REQUEST FOR
CLIMATE SIMULATION LABORATORY
COMPUTATIONAL RESOURCES – Development

February 1, 2006 – July 31, 2007

CCSM Proposal for Development Runs
February 1, 2006 – July 31, 2007

I. Introduction

The Community Climate System Model (CCSM) project is a multi-agency and nationwide activity to develop and assess a state-of-the-art global climate system model and apply it to grand challenge climate issues. The development and assessment of this modeling system has been ongoing for the past ten years. The simulations produced by the CCSM have improved continuously over this time period, and the results from the model are an important contribution to international studies, such as the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). In fact, the CCSM has contributed more runs and results to this assessment than any other climate model, and it will feature very prominently in the AR4. There will also be a special issue of the *Journal of Climate*, to be published in 2006, comprising 26 papers analyzing CCSM3 results and scenarios. Even now, thoughts are turning towards the IPCC Fifth Assessment Report and what should be contained in CCSM4. It is expected that significant progress will be made toward an Earth System Model that has an interactive carbon, and possibly nitrogen, cycle. Very significant Climate Simulation Laboratory (CSL) resources will be needed for this effort to include biogeochemistry components and possibly an atmospheric chemistry component.

II. Accomplishments

Development work continues on all four physical components of the CCSM and in biogeochemistry and atmospheric chemistry. The atmosphere component is transitioning from the spectral to the finite volume dynamical core, because the latter's conservation properties are very important for chemical and other tracers. This has involved significant exploration of the sensitivities of the finite volume core. New parameterizations are being evaluated for the ocean component, and also work has been continuing for the transition to the revised and updated version 2 of the Parallel Ocean Program (POP). Similarly, new developments to the sea ice component are also being evaluated.

Significant development of the land component has also taken place. This includes moving toward interactive vegetation modules, such that the vegetation properties and types depend on atmospheric temperature and precipitation. This allows the vegetation to change as the climate warms, for example, which will change the rate at which land vegetation takes up carbon dioxide from the atmosphere. Another development is the inclusion of a dust cycle, with varying amounts of dust being taken up by the atmosphere, transported to different locations, and being deposited on land or in the ocean. This is a significant source of minerals into the upper ocean. Considerable further development of the land component is needed, so that a realistic carbon/nitrogen cycle can be included in CCSM.

The carbon-climate coupled model developed by the Biogeochemistry Working Group (BGCWG) has now been ported to and validated in the CCSM3 framework. Further development and testing is required for this to become an integral part of a carbon-climate version of CCSM4. Considerable development of the chemistry model MOZART to bring it into the atmospheric framework has also occurred, which will also be a future development path for the CCSM4.

The CCSM project has come a long way since its inception. Nevertheless, there remain significant weaknesses in the climate simulations, especially related to the tropical Pacific and El Niño Southern Oscillation (ENSO). In addition, it is very important to increase the capability of the CCSM in terms of biogeochemistry and chemistry. These two “axes” of development have been laid out in the CCSM Science Plan at http://www.ccsm.ucar.edu/management/sciplan2004-2008, which was published in June 2003. The purpose of this document is to seek resources from the CSL to continue to carry out this development program. The total request is for 1008K GAUs over 18 months, or 56K GAUs per month.

The CSL computer resources are the lifeblood of the CCSM project. Indeed, CCSM scientists have used over 98% of the computer resources awarded in August 2004 by the CSL panel for development purposes. These resources are actively managed across the entire project and are based on the priorities for completion of projects, as determined by the Scientific Steering Committee (SSC), as the science evolves. The CSL resources are the glue that keeps the CCSM functioning as a community project. The remainder of this document contains input from the CCSM Working Groups that describes the proposed scientific use of CSL resources for development runs.

III. CCSM Working Group Requests

A. Atmosphere Model Working Group (AMWG)

1. Research Plan

As in previous years, the AMWG will continue to work on specific science objectives and the development of a state-of-the-art atmospheric general circulation model for CCSM. We will focus on:

a) understanding Earth's climate using the Community Atmosphere Model (CAM) and other CCSM model components.

b) understanding the behavior of our current model and the processes controlling that behavior.

c) improving the representation of processes that are poorly represented in CAM.

d) adding new capabilities to CAM important for understanding chemistry, aerosols, and climate.

These issues provide the central focus for our ongoing research effort and contribute to our scientific objectives. Our efforts are evenly divided among the four themes. Progress requires a substantial (human and computation) effort in model development. We describe that development effort here. Our research agenda can broadly be described by two categories and there is a strong overlap between the two.

Category One of the research agenda is a continuing attempt to improve the formulation of certain processes in our model that we believe hinder our ability to simulate the atmosphere. We believe that many of the problems seen in CAM and CCSM simulations are functions of deficiencies in these formulations of specific processes, and we continue to aggressively work on them. Among these are problems associated with position and seasonal migration of the intertropical convergence zone (ITCZ), variability and lifetime of convection, and interaction of the finite volume (FV) dynamics of the CAM with other components of the coupled climate system. We are attempting to understand the fundamental reasons for these deficiencies and work to improve their representation in CAM. Many of the deficiencies are intimately tied to interactions with the ocean model, and we have initiated an active collaboration with the Ocean Model Working Group (OMWG) and the broader research community through the formation of a Tropical Variability Task Team (TVTT). We are now performing simulations with a number of variations in the current CAM parameterizations devised to identify sensitivities in the simulation to variations in the representation of processes. For example, with the OMWG, we have started exploring the sensitivity of ENSO amplitude and period to variations in the altitude of the convective heating, or the efficiency of mixing (laterally and horizontally) of momentum in the boundary layer. In collaboration with the TVTT, the Climate Process Teams (CPTs), universities, and postdocs, we are continuing to focus on the shallow convection, deep convection, and turbulent boundary layer parameterizations.

