CCSM

Community Climate System Model

CSL Accomplishments Report
January – December 2006

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CCSM DEVELOPMENT ACCOMPLISHMENTS

Abstract

Most of the CSL resources given to CCSM Development have gone to the development of an interim version, CCSM 3.5, that is a mid-point in the development of CCSM 4, which is slated to be released in June 2009. This has included major upgrades to the atmosphere and land components, and new versions of the POP and CICE codes for the ocean and sea ice components. This interim version will be used to add a full carbon cycle to an up-to-date physical CCSM, and so there has been considerable development work in both chemistry and biogeochemistry aspects. Resources have been used by the Software Engineering group to improve the CCSM software, and to include and test all this development. There has also been work by the Paleoclimate and Climate Change groups into different uses of, and paradigms for, the CCSM, and development resources have been used to test and run these paradigms.

Atmosphere Model Working Group (AMWG)

The AMWG used most of its development allocation over the last year. The allocation was used to make runs to understand, diagnose, and document the behavior of CAM. The goal was to improve the scientific and software engineering evolution of the model beyond CAM3. This effort included debugging, testing, and many exploratory runs to understand and document aspects of the new scientific and software functionality.

Substantial software engineering changes were made to CAM. Much of this work was done by the CSEG group under a separate allocation, but significant resources also were independently employed using AMWG resources in adding new parameterizations to the model, developing test procedures for the model and the new parameterizations, and helping to refactor the code (with simulation validation and debugging) to produce a model that could also be used for the next generation CCSM using a single executable "sequential CCSM" paradigm.

The following component variations were explored during the year, and the AMWG development allocation was devoted to their evaluation.

1. A new cloud microphysical parameterization that includes prediction of drop number, and mixed phase processes (Morrison and Gettelman).

2. Modifications to a number of aerosol components: scavenging, optics, and interactions with cloud microphysics (Rasch, Coleman, Mahowald, Bond, and

Ghan)

3. Deep Convective Momentum Transport (Richter and Rasch, Wu and Zhang)

4. Variations of deep convective closure (Neale and Mapes, and Zhang and Wu)

5. New Shallow Convection and PBL parameterizations (Bretherton and Park)

6. Variations on the Cloud Fraction formulation to improve polar cloud behavior (Vavrus and Park)

7. Model revisions to allow CAPT style model evaluation and testing (Williamson and Olson, Klein and other members of the CAPT team)

8. Revisions to the radiation parameterization to allow additional diagnostic calculations, and more flexibility in characterizing the optical properties of atmospheric constituents (Rasch and Coleman, Conley, Collins)

9. The prediction of cloud drop number and its interaction with aerosols: first and second indirect effects (Ghan, Gettelman, and Morrison).

10. A flow dependent horizontal diffusion parameterization similar to that proposed by Smagorinsky (Chen and Rasch).

11. A quasi-isentropic vertical layering distribution (Chen and Rasch)

During the exploration of these models variations many 5, 10, and 20 year simulations were made to allow comparison to other model configurations and observations.

It was a very productive year. The deep convective parameterization modifications received the most intense attention (and computer resources) by the AMWG (and other working groups) community at large, and those efforts matured to the stage requiring long coupled simulations (performed under the production allocation, and thus described in more detail under that section of the report). Many of the other parameterizations (specifically the quasi-isentropic layering, polar clouds, PBL and shallow convection, and cloud microphysics) have only recently reached the stage of maturity that merit long coupled runs, and we anticipate committing more major changes to the atmospheric model in the very near future! We believe this last year may have been the most fruitful in many years in terms of major advances to the atmospheric model component.

Ocean Model Working Group (OMWG)

The major activity of 2006, in preparation for CCSM3.5, has been the development and testing of the following ocean physics improvements in the ocean component of CCSM, both singularly and in combination, as well as in both uncoupled and coupled configurations :

1. Enhanced vertical mixing over rough bottom topography

2. Lax-Wendroff advection of active and passive tracers

3. Resolved tropical instability waves through reduced ocean viscosity.

4. Mesoscale eddies in the mixed-layer

5. Vertical variability of mesoscale eddy mixing

6. Increase in the number of vertical ocean levels from 40 to 60

7. Modified ocean topography to improve the Indonesian through-flow, the equatorial ocean near the Galapagos Islands, and the mode waters of the North Pacific.

These developments have improved the uncoupled ocean in several respects, including equatorial stratification, coastal upwelling, Indian Ocean temperature and salinity, and the representation of tropical instability waves.

Another planned development has led to a demonstration that the HYCOM model can be used as the ocean component of CCSM. HYCOM uses a hybrid vertical coordinate that changes from depth near the surface to density in the deeper ocean. Eric Chassignet (FSU) has run successful short period integrations of the fully coupled CCSM with HYCOM. Comparison of the results with those using the POP code will be made shortly.

Polar Climate Working Group (PCWG)

During 2006, numerous simulations have been performed in the transition to and testing of a new sea ice model, development and testing of a slab ocean component, and examination of an alternative cloud parameterization and its influence on polar climate.

