CCSM Development Accomplishments Report

September 2004 – December 2005

CCSM Development Allocation Accomplishments
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I. Atmosphere Model Working Group (AMWG)

The AMWG used its development allocation for three main purposes: to understand, diagnose, and document the behavior of the Community Atmosphere Model (CAM3); to continue the evolution of the model beyond CAM3, including debugging and software engineering; and to understand and document aspects of the new functionality of the model.

Substantial software engineering changes were made to CAM to more effectively isolate the points of interaction between model components and the rest of the CAM infrastructure. More components have an Earth System Modeling Framework (ESMF) type structure of "Initialize", "Run" and "Finalize," which moves the model toward ESMF compatibility. We also made a number of changes to the model to facilitate the inclusion of other dynamical cores, particularly cores that will allow CAM to use model grids that are not oriented by latitude and longitude (e.g., cubed sphere and icosahedral/ triangular meshes). Extra software engineering features were also added, including Single Program-Multiple Data (SPMD) optimizations and extensions for CRAY and NEC platforms, changes to support IA64 clusters, and a number of bug fixes to improve model behavior in non-standard model configurations. When modifications were made to the model that resulted in non-bit-for-bit changes to the simulation, a 20-year simulation was run to allow comparison to the previous model climatology.

The AMWG also continued to explore a number of alternate physical parameterizations for CAM that can be used as options for exploratory work. They are not yet ready for long coupled simulations, but to assess their impact, we frequently made 5 to 10 year runs. These modifications include two alternate optional formulations for the turbulent boundary layer processes that replace the Boville and Holtslag formulation; two alternate formulations for the parameterization of shallow convection (trade cumulus) following the work of McCaa and Bretherton and Zhu and Bretherton; and three optional formulations for the parameterization of deep tropical convection. We also explored variations on the ozone data sets used in the model, and made changes to the parameterizations of ice and liquid microphysics and their optical properties. In collaboration with the Land and Biogeochemistry Working Groups, we continued to develop the aerosol package, improving the representation of sea salt aerosols and the characterization of dust and sea salt. Simulations were also made to explore the role of various aerosols forcings (direct, indirect, absorbing, and scatter aerosols) and sensitivities to aerosol scavenging parameterizations.

Changes were also made to the model to improve its use for the CAPT (DOE’s Climate Change Prediction Program-Atmospheric Radiation Measurement Parameterization Testbed) project. The model was modified to make it fully compatible with the Whole Atmosphere Community Climate Model (WACCM) project, and a similar configuration was optimized for tropospheric chemistry/climate problems.

II. Ocean Model Working Group (OMWG)

The OMWG development allocation supported specific science objectives and maintaining a state-of-the-art ocean component for CCSM. Key accomplishments are:

A. The 1/10th-degree global ocean model was ported from the Earth Simulator to NCAR machines. It is now configured to use 32 eight-way nodes on Bluesky.

B. The Parallel Ocean Program (POP2) model was demonstrated to reproduce the current CCSM ocean component once identical configurations were used. Several POP2 features were then reincorporated back into the CCSM version of POP2.

C. The Hybrid Isopycnal Coordinate Ocean Model (HICOM) was successfully incorporated within the CCSM framework.

D. Tropical instability waves are now being represented faithfully.

E. The exchange through the Strait of Gibraltar and downstream gravity current entrainment has been parameterized.

F. The parameterization of unresolved mesoscale eddies has been advanced to include an anisotropic version, the diapycnal mixing due to mixed-layer eddies, and theoretical ideas about depth and horizontal dependencies.

G. Problems with the CCSM simulation of the North Atlantic were investigated by modifying the interpolation and extrapolation procedures around Greenland, and by compensating for the bias in the Gulf Stream trajectory by using "semi-prognostic momentum nudging."

H. A North Pacific configuration of the sigma coordinate Regional Ocean Modeling System (ROMS) is now using boundary conditions generated by the CCSM POP ocean model.

I. Preliminary evaluation of alternative advection schemes has been completed.

III. Land Model Working Group (LMWG)

The LMWG initiated a project to improve the hydrologic cycle in the Community Land Model (CLM). The LMWG is aware of several important biases or deficiencies in CLM. This includes processes such as the interception of precipitation by foliage, soil moisture and its effect on latent heat, and subgrid-scale distribution of precipitation. In addition, CCSM has significant annual dry biases in precipitation in Southeast United States, Amazonia, and Southeast Asia. A series of experiments were performed to improve these biases. Alternative parameterizations of key hydrologic processes were evaluated on their ability to improve the simulated climate. This work is ongoing and continues to be a major focus of the working group.

