. This is more than triple the most optimistic estimate for participation. To date, there are over 400 analysis projects registered at PCMDI. Several more are being added every week. This is the largest, most comprehensive, highest profile and, arguably, most successful project ever organized by WGCM. The Coupled Model Evaluation Project (CMEP) set up through US CLIVAR and funding awarded for 18 PIs to analyze, at a minimum, 20th century IPCC runs from US models in the IPCC model dataset at PCMDI; US CLIVAR is promoting CMEP for its Climate Change Science Program (CCSP) reports.

WGCM, the WGCM Climate Simulation Panel and the international climate science community wish to formally thank PCMDI for their invaluable contribution to the collection, archival and distribution effort for the IPCC multi-model analysis activity.

WGCM has received many emails expressing thanks to WGCM for organizing this activity. This is by far the most unsolicited response we have had to any WGCM project.

One category of respondents is from experienced climate science researchers, an example of which is:

Thanks for…a rather remarkable and successful effort to bring together data and analysts to fast-track research for the AR4 -- Dr G. Takle, Iowa State University.

Another category of respondents is from young scientists who were able to gain unique career experience through this project, an example of which is:

Thanks for letting me have access to the model data. This gave me an opportunity I wouldn't normally have had, and it has gotten me involved in model analysis and doing research I don't think I would have done otherwise --Dr N. Diffenbaugh, Purdue University.

Finally, a third category is from institutional or programmatic respondents, an example of which is:
The ENSEMBLES Management Board wishes to inform WGCM and PCMDI how useful the IPCC database is proving and to urge that it be maintained as long as possible -- Dr D. Griggs, Hadley Centre.

During its session, the WGCM addressed several issues relating to CMIP and IPCC:

a) Issue: ENSEMBLES wishes to set up a mirror site for PCMDI IPCC-data to match the ENSEMBLE requirement but also to satisfy the IPCC-DDC needs. Data access will be restricted to the ENSEMBLES participants.

WGCM response: ENSEMBLES researchers can either access the multi-model data through the WGCM Climate Simulation Panel in the usual way, or a representative from ENSEMBLES can travel to PCMDI and download multi-model data on discs to be carried back to Hamburg.

b) Issue: What is the relationship between CMIP and the IPCC? (IPCC WG1 suggests having a person from WG3 familiar with scenario development on WGCM).

WGCM response: Clearly, CMIP and IPCC are inextricably linked, though CMIP (and WGCM) still have as a high priority the scientific understanding of processes and responses of the AOGCMs. WGCM recognized the need to invite a representative from WG3 to brief WGCM at annual meetings regarding developments in the area of scenarios that would eventually impact the modelling groups regarding future assessments. WGCM co-chairs will also write letters to the IPCC chair and WG co-chairs regarding scenario development emphasizing linkage to previous scenarios and a small number of new scenarios.

c) Is WGCM/CMIP going to be a provider of model data in the future (AR5 and beyond)?

WGCM response: Yes, the community WGCM represents must continue to take ownership over this activity for the mutual benefit of the community.

d) Is the oversight of data similar between CMIP and the IPCC, and how is access to the model data best managed?

WGCM response: Yes, oversight is similar, and we will continue to have the WGCM Climate Simulation Panel have a look at all submitted analysis and data access requests, but Panel members need only respond if they have specific comments.

e) CF-netCDF very successful- is it demanding of resources?

WGCM response: WGCM will form a steering group. Drs R. Stouffer and K. Taylor will write up terms of reference and suggest members.

f) What about commercialization of data?

WGCM response: WGCM Climate Simulation Panel will keep an eye out for commercial applications, and advise such requests that the model data are for academic research applications only for publication in the peer-reviewed literature. Any commercial applications would have to contact the modelling groups directly. The U.S. groups noted that they would have to make their model data available for such uses.

g) The Radiative Transfer model Intercomparison Project (RTMIP) and Forster results show large differences in forcing and radiation codes-this needs to be addressed.

WGCM response: Co-Chairs Drs J. Mitchell and G. Meehl agreed to contact the GEWEX Radiation Panel to alert them to this issue and request guidance regarding possible actions.

4.3 Cloud Feedback Model Intercomparison Project (CFMIP) (Dr C. Senior)

CFMIP is a WCRP sponsored research project specially focussed to provide a systematic intercomparison of cloud feedbacks in climate models as part of a programme to provide continuing documentation of the strength of cloud feedbacks in climate models and an evaluation of the performance of climate models in simulating aspects of clouds that are important in cloud feedbacks.