1. **Sea ice model development:** As part of the CCSM4 model development, the Polar Climate Working Group will adopt the Los Alamos National Laboratory CICE4.0 model as the new sea ice component. This model has improvements in software engineering infrastructure, the treatment of snow cover, and mechanical redistribution (ridging) of the ice cover. Incorporation into the CCSM coupled system and substantial testing of this model have been performed under the 2006 CSL allocation. Simulations have also been performed for the development and testing of additional sea ice model parameterizations. These include an improved sea ice radiative transfer treatment, and melt water ponding on the ice surface. Stand-alone and coupled simulations have been used in the development, testing,

and incorporation of these new parameterizations into CICE4.0.

2. **Slab Ocean Model development:** A number of simulations were performed for the development and testing of a slab ocean model (SOM) component. The PCWG has a specific interest in this model because it allows for atmosphere-sea ice-slab ocean model simulations and replaces the internal SOM that was used in stand-alone sea ice integrations. This SOM model has been adopted by CCSM as a standard component.

3. **Cloud model parameterizations:** A long-standing bias in CCSM coupled model simulations is the presence of anomalously large low cloud cover in high latitudes. Alternative cloud parameterizations have been tested under previous CSL allocations which reduce this bias. During 2006, we have performed additional simulations to examine the sensitivity of the coupled CCSM to increasing CO2 levels in the presence of a more realistic polar cloud cover. The simulated polar amplification is considerably affected and reduced by up to 20% at transient 2XCO2 conditions with the different cloud scheme.

Land Model Working Group (LMWG)

The LMWG used its development allocation for five main purposes: a) improving biogeophysical and hydrological parameterizations to correct biases or deficiencies in the model; b) improving the representation of permafrost in the model; c) adding an urban land cover parameterization; d) improving the terrestrial carbon cycle model; and e) developing a high-resolution version of CLM. Significant progress has been made in all five areas. Specific accomplishments include:

1. **Finalized the new Community Hydrology Project scheme:** The new version of the model (CLM3.5) corrects several important biases or deficiencies in CLM. This includes processes such as the interception of precipitation by foliage, runoff, soil moisture and its effect on latent and sensible heat fluxes. Work during the past year has focused on bringing in and testing a suite of changes to land biogeophysics, a new canopy integration scheme, a fully revised hydrology scheme that includes a new groundwater component, a new soil evaporation resistance function, and a new canopy interception formulation.

2. **Improved simulation of soil temperature and soil moisture, especially for the high-latitudes:** Incorporated the previously ignored thermal and hydrologic properties of soil organic matter and added soil carbon content to the soil dataset. New parameterization designed to dovetail with carbon cycle code. Further improvements to soil temperature dynamics have been realized by increasing the depth of the soil column to 50m by adding 5 new layers that provide thermal inertia to the system.

3. **Successfully developed and tested an urban land cover parameterization:**

4. **Continued development of CLM-CN in collaboration with BGCWG:** Recent developments include a revised strategy for spin-up and improved vegetation productivity in cold climates.

5. **Developed a prototype version of a high-resolution version of CLM:** Software engineering has been completed to permit the land model to operate on a spatial grid that is independent of the atmosphere model. Efforts continue to downscale the temperature and precipitation forcing from CAM to the high-resolution CLM.

6. **Continued work towards the incorporation of a prognostic canopy air space into CLM so that heat, moisture, and CO_2 can be stored in the canopy:** This work, which is expected to greatly improve the simulated diurnal cycle and numerical stability of the model, is still in the development and testing phase.

7. **Correct and test a number of bugs or deficiencies in the model, including a restructuring of RTM, improved error checking, and correcting a bug in the snow age calculation:** Extensive revision of the diagnostics package has also been completed.

Biogeochemistry Working Group (BGCWG)

The biogeochemistry working group has been using the CSL allocation for several development projects. All are towards the goal of a new carbon cycle for inclusion in the CCSM4, and a full list is included here:

1. **Evaluation of the marine biogeochemical parameterizations with a new advection scheme:** A new advection scheme for the ocean model has been designed that significantly reduces the magnitude of advective over- and under-shoots, while not introduced excessive numerical diffusion. Multi-decadal experiments have been performed to assess the impact of using this new advection scheme on the Biological Elemental Cycling (BEC) marine biogeochemical parameterization. Preliminary analysis shows that using the new scheme does reduce the presence of non-physical tracer values. The scheme does modify some aspects of the nutrient cycles. Analysis of these model runs is continuing.

2. **Improvement in nitrogen and iron cycles in the BEC model:** Development work this year has focused on improving the treatment of both the nitrogen and iron cycles in the BEC model. The parameterizations for the diazotrophic, nitrogen fixing phytoplankton group have been improved, including preliminary work allowing this group to access dissolved organic phosphorus pools. The iron cycle parameterizations for the coastal/sedimentary iron source and for particle scavenging of dissolved iron have been significantly modified. The improved model does a much better job at reproducing the observed distributions of

dissolved iron in the oceans.