Category Two of the research agenda is designed to further our understanding of atmospheric processes and the ways that they interact with other components of the climate system. For example, we are planning major revisions to the model cloud and aerosol microphysics over the next year. Our revisions to the cloud microphysical parameterization will include explicit prediction of the mass and number of liquid and ice phase condensate and their interactions with aerosol. We plan to increase the number of prognostic variables associated with water from our current value of 3 (masses of water vapor, liquid, and ice) to as many as 10 (mass of vapor, mass and number for various types of liquid and ice condensates). These revisions allow us to study aerosol direct and indirect effects much more realistically than the current parameterizations. Such a complex scheme may prove too costly for the final production version of CAM4, but we believe that exploratory studies will help to identify where compromises can be made. We are also exploring revisions to the formulation of cloud fraction, cloud overlap, and the inhomogeneities in water substances to explicitly acknowledge the subgrid-scale nature of these fields via a statistical (probability distribution function, PDF) approach. The PDF approach to cloud properties is intimately tied to the formulation of the cloud microphysics and radiative transfer, and an investigation of these interactions will also take place over the next year through a microphysics task team that we have recently formed.

The improvements to the microphysics of clouds are intimately connected to the representation of aerosols. We are nearing completion (in collaboration with the BGCWG and Chemistry-Climate Working Group) of a bulk aerosol module that produces predicted concentrations of four sizes of sea salt and dust and carbonaceous aerosols, in addition to the sulfate aerosol module released with CAM3. Adding to our understanding of cloud and aerosol processes in the atmosphere provides a natural prelude to the studies of climate sensitivity that have formed as a continuing area of focus to members of the AMWG over the last 10 years. We have also begun explorations of the role of various types of turbulent mountain stress and form drag that have not been represented in earlier versions of CAM. These new representations substantially change the stationary wave pattern in the Northern Hemisphere and may have an effect on the "excessive sea ice problem" seen in our current coupled CCSM simulations.

Finally, we continue to explore the sensitivity of the model simulations to variations in vertical and horizontal resolution and to the numerical methods used to solve atmospheric dynamics and transport. We make simulations with both comprehensive physical parameterizations and using simplified representations for physical processes (for example, "waterworld" simulations and Held-Suarez type simulations).

Although it will not form the bulk of our model development activity, we also interact with other working groups on diagnostic features that improve our ability to understand component processes. For example, we are working with the BGCWG to carry carbon, oxygen, and hydrogen isotopes and allow the monitoring of isotopic fractionation processes during transport and phase change. We also work with NCAR's Atmospheric Chemistry Division, with the Whole Atmosphere Community Climate Model (WACCM) group, and with the Chemistry-Climate Working Group (ChemWG) to formulate a model useful for representing interactive photochemistry and its interaction with Earth’s system. We have recently developed (with the ChemWG and the Atmospheric Chemistry Division) a version of CAM that provides the capability for offline transport studies (e.g., studies in which the model must conform on an event-by-event basis with observed meteorology).

2. Scientific Objectives

a) Certainly one of our primary goals is to produce a state-of-the-art general circulation model for the research community. We are working toward a model that substantially reduces the biases present in CAM3 that we believe are associated with physical processes like convection, boundary layer turbulence, clouds, etc. The next generation model must be able to run in a fully coupled mode without the problem with sea ice growth in the North Atlantic that is present in CCSM3 with the FV dynamical core. It is critical that we achieve a viable coupled simulation with the FV core if it is to be used for the next generation chemistry-climate model, but it is worth noting that the same biases exist in the other dynamical cores, although the biases are somewhat smaller and do not exceed the threshold that triggers excessive sea ice growth when they are run in coupled mode. We also are working to produce a model that provides new functionality designed to allow the CCSM to deal with new classes of problems in chemistry-climate interactions and biogeochemical cycles.

b) Aerosol/cloud interactions are believed to be one of the critical controlling sets of processes in Earth’s system. We have embarked on a systematic effort to improve the representation of these processes in CAM, and we will use the resulting model to study their role in Earth’s system. We will use the model to help in understanding the processes that control aerosol distributions in the atmosphere, to improve their representation, and to examine their direct and indirect effect on Earth's climate. We are working with the newly formed ChemWG on this project.

c) Understanding the interaction between the processes controlling the hydrologic cycle and the other components of the general circulation. In particular, we will continue to focus on transient features of precipitation (the diurnal variation of precipitation, the biases in the sub-diurnal timescale episodic nature of convection in our model) and biases in the ITCZ features in our model.

3. Computational Requirements

We have formulated our proposal in the context of a series of runs with the FV model. Our baseline model is assumed to be a 30-level 2x2.5-resolution configuration. The baseline model will cost about 35 GAUs per year. The table below lists a set of 10-year runs that span the spectrum of projects discussed previously. We have found that a 10-year run is the minimum length required to allow the land-atmosphere system to approach an equilibrium, and this length run reduces the interannual variability of the system sufficiently that a first look at the atmospheric climate is viable.

These runs are designed to explore the effect of improved processes (convection, cloud properties, momentum transport, etc.) on the climate and to explore new climate interactions (e.g., aerosol/cloud indirect effects). The runs labeled "revised physics" will include some combination of alternate convection, shallow convection, turbulent mountain stresses, boundary layer parameterizations, and cloud fraction parameterizations. They are grouped together because they all cost approximately the same amount. The runs labeled IPA are runs employing the independent pixel approximation. These runs can vary widely in cost depending on the precise configuration. We have assumed that our standard configuration will double the cost of a "cloud microphysics run." The IPA tests will be an important component in our evaluations of the model including the new cloud microphysics.

