DRAFT

Community Climate System Model
Program Plan FY 2005-2006

The Community Climate System Model Science Plan and Business Plan published in June 2003 laid out an ambitious road map to improve the capabilities of the Community Climate System Model (CCSM) and apply the model to scientific questions and questions about the future of Earth's climate of interest to society. The plans called for the inclusion of new terrestrial and chemical processes important for the complete representation of the climate system, an increased resolution in the treatment of climate processes, and much increased resolution in the climate futures information that can be obtained from the CCSM. Lastly, the plans emphasized that the basic "core" components of the modeling system (atmosphere, ocean, ice, land) needed to be continuously challenged and improved as new observations and new representations of physical processes become available. These thrust areas were to be supported through substantial increases in human and computer resources. In fact, a start was made on the implementation of the human resource part of the plans in FY04 through reallocation. However, the increase in resources that was expected through the Climate Change Science Plan has not materialized, and the prospects for the next couple of fiscal years are, at best, level resources. While there is some hope of increased computer resources through the Department of Energy (DOE) initiatives with the CRAY machines, NCAR's Climate System Laboratory (CSL) computer resources will be level until at the earliest January 2006. In light of this reality, it is necessary to re-examine priorities and lay out a plan of work consistent with the present priorities and likely available resources over the next two years.

I. DEVELOPMENT OF THE CCSM MODEL

There seems to be no obvious reason to change the priority of overall development of the CCSM. Making the climate model more complete with chemistry and missing physical processes; more useful with higher resolution information and better software; and more accurate through continued development of the representations of the basic physical processes are the right directions. The pace at which these directions are pursued must be flexible and opportunistic.

a. <u>A More Complete CCSM</u>

The development of the biogeochemistry capability in the CCSM has good momentum with many scientists actively working on the project. The scientific questions that guide the development are as follows. What are the carbon/climate feedbacks? How do the biogeochemical cycles of nitrogen, iron, sulfur, and other nutrients influence carbon/climate feedbacks? How do reactive chemistry and aerosols change and respond to biogeochemical processes, clouds, and climate? How do land use, land cover change, and water use modify biogeochemical processes? The plan is to have a fully coupled biogeochemistry code within the CCSM3 framework over the next two years. This will have a new terrestrial carbon cycle model with the Community Land Model (CLM) that includes an advanced treatment of prognostic phenology, a dynamic nitrogen cycle, and carbon-nitrogen coupling and multiple agricultural plant functional types. It will also have a more sophisticated ocean carbon cycle component with an advanced ecosystem approach including the effects of multiple nutrient loading. The Biogeochemistry Working Group (BGCWG) and the Land Model Working Group (LMWG) lead these developments.

The reactive chemistry capability of the CCSM is an active interest of many scientists. The plan is to incorporate many aspects of the reactive chemistry that has been developed in the context of the MOZART off-line model and the WACCM model into the Community Atmospheric Model (CAM). Of particular interest will be the representation of the chemistry and physics of aerosols and their effects on the climate system. The BGCWG and the Atmosphere Model Working Group (AMWG) are leading this effort and will be using the Finite Volume (FV) version of CAM for this purpose.

There is a need to add the capacity for the simulation of the behavior of land ice in the CCSM. The Paleoclimate Working Group (PaleoWG) has advanced this requirement and it is also of interest to the LMWG and the Climate Change Working Group (CCWG). There is a scientific visitor that is interested in doing this work.

b. A More Useful CCSM

There is a lot of interest in the rather heroic accomplishment of an extensive suite of T85 control runs and Intergovernmental Panel on Climate Change (IPCC) experiments in support of the 4^{th} Assessment Review (FAR). The high computational cost of T85 has put a tremendous strain on the available resources, and it seems impossible to follow on to T170 without a significant source of new computer cycles and storage (perhaps from DOE CRAYs?). Even T170 type resolution will fall well short of being able to tackle the question of coastal upwelling effects and changes in precipitation distribution in continental regions such as the U.S. The use of the Regional Climate Model (RGM) approach for both up-scaling and downscaling issues appears to be promising. So far, most of the activity has been of the bootstrapping kind, but there remains interest in the community and funding agencies to explore this approach, and we should continue to encourage the activity. The CCWG and the Ocean Model Working Group (OMWG) have provided an initial allocation of computer resources in their proposals to encourage this work. A workshop will be held in March 2005 at NCAR to try to further develop the activity.