3. **Improvements in the nitrogen and carbon cycles in the terrestrial model:** Offline simulations were performed to test the sensitivity of CLM-CN to a small increment in atmospheric CO_2, as part of the exploration of spin-up dynamics in the fully-coupled climate-carbon-nitrogen simulations. A series of offline simulations was performed to test the switch from three to four soil organic matter pools for the new round of fully-coupled spin-up experiments. Several different approaches were tested to further improve the accelerated decomposition approach to CLM-CN spin-up. Extensive series of simulations was performed to evaluate the performance of CLM-CN in arctic climates, particularly for tundra and larch vegetation types. This investigation resulted in the identification of several changes, some to model physics and others to model biogeochemistry, which are consistent with observations and improve model performance in cold climates. New simulations are underway now to test the implementation of dynamic land use algorithms for the carbon and nitrogen cycles.

4. **Improvements in the dust/land interactions in the model:** The dust model was coupled to the dynamic vegetation model and the CLM-CN for testing the ability of the model with the new hydrology to produce realistic dust distributions when coupled to prognostic vegetation.

Chemistry Climate Working Group (ChemWG)

The chemistry climate working group used its development resources towards accomplishing two primary goals: i) to find methodologies for incorporating the effects of chemistry and aerosols within the operational constraints of a climate model; ii) to simulate the interplay between climate, chemistry and aerosols using a state-of-the-art representation of chemistry and aerosols. Resources were used in the following areas:

1. **Basic model development:** At the beginning of this development period the CAM model with chemistry was still in its infancy. Significant development was needed to bring the model up to state-of-the-art chemistry climate and chemistry transport model. Development included integrating the CAM and MOZART aerosol parameterizations consistently within the CAM framework; incorporating the ability to use prescribed chemistry or aerosols within the chemistry module; and the incorporation of online photolysis and dry deposition into CAM.

2. **New chemical mechanisms:** Two updated chemical mechanisms have been developed for use in CAM. In the first of these, the default tropospheric chemical mechanism is reduced, but in such a way as to capture the fundamental non-methane hydrocarbon chemistry. Importantly, the reduced scheme includes a parameterization of isoprene oxidation, retaining the capability of simulating the effect of increased isoprene emissions under a warming climate. This scheme reduces the computational cost of simulating chemistry by approximately two.

The second chemical mechanism includes both relatively simple tropospheric and stratospheric chemistry and may alleviate the necessity of using a fixed stratospheric distribution of ozone in simulations of tropospheric chemistry.

3. **Incorporation of biogenic emissions in the CLM:** A biogenic volatile organic compound emission scheme (Model of Emissions and Gases and Aerosols from Nature, MEGAN) was developed for incorporation into the CLM.

4. **Expansion of the Secondary Organic Aerosol Scheme:** This scheme was expanded in CAM to include isoprene and aromatics.

5. **Development and testing of DART/CAM-CO data assimilation system:** Data assimilation and forecasting are important mechanisms for evaluating and testing chemical models against data. To this end, ensemble data assimilation of carbon monoxide has been implemented into CAM. One-month test runs consisting of 20-40 ensemble members were conducted assimilating both meteorological observations (radiosonde temperature and satellite-derived winds) and MOPITT CO retrievals into CAM.

6. **Development of offline WACCM:** Offline simulations using analyzed fields have been a traditional means of evaluating chemical models against the very episodic nature of chemical measurements. In the past year an offline version of the WACCM model was developed. In offline WACCM analyzed winds drive the model throughout the troposphere and lower stratosphere, but the upper reaches of the model freely evolve. This development of this model completes the task of putting ACD global models into the CAM framework.

Paleoclimate Working Group (PaleoWG)

Permian Simulations

The latest Permian simulation of CCSM3 for $10XCO_2$ indicated very inefficient mixing of surface waters to depth. A transient simulation for the latest Permian was carried out to investigate this behavior for lower levels of CO_2. Starting from the end of the $10XCO_2$ simulation, CO_2 levels were reduced by 1% per year to $1XCO_2$ levels, which took ~230 years of simulation. Time series of ideal age in the North Panthallasic Ocean indicate that ocean mixing begins to dramatically decrease around $2XCO_2$. Thus, there appears to be a critical point at which mixing shuts down for this time period.

Using the sea surface temperatures from the 10X and $1XCO_2$ Permian simulations, a CAM3 standalone version of the Permian was developed. This model was used to investigate mechanisms for the megamonsoon during this time period. It was found that the major mechanism for monsoonal precipitation patterns is the spatial distribution of tropical SSTs, and not the land sea contrast in surface temperature.

Climate Change Working Group (CCWG)

Climate Change Working Group development runs in 2006 have focused on collaborative work with the Paleoclimate Working Group investigating the impact of ice water melting on the thermohaline circulation (THC) for the present day and last glacial maximum conditions. These simulations will provide a baseline for assessing the impact of the interactive glimmer ice model that is currently under development at Los Alamos.