- Experiment protocol is +/-2K atmosphere only and 1xCO_2 and 2xCO_2 'slab' experiments
- Project leaders are Drs B. McAvaney (BMRC) and H. Le Treut (LMD), but recent progress has been driven at the Hadley Centre mainly by Drs M. Webb and K. Williams

The key features and issues of CFMIP include:

- It's a MIP, but not as we know it… Acceptance of process oriented diagnostics e.g. ISCCP simulator into main stream; high temporal sampling of data etc
- Low cloud has been identified as the main source of uncertainty in climate sensitivity
- Studies to 'evaluate' important feedbacks are in progress
- 'Metrics' based on the key feedbacks are being developed
- CFMIP heavily quoted in IPCC AR4
- Participation has been a struggle. This may be due to co-incident timescales with AR4 and prioritisation of groups to produce coupled runs for AR4
- Lack of use of data on sub-projects. Individuals have used CMIP transient data where the absolute requirement of e.g. ISCCP diagnostics are not needed

Future plans for the project:

- To re-activate other sub-projects on water vapour, surface radiation etc. The advantage of using CFMIP data is to make the link with cloud feedbacks
- To hold a second CFMIP meeting (Spring 2007). This will kick start more work and show what data are available and what further work is needed for AR5
- To migrate data to PCMDI. Data would be open to everyone and analogous to CMIP data. Does WGCM support this?
- To incorporate CFMIP protocol into AR5 (ISCCP simulator mandatory)
- To further develop links with NWP/Process community (e.g. through GCSS)

4.4 Historical Forcings (Dr R.J. Stouffer)

There is need to organize collection of radiative forcing constituents and involve experts in evaluating the inputs. Groups were required to submit these time series to PCMDI as part of the AR4 activity. It is unclear that groups have responded to this request or if experts know or are interested in evaluating these data sets. One needs to know the way to improve this situation.

4.5 Initialization of coupled models (Dr R.J. Stouffer)

Most groups involved in the AR4 process use some variant of the Stouffer et al (Stouffer, R.J., A.J. Weaver, and M. Eby, 2004: A method for obtaining pre-twentieth century initial conditions for use in climate change studies. Climate Dynamics, 23, 327-339) method to find ca. 1850 control climate state. Many groups are now experimenting with prediction of the first kind using ocean data assimilation. These efforts typically use data obtained from the 1960's and later.

4.6 Decadal Variability (Dr T. Delworth)

A perspective on some recent developments in research on decadal variability and predictability was presented. One of the key emerging themes is an emphasis on the Atlantic Multidecadal Oscillation (AMO), and its impact on climate. The AMO is characterized by a pattern of Atlantic SST anomalies of one sign north of the Equator, and opposite sign south of the Equator. Results were presented from several recent studies demonstrating the impact of the AMO on features such as Sahelian and Indian summer rainfall, tropical wind shear related to hurricane intensity, and summer climate over both Europe and North America. Research was also highlighted discussing aspects of decadal scale predictability of such phenomena, with at least one model showing decadal scale predictability of temperatures for continental locations. It was also pointed out that decadal scale fluctuations in the Indian and Pacific sectors have strong impacts on climate fluctuations elsewhere. For example, recent work has related decadal scale changes in Pacific sea surface temperature to persistent patterns of drought over North America.

4.7 Detection and attribution of climate change (Dr D. Karoly)

The session was given a report on the WMO CCl/CLIVAR Expert Team of Climate Change Detection, Monitoring and Indices (ETCCDMI). The IDAG typically meets once every 3 years. The group has unofficial link with IDAG (International Ad hoc Detection and Attribution Group) jointly funded by DoE and NOAA in US. This group typically meets every year and reviews methods and results in attribution of climate change. Recent review papers include: IDAG paper, J Climate, 2005; CLIVAR Detection and Attribution paper, Hegerl et al., 2006; IPCC AR4 chapter, Hegerl and Zwiers, 2007.

Detection and Attribution (D&A)

- quantifies relative importance of different forcing factors in observed climate change,
- evaluates performance of climate models in simulating climate variations over the 20th century,and
- can be used to constrain future global or regional climate projections and to estimate uncertainties.

WGCM was requested to consider the following:

- D&A studies are difficult to carry out using existing IPCC 20C runs as they don't isolate different forcings
- Requests for additional runs and data from AR4 models with
  - ALL forcings runs generally provided, some groups provided GS runs
  - New runs with individual forcings: GHG (or ALL – GHG), NAT, in addition to ALL
  - Must have 3-4 member ensembles for each forcing
  - Already available from GFDL2.1, MIROC Med, HadCM3, PCM but data not at PCMDI
  - Land-use, land-cover changes.

Additional requests include

- Longer control run data, where available
- Monthly mean Tmax, Tmin

4.8 Palaeoclimate modelling (Dr P. Braconnot)

In its second phase, the Paleoclimate Modeling Intercomparison Project (PMIP2) had to face the constraints of the AR4, to have enough analysis of the new simulations that could be used as a basis for AR4 chapter 6 on paleoclimate. The first results of the new simulations for the mid-Holocene (6000 years ago) and last glacial Maximum (21000 year ago) arrived in March in the database. Several sub-projects were launched. The rules to participate in a subproject follow the one for CMIP, and are simple. Each sub-subject should favour model-data comparisons and consider all the model simulations in the database. Information is provided on the website (http://www-lsce.cea.fr/pmip2), as well as the list of the 36 ongoing projects.

There are now 9 model simulations for 6ka and 7 for 21ka with coupled ocean-atmosphere models. For most of the groups the model version is the same as the one used in AR4. This offers the possibility to evaluate climate models under different forcings. Most of the groups also faced difficulties with interactive vegetation modules. They will join the database in a second step. At the moment only two of these simulations are available for 6ka. Other models will join the database in the coming months.