A significant portion of the LMWG allocation was used in the continued development of the terrestrial carbon cycle and vegetation dynamics for CLM. Of central importance is how well the terrestrial carbon cycle is simulated and its vegetation maintained given the known temperature and precipitation biases in CAM. CAM/CLM simulations showed that the model can simulate a credible carbon cycle but that precipitation biases in Southeast United States and Amazonia hinder the ability of the model to accurately simulate vegetation feedbacks in these regions.

IV. Biogeochemistry Working Group (BGCWG)

The BGCWG usage of resources under this development proposal can be broken down into the following categories: development and evaluation of marine and terrestrial biogeochemical parameterizations, and development of software infrastructure to couple these parameterizations and initial coupled experiments and other development (chemistry and aerosols).

A. The coupled marine Biogeochemistry/Ecosystem/Circulation (BEC) model was ported to CCSM3 from a preliminary version of CCSM2, and parameter values were optimized for the new physical circulation. Longer integrations were performed than were done previously, necessitating modifications to the parameterizations of sinking particle remineralization and redissolution of dissolved iron. Additionally, a new water-column denitrification loss term for nitrogen was incorporated into the model, balancing the existing nitrogen source from nitrogen-fixing phytoplankton.

The BGCWG CSL allocation was used to support a range of critical land model development activities over the past year. Various land hydrology parameterizations were explored to determine the dominant controls on the carbon cycle and to evaluate the effects of parameter variation on carbon fluxes. This testing resulted in an improved land hydrology parameterization that has now been extensively tested (Lawrence et al., 2006, in prep.). The coupled carbon-nitrogen cycle spin-up algorithm developed for the offline model Biome-BGC (Thornton and Rosenbloom, 2005) was incorporated into CLM3-CN (carbon nitrogen) and tested in the context of offline and coupled simulations. This mechanism was found to operate correctly when implemented in the new model, and it was used to initialize a number of experiments (Thornton and Zimmermann, 2006, submitted). Development and testing was performed to integrate time-varying fields for nitrogen deposition, and a new algorithm was developed to provide a prognostic solution for biological nitrogen fixation. The ability to shift the sub-grid fractional cover of plant functional types in response to time-varying fields of historical land use and land cover change was added, including the mechanisms required to maintain conservation of mass for the water cycle under shifting fractional cover. This mechanism was tested extensively in the land cover change experiments carried out under the LMWG allocation. A new fire algorithm was implemented in CLM3-CN, borrowing the algorithm from the CLM dynamic vegetation model (CLM-DGVM) code and migrating it from an annual time step to the radiation time step (hourly). Preliminary testing of this algorithm has been carried out and additional testing is planned for 2006. Finally, the BGCWG allocation has been used to develop and test the incorporation of a fully prognostic ^{13}C isotope component within CLM3-CN. Preliminary results from this development work were presented by Neil Suits (Colorado State University) at the 2005 Fall meeting of AGU.

B. The terrestrial and marine biogeochemical parameterizations are intended to be components of a coupled climate-carbon cycle model. To couple the independent biogeochemistry parameterizations to each other and to the physics, additional software infrastructure for CCSM3 has been developed and tested. This infrastructure facilitates the passing of CO_2 fluxes from the ocean and land components to the atmosphere component. Additionally, hooks have been introduced into the atmospheric component to couple these fluxes to a transported CO_2 constituent and to the radiation modules. Initial multi-decadal length coupled runs have been performed that incorporate both the terrestrial and marine biogeochemical parameterizations.

C. The online atmospheric chemistry was significantly improved. Starting from the WACCM version of CAM (as it has a representation of stratospheric chemistry), the chemistry was modified to fit the CAM model vertical extension and the requirements from tropospheric chemistry, including aerosols. In the developed version, we have included in CAM the tropospheric chemistry module from the NCAR Atmospheric Chemistry Division (ACD) chemistry-transport model MOZART; the interaction with the climate is through the radiative forcing of aerosols and greenhouse gases. This version simulates the evolution and chemical transformation of 97 tracers; it is therefore 5 to 6 times more expensive than the version of CAM without chemistry. In addition, development of the prognostic sea salt and dust modules was done on this allocation (papers cited in the production proposal).