Two present day simulations were run, one with the Bering Strait open and the other with the Bering Strait closed. Each simulation consisted of a control run and a freshwater hosing run. Results show that the THC declines similarly with an open and closed Bering Strait during hosing. However, the recovery of the THC is delayed by about a century in the closed Bering Strait run than in the open Bering Strait run after the hosing is turned off. The closed Bering Strait prevents the added freshwater from being transported from the Atlantic into the Pacific via the Arctic, as in the open Bering Strait case. Further, the freshwater supply is elevated significantly after the hosing by exporting the freshwater stored in the Arctic during hosing, as sea ice, back to the North Atlantic. This stabilizes the surface stratification there, and suppresses the recovery of the deep convection.

These CCWG open and closed Bering Strait simulations were compared against a third run carried out by the Paleoclimate working group under LGM conditions with a closed Bering Strait. Results show that the THC responds to the freshwater forcing similarly when the freshwater forcing is turned on, and during the 50-year period right after the termination of the freshwater forcing in all three freshwater forced runs. After that, the recovery of the THC is quicker in the open Bering Strait run than in the closed Bering Strait and LGM runs. Analysis indicates that removal of the added freshwater in the subpolar North Atlantic is quicker in the open Bering Strait run than in the other two runs with a closed Bering Strait, owing to a transport of the freshwater anomaly out of the Atlantic through both ends of the Atlantic, especially at the northern end. A significant portion of the freshwater exported into the Arctic from the North Atlantic is further transported into the North Pacific via a reversed Bering Strait throughflow in the open Bering Strait run which speeds up the freshwater removal. This Arctic to Pacific transport is absent in the two runs with a closed Bering Strait. Although the background conditions are quite different between the present day closed Bering Strait run and the LGM run, the response of the THC to the added freshwater forcing in the North Atlantic is more consistent between these two runs, but different from the run with an open Bering Strait.

IPCC Data Analysis

Considerable work went into preparing the NCAR IPCC data leading up to the February 2 2007 release of the IPCC Summary For Policymakers. In addition to the IPCC data archives maintained at PCMDI, additional NCAR IPCC data are served to the public from the ESG data portal at NCAR in both netCDF and GIS formats.

Software Engineering Working Group (SEWG)

The SEWG supports the activities of all the working groups by testing each CCSM revision to ensure that it runs on all production platforms and meets key production requirements. Currently, new CCSM revisions are being constructed due to new scientific and software development in CCSM component models, as well as to modifications in the current coupling software to enable the transfer of new bio-geochemical fluxes and tracers. CCSM revisions are also created for patches made to the CCSM3.0 release. We project that at least four revisions will normally be created each month.

The CCSM model is comprised of five components, and there are up to three different versions of each component, including typically an active component, a data component, and a "dead" component used purely for testing purposes. Various component combinations, as well as different resolutions for each component, were tested for each new revision. Testing involved the validation of exact restart capability for different configurations and resolutions of the model, the exercise of various compiler debugging features in order to expose potential bugs, the optimization of performance and the overall system load balancing on production platforms.

The scope and parameter space of CCSM testing has substantially increased over the last year. New features are continuously added to the various component models that require validation tests. These features include new physical parameterizations, changes to the build system, new features in the CCSM scripts, changes to the CCSM code that is shared between all CCSM model components, and structural improvements in the components. More recent tests have also been added to exercise the transfer of bio-geochemical fluxes and tracers between components, the activation of atmospheric chemistry, the addition of new model components, such as POP2, and the ability to run CCSM as either a single executable or in its original multiple executable implementation. In addition, the test suite has also been expanded to include new production level tests.

The development portion of the CSL allocation has been utilized to perform hundreds of short tests to verify and validate the functionality of CCSM each time a new version of the CCSM model system is tagged in the CCSM Subversion repository. CCSM tests were also performed to validate new features contributed by our collaborators in the Department of Energy's (DOE) Scientific Discovery through Advanced Computing (SciDAC) and NASA's Earth System Modeling Framework (ESMF) projects.

CCSM PRODUCTION ACCOMPLISHMENTS

Abstract

The CSL resources given to CCSM Production have been used in two main categories. The first category is 100 year runs of the coupled model to evaluate parameterization upgrades in the component models. For example, three different revised deep convection schemes in CAM have been implemented, and their effect on the tropical Pacific and ENSO can only be evaluated by 100 year coupled runs. This comparison has been successful in producing the first CCSM runs where the ENSO frequency does not peak at 2 years, but at longer periods more in line with observations. The second category of runs is to use the standard, released CCSM 3 to address interesting scientific questions. Good examples are the large ensemble of runs by the Climate Variability and Climate Change WGs to answer how large an ensemble is needed, and the simulations of the mid-to-late Holocene and 8.2 thousand years ago by the Paleoclimate WG.

Atmosphere Model Working Group (AMWG)

The AMWG used its production allocation entirely this last year.

A series of CAM/slab ocean model runs were made to examine the climate sensitivity of the Finite Volume version of CAM, which has a distinctly different signature than the model using the spectral dynamical core. We have at this time concluded that the difference in climate sensitivity is not due to variations in tuning parameters within the physical parameterizations, or due to the time step over which the physical parameterization are advanced. The sensitivity seems to be due to the dynamical core itself, and more study to understand this will be required.