An important milestone of the year was the first meeting of PMIP2 organised last April in Giens (south of France). The meeting was supported by French institutions (CNRS, CEA), WCRP/CLIVAR, and IGBP/PAGES. The objectives of this meeting were to:

- review the results of the coupled simulations of the mid-Holocene and LGM, *(climate sensitivity, the role of ocean, land-surface and sea-ice feedbacks, THC, and internannual to multi-decadal variability);*
- present new data syntheses: changes in mean climate and in short-term climate variability
- discuss model-data comparisons
- experimental protocol for Early Holocene and last glacial inception
- discuss water hosing experiment (CMIP/PMIP, paleo?)
  - extract and synthesise key results and diagnostics that are relevant for future climate change and IPCC-AR4.

A short report of the workshop was published in EOS (Crucifix et al. vol. 86, 12 June 2005). The following analysis and papers emerged from the discussions of the workshop:

- Global benchmarking (Harrison et al. in prep)
- Climate sensitivity of polar regions (Masson et al., Climate Dynamics in press)
- LGM:
  - Model-data comparison over Eurasia and North Atlantic (Kageyama et al. submitted)
  - Tropical cooling (Schneider et al, in preperation)
  - Deep ocean and THC (in preperation)
- 6ka :
  - NAO (Gastone et al, GRL, 2005)
  - Sahel variability (Zhao et al. in preparation).

The major results of these papers were shown as illustration of the work. For the other time periods (Early Holocene and last glacial inceptions, the presentations concerned individual simulations and new data synthesis. Also the time frame of the Early Holocene was decided to be 9.2ka). The last part of the workshop was devoted to the definition of a paleohosing experiment. Several groups are interested to have a "realistic" simulation to be able to test model results (geographical extent and timing) against paleodata. Two time periods were proposed and retained: the Youger Dryas and the 8.2 ka event at the beginning of the Holocene. The definition and the experimental set up were discussed and a proposal has been prepared.

5. OTHER ACTIVITIES

5.1 C4MIP: Coupled Climate Carbon Cycle Model Intercomparison Project (Dr C. Jones)

The field of coupled climate-carbon cycle GCMs is still relatively young field – it is just 5 years since the results of the first model were published. There are now 10 models (6 GCMs, 4 EMICs) in the intercomparison. The results show a unanimous consensus of positive feedback (i.e. climate change will weaken the natural carbon sink and hence increase CO_2 in the atmosphere), but the strength of this feedback is very uncertain – with almost an order of magnitude range across models. The first paper on C4MIP (by Friedlingstein et al) has just been accepted for publication in Journal of Climate. It shows a feedback analysis of the C4MIP transient (A2 emissions scenario) runs. The conclusion is that most of the spread between models comes from different terrestrial behaviour rather than different ocean behaviour. It also shows that even the models with similar net feedback strength have a different balance of mechanisms which contribute to it. In summary, the feedback will be stronger for:

- higher climate model sensitivity to CO_2
- stronger sensitivity of terrestrial or oceanic carbon cycle response to climate changes and smaller for:
- stronger sensitivity of terrestrial or oceanic carbon cycle response to CO_2 increase.

A sensitivity study with a simplified model has shown that vegetation uptake of carbon response to climate may be the most important of the carbon cycle parameters (rather than CO_2 fertilisation or respiration response to temperature - the two factors highlighted to date). Sensitivity of the feedback strength to climate sensitivity is possibly more important still. It also turns out that the historical record of CO_2 changes is only a weak constraint on future feedback strength. Parameter perturbations in the simple model which match the historical record can give very different future projections.

C4MIP "phase 1" was intended to be a terrestrial carbon cycle simulation of the 20th century forced by observed SSTs and CO_2. However, only 2 of the 10 groups (Hadley and NCAR) have performed it. One reason is that it is thought that the absence of a formal treatment of land-use change in these models makes comparison with the observations difficult. It is thought that vegetation recovery from past land-use has played a significant role in the 20th century carbon balance, and so simulations without it cannot be expected to reproduce the observations (in much the same way that early climate models didn't include aerosol forcing). Instead it is hoped that validation against regional or process based observations (such as Fluxnet towers) may be able to constrain model behaviour. This has still to be investigated.

The main conclusions of the C4MIP paper are:

- the climate-carbon cycle feedback, is positive (10/10 models)
- climate impact on the biosphere is negative (10/10), overall effect (climate + CO_2) is negative (10/10)
- climate impact on ocean carbon uptake is negative (10/10) but overall effect is unclear (some models have greater CO_2 than climate increase, others have greater climate than CO_2 effect).
- we need intelligent experimental design to help constrain the models with relevant observations

- some key mechanisms are still missing in these models, but are being developed (e.g. land-use change, fire, nitrogen cycling).

5.2 Data Management (Drs K. Taylor and R. Stouffer)

WGCM discussed the challenges faced in sharing model output with a wide community of researchers. The focus was largely on model output served in support of the IPCC's Fourth Assessment Report. Modelling groups rewrote their model output in compliance with strict requirements, which were agreed upon, in scope, at the Seventh Session of the WGCM. The output was then sent to a repository at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) where it was made available to a wide community of researchers.

As the value of coordinated modeling activities becomes more apparent and benchmark experiments such as AMIP and CMIP become routine parts of the model development cycle, it is desirable to establish a common approach to the sharing of model output. The IPCC exercise offered an opportunity to continue taking steps toward that goal. In contrast with previous intercomparison projects, a larger burden was placed on the modeling groups to satisfy precisely defined requirements for both the format and structure of the output, as well as the metadata to be included. Model documentation was also required in a uniform format. The scientific payoff for all the effort is that more than 300 users are analyzing model output from 21 different models, and more that 100 (possibly 200) manuscripts have been already written, based, at least in part, on the IPCC database. The database will likely attract continued scientific interest for several years.