Experiment	**# of runs**	**Model Config**	**# of Years**	**GAU/ year**	**Total GAUs**	**Priority**
Revised physics	100	FV2x2.5	10	35	35,000	High
Aerosols	10	FV2x2.5	10	70	7,000	High
New cloud microphysics	15	FV2x2.5	10	105	15,750	High
IPA	10	FV2x2.5	10	210	21,000	Medium
Vertical resolution	10	FV2x2.5	10	70	7,000	Medium
Horizontal resolution	15	FV1x1.25	10	140	21,000	Medium
Horizontal resolution	4	FV0.5x0.5	10	560	23,000	Low
Slab Ocean Model (SOM)	15	FV1x1.25	10	35	5,250	Medium
Total					135,000	

B. Chemistry-Climate Working Group

1. Scientific Background

The composition and photochemistry of Earth's atmosphere has been profoundly changed by anthropogenic activities through the emissions of trace gases and aerosols. The atmospheric circulation and hydrological cycle are impacted by these changes in atmospheric composition through changes in the atmospheric radiative forcing, the modification of cloud processes, and the impact on the land surface. Atmospheric trace constituents impact ecosystems directly through nutrient cycling, indirectly by altering the light and water availability to various ecosystems, and also through the damage of plant tissue at high concentrations of oxidants and acids. This is a dynamic system in that key trace species are created and/or destroyed in the atmosphere by photochemistry and physical processes of the climate system. Changes in near-surface air quality can also have profound impacts on human health.

Recently, a ChemWG has been formed to include the effects of atmospheric chemistry in the CCSM (http://www.ccsm.ucar.edu/working_groups/Chemistry/index.html). The working group held a planning meeting in June 2005 and identified four high priority research and development areas. The first two areas listed below require major model development and are regarded as critical for predicting atmospheric composition. The third area requires a number of sensitivity tests to determine the strength of the coupling between atmospheric chemistry, atmospheric aerosols, the biosphere, and climate. The final area is in some sense pret-a-porter and thus ready for production runs in the coming year and not treated here.

a) Aerosol effects on clouds, energy, and the hydrological cycles.
b) Chemistry, transport, and washout in convection and microphysics parameterizations.
c) Atmospheric chemistry and aerosols interactions with the land.
d) Hemispheric pollution to regional air quality.

2. Research Plan

To date the impacts of chemistry have been highly parameterized or neglected within the CCSM. The immediate goals of the ChemWG are to understand and model the key interactions between climate and chemistry (including ozone, other trace gases, and aerosols) and to find possible methodologies for incorporating the effects of chemistry and aerosols under the operational constraints of a climate model.

Recently, CAM has been modified to simulate both tropospheric and stratospheric chemistry. In addition, a new bulk aerosol scheme is now available, which is consistent with this chemistry and includes the effects of ammonia, nitrate, and secondary organic aerosols. This leaves the ChemWG in an ideal position to address its immediate goals. However, further development is needed particularly in:

a) Chemistry and physical parameterizations. Chemistry has just recently been imported into the current version of CAM. Some aspects of the formulation of chemistry in CAM are incomplete. In addition, the physical parameterizations within CAM are in a state of flux. Proposed simulations include:

- Tests of the new physical parameterizations with respect to their impact on chemistry and evaluation against chemical measurements. New physical parameterizations that are under consideration for CAM4 include those for the boundary layer, deep and shallow convection, microphysics, and cloud overlap.

- Developing a new formulation for aerosol scavenging consistent with the explicit calculation of aerosol activation (necessary to simulate the indirect effect). In addition, the washout of chemical species within CAM needs to be updated and calculated in a consistent manner with the microphysics.

b) Aerosols, the direct effect. At present the prognostic bulk aerosol scheme incorporated into CAM uses fixed oxidant fields. This scheme also does not include the effects of secondary organic aerosols, ammonia, or nitrate. We propose here a series of development efforts to increase the complexity of the aerosols and sensitivity tests to examine the sensitivity of climate to the proposed changes. Proposed tests include:

- Introduction of chemically active oxidants consistent with local conditions and meteorology, as well as the historical and predicted changes in emissions. In addition, we will include the effect of ammonia, nitrates, and secondary organics in our aerosol parameterization.

- Generalize the aerosol representation to treat a modest number of aerosol modes, each composed of an internal mixture of multiple aerosol components, with the mass and number of each component predicted. We refer to this as the modal aerosol scheme in the table below.

- Introduction of a more explicit treatment of aerosols using a fully resolved bin representation, at least for a select group of aerosols. A number of candidate schemes for this process have already been introduced into CAM.

c) Aerosols, the indirect effect. At present no indirect effect has been incorporated into CAM. Recently, a microphysics task force has outlined a strategy (http://www.cgd.ucar.edu/cms/meetings/microphys/) to implement a microphysical scheme more fully consistent with the simulation of the indirect effect. The link between an aerosol scheme and microphysics lies in the calculation of droplet and ice crystal nucleation. Proposed tests include:

- Introduction of a parameterization to link nucleation to aerosol properties. One parameterization has already been implemented into CAM. We will test the climate sensitivity to the indirect effect using the different aerosol and chemistry schemes outlined above.

- The nucleation of cloud and ice crystals is sensitive to the aerosol composition, including the presence of organic films. We will test the sensitivity of CAM to aerosol composition.

d) Feedbacks between chemistry and biogeochemistry. Feedbacks between atmospheric chemistry and the land model impact atmospheric chemistry, the land model, and the hydrological cycle. Here we will explore various feedbacks between atmospheric chemistry and the land surface. A proposed scenario for examining these feedbacks can be found at http://www.csm.ucar.edu/working_groups/Chemistry /index.html. Proposed simulations include:

- The sensitivity of atmospheric emissions of biogenic species to the land model. Impacts on climate may include changes in the aerosol distribution, hydrological cycle, ozone distribution, and nitrogen deposition. All of these will in turn impact the land model.

- The sensitivity of nitrogen deposition, changes in diffuse/direct radiation and ozone on the land model. Feedbacks between changes in the land model and atmospheric chemistry and radiation need to be explored.

e) Reduced chemical mechanisms. Reduced chemistry mechanisms are one methodology for incorporating chemistry into climate models, but at a lower cost. The solution and climate feedbacks of using reduced mechanisms need to be tested against the following metrics: the ability to capture the direct and indirect impacts of aerosols; the ability to capture nitrogen deposition and the surface ozone concentration; and the ability to capture the radiative impact of ozone, especially in the upper troposphere and lower stratosphere.