V. Polar Climate Working Group (PCWG)

Since September 2004, a number of model simulations have been performed using CSL resources to improve the polar climate simulations and to elucidate important aspects of the polar climate system. The accomplishments from these studies are outlined below. Development work has addressed some of the most significant biases in the Polar Regions and improved the physical realism of the sea ice model. Our accomplishments include:

A. Diagnosis of alternative cloud parameterizations. Two significant errors in the simulation of the Arctic in CAM3/CCSM3 are excessive wintertime cloudiness and surface warmth. Because the vast majority of simulated wintertime cloud cover is low cloudiness, which is known to warm the surface, these two errors are probably linked. A number of modified cloud parameterizations have been tested in the model in an effort to improve these biases. In particular, a modification to the prognostic cloud amount formula has been applied that reduces low stratus cloud fractions under very dry atmospheric conditions. This alteration causes a large decrease in simulated Arctic low cloud amount during winter, but it has little effect during summer or in other regions during any season. The reduction of low cloudiness with the new parameterization produces much better agreement with observations and mitigates the model's surface warm bias by up to a few degrees. Results are documented in Vavrus (2005).

B. Development of an improved sea ice shortwave parameterization. In CCSM3, the absorption/transmission of shortwave radiation through ice is based on an old and simple prescription method. An improved shortwave radiation parameterization for snow and sea ice has been developed. It is based on a delta-Eddington multiple scattering framework whose optical properties are derived from extensive Surface Heat Budget of the Arctic (SHEBA) spectral albedo and transmission measurements. This improved parameterization has been incorporated and tested in the sea ice model. It is more consistent, accurate, and general than the standard shortwave parameterization. The delta-Eddington shortwave has higher albedo for bare ice than CCSM3, but it penetrates more of the absorbed shortwave below the surface layer and into the underlying ocean. A flexible scheme for tuning the shortwave albedos is included, based on parameters scaled to the SHEBA observed albedo standard deviations. Final CCSM3 impact assessment awaits improvements in snow metamorphosis and melt pond prescription. A technical note discussing this work is under preparation (Briegleb and Light, 2006).

C. A number of other ice model improvements have been made under our development allocation. These include an improved "prescribed ice" model for simulations that require a specified ice concentration, improved software engineering features, and improved model diagnostics.

VI. Paleoclimate Working Group (PaleoWG)

A. Coupled Ocean Acceleration Testing. PaleoWG resources have predominately gone into developing a synchronously coupled accelerated spin-up procedure appropriate for past (and future) climate change. The goal is to provide a solid estimate for how much computing time needs to be allocated to doing fully coupled paleoclimate modeling. The method we have tested is based on the ocean acceleration procedure described in Danabasoglu (2004), but we have employed it in the fully coupled model and verified that it is well-behaved and rapidly diminishes top-of-atmosphere and surface energy budget residuals in doubled and quadrupled carbon dioxide simulations to levels acceptable for paleoclimate modeling. These simulations branched off the T31x3 2x and 4x simulations conducted previously at NCAR, and they represent the only quasi-equilibrated doubled and quadrupled carbon dioxide runs conducted with CCSM3. This method allows a 4 to 5 times acceleration of the coupled simulation (initial and final unaccelerated phases are necessary, hence the range of possible overall acceleration factors). The fact that software engineering considerations (as discussed in Danabasoglu, 2004) prevent us from using an acceleration faction greater than 5 limits further speed-ups. The results of this work are summarized at http://www.cgd.ucar.edu/ccr/paleo/timeseries2/ccsm3.T31_accelerated.html) and in an article in preparation (Huber et al., 2006, in prep). The end result of this investigation is that this acceleration technique appears to work and shortens a 3000-year simulation to approximately 600 years. Our recommendation based on this is that fully coupled deep paleoclimate simulations should request >600 years per simulation.

B. Deep Time Paleochemistry. On the “deep time” side, Kiehl’s long Permian (251 mya) simulations were continued. These are the first realistic fully coupled climate simulations of this time period, and they were conducted with a ten-fold increase in CO_2 compared to the present. At 2700 years, this is the longest continuous simulation of CCSM3 to date. The length of the simulation ensures that the entire coupled system is in an equilibrium state. To understand the role of changes in CO_2 relative to changes in paleogeography, we carried out a parallel simulation assuming present levels of CO_2 for 900 years. This simulation has not reached an equilibrium state, but it does indicate that CO_2 levels are the dominant factor in determining deep ocean ideal age. These simulations transitioned from the development (5000 GAUs) to production (15,000 GAUs) allocation as they appropriately demonstrated that the simulations were functional. The ten-fold simulation is described in Kiehl and Shields (2005). A manuscript describing the ten-fold versus the one-fold latest Permian simulations is currently being written and will be submitted to *Paleoceanography*.