There are several reasons why scientists found it relatively easy to analyze model output in the IPCC database. The variables collected and the experiments performed were precisely defined, and nearly all the model output was passed through a common set of output routines, which ensured compliance with strict requirements for metadata and data structure. This output software, called the Climate Model Output Rewriter (CMOR), was designed for easy adaptation to the needs of other model intercomparison projects, so that the investment in learning how to meet the IPCC requirements will facilitate participation in future projects.

The output in the IPCC database is accompanied by considerable metadata that has been written in accord with the increasingly popular Climate and Forecast (CF) Metadata Conventions for netCDF files. These conventions ensure that the data are largely "self-describing" so that scientists can automatically extract both the data and other information needed to perform analyses. As a simple example, the CF conventions make it possible to automatically recover the geophysical location of the data values, as well as any other coordinate information.

Although the collection and distribution of model output in support of the IPCC AR4 has gone relatively smoothly, several lessons have been learned that should improve future exercises of this sort. The planning process needs to begin much earlier next time to allow for more thoughtful examination of model results. Based on the uses made of the current suite of output, the list of standard output should be modified, especially to help in diagnosis of the ocean simulations. Several suggestions have been made to better serve the analysts, including refinement of the registration procedure, and automated notification of errors identified in the database. It would be particularly useful if an ability was added to subset or aggregate data at the request of the user. It was noted that tools need to be developed to process data stored on non-standard grids (e.g., tripolar, geodesic, "thin" grids) so that mapping ocean output to Cartesian latitude/longitude grids could be avoided. The attractiveness of moving toward a more distributed database is also becoming recognized. If the groups producing the model output were able to serve it, some of the bandwidth and logistical problems transmitting data to a central repository would be avoided. The groups could also immediately correct their output when errors are found. In order for such a distributed database to work as well as the present one, quality control would have to be run across the network, and the current rudimentary capability to make it look like distributed data comes from a single location would need to be improved.

Action items:

a) It was recommended that the WGCM formally recognize and thank the individuals who rewrote the model output and sent it to PCMDI, along with the groups carrying out the simulations, as a small gesture of appreciation for their roles in making the IPCC exercise successful.
b) It was also suggested that other model intercomparison projects be encouraged to adopt the model output requirements established for the IPCC output.
c) It was specifically recommended that the WGCM nurture and promote the CF conventions by endorsing a "white paper" describing the governance and development of these conventions.

d) It was recommended that an oversight committee be established.
e) It was recommended that a committee be set up to oversee the development of future variable lists for the IPCC exercise.

6. INTERACTIONS WITH OTHER PROGRAMMES

There were presentations at the session on Carbon Cycle Modelling (Dr C. Le Quéré), ESSP/Global Carbon Project (Dr C. Le Quéré), Biosphere Modelling (Dr C. Le Quéré), C4MIP (C. Jones), THORPEX (Dr D.S. Richardson) and CliC (Dr V. Lytle). In a discussion session, the topic, 'Future Perspectives of WGCM' was revisited and there were discussions on 'Earth System Modelling' and 'Next-generation Modelling'.

6.1 Carbon cycle modelling (Dr C. Le Quéré)

The presentation summarized the recent progress in carbon cycle research. Developments have been made independently on ocean and land carbon cycle modeling.

6.1.1 Ocean modelling

Anthropogenic CO_2 uptake

Ocean models can reproduce the observed estimates of anthropogenic CO_2 uptake within the uncertainty of the data. Model results are close to one another for the present, but differ for the future because of differences in the vertical transport of carbon in the intermediate and deep ocean.

Changes in ocean pH

The effect of pH on marine biogeochemistry is poorly understood. Some groups have shown that the low pH associated with high CO_2 conditions is detrimental for organisms that form shells of calcium carbonate or opal, and would induce changes in ecosystem composition. However, the impact of the latter on CO_2 is not known.

Role of dust as Fe fertilizer

The role of enhanced Fe fertilization during glacial-interglacial cycles has been limited to less than 30 ppm based on the timing of events and on the changes in export production estimated from proxy data. The remaining 50-80 ppm decrease must be explained by either (1) changes in ice cover and its impact on air-sea fluxes, (2) changes in surface stratification, or (3) changes in deep ocean stratification. Ocean physical models are unable to reproduce hypotheses (2) and (3) because they produce too much vertical diffusion (partly numerical).

Ongoing projects/model developments

- OCMIP (Ocean Carbon-Cycle Model Intercomparison Project) has just finished its phase III which focused on interannual variability. Simulations over the 1948-2002 period were done by at least 7 groups and archived at the IPSL in Paris (www.ipsl.jussieu.fr/OCMIP).

- A comparison of the ocean part of C4MIP models is underway, with funding from the European Carbo-oceans project (led by Dr C. Heinze).

- IOCCP (International Ocean Carbon Coordination Project) is helping to co-ordinate observations and databases.

- Individual model developments are primarily focused on the ecosystem aspects.