3. Resources Requested

In all cases we intend to run sensitivity tests in the FV2x2.5 version of the CAM stand-alone model in both the present and 2100 climate. The future climate will include projected emissions for 2100 in all relevant species. The FV version of CAM is the version most suitable for chemistry. When appropriate, simulation results will be compared against available observations using the newly developed CAM-offline model. This model is driven by analyzed meteorological fields (e.g., from the National Centers for Environmental Prediction, or NCEP) so as to simulate the actual meteorological conditions during field campaigns.

The table below lists a set of runs that encompass the development projects previously listed. In most cases we will use interactive chemistry. In simulations that require significant development, we have requested additional runs so as to examine the sensitivities with respect to important parameters. Many of the charges are estimated, assuming modest increases for the new parameterizations and more sizeable increases for changes in the aerosol schemes. Timings of a preliminary reduced chemistry mechanism have been taken into account. Simulation lengths of five to ten years are requested, except for those involving the stratosphere or the Community Land Model (CLM), which are taken to be ten years. We have budgeted runs to both drive a stand-alone CLM model with imported nitrogen, ozone, and radiation fields, and to run interactive CLM simulations with chemistry.

Experiment	**# of runs**	**Model Config**	**# of Years**	**GAU/ year**	**Total GAUs**	**Priority**
(A1) Sensitivity to convection	9	FV2x2.5	5	156	7,020	High
(A2) Sensitivity to boundary layer	6	FV2x2.5	5	156	4,680	High
(A3) Sensitivity to cloud	6	FV2x2.5	5	156	4,680	High
(A4) Sensitivity to microphysics	9	FV2x2.5	5	160	7,200	High
(B1) Bulk Aerosols	3	FV2x2.5	5	36	540	Medium
(B2) Bulk Aerosols, Direct Effect w/Chemistry	3	FV2x2.5	5	150	2,250	High
(B3) Modal Aerosols, Direct Effect w/Chemistry	12	FV2x2.5	5	180	10,800	High
(B4) Modal Aerosols, Direct Effect w/Imported Chemistry	3	FV2x2.5	5	60	900	High
(B5) Binned Aerosols, Direct Effect w/Chemistry	6	FV2x2.5	5	300	9,000	Medium
(C1) Bulk Aerosols, Indirect Effect	6	FV2x2.5	5	46	1,380	High
(C2) Bulk Aerosols, Indirect Effect w/Chemistry	6	FV2x2.5	5	160	4,800	High
(C3) Modal Aerosols, Indirect Effect w/Chemistry	9	FV2x2.5	5	190	8,550	High
(C4) Modal Aerosols, Indirect Effect w/Imported Chemistry	3	FV2x2.5	5	70	1,050	High
(C5) Binned Aerosols, Indirect Effect w/Chemistry	6	FV2x2.5	5	300	9,000	Medium
(D1) Biogenic Emissions from CLM	6	FV2x2.5	10	150	9,000	High
(D2) Driver for CLM sensitivity to Chemistry	2	FV2x2.5	10	150	3,000	High
(D3) Driver for CLM sensitivity to chemistry and aerosols	2	FV2x2.5	10	180	3,600	High
(D4) Stand-alone CLM sensitivity	6	FV2x2.5	10	4	240	High
(D5) Interactive CLM sensitivity to chemistry	2	FV2x2.5	10	180	3,600	High
(D6) Interactive CLM sensitivity to chemistry and aerosols	4	FV2x2.5	10	150	6,000	High

(E1) Reduced Mechanism Troposphere Radiative Effect	6	FV2x2.5	10	90	5,400	High
(E2) Reduced Mechanism Stratosphere Radiative Effect	6	FV2x2.5	10	180	10,800	High
(E3) Reduced Mechanism – Direct Effect	6	FV2x2.5	10	120	7,200	High
(E4) Reduced Mechanism - Indirect Effect	6	FV2x2.5	10	130	7,800	High
(E5) Reduced Mechanism - Effect on CLM	4	FV2x2.5	10	90	3,600	High
CLM spin up for above runs	16	FV2x2.5	~45	4	2,910	High
Total					135,000	

C. Ocean Model Working Group

1. Research Plan

The proposed ocean model development comes in two flavors: support of specific science objectives and maintaining a state-of-the-art ocean component for CCSM. The former is imperative if CCSM is going to fully contribute to science, as described in the OMWG production proposal. On the latter, it has been argued (by others) that the CCSM3 ocean is at the forefront of ocean climate models. To maintain this position will require a continual high level of effort and support.

The key development in support of science objectives is a new version of the ocean model. It is to be based on the latest POP2 from Los Alamos National Laboratory (LANL) that was incorporated into CCSM over the last year. The final CCSM features, including diagnostics packages and netCDF files, will have been added by the end of the current allocation. Also completed are a number of model developments that can be separated into those with fast timescales and those with slow timescales. The former includes a new tracer advection (NTA), an anisotropic version of the Gent-McWilliams eddy mixing parameterization (AGM), and a reduced lateral viscosity (RLV), whose incorporation allowed the realistic representation of Tropical Instability Waves (TIW). Among the latter are parameterizations of the Gravity Current Entrainment (GCE) associated with deep ocean overflows, of the lateral mixing due to mesoscale eddies in the well-mixed layer of the upper ocean (MLE), and spatially varying Gent-McWilliams eddy mixing in the ocean interior (SGM).