A number of long standalone CAM simulations were made to explore the behavior of the new formulations for dust and sea salt (changed size and optical properties) aerosols (in collaboration with the BGC and Land working groups), and studies to understand the role of scavenging parameterizations in controlling the distribution of aerosols. Runs were also made to explore the sensitivity to horizontal resolution. By changing horizontal resolution first from 2x2.5 to 1.9x2.5 (to optimize processor utilization and load balancing), and then reducing the resolution to 0.9x1.25 (done in collaboration with Art Mirin and others at LLNL and R. Rood).

A number of coupled simulations (minimum integration period of 50 years, mostly 100 years, and sometimes 400 year lengths) were made in the fully coupled model configuration. The longest runs were performed to produce a climatology against which other configurations (or runs on other computer platforms) were to be compared. Some of the other simulations varied atmosphere components (convection, horizontal diffusion); or varied the ocean model configuration (POP2, and variants of diffusion, GM formulation, and tracer advection algorithms), A sequence of simulations in which convective momentum transports (Richter, Wu) and closure assumptions (Neale, Zhang) were varied were made with a particular focus on tropical variability with the goal of providing an atmospheric model for the CCSM3.5 interim model configuration. These simulations (in addition to those done at ORNL) provided the model output used for the major model evaluation performed in the CCSM 3.5 planning phase.

Ocean Model Working Group (OMWG)

The OMWG has used CSL production resources for the following projects:

1. Global eddy resolved ocean integration to study the impact of mesoscale eddies on ocean climate, in particular the distribution of deep tracers. The integration is ongoing, with completion of a full annual cycle in 2007.

2. North Atlantic nudging experiments, where the path of the Gulf Stream is forced to follow more closely the observed path. The impact of the usual poor representation of the Gulf Stream in CCSM3 on fully coupled simulations was found to be relatively modest in the context of global climate.

3. A series of experiments were run in support of a paper; "Reduced viscosity in the ocean component of the community climate system model." In particular, the CCSM3 control at T42x1 was rerun first without Smagorinsky mixing, then with the lowest possible ocean viscosity. The major improvements to the coupled solutions are reduced sea-ice in the Labrador and Bering Seas, and stronger tropical instability wave activity.

4. Coupled and uncoupled integrations with the Mediterranean Overflow, closed, open and parameterized, were in support of a paper "On the effects of parameterized Mediterranean Overflow on North Atlantic ocean circulation and climate.” The climate impact of the parameterized overflow is an interesting pattern of varying ocean-atmosphere coupling as defined by the change in surface heat flux per degree of SST change. However, the signals are relatively weak, so the impact on the global climate is not overly significant.

Polar Climate Working Group (PCWG)

During 2006, numerous simulations have been run by the PCWG with the aim of understanding important processes in the polar climate system and their global effects. Accomplishments from these studies are discussed briefly below.

1. **Diagnosis of the influence of changing ice-ocean freshwater exchange in future climate model projections:** Experiments with increasing CO2 levels have been performed to elucidate the impacts of changing ice-ocean freshwater exchange in the climate system. These simulations suggest that changes in ice-ocean freshwater exchange in a warming climate have a considerable impact on future ocean heat uptake in both the Arctic and Southern Ocean. Additionally, the reduction in ice transport and melting in the northern North Atlantic with a thinning Arctic ice pack appears to stabilize the meridional overturning circulation response in the warming climate. Results from these studies were recently presented at the fall, 2006 American Geophysical Union (AGU) meeting and will be the subject of future papers.

2. **Diagnosis of the impact of snow cover on global climate:** The response of the climate system to snow cover has been explored through a series of simulations with CCSM3. A previous allocation supported a simulation in which all terrestrial snow cover was eliminated in the model. This run was compared with additional simulations under the present CSL allocation that isolated the regional dependence of snow cover. These regional runs demonstrated that the pronounced teleconnective atmospheric response in the Pacific in the absence of all snow cover was forced almost entirely from Eurasia (particularly the Tibetan Plateau), while the positive NAO anomaly present in the absence of snow cover stemmed mostly from North America. A paper discussing this work is in press at Climate Dynamics (Vavrus, in press) and additional papers are in preparation.

3. **Studies on high-latitude abrupt climate change:** Several experiments have been performed to further explore abrupt climate change driven by a rapid freshening of the northern North Atlantic. This includes analysis of simulations for present day, last glacial maximum, and 4XCO2 conditions. The research finds that the magnitude and transient response of the abrupt change is highly dependent on the background climate state. Two papers have been submitted on this work (Bitz et al., submitted; Cheng et al., submitted). The mechanisms responsible for the tropical Atlantic teleconnected response to this abrupt high latitude climate change are also being investigated. Both atmospheric and oceanic mechanisms act to cool the midlatitude North Atlantic sea surface in response to the abrupt high latitude change. A paper discussing these results is in preparation (Chiang et al., in preparation).