6.1.2 Land modelling

Update on carbon sinks

The large CO_2 sink in the Northern Hemisphere has been known for a long time, but the underlying processes responsible for it are still not clear. The first hypothesis involves CO_2 fertilization on land: forests artificially fertilized by CO_2 grow ~25% more at $2XCO_2$, although it is not yet determined if this effect lasts beyond a few years. The second hypothesis involves N fertilization, either from anthropogenic input of industrial fertilizers or from the enhanced recycling of organic matter under warmer conditions. The third hypothesis involves the re-growth of forests which have been cut down at the beginning of the 20th century and were later abandoned. This effect can account for the entire CO_2 sink over North America.

Interannual variability (IAV) in CO_2 has been used to help constrain the models. From observations, we know that IAV originates primarily from the tropics. Models can reproduce largely the observed IAV, but the underlying processes are unconstrained. Recent studies suggest that up to 50% of the IAV can be caused by fires, although many models do not yet include fires.

The recent drought in Europe (2003) has induced a source of CO_2 to the atmosphere of 0.5 PgC/y, which suggest that increased droughts under warming climate may lead to a reduced CO_2 sink on land.

Model estimates of changes in the land CO_2 sink in 2100 produce a range of 200 ppm in atmospheric CO_2 for a given climate, as large as the range between different emission scenarios.

Role of fires

Fires are now recognized as a large source of CO_2 variability and an essential component of terrestrial CO_2 models. Fires are governed by the quantity of combustibles, the humidity, and the ignition (human- or lightning- induced). Human-induced emissions have increased in the past 20 years.

6.1.3 Ongoing projects/model developments

1. C4MIP is underway. A series of experiments is repeated by ~10 groups, but no common funding is in place.

2. Carbo-Europe (carbon budget of Europe) funded by the EU.

3. US Carbon Plan (carbon budget over the US) funded by the US.

6.2 The Global Carbon Project (Dr C. Le Quéré)

The Global Carbon Project (GCP) is a project of IGBP, WCRP, IHDP and Diversitas under the Earth System Science Partnership. The science plan of the GCP is separated into three frameworks: (1) patterns and variability, (2) mechanisms and feedbacks, and (3) carbon management. Links with the WGCM are mostly through (2).

The GCP has made an initial assessment of the vulnerabilities of the Carbon-Climate system. It has described the size and likely vulnerability of the different carbon pools and processes in the oceans and on land (Towards CO_2 stabilization: Issues, Strategies and Consequences, A SCOPE/GCP Rapid Assessment Project. C.Field and M.Raupach, Editors). The ongoing activities of the GCP partly focus on pools and processes that have a risk over the coming century of up to 200 ppm of atmospheric CO_2 (rivaling the fossil fuel), and which are not included in most climate simulations. The GCP also looks at potential feedbacks that include the human dimension.

The following activities are currently underway:

1. Vulnerability of the permafrost-C-climate system. The amount of carbon frozen in soils needs to be better assessed, its spatial distribution and Southern boundary dynamics needs to be better known, and modelling work needs to explore the effect of warming on emitted C. The following workshops have been funded to explore these issues:

- two workshops in 2006 will make an overall assessment of permafrost C. (funding National Center for Ecological Analysis and Synthesis, Field and Canadell)

- one workshop in 2005 will focus on below-ground carbon pools in permafrost regions. (funding European Science Foundation, Kuhry)

- one workshop in 2007 as part of the International Polar Year, (funding ICSU, IGBP/WCRP, Canadell)

2. Vulnerability of carbon pools in tropical peatlands. Here again, the total amount of carbon in tropical peatlands needs to be better assessed. The impact of land use on peatlands needs to be taken into account because the drying of peatlands makes them prone to fires, which then release large concentrations of carbon. The following workshops or activities have been funded to explore these issues:

- two workshops in 2005 and 2006 with topic Tropical Peatland Synthesis: Carbon stocks, Drivers of change, Biogeochemical modeling, Input into GCMs. (funding by APN, Parish & Canadell)

- one project (2005-2008) with topic Tropical forests and climate change adaptation: criteria and indicators for adaptive management for reduced vulnerability and long-term sustainability (funding by EU project CIFOR, Indonesia, Murdiyarso et al.)

3. Vulnerability of terrestrial carbon to droughts. The GCP is starting an activity on this topic. One workshop will be held next year to estimate the impact of droughts on gross primary production, heterotrophic respiration, and fires.

- workshops in 2006 (June 5-9, Canberra) with topic Drought impact on the Carbon cycle, (funding sought by Field and Canadell)

6.3 Ecosystem modelling (Dr C. Le Quéré)

Marine Ecosystems

Marine ecosystems interact with climate through the following pathways:

Direct pathways
- absorption of solar radiation (and shading of sub-surface) by phytoplankton

Indirect pathways
- CO_2 fluxes
- DMS (dimethylsulfide) fluxes

Marine ecosystems also use Fe from atmospheric dust deposition, and nutrients (P, N, Si and Fe) from river input.

Models of marine ecosystems have increasing levels of complexity:

1. Nutrient restoring models or export models only simulate the transport of carbon from the surface to the deep ocean, but do not take into account the complexity of ecosystems.

2. NPZD models (Nutrient-Phytoplankton-Zooplankton-Detritus) represent one phyto- and one zoo- plankton. They are fast and predictable models and are widely used. The published coupled-carbon models of the IPSL and Hadley Centre used NPZD models.