Maintaining a state-of-the-art ocean component requires continual model improvement. The highest priority over the next 18 months will be the reduction of long-standing biases in the coupled CCSM that can be attributed to the ocean model or atmosphere-ocean coupling. The primary emphasis in this proposal is the improvement in tropical ocean and coupled biases. This effort is guided by the informal TVTT that gathers about once a month to review the latest results and put forward new hypotheses concerning tropical variability problems in CCSM. An increasingly important aspect of this activity is interaction with the theoretical and observational communities. A very successful example of this interaction is the ocean mixing CPTs, with the GCE and MLE parameterizations tangible results. The OMWG is also becoming more involved with observational field campaigns that are being planned as part of the U.S. Climate Variability and Predictability program. These come under the scrutiny of the newly formed Process Study and Model Improvement Panel (PSMIP) with which the OMWG has close connections. The two proposed campaigns of most relevance to our work are Variability of the American Monsoon Systems (VAMOS) Ocean-Cloud-Atmosphere-Land Study (VOCALS) and Pacific Upwelling and Mixing Physics (PUMP). The other important example of community led model development is a suite of experiments stemming from the Workshop on Correcting Tropical Biases (CTB), three of which naturally fall to the OMWG.

2. Science Objectives

The overall objective is to deliver a package of model improvements to the CCSM community and specifically to the science outlined in the production proposal. The science objective is to understand the behavior of the various model developments, both individually and as they interact with the others. Such interactions are often surprising and must be investigated before a new model is adopted. To date these have been tested exclusively in low-resolution models and only individually. The plan is to expand this testing to higher, more state-of-the-art climate resolution and to the various interactions.

a) A September 2005 workshop on CTB initiated a multi-institutional effort to address common coupled model problems. In particular, a number of experiments were designed to investigate potential sources of the problems, and each is to be performed by multiple groups. Three of these naturally fall to the OMWG and are to be completed by June 2006. The first experiment is to test the hypothesis that the excessive cold tongue is a result of upwelling water that is too cold. As such the results will be directly relevant to the observational plans and data analysis of PUMP. The second experiment is designed to quantify the ocean's role in generating conditions off the west coast of South America, where CCSM and other coupled model sea surface temperatures (SSTs) have the largest biases (>5°C too warm). These results will have a direct bearing on VOCALS. The third experiment will test the hypothesis that the anemic variability in CCSM3 tropical winds, in particular westerly wind bursts, is responsible for the deficient behavior of the equatorial ocean and hence coupled tropical variability.

Within the CCSM community itself, poor tropical variability at all timescales has led to the formation of an informal TVTT, which has put forward several promising ideas that will be systematically explored. These can be classified as oceanic, coupled, and atmospheric in nature. To date, only the oceanic TIW question has been successfully concluded. Two other oceanic issues have just started to be investigated: the propagation and reflection of ocean Rossby and Kelvin waves may be too permissive in the CCSM ocean, and eastern ocean boundary processes have important remote effects. The coupled questions that are on the table include the role of atmospheric "noise," associated with the Madden-Julian Oscillation (MJO) in modulating coupled variability, the sensitivity of ENSO frequency to the latitudinal extent of the wind response to SST variability, and how the diurnal cycle of SST affects the atmosphere and climate. The atmospheric question that is the primary concern of the OMWG is weak trade winds along the equator. In collaboration with the AMWG, a serious attack on increasing these winds in the coupled model will be launched. One tactic will involve the vertical physics and the other the horizontal. The latter simply involves adding lateral diffusion to bring the excess off-equator westward momentum into the region of the equatorial deficit. The two ways put forward so far to bring momentum down from above are through the diabatic heating profiles and the vertical momentum transport associated with convection.

3. Proposed Experiments

a) Test individually and in combination the above three slow timescale developments in the standard, nominal 1-degree uncoupled forced ocean, hereafter denoted as x1ocn. In addition to the three individual tests and one with all three, one pair (NTA + RLV) will be tested. These choices reflect the preliminary low-resolution result that, although there are positive impacts of AGM in western boundary current regimes, it may produce an unacceptable Antarctic Circumpolar Current. In the event that this result does not hold in x1ocn, a combination of all three may still be viable. Otherwise (NTA + RLV) will likely emerge as the candidate fast physics package for the new ocean model. Tests of the fast physics only require 50-year integrations. This is sufficient time for the initial transient to die out (order 10 years), and to reach far enough (40 years) into the advective timescale to make quantitative assessments of model improvements or degradations. The last 10 years will be used for the analysis on which these decisions will be made.

b) Test individually and in combination the slow timescale developments. The strategy is the same as for a), in that each of the three developments will be tested individually and all together. GCE should be independent of the two eddy mixing developments, therefore, the only pair to be tested is MLE + SGM. These two schemes need to be merged in a transition layer between the adiabatic ocean interior and the diabatic mixed layer, so a clear demonstration of how this is working in x1ocn is essential. These developments all impact the deep ocean either directly or through its connection with the upper ocean, so longer x1ocn integrations are needed to get any idea of the behavior over long timescales. The minimum integration time for this purpose is 200 years.

c) To test the new ocean model, the fast and slow timescale physics developments will be combined, and a 100-year compatibility test will be conducted in x1ocn to ensure that both the fast and slow physical behavior is acceptable. The combined ocean physics will then be coupled in a T85x1 configuration. Not only is this necessary to have confidence in the new physics in coupled mode, as would a more economical T42x1 run, but it serves to maintain OMWG experience with T85 atmospheres that was gained with the last IPCC exercise and will be absolutely critical to the next. These integrations will be carried out under OMWG developments before the new ocean model is passed on for use in a variety of production experiments.

d) Contribute to CTB by integrating the current T42x1 in three experiments following the protocol defined at the workshop. In the first experiment, the equatorial upwelling will be perturbed in a prescribed fashion to test the hypothesis that the excessive cold tongue is a result of upwelling water that is too cold. As such the results will be directly relevant to the observational plans and data analysis of PUMP. The second experiment will similarly prescribe the upwelling and forcing conditions off the west coast of South America, where CCSM and other coupled model SSTs have the largest biases (>5°C too warm). These results will have a direct bearing on VOCALS. The third experiment will test the hypothesis that the anemic variability in CCSM3 tropical winds is responsible for the deficient behavior of the equatorial ocean and hence coupled tropical variability. The CTB protocol demands that these experiments be fully coupled and T42x1 is proposed. However, they are designed to test hypotheses and to probe common weaknesses in current climate models. As such, neither long integrations nor tracers are necessary. However, the most telling measure will be the ENSO variability, and from past experience the minimum integration time to have a first order characterization is 50 years.