4. **Assessment of the influence of a seasonally ice-free Arctic on atmospheric conditions:** Observations and model projections suggest that a seasonally ice-free Arctic may be reached in the next 50-100 years. Simulations have been performed to isolate the influence that these changing Arctic conditions will have on the atmosphere. These include atmosphere-only simulations forced with a variety of lower surface boundary conditions, including present-day sea ice cover and seasonally ice-free Arctic conditions. Preliminary analysis from these runs was presented at the fall, 2006 American Geophysical Meeting (AGU) and will be the subject of future manuscripts.

Land Model Working Group (LMWG)

A series of offline and CAM/CLM runs have been completed to document the new version of the model, CLM3.5. Particular emphasis has been devoted to an evaluation of changes to the model climate, climate variability, and runoff, as well as spin-up timescales.

Resources have also been devoted to the evaluation of the impact of soil organic matter and a deeper soil column on projected near-surface permafrost degradation during the 21st century. A series of transient offline simulations have been performed using 6-hourly forcing from CCSM production runs b30.30e (20th C) and b30.040e (A1B) to evaluate the sensitivity of near-surface permafrost degradation to the insulative effects of organic soil and to the thermal inertia provided by the deep soil layers. Initial results indicate that organic matter and a deeper soil column both work to slow down permafrost degradation, but that by the end of the 21st century, even with these processes included, near-surface permafrost has degraded dramatically.

An extension of a series of simulations using CAM/CLM/slab ocean model has been performed to extend the analysis of the importance of surface hydrology and vegetation to climate sensitivity to the importance of snow to climate sensitivity. These experiments highlight the role of snow, soil water, and dynamic vegetation in determining climate sensitivity. An intriguing result is that the initial simulation of snow cover extent appears to have a direct bearing on the climate sensitivity of the model.

Biogeochemistry Working Group (BGCWG)

The BGC WG has used most of its CSL allocation in preparation for the CCSM4 coupling which should include the carbon cycle. Much of our time has been for testing the new carbon cycle modules, but a full list of projects is included here:

1. **Incremental coupling of terrestrial and marine biogeochemical parameterizations to the CCSM3 climate model:** The terrestrial and marine biogeochemical parameterizations that have been developed previously have been incorporated into the CCSM3 climate model. In order to produce a stable carbon simulation, it is necessary to incrementally couple the biogeochemical parameterizations to each other and an atmospheric CO2 tracer that is also used in radiation computations. This incremental process involves selectively turning on different physical and carbon feedbacks in the system and allowing the parameterizations to equilibrate. Because of differences in the models and parameterizations, techniques previously used to achieve a stable carbon simulation in CSM1.4 were not successful and had to be modified. The modified approach has now succeeded in producing a 1000 year stable carbon climate

control run.

2. **Transient fossil fuel emission experiments in CCSM3:** A first sensitivity experiment has been performed with respect to the control run described above. Fossil fuel emissions from the historical period 1870 to 2000 have been added to the model, leading to ocean and land uptake of anthropogenic CO2, and warming due to the increase of atmospheric CO2. The carbon cycle co-evolves with the climate, allowing for analysis of how they impact each other. Results from this experiment are currently being analyzed. More experiments are expected to follow where we will include other forcings that are relevant to both the carbon cycle and the climate.

3. **Offline CLM-CN simulations:** Offline simulations testing the influence of increasing CO_2 and increasing N deposition were performed on the production allocation. This suite of simulations was also used to test the influence of altered base state on climate-carbon cycle dynamics. These simulations formed the basis for a manuscript submitted in October 2006 to Global Biogeochemical Cycles. Offline spin-up simulation on FV 1.9x2.5 grid, implementing the improvements for Arctic regions, improved spin-up methodology, and integrating the latest CLM hydrology from the LMWG is now under way using the production allocation.

4. **Simulations of the impact of changes in dust iron sources on ocean biogeochemistry**: Simulations have been conducted with the ocean Biogeochemical Elemental Cycling (BEC) model to address the role of the mineral dust iron source in driving marine biogeochemical cycles, and to study important feedbacks in the marine N cycle. A series of 40 year simulations using atmospheric dust deposition scenarios generated under different climate regimes was used to quantify the impacts of this key iron source on air-sea CO2 exchange and marine biogeochemical cycles (Moore et al., 2006 in Tellus). A series of longer simulations (200 years) examined the feedbacks and controls on nitrogen fixation and denitrification in the oceans and their influence on air-sea CO2 flux (Moore and Doney, in press, Global Biogeochemical Cycles).

5. **Evaluation of existing terrestrial and carbon cycle models against data:** A variety of surface carbon, oxygen, and nitrogen fluxes from ocean and terrestrial biosphere models, fossil fuel databases, and ocean climatologies were run in the MATCH atmospheric transport model. The resulting seasonal and interannual variability in atmospheric CO2 and APO (atmospheric potential oxygen) was compared to available observations with the goals of testing the model's ability to reproduce the observed variability, and quantifying the relative contributions of land, ocean and fossil fuel fluxes to that variability.

6. **Evaluation of model aerosol distribution:** C. Heald (university collaborator) evaluated the standard CAM chemistry-aerosol simulation with in situ and satellite observations. Especially of interest was the secondary organic aerosol

generated in the model.