Probably the single most important output variable of climate scenarios is the precipitation over land. As such, it is vital to continue to investigate ways to improve the representation of hydrological processes in the CLM. The LMWG intends to investigate the application of the Variable Infiltration Model at high resolution over the continental U.S. as a contribution in this direction.

CCSM software development efforts should be able to play a key role in the creation of a more easily extensible, user-friendly, and portable CCSM model. Two current SEWG projects are aimed directly at this goal. The creation of a single-executable SPMD implementation of the CCSM coupled model system that can run as either a sequential or concurrent application will result in numerous improvements to the CCSM model. Since SPMD is a "sweet spot" for vendor tools, a single-executable version of CCSM will greatly simplify the process of error tracing, portability to new platforms, performance monitoring, and analysis. The resultant code will eliminate the need for stand-alone versions the CCSM model components (e.g., standalone CAM) thereby permitting scientific development to occur across all model components (e.g., CAM, CLM, POP, CSIM) on one model system. It will also result in simplified code maintenance and testing. The current goal is to utilize the ESMF framework to create the next-generation single-executable CCSM model system. A detailed ESMF evaluation plan has already been formulated to reach this goal.

Currently, several types of data models exist in the CCSM3 system. Existing CCSM3 data models run as independent executables. Many stand-alone component versions also carry embedded/non-standard data models (such as the data ocean model in stand-alone CAM). There is no uniform set of basic functionality across these data models, which makes it very difficult to construct experiments such as those needed for the C4MIP protocol. The creation of a new set of CCSM3 data models that implement architecture, shared code, and a uniform set of basic functionality would be an important step in increasing the usability of the CCSM system. In particular, new data models, such as a Slab Ocean Model, could be incorporated easily into the CCSM system. These new data models will be constructed such that they will work both within the released CCSM3.0, code as well as within a future single-executable version of CCSM.

Creating a more useful CCSM also involves ongoing software development efforts including community support, the porting of CCSM3 to Linux, SGI Altix, and Cray X1 architectures, performance analysis for existing and new platforms, and continuous testing of the CCSM model.

c. A More Accurate CCSM

There are persistent biases in the coupled simulations with CCSM. Recently, there has been a renewed call from the Climate Advisory Board (CAB) for a systematic and vigorous approach to tackle these biases. This is a marshalling theme for the continued emphasis on the overall improvement of the representation of the basic physics in the CCSM as expressed in the plans of the component model working groups (AMWG, OMWG, LMWG, and Polar Climate Working Group (PCWG)).

There is some thought that there should be a much deeper investigation of the physical balances that result in the biases that are displayed. It would be helpful to encourage more detailed analysis by groups at NCAR and elsewhere that have the interest and expertise to delve into these questions. It would also be very useful if there could be assessments made of the seriousness of the biases taking into account the uncertainty of the measurements of the properties of the climate system.

It may also be opportune to consider developing a different approach to the modeling problem. There is evidence that the biases in the tropics are connected with the behavior of the atmosphere and ocean as a coupled system. It might be expected that solutions to the bias problems are most likely to be found by approaching the problem in a coupled way and by examining the whole of the physics that defines the coupling. The biases in the Arctic simulations are likely highly dependent on the representations of the snow, ice, water, and land processes. Perhaps the biases should again be approached in a coupled way, but in this case, it may be possible to simplify the treatment of the far field. In the Antarctic, the biases will likely be strongly connected to the interaction of the ocean with the ice edge, and this must surely involve ocean circulation and physics, as well as ice processes. Perhaps it would be appropriate to invest some resources in a preliminary exploration of the coupling issues on a fundamental level, i.e., a level that could not be put into actual practice in the present computer resource situation in anticipation of significant new computer resources in the FY07 time frame.