4. Computational Requirements

a) Each of the proposed 5 tests of the fast physics will be a 50-year integration of x1ocn. They will include two passive tracers, because their behavior is the motivation behind NTA, making the computational cost about 50 GAUs/year. Therefore, the total 250 years will need about 13 kGAUs to complete. Here and below, it is assumed that the computational cost of the new developments will be about the same as the code they replace, as found to be the case at low resolution.

b) Each of the proposed 5 tests of the slow timescale physics will be a 200-year integration of x1ocn. They need not include extra tracers, so the computational cost will be 45 GAUs/year. Therefore, the total 1,000 years will use 45 kGAUs.

c) A 100-year integration of the x1ocn with the combined fast and slow timescale physics will require only about 5 kGAUs. The shorter 50-year integration of T85x1 needs 13 kGAUs.

d) The computational cost of 50 years of T42x1 is 3.5 kGAUs. Therefore, the resources needed for 3 such experiments are about 11 kGAUs.

e) Checking out 6 hypotheses, each with 2 variants in x1ocn, means 12 experiments of 50 years each with x1ocn and 6 fully coupled T42x1 integrations of 50 years each. The respective computational costs are 27 and 21 kGAUS.

Experiment	**# of runs**	**Model Config**	**# of Years**	**GAU/ year**	**Total GAUs**	**Priority**
a) Fast Processes	5	x1ocn+tracers	50	50	13,000	High
b) Slow Processes	5	x1ocn	200	45	45,000	High
c) New Ocean Model	1	x1ocn	100	45	5,000	High
	1	T85x1		256	13,000	Medium
d) CTB	3	T42x1	50	70	11,000	Medium
e) TVTT	12	xlocn	50	45	27,000	Medium High
	6	T42x1	50	70	21,000	Medium High
Total					135,000	

D. Land Model Working Group (LMWG)

The inclusion in climate models of the exchanges of energy, water, and momentum between land and atmosphere has greatly altered our perception of the role of land in the climate system. It is now widely recognized that the land surface provides significant feedbacks to climate, that natural and human-mediated changes in land use and land cover alter climate, and that adequate parameterization of the physical and biological controls of evapotranspiration are necessary to accurately simulate surface climate. In developing the initial land surface models for use with climate models, emphasis was placed on the biogeophysical boundary conditions (albedos, upward longwave radiation, sensible heat flux, latent heat flux, surface stresses) required by atmospheric models. Further advancement in land surface modeling is being achieved by combining the relevant biogeophysical, biogeochemical, hydrologic, and vegetation processes into a comprehensive model of land-atmosphere interactions that is physically and biologically realistic.

Model development to be conducted over the next 18 months, under the auspices of the LMWG, falls into five areas: a) improving biogeophysical and hydrological parameterizations to correct biases or deficiencies in the model; b) representing permafrost in the model; c) adding an urban land cover parameterization; d) simulating the terrestrial carbon cycle and vegetation dynamics; and e) developing a high-resolution version of CLM.

1. Surface Biogeophysics and Hydrology

The LMWG is aware of 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 heat, and subgrid-scale distribution of precipitation. These biases are being addressed in a LMWG project to improve the hydrology of CLM. Changes to hydrologic parameterizations can be tested and documented in 25-year Atmosphere Model Intercomparison Project (AMIP) type simulations of FV CAM/CLM at 2x2.5-degree resolution.

The LMWG is also developing and testing new formulations of surface fluxes for use with CLM. Of particular concern is within canopy turbulence and the parameterization of soil evaporation and their effect on surface fluxes from the ground. Prognostic canopy air space is being added to CLM so that heat, moisture, and CO_2 can be stored in the canopy. This is expected to greatly improve the simulated diurnal cycle and numerical stability of the model.

2. Permafrost

Recent analysis of permafrost in CCSM indicates that permafrost may degrade rapidly as atmospheric greenhouse gas concentrations continue to rise. Although the simulation of permafrost in CCSM is reasonable, there are a number of improvements to CLM that will provide tests of the robustness of the permafrost predictions and evaluate potential feedbacks on climate. These improvements include increased soil depth, introduction of dynamic fractional wetland land cover, a representation of soil organic matter, and interactive soil carbon pools. The development of these aspects of CLM can be conducted with CLM coupled to FV2x2.5 CAM.

3. Urban Land Cover

An urban land cover parameterization is being developed for CLM to examine the impact of urbanization on climate. This parameterization will be tested and evaluated with the T85 CAM/CLM to provide high spatial resolution and to complement production simulations by the LMWG that examine the impact of land cover change on climate.

4. Carbon Cycle and Vegetation Dynamics

Recent developments in CLM allow for the simulation of the terrestrial carbon cycle and vegetation dynamics. These capabilities have been developed independent of ongoing CLM developments in the hydrologic cycle and surface biogeophysics. In addition, models of the terrestrial carbon cycle (CLM-CASA', CLM-Carbon Nitrogen, or CLM-CN) are different from that of vegetation dynamics (CLM-DGVM), which uses concepts of a dynamic global vegetation model to allow vegetation biogeography to change over time as climate changes. Major developmental tasks in the LMWG are to merge the carbon cycle with vegetation dynamics to have a consistent model of terrestrial ecosystems; to ensure that CLM improvements in hydrology and biogeophysics do not adversely affect the simulated vegetation; and to understand how well the terrestrial carbon cycle and vegetation are simulated and whether vegetation is maintained given known temperature and precipitation biases in CAM.