3. Dynamic Green Ocean Models I include more than one phytoplankton, in effect taking into account the ecosystem composition in its simplest form. The current coupled-carbon models of the IPSL and Hadley Centre include DGOMI models.

4. Dynamic Green Ocean Models II include up to 10 plankton functional types. Several versions of these models are under development and none have been coupled to climate models yet. Much effort is being put to estimate unconstrained parameters from databases and to develop evaluation data. These model developments are being made in co-ordination with the IMBER and SOLAS projects.

Terrestrial Ecosystems

Terrestrial ecosystems interact with climate through the following pathways:

Direct pathways
- surface roughness
- albedo (especially in snow-covered regions)
- evapo-transpiration (including heat budget)

Indirect pathways

- CO_2 fluxes
- CH_4, N_2O, NO_x, CO, VOC

Disturbances (mainly fires) release large quantity of trace gases to the atmosphere. The vegetation cover also plays a role in the emission of dust and in the river input of nutrient to the oceans.

Models of terrestrial ecosystems differ in their function more than in their complexity:

1. Land Surface Models (LSM) aim to produce surface boundary conditions for climate models. They calculate the energetic and hydrological balances, have static vegetation, and no carbon. They typically run on the time-scale of the parent climate model (~30 min.).

2. Terrestrial ecosystem models (TEMs) aim to reproduce carbon budgets. They produce a hydrological balance and a carbon cycle, but not an energy budget. They typically run on time-scales of months to years.

3. Dynamic Global Vegetation Models I are TEMs that include vegetation dynamics.

4. Dynamic Global Vegetation Models II combine a TEM and a LSM and are used in coupled models.

5. Dynamic Global Vegetation Models III are advanced versions of DGVMII including fires, land-use change, and other trace gases.

7. ADMINISTRATIVE MATTERS

7.1 Membership

The JSC at its 26th session in March 2005, considered the proposals submitted by the WGCM co-chairs for the memberships of the group. Drs J. Mitchell and G. Meehl were re-appointed as Co-Chairs with immediate effect for terms ending 31 December 2007. The term of Dr T. Delworth, which expired on 31 December 2004, was extended by two years. Drs G. Hegerl, M. Latif and A. Noda, whose terms ended 31 December 2004, had left the group. Drs D. Karoly (Univ. of Oklahoma), M. Giorgetta (Max Planck Institute, Germany), C. Le Quéré (Max Planck Institute fur Biogeochemie, Germany), M. Kimoto (Univ. of Tokyo) and F. Giorgi (International Centre for Theoretical Physics, Italy) have accepted invitations to be members of the group for an initial term of four years effective 1 January 2005. The group was thus now constituted as follows:

Membership	Expiry of appointment	
J. Mitchell (Co-Chair)	31 December	2007
G. Meehl (Co- Chair)	"	2007
C. Boening (ex-officio, Co- Chair, WGOMD)	"	2005
P. Braconnot	"	2005
T. Delworth	"	2006
G. Flato	"	2007
M. Giorgetta	"	2008
F. Giorgi	"	2008
A. Hirst	"	2005
D. Karoly	"	2008
M. Kimoto	"	2008
C. Le Quéré	"	2008
B. McAvaney	"	2005

8. DATE AND PLACE OF THE TENTH SESSION OF WGCM

At the kind invitation of Dr G. Flato, Canadian Centre for Climate Modelling and Analysis, Climate Research Division, Canada, the next session of WGCM, the tenth, would be held at Victoria, BC, Canada, 25-27 September 2006, with a joint session with IGBP/AIMES on 27 September.

9. CLOSURE OF THE SESSION

The participants expressed their thanks to the local organizers Prof. J. Mitchell and to the staff of the Met Office, UK, for hosting this session, for the excellent arrangements made and the facilities and hospitality offered. The ninth session of WGCM was closed at 12.30 hours on 5 October 2005.

10. WGCM-WMP JOINT SESSION

On October 5, WMP and WGCM had a joint session for half a day, which included presentations from WGNE (Dr A. Lorenc), GEWEX/GMPP (Dr J. Polcher), CliC (Dr V. Lytle), WGOMD (Dr H. Cattle), WCRP Task Force on Seasonal Prediction (TFSP) (Dr B. Kirtman), WGSIP (Dr B. Kirtman), Monsoon Modelling (Dr J. Slingo), WOAP (Dr K. Trenberth) and AMIP (Dr D. Bader).

APPENDIX A

WGCM-9 Session, 3-5 October 2005
LIST OF PARTICIPANTS

Dr D. BADER
Director, PCMDI
Lawrence Livermore National Laboratory
P.O. Box 808, L-264
Livermore, CA 94550
USA
Tel: +1-925-422-xxxx
Fax: +1-925-422-7675
Email: bader2@llnl.gov

Dr H. BANKS
Manager, Ocean and Sea Ice Modelling
Met Office
Fitzroy Road
Exeter Devon EX1 3PB
UK
Tel: +44-1392-884956
Fax: +44-1392-885681
Email: helene.banks@metoffice.gov.uk

Dr O. BOUCHER
Met Office
Head of Climate, Chemistry, and Ecosystems Team
FitzRoy Road
Exeter EX1 3PB
UK
Tel: +44-1392-886910
Fax: +44-1392-885681
Email: olivier.boucher@metoffice.gov.uk