C. Interactive Ice Sheets. A relatively small amount of computing time was devoted to initial exploratory studies of integrating the Genie Land-Ice Model with Multiply-Enabled Regions (GLIMMER) into CCSM. This work was performed by Bill Lipscomb, Los Alamos National Laboratory, while visiting NCAR in October. We are very excited by progress in this area, and we are including a request for further resources be allocated to this in the next CSL allocation.

VII. Climate Change Working Group (CCWG)

A. Developing a new Regional Climate Model. A Regional Climate Model (RCM) provides high-resolution climate scenarios important for impact assessment and resource management, and can also be used to study the upscale impact of regional climate forcings when nested within a global model. A new RCM has been developed based on the Weather Research and Forecasting (WRF) model. The WRF model was designed specifically for high-resolution applications, and the WRF model is now suitable for regional climate simulations using 1-30 km grid spacing. In this project, several changes have been implemented including modification to the treatment of lateral boundary conditions and the updating of sea surface temperature, vegetation parameters, and albedo. Several projects have begun using the WRF model for upscaling and downscaling research.

B. Downscaling climate information. Through an evaluation of cold-season and warm-season long-term continuous simulations driven by the National Centers for Environmental Prediction (NCEP) and NCAR reanalyses, the WRF model has been established as a useful tool for downscaling climate information. As a first step towards a two-way interacting WRF-CCSM system, multi-year integrations of the WRF model driven by CCSM-derived boundary conditions have been performed. These downscaling experiments have shown sensible precipitation and surface temperature variability.

C. Understanding the value of high-resolution RCM simulations of the cold-season climate of the Western United States using grid spacings of 30 km and 6 km has shown that high-resolution long-term simulations can provide realistic small-scale spatial variability of precipitation and surface temperature and improved rain shadows in the lee of high terrain. Substantial improvement in snowpack occurred locally using higher resolution, yet biases in precipitation and temperature and details of the land surface model may have resulted in a poor comparison with observations at selected observing stations. This work was presented at the AGU meeting in December 2004 and at the AMS Annual Meeting in January 2005.

D. Long-Term simulation of warm season rainfall. The WRF model has been used to identify and understand errors in long-term simulation of warm season rainfall. Analysis of a continuous simulation and a series of concatenated weather forecasts for the case study of the 1993 Mississippi basin flood has highlighted deficiencies in the long-term simulation of warm season rainfall. The continuous simulation showed a lack of precipitation whereas the weather forecasts showed an excess. Analysis has shown differences in the time-average dynamic forcing for precipitation and the time-average diurnal cycle of the boundary layer structure. This lack of precipitation appears to be robust in its choice of physics parameterizations and land surface initial states. Work is under way to assess the constraints of domain size and boundary locations on the large-scale solution and subsequent impact on precipitation. This work was presented at the Regional Climate Modeling Workshop held at NCAR in March 2005.

E. Linking WRF and CCSM for upscaling research. It is desirable for both WRF and CCSM to have compatible physics, at least for those processes that are thought to be scale independent. As a first step, the CAM3 radiation parameterization from CCSM has been implemented into WRF. Multi-year tests of WRF with CAM3 radiation have shown the system to be stable and produce sensible temperature profiles and precipitation distributions.

VIII. Software Engineering Working Group (SEWG)

The SEWG implemented a new comprehensive and extensible test suite for CCSM, and they subsequently utilized the development portion of the CSL allocation time to perform thousands of short test runs that verified and validated the functionality of CCSM each time a new version of the model was tagged in the Concurrent Version System (CVS) source code repository. The scope of CCSM testing was also directly responsible for the successful release of CCSM3.0.

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 validation of exact restart capability for different configurations and resolutions of the model, exercise of various compiler debugging features to expose potential bugs, optimization of performance, and 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 share code, and structural improvements in the components. More recent tests have also exercised the transfer of biogchemical fluxes and tracers between components and the activation of atmospheric chemistry.

The development portion of the CSL allocation was also utilized to improve the efficiency of runs performed both on Bluesky and Blackforest. In particular, numerous fully coupled configurations were rerun with the goal of improving load balancing optimization and overall configuration efficiency. The resulting data can be utilized by CCSM users to design standard load balanced configurations for various applications.

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.

Performance of CCSM3 for the standard supported resolutions is:

T31x3 Bluesky:	24 simulated years per day on 64 processors
T42x1 Bluesky:	8.5 simulated years per day on 128 processors
T85x1 Bluesky:	3.5 simulated years per day on 192 processors

IX. References

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