7. **Simulation of dust/climate interactions:** Dust response to climate and the response of climate to dust were simulated and published in a series of papers looking at the current climate and the Sahel precipitation, preindustrial, doubled-carbon dioxide and last glacial maximum climates.

Chemistry Climate Working Group (ChemWG)

Production resources were primarily used to evaluate new model developments in longer simulations and to evaluate chemistry in CAM against measurements. Since the simulation of chemistry typically increases the cost of CAM by a factor of five, even relatively short chemistry simulations are expensive. CSL resources were used in the following projects:

1. **Simulations of Boreal Biomass Burning:** Biomass burning has an important impact on climate through emissions of tracer gases and aerosols. Climate change is expected to increase boreal biomass burning in the future. Runs were used to simulate the radiative impact of the 2004 Alaskan fires, the largest fire season on record in Alaska. Simulated radiative forcing, aerosol optical depth and trace gas concentrations were evaluated against satellite and aircraft measurements.

2. **Response of tropospheric chemistry and climate to perturbed emissions over the United States and Southeast Asia:** Twelve 15 year simulations, in collaboration with NASA Goddard Institute for Space Studies, were aimed at identifying the impact of specific emission reductions on air quality and climate (e.g., temperature and precipitation). Results from this analysis will be used for a Department of Energy Climate Change Science Program report.

3. **Simulations of biogenic emissions:** Several full-year simulations evaluated the newly developed Model of Emissions and Gases and Aerosols from Nature (MEGAN) biogenic emission scheme in the CLM and the expanded CAM SOA (Secondary Organic Aerosol) scheme.

4. **Simulations of tropical variability:** Five 12 year simulations of chemistry were used to evaluate the simulation of chemistry against available observations in the tropics and subtropics.

5. **Simulations using offline-WACCM:** Several full year simulations of the offline WACCM model were run to evaluate the model against stratospheric climatology.

6. **Aerosol simulations:** A number of different aerosol parameterizations can be currently run in the CAM model with chemistry: ACD aerosols and interactive chemistry, ACD aerosols with prescribed chemistry, CGD aerosols with interactive chemistry, CGD aerosols with prescribed chemistry, and prescribed

aerosols. CSL resources are being used to ascertain the difference between these aerosol prescriptions for use in CAM4.

7. **Physical parameterizations:** A number of different convective schemes and boundary layer schemes are being considered for CAM4. CSL resources are being used to evaluate these various schemes from a chemical viewpoint.

8. **Model Intercomparison:** CSL computational resources have allowed simulations using the CAM model with chemistry to be compared against numerous other global chemistry transport models through the HTAP (Hemispheric Transport of Air Pollutants) project.

Paleoclimate Working Group (PaleoWG)

1. **Mid-to-late Holocene Transient Simulation:** A mid-Holocene (6000 to 3600 years ago) transient simulation with CCSM3 T31x3 and using predictive vegetation in the land model has been completed. This simulation was designed to understand how much climate variability is due to insolation variations and volcanic activity and how much is related to internal variability of the system. Analyses of this simulation are in progress. Surface climate trends are related to the trends in the forcing, while in the deepest levels of the ocean, trends in the first 1500 years are related to spinup. Global and regional scale climate shifts have been identified in this transient simulation. These are being investigated to isolate the causes and mechanisms and their relationship to rapid shifts observed in the proxy record during this time period. A comparison in North Africa climate-ecosystem is also made with a transient simulation of FOAM. The overall trend is similar in both models. The CCSM3 seems to exhibit relatively more gradual changes. The CCSM3 mid-Holocene transient simulation will also be compared to a shorter completed simulation (CCSM Development) that accelerated orbitally-driven solar variations, a technique that if successful will allow much longer transient Quaternary simulations with CCSM.

2. **Abrupt Climate Changes during the Late Quaternary:** Proxy records indicate that the locations and magnitudes of freshwater forcings to the Atlantic Ocean basin as iceberg discharges and meltwater input influenced the responses of the North Atlantic thermohaline circulation and global climate, but the mechanisms are still not fully known. LGM simulations have been performed with CCSM3 T42x1 in which the magnitude of the freshwater forcing has been varied from 0.1 to 1 Sv and inserted either into the northern North Atlantic Ocean or the Gulf of Mexico. These results show interesting differences in terms of the regional and seasonal responses, and the temporal behavior during and after the freshwater event. At some locations, the cooling of sea surface temperatures in the eastern Atlantic is proportional to the magnitude of freshwater that is applied or advected to sites of ocean convection, while other locations exhibit a threshold response.

Sea ice is important for explaining the response at northern high latitudes.

3. **8.2ka realistic simulations:** Two simulations were completed with freshwater forcing in the Labrador Sea, designed to mimic the flood of Lake Agassiz through Hudson Strait at 8.2 ka. In each of these simulations, 2.5 Sv of freshwater was added over a period of 1 year and then the system was allowed to recover. The simulations were both branched off the 8.5 ka control simulation (b30.102), but began at different years of the control simulation in order to assess the effects of initial conditions on the response to freshwater forcing. In each simulation, climate anomalies were short-lived, on the order of a decade or less. This contrasts with both paleoclimate proxy evidence and other model simulations of the 8.2 ka event, in which anomalies persist for ~100 years. These results were presented at the PAGES/CLIVAR 8.2 ka workshop in Birmingham, UK in October.