Dr P. BRACONNOT
Laboratoire des Sciences du Climat et de l'Environnement
Unité mixte CEA-CNRS
Orme des Merisiers, Bat. 709, CE-SACLAY
F-91191 Gif-sur-Yvette Cedex
FRANCE
Tel: +33-1-69-08-77-21
Fax: +33-1-69-08-77-16
Email: Pascale.Braconnot@cea.fr

Dr H. CATTLE
Director
International CLIVAR Project Office
National Oceanography Centre
Empress Dock
Southampton SO14 3ZH
UK
Tel: +44-2380-596208
Fax: +44-2380-596204
Email: hyc@noc.soton.ac.uk

Ms A. CHAUTARD
World Climate Research Programme
World Meteorological Organization
7 bis, avenue de la Paix
Case postale 2300
CH-1211 Geneva 2
SWITZERLAND
Tel: +41-22-730-8430
Fax: +41-22-730-8036
Email: AChautard@wmo.int

Dr C. COVEY
PCMDI
Lawrence Livermore National Laboratory
P.O. Box 808, L-264
Livermore, CA 94550
USA
Tel: +1-925-422-1828
Fax: +1-925-422-7675
Email: covey1@llnl.gov

Dr T. DELWORTH
Geophysical Fluid Dynamics Laboratory
Princeton University
PO Box 308
Princeton, NJ 08542
USA
Tel:
Fax:
Email: tom.delworth@noaa.gov

Dr G. FLATO
Meteorological Service of Canada (MSC)
University of Victoria
Canadian Centre for Climate Modelling and Analysis
P.O. Box 1700, MS3339
Victoria, BC V8W 2Y2
CANADA
Tel: +1-250-363-8223
Fax: +1-250-363-8247
Email: greg.flato@ec.gc.ca

Dr M. GIORGETTA
Max Planck Institute for Meteorology
Bundesstrasse 53
D-20146 Hamburg
GERMANY
Tel: +49-40-41173-358
Fax: +49-40-41173-298
Email: giorgetta@dkrz.de

Dr F. GIORGI
International Centre for Theoretical Physics (ICTP)
Physics of Weather and Climate Section
P.O. BOX 586, Strada Costiera 11
I-34100 Trieste
ITALY
Tel: +39-040-2240-425
Fax: +39-040-2240-449
Email: giorgi@ictp.trieste.it

Dr T. HIRST
CSIRO Atmospheric Research
PMB 1
Aspendale, Victoria 3195
AUSTRALIA
Tel: +61-3-9239-4531
Fax: +61-3-9239-4444
Email: tony.hirst@csiro.au

Dr C.P. JONES
Met Office
Numerical Weather Prediction
Fitzroy Road
Exeter EX1 3PB
UK
Tel:
Fax:
Email: cp.jones@metoffice.com

Dr D. KAROLY
Williams Chair and Prof.essor of Meteorology
University of Oklahoma
School of Meteorology
100 E. Boyd Street
Norman, OK 73019
USA
Tel: +1-405-325-6446
Fax: +1-405-325-7689
Email: dkaroly@ou.edu

Professor M. KIMOTO
University of Tokyo
Centre for Climate System Research (CCSR)
5-1-5 Kashiwanoha, Kashiwa-Shi
Chiba 277-8568
JAPAN
Tel: +81-04-7136-4371
Fax: +81-04-7136-4375
Email: kimoto@ccsr.u-tokyo.ac.jp

Dr C. LE QUERE
University of East Anglia
School of Environmental Sciences
Norwich NR4 7TJ
UK
Tel: +44-1603-592532
Fax:
Email: c.lequere@uea.ac.uk

Dr A. LORENC
Head of Data Assimilation and Observation Processing
Met Office
FitzRoy Road
Exeter EX1 3PB
UK
Tel: +44-1392-88-6227
Fax: +44-1392-88-5681
Email: Andrew.Lorenc@metoffice.com

Dr G.A. MEEHL
National Center for Atmospheric Research (NCAR)
Climate and Global Dynamics Division
P.O. Box 3000
Boulder, CO 80307-3000
USA
Tel: +1-303-497-1331
Fax: +1-303-497-1333
Email: meehl@ncar.ucar.edu

Professor J. MITCHELL
Met Office
Fitzroy Road
Exeter EX1 3PB
UK
Tel: +44-1392-884604
Fax: +44-1392-884400
Email: john.f.mitchell@metoffice.gov.uk

Dr V. POPE
Met Office
Fitzroy Road
Exeter EX1 3PB
UK
Tel:
Fax:
Email: vicky.pope@metoffice.com

Dr D. RICHARDSON
Met Office
Assimilation Studies Manager
FitzRoy Road
Exeter, Devon EX1 3PB
UK
Tel: +44-1392-886424
Fax: +44-1392-885681
Email: david.s.richardson@metoffice.gov.uk

Dr V. SATYAN
World Climate Research Programme
World Meteorological Organization
7 bis, avenue de la Paix
Case postale 2300
CH-1211 Geneva 2
SWITZERLAND
Tel: +41-22-730-8418
Fax: +41-22-730-8036
Email: VSatyan@wmo.int