Finally, it is likely that some level of biases in the climate simulations will remain no matter what. It is important to know what level of bias can be tolerated for different types of uses and questions. This question seems particularly important for the progress of the biogeochemistry and land surface initiatives where, for example, precipitation amounts and distribution are vital to the behavior of the biochemical system.

II. SCIENTIFIC EXPERIMENTS WITH CCSM3

The CCSM runs in support of the IPCC FAR will be completed by the end of November 2004, as will all the control runs that support the release of CCSM3. In addition, the many runs with CCSM3 needed to support the special issue of the *Journal of Climate* on CCSM will be completed. Most of the scientific articles that document and illustrate the nature of the capabilities of CCSM3 will have been submitted. The CCSM project will then turn to spend the next couple of years exploiting CCSM3. The flowing is a consolidated list of major experiments that will be undertaken along with an indication of which working groups will be involved. These experiments have been awarded (mostly) the necessary computer resources to accomplish the tasks, and an explosion of new science is expected.

a. Abrupt Climate Change

This topic will be addressed through a joint project of the OMWG, the PaleoWG, and the PCWG. This is a new way of doing business for the CCSM science program. The program will involve three groups of integrations; equilibrium simulations of paleo conditions; a series of freshwater event simulations; and then a series of ocean and sea ice process studies. The experiments will be directed and analyzed by a task force, the Abrupt Change Task Force (ACTF).

b. Climate Effects of Changing Land Cover

The LMWG will explore the role of changing land cover in the past through simulations of the late 19th and 20th century climate using CCSM3 and time-dependent surface characteristics. This experiment will closely parallel the IPCC integration for the 19th and 20th century that have been accomplished by the CCWG, so as to try to measure the effects of the changing land surface on the simulation of the climate. As well, an attempt will be made to construct a credible scenario of land surface changes to continue the simulation through the 21st century in comparison with one of the CO_2 scenarios undertaken for the IPCC by the CCWG.

c. Eddy Resolving Ocean

A complete annual cycle of a 1/10 degree global ocean configuration will be conducted by the OMWG. It is the minimum integration that will contribute to coastal processes and coupling research objectives, and also the maximum that the CSL computer allocation can support. Ocean mesoscale science will utilize the solution for guidance and as a baseline "truth" for the ocean mixing project concerning eddy-mixed layer interaction in collaboration with scientists in the AMWG. In addition, high frequency forcing will be used so that the role of eddies in extracting wind energy and making it available for mixing can be assessed and hopefully parameterized. This run will also provide the high horizontal resolution behavior of eastern boundary upwelling and equatorial undercurrent termination for these studies and for studies of tropical variability that are of interest to the Climate Variability Working Group (CVWG).

d. Equilibrium and Transient Climate in the Mid-Holocene

The PaleoWG will conduct a major experiment to examine equilibrium solutions, as well as transients for external forcing conditions corresponding to the mid-Holocene (8ka to 3ka). The major difference in forcing in this time period is a result of different latitudinal and seasonal distributions of solar insolation. These integrations will be of interest to the CCWG, as they will complement the time slice experiments at 6ka that will be the mainstay of paleoclimate integrations conducted for the IPCC FAR.