5. High-resolution CLM

The LMWG has initiated a project to develop a high-resolution version of CLM that allows the land model to operate on a spatial grid independent of the atmosphere model. CLM will be coupled to CAM on its native grid so that all land-atmosphere communication occurs on the atmosphere model resolution. The atmospheric forcing will be downscaled from the coarse resolution CAM to the high-resolution CLM. This necessitates development of downscaling procedures by which the atmospheric data is downscaled to a higher resolution grid, accounting for topographic variations. Model development will occur in the framework of 0.5-degree CLM coupled to FV2x2.5 CAM. A precise estimate of the GAU requirements for this project is not possible. Instead, computational costs are estimated based on the proportional increase in the number of CLM grid boxes.

Experiment	# of runs	Model Config	# of Years	GAU/ year	Total GAUs	Priority
Hydrology development	18	FV2x2.5 CAM/CLM	25	30	13,500	High
Biogeophysics development	18	FV2x2.5 CAM/CLM	25	30	13,500	High
Permafrost	14	FV2x2.5 CAM/CLM	25	30	10,500	Medium
Urban	3	T85 CAM/CLM	25	140	10,500	Medium
Carbon-hydrology development	5	FV2x2.5 CAM/CLM	200	30	30,000	High
DGVM-carbon development	5	FV2x2.5 CAM/CLM	200	30	30,000	High
High-resolution land model (0.5^o)	20	FV2x2.5 CAM/CLM	5	90	9,000	Medium
Total					117,000	

E. Biogeochemistry Working Group

The overall goal of the BGCWG is to improve understanding of the interactions and feedbacks between the physical and biogeochemical climate systems under past, present, and future climates. This requires development, evaluation, and coupling efforts for a suite of global, prognostic biogeochemical component models (land, ocean, and atmosphere) within the CCSM.

1. Scientific Background

Current state-of-the-art modeling for climate predictions requires coupled-carbon climate models capable of simulating not only the physical climate, but also the biogeochemical responses that control the carbon dioxide in the atmosphere. Full-complexity model simulations of the coupled system have been performed by several modeling groups for the current climate and future scenarios. However, predictions of carbon dioxide concentration in the future vary widely, even under the same anthropogenic emissions scenario, because of differences in feedbacks between the physical climate and biogeochemistry as included in existing models. Several reasons for these differences have been proposed, including sensitivity of the Amazon precipitation to changes in climate, as well as differences in the terrestrial ecosystem response to hydrology and temperature. Studies using the first version of the NCAR Climate System Model (CSM1.0) coupled carbon simulations have provided exciting new results including: a) faster fossil fuel carbon dioxide emitted and less carbon stored in the ocean or land due to limits on the ability of these reservoirs to take up the anthropogenic carbon; b) on decadal and longer timescales, natural biogeochemical variability such that ocean and land carbon storage tend to be anti-correlated in time; and c) trade offs between hydrology and temperature control land carbon dioxide flux responses to climate.

CCSM is well poised to resolve some of these uncertainties, since within the CCSM3 framework, three different terrestrial carbon models have been implemented. A new project was proposed at the June 2005 CCSM workshop, called the land model carbon intercomparison task force, which has set up a protocol and metrics to determine how to best simulate the terrestrial carbon cycle (http://www.ccsm.ucar.edu/working_groups/Biogeo/). The main goals over the next 18 months for the BGCWG will be the comparison of the existing land carbon models and the development of a third generation land carbon model with the best characteristics of the current generation of models. Resources from the Department of Energy (DOE) will be made available to run simulations of existing land carbon models to test their behavior under long and short timescales, in addition to resources at the Program for Climate Model Diagnosis and Intercomparison (PCMDI) to archive simulation output to allow the wider CCSM community to evaluate the model output. In addition, we hope that the protocol and metrics developed by the CCSM community will be used by the wider scientific community to evaluate and improve other centers' carbon models. Here we ask for resources to incorporate the changes in the terrestrial carbon models to build the next generation terrestrial carbon model that will result from this intercomparison.

Additionally, resources are requested for further development of the ocean carbon cycle model. These resources will be used to evaluate the impact of changes in the base ocean model on ecosystem parameterizations and to develop adjustments to the ecosystems parameterizations in response to these evaluations. Anticipated base model changes include updates to physical parameterizations, such as the mesoscale eddy and planetary boundary layer mixing schemes, the use of alternative tracer advection schemes, and the parameterized diurnal cycle, which is already used in the x1 ocean configuration. Also requested are resources for the further development of biogeochemically important aerosol species (e.g., dust), the iron solubility of the dust iron, and atmospheric tracer modeling.

In the past, biogeochemical modeling within the CCSM has taken place at T31x3, which allowed us to explore a large parameter space range during model development. There are some indications, however, that improved spatial resolution may improve several persistent biases in the simulated biogeochemical fields. The bulk of the development work will continue at T31x3, but over the next 18 months, we also plan to start testing simulations at higher resolutions, T42x1 or even T85x1. Half of these experiments will be included under production and half under development, since they will involve both simulations of existing components, as well as modification and improvements to existing components.

2. Research Plan and Computational Requirements

Investigating the complex, regional interactions of climate and biogeochemistry and the responses and feedbacks on natural and anthropogenic climate change require fully coupled, global three-dimensional climate-biogeochemistry models. The BGCWG research plan and corresponding request for CSL model development resources over the next allocation period can be broken down into three main areas of evaluation and development: a) terrestrial carbon component; b) ocean carbon component; and c) biogeochemically important aerosol component.

Development of the terrestrial carbon component will take place based on the results of the land carbon model intercomparison project. The goal of this project is to compare three existing land carbon models and produce a new, better component, which for the sake of simplicity, we refer to as the “Community Terrestrial Biogeochemistry Model” (CTBM). This new model will be further developed during the next 18 month period. Additionally, simulations at higher resolution than T31 or T42 will be conducted to test the model’s sensitivity to resolution and make improvements as required.