Dr C. SENIOR
Met Office
Head of Understanding Climate Change
Hadley Centre for Climate Prediction and Research
FitzRoy Road
Exeter, Devon EX1 3PB
UK
Tel: +44-1392-886895
Fax: +44-1392-885681
E-mail: cath.senior@metoffice.gov.uk

Dr R. STOUFFER
Princeton University
Geophysical Fluid Dynamics Laboratory
Room 232
P.O. Box 308
Princeton, NJ 08542
USA
Tel: +1-609-452-6576
Fax: +1-609-987-5063
Email: Ronald.Stouffer@noaa.gov

Dr K. TAYLOR
Lawrence Livermore National Laboratory
L-264
P.O. Box 808
Livermore, CA 94550
USA
Tel:
Fax:
Email: taylor13@llnl.gov

APPENDIX B

WGCM-9 SESSION, 3-5 OCTOBER 2005
AGENDA

<u>WGCM Session</u>

Monday, October 3

9.00 Welcome -*J. Mitchell, G. Meehl, V. Satyan*

Introductions

Times, agenda, local arrangements

9.20 Review of WCRP events, developments

JSC-XXVI session -*J. Mitchell*

9.35 CLIVAR SSG and ICPO - *G. Meehl*

9:45 Other modelling activities

SPARC (including interaction with WGCM) - *A. O'Neill*

Regional Modelling-update - *F. Giorgi*

10.30-11.00 Coffee break

11.00 Other WCRP programmes and WGCM relevant activities

IPCC

- Fourth Assessment – update - *G. Meehl*
- Workshops:
  - Hawaii Workshop, March 2005 - *G. Meehl*
- Issues

TGCIA - *J. Mitchell*

WGSF - *P. Braconnot*

12.30-13.45 Lunch break

13.45 News from relevant national and multinational projects

Earth Simulator - *M. Kimoto*

PCMDI - *D. Bader*

14.30 Reports from modelling groups

BMRC - *A. Hirst*

CSIRO - *A. Hirst*

15.00-15.15 Coffee break

15.15 Reports from modelling groups (continued)

Hadley Centre	- *V. Pope, H. Banks, O. Boucher*
CCCM	- *G. Flato*
NCAR	- *G. Meehl*
GFDL	- *T. Delworth*
Japanese groups	- *M. Kimoto*
French groups	- *P. Braconnot*

18.00 Close of day's session

Tuesday, October 4

9.00 Data Management issues - *lead R. Stouffer and K. Taylor*

9.30 WGCM activities

(i) CMIP/IPCC Model Analysis - *G. Meehl, C. Covey*

(ii) CMIP: The Next CMIP activity -*G. Meehl, C. Covey*, *R. Stouffer*

a) Definition

b) Role of CMIP oversight panel

c) Role of PCMDI

10.30-10.45 Coffee break

10.45 WGCM activities (continued)

(iii) CFMIP/Idealised experiments - *C. Senior*

(iv) Forcing scenarios - *R. Stouffer to lead*

(v) Initialization of models - *R. Stouffer*

(vi) Climate Change Detection, ET/CCD - *D.Karoly*

12.30-14.00 Lunch break

14.00 WGCM activities (continued)

(vii) Paleoclimate Modelling - *P. Braconnot*

(viii) Atmosphere– Ocean variability and Decadal Predictability - *T. Delworth, M. Giorgetta*

15.00-15.15 Coffee break

15.15 WGCM activities (continued)

(ix) Carbon cycle Modelling - *C. Le Quéré*

(x) ESSP/GCP - *C. Le Quéré*

(xi) C4MIP - *C. Jones*

(xii) Biosphere Modelling - *C. Le Quéré*

18.00 Close of day's session

Wednesday, October 5

9.00 WGCM activities (continued)
- Issues for WGCM
    - Interaction with THORPEX - *D.S. Richardson*
    - Interaction with WCRP projects
        - CliC - *V. Lytle*
        - *Other projects*
- Revisit ' Future Perspectives of WGCM' - *Discussion*
    - Earth System Modelling
    - Next-Generation Models

10.30-11.00 Coffee break

11.00 Issues for discussion in the joint session with WMP**.**

Other business:
- Next session- time, place
- WGCM Membership issues

12.30 Close of WGCM-9 session

Joint session of WMP- WGCM, 5 October 2005

Session 14.30-18.00 hrs

14.30 Welcome and outline of joint WGCM-WMP session (*J. Shukla, J. Mitchell*)

(i) WMP Objectives and Scope: Coordination of Pan-WCRP Modelling Activity (*J. Shukla) (15 minutes)*

(ii) WGCM Objectives, Scope and Report (*J. Mitchell) (15 minutes)*

(iii) Reports from

- WGNE - *A. Lorenc (15 minutes)*
- GEWEX/GMPP - *J. Polcher (15 minutes)*
- CLIVAR/ WGOMD, WGSIP - *C. Boening, B. Kirtman (20 minutes)*

15.50-16.10 Coffee break

- CliC - *V. Lytle (15 minutes)*
- TFSP - *B. Kirtman (15 minutes)*

- Monsoon Modelling (GEWEX/CLIVAR) *- J. Slingo (20 minutes)*
- WOAP - *K. Trenberth (15 minutes)*
- AMIP *- D. Bader (10 minutes)*

17.30 Discussion

18.00 Closure of the session