e. Carbon Cycle and Feedbacks

The BCGWG will lead three major experiments to investigate the carbon cycle and its feedbacks. Using the coupled carbon cycle model intercomparison methodology (C4MIP), simulations of the atmosphere/land coupled carbon cycle will be conducted. The experiments will require about 1000 years of off-line CLM and 1000 years of CAM/CLM simulations at T31. The CLM-Carbon/Nitrogen Model (CN) developed by the LMWG includes the impact of nitrogen limitation on the terrestrial biosphere; an important impact that is not considered by scientific studies previously published in the literature. Using the ocean ecosystem model (ECO) within the CCSM3, spin-up and equilibrium simulations of ocean carbon uptake in pre-industrial conditions will be conducted to determine equilibrium conditions, as well as to spin up the model for the coupled carbon cycle simulations. The ECO model includes more sophisticated consideration of the ocean ecosystems, iron limitation, and nitrogen fixation. This spin up will require 100 years of integration with the 3-degree ocean model. Based on the previous two simulations, a coupled ocean/land carbon experiment will be conducted with nitrogen limitation on land, iron limitation in the ocean (and nitrogen fixation), and desert dust simulations of iron deposition from the atmosphere component. This last experiment will require approximately 1800 years of spin up, control, and experimental simulation.

f. Chemistry and Climate

The BGCWG, in collaboration with the AMWG, will also conduct experiments to investigate the interaction between reactive chemistry, aerosols, and the climate. In the coupled chemistry/climate model, simulations of ozone and the nitrogen cycle will be undertaken to improve the understanding of the feedbacks. This will require 180 years of simulations using different control and climate scenarios. The study of natural aerosol interactions in the pre-industrial, current, and future climate will be undertaken to understand how the direct radiative forcing of these aerosols modifies their own source, the climate, and how they respond to anthropogenic climate change. Using a slab ocean model with CAM at T42, about 120 years of simulations will be undertaken to explore this subject. Isotope and tracer code experiments will be used to increase the understanding of transport and transformation processes in the atmosphere.

g. High Resolution Climate Simulations

There is a continuing question of the effect of horizontal and vertical resolution on the simulations of climate, and in particular for climate change scenarios. Comparisons of runs of CCSM3 at increased horizontal resolution showed improvements in some aspects of the simulated climate, but no change in other aspects. The CCWG, in collaboration with the AMWG, will conduct a couple of pilot integrations at T170 to begin to explore the issue. To obtain sufficient samples, the required experiments will have to be completed on non-NCAR machines, possibly DOE computing facilities or the Earth Simulator.

h. Dissecting Climate Variability in CCSM3

The CVWG will lead a large series of AMIP-style integrations to elucidate the role of various physical factors in the variability exhibited by the CCSM. The emphasis is on the production of ensembles of runs that have different experimental conditions to get at the important physical mechanisms. These integrations will also be of interest to the OMWG and the AMWG in their studies of ocean-atmosphere interaction.

i. An Ensemble of IPCC Scenarios

A start will be made to construct a large ensemble (30 members) of climate simulations where the model is forced by the same 2001-2050 business-as usual climate change scenario, and members differ only in their initial conditions. While there are only sufficient resources presently allocated from the CSL to compute 10 members of such an ensemble at T42, there could be sufficient interest generated by this work to secure additional computing time from elsewhere to complete the ensemble. These experiments are in collaboration with the CCWG.

j. Arctic Influences on Global Climate and Climate Sensitivity

The PCWG will lead a series of studies that are aimed to elucidate the role of the Arctic in determining the climate and climate sensitivity in other geographic regions, as well as through global measures. These studies will be of interest to the CVWG as there is a connection between Arctic sea ice and the North Atlantic Oscillation, as well as a connection between Antarctic sea ice, El Niño-Southern Oscillation, and the Southern Annular Mode. The experiments will also be of interest to the CCWG in their interpretation of IPCC integrations as the results will help to understand the sources of climate sensitivity.

III. **CCSM COMMUNITY SUPPORT**

Apart from the intense involvement with the CCSM community through the Climate Advisory Board, the Scientific Steering Committee, and the nine CCSM Working Groups, the project will continue to support the CCSM model code on the designated platforms in accordance with the CCSM policy, as well as provide the support required for access to all of the data comprising the control runs for CCSM3 in accordance with the CCSM Data Policy. This support is part of the on-going work of the CCSM Software Engineering Group.

The CCSM Project Office will continue to organize and support the meetings of all the committees and working groups of the CCSM to the extent that the budget permits. The CCSM will hold the annual CCSM workshop in 2005 and 2006.