Climate Variability Working Group (CVWG)

In 2006, the CVWG completed a new 5-member ensemble of AMIP integrations using observed monthly SST forcing confined to the global tropics (20ºN-20ºS), and observed long-term monthly mean SSTs outside of the tropics, for the time period 1871-1949. These integrations were run with CAM3 at T85 resolution, and complement the existing AMIP runs for the period 1950-2001. These experiments will allow an assessment of tropical SST forcing of climate variability worldwide during 1871-1949, including the 1930's "dust bowl" years over the central United States.

The CVWG is continuing to complete a set of IPCC scenario runs with CCSM 3 at T42 resolution in conjunction with the Climate Change Working Group (CCWG), a project begun in 2005. The purpose of these experiments is to provide a large ensemble (~ 30 members) of integrations driven by a fixed, standard "business-as-usual" climate change scenario during 2000-2061. Such a large ensemble will allow an assessment of uncertainties in climate projections resulting from intrinsic system variations, as well as the evolving properties of interannual variability. To date, 8 ensemble members have been completed and are being analyzed. The ensemble members all begin from the same ocean/land/sea ice conditions taken from the last year of the 1870-1999 historical runs, with different atmospheric initial conditions.

Under the previous CSL allocation, a coupled model configuration consisting of a prognostic ocean mixed layer model coupled to the thermodynamic component of the CCSM Sea Ice Model version 4 (CSIM4) and to CAM2 was completed. A long control integration, as well as additional experiments, have been completed and the results reported in Cassou et al. (2006) and Kwon and Deser (2006). This model configuration is being used by university colleagues (A. Clement, RSMAS) as well as NCAR scientists (Okumura and Deser).

Climate Change Working Group (CCWG)

The 2006 Climate Change Working Group (CCWG) CSL productions runs involve carrying out a very large suite of runs designed to resolve climate change signals within the larger ensembles of runs and collaborative runs with the Ocean Model Working Group to investigate the Stocker and Schmittner hypothesis. While a few of the proposed research areas needed to be dropped due to the reduced allocation that was received, significant progress was made in the other research areas.

Large ensembles and climate change signals (with CVWG)

The bulk of our effort went into carrying out the large ensemble collaboration with Climate Variability Working Group. The goal is to investigate the uncertainties in climate projections resulting from intrinsic variations of the climate system in order to assess the optimum number of ensembles to run in future climate change simulations. This project is still in production and, currently we have 8 of the ensemble members completed. The process consists of carrying out an 1870 to year 2000 historical run, then the different ensemble members were branched off using ocean conditions at January 1 2000, and various atmospheric conditions from around the January 1 date. Analyses of the spread of the runs by the Climate Variability WG indicate that this is sufficient produce the desired divergence between the individual runs in the ensemble. We have finished the Climate Change WG portion of the ensembles, and the rest of the work will continue through the spring of 2007 using the Climate Variability WG account.

Climate Sensitivity

A widely cited study by Stocker and Schmittner (1997) suggested that the stability of the thermohaline circulation under increasing greenhouse gas forcing could depend not only on the asymptotic level of GHG concentrations, but also the rate at which that level is approached, with faster increases being more likely to lead to a collapse of the Atlantic meridional overturning (MOC). These experiments were conducted with an intermediate complexity model that lacks representation of many physical processes. In collaboration with scientist at CRIEPI, we conducted a series of experiments using CCSM3 with idealized GHG increase scenarios for rates of increase in CO2 between 0.25% and 4% per year, with stabilization extensions at 2x, 4x, and 8x times present day CO2 concentration. To explore the behavior of the system in the limit of extremely fast CO2 increase, we conducted an experiment with instantaneous quadrupling of CO2 using our CCWG CSL allocation. This experiment was run for approximately 200 years. In none of our cases, including instantaneous quadrupling, does the MOC collapse, or show what would be considered "abrupt" change. For a given level of CO2, experiments with faster rates of increase show a smaller decline in the MOC during the transient forcing phase of the experiments. However, all of the stabilization experiments asymptote to similar degrees of MOC decline, irrespective of the rate at which CO2 increased. In short, we find no support for the Stocker-Schmittner hypothesis.

Software Engineering Working Group (SEWG)

New CCSM scientific development is currently being done in a 1.9x2.5_gx1v4 configuration utilizing POP2 and the CAM finite volume dynamical core. The current performance of the development version of CCSM3 (on blueice) for several supported resolutions is summarized below:

Resolution	Utilization	#Pes	Years/Day	Pe-hrs/Year
T42	78.84 %	112	10.73	125.25
1.9 x 2.5	79.75 %	112	8.42	159.54
T85	68.16 %	224	6.37	421.73
1 x 1.25	78.28 %	224	3.03	885.98

The production portion of the CSL allocation has been utilized to perform several 50-100 year validation simulations of the development CCSM code base.

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