Development of the ocean carbon component will continue. An ocean carbon model intercomparison project may be initiated, but now there is only one model in CCSM3. However, comparisons to available observations, community input to the model, and suggestions for improvements will be made during the next 18 months. Additionally, this model has been developed using the x3 ocean model, and in the future, we hope to be able to run the model at higher resolution. Thus, we will begin tests to evaluate the simulations using the x1 ocean model and incorporate required improvements to the biogeochemical parameterizations as needed (tests using existing model will be included under production side of proposal). Fully coupled simulations of both the land and ocean carbon models will be conducted for short periods using both the T42x1 and T85x1 models.

Development of biogeochemically important aerosols and other atmospheric constituent will continue. Included in the CAM/CLM framework is the ability to interactively predict mineral aerosol entrainment, transport, and deposition, as well as the ability to include the impacts of the aerosols on climate. These aerosols will be moved to the fully coupled system and tested within the framework of the fully coupled carbon model at T31x3. Further development of such important problems, such as iron solubility (needed for coupling to marine biogeochemistry module) and other nutrient deposition, will also take place. In addition, development of atmospheric codes for diagnostics of carbon dioxide concentrations, etc., will take place under this heading.

Experiment	**# of runs**	**Model Config**	**# of Years**	**GAU/ year**	**Total GAUs**	**Priority**
CLM carbon cycle development	1	CLM, T42, CC/N	1000	2	2,000	High
	1	CAM-CLM, T42, CC/N	500	45	22,500	High
Ocean carbon cycle development	1	POP only, x3, ECO	500	6	3,000	High
Resolution experiments: Ocean	1	POP only, x1, ECO	250	150	37,500	Medium
Land	1	CAM-CLM, T85, C/N	50	300	15,000	Medium
	1	CLM CTBM T85	2000	4	8,000	Medium
Fully coupled resolution experiments	1	Fully Coupled, T42-x1, CTMB, ECO	30	200	6,000	Low
Fully coupled resolution experiments	1	Fully Coupled, T85-x1, CTMB, ECO	30	900	27,000	Low
Aerosol/tracer development	1	CAM+aerosols/tracers, T42	560	25	14,000	High
Total					135,000	

F. Polar Climate Working Group (PCWG)

The primary goal of the PCWG is to improve our understanding of the role of the Polar Regions in global climate. Towards this end, we seek to better simulate important aspects of the coupled polar climate system, including individual component systems, ice/ocean/atmosphere/land interactions, and coupled feedbacks. As discussed below, there are a number of sea ice model developments under way. Additionally, there is work under way to improve our efforts to validate the sea ice model simulations. This will directly contribute to our development work by providing a better framework to assess new model physics.

1. Melt Pond and New Shortwave Parameterization

Melt ponds are ubiquitous on the summer Arctic sea ice and have an important influence on the surface albedo and heat budgets. In the current version of CCSM, these effects are not explicitly included, although the bare sea ice albedo is lowered to represent melt pond effects. While providing a reasonable fit to the present observed albedo, this does not allow for changes in melt pond coverage to affect the albedo. This may impact both the simulated variability and change in high latitudes.

Work on an improved shortwave (SW) radiation parameterization for snow and sea ice has been accomplished under our previous CSL development work. 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 over both bare sea ice and melt ponds. This improved SW is more consistent, accurate, and general than the present sea ice SW.

Work is under way to develop and implement an explicit melt pond parameterization into CCSM. This parameterization incorporates melt pond measurements taken during the SHEBA field program and allows for changing pond characteristics based on the surface melting rates. These pond characteristics will affect the simulated surface albedo. Simulations to test the parameterization in the active-ice-only framework are required, and runs of the coupled system will be needed to examine the climate impacts of this parameterization.

We will perform simulations with the new melt pond parameterization coupled to the improved SW parameterization. This new delta-Eddington multiple scattering SW parameterization has been incorporated into the CCSM Sea Ice Model (CSIM) using specified melt pond properties. The development of a melt pond parameterization will increase the realism of the effects of this improved SW on climate simulations.

2. Alternative Ridging Scheme

A recent study by Bill Lipscomb and Elizabeth Hunke (LANL) suggests an alternative parameterization for the ridging of sea ice. This parameterization has been shown to improve model stability and has other improvements on the CSIM. In particular, it may reduce the summer time ridging of sea ice that likely plays a role in the low summer sea ice concentrations that are present in the CCSM simulations. We plan to test this new model parameterization within the CCSM. This will require active-ice-only simulations and a fully coupled model integration to assess the climate impacts.

3. Other Miscellaneous Model/Software Engineering Improvements

The PCWG is developing a number of other sea ice model improvements. These include improvements to the snow model physics, surface flux parameterizations, and software engineering enhancements. While many of these developments are being done offsite, primarily in the Los Alamos Sea Ice Model (CICE), we anticipate that they will be incorporated into CCSM in the near future. This will require numerous test simulations in the active-ice-only framework and simulations with the fully coupled model to assess the effects on the full climate system. More specifically, we anticipate the following model runs will be performed:

a) Runs to examine the difference in simulated climate between CSIM and CICE. This will allow us to assess whether CICE should be adopted as the base code for CCSM. This will require both active-ice-only and fully coupled integrations.

b) Simulations to test snow model developments, including runs with additional layers in the snow model and runs with improved snow physics, such as a snow aging parameterization.

c) Simulations on a tripole grid in the active-ice-only, ice ocean coupled, and fully coupled configurations to examine the climate effects of this modified grid.

d) Simulations to address the climate effects of other sea ice model developments as they become available.

4. Validation Studies

Efforts to validate the sea ice model are complicated by the limited observational information on the ice cover and by large discrepancies in different accepted “observed” surface forcing data sets that produce considerably different sea ice simulations. This makes it difficult to determine whether new model developments actually improve the sea ice simulation. In an effort to quantify the uncertainty in model simulations due to model forcing versus that due to model physics, we plan to perform a number of simulations in the active-ice-only framework. These will include simulations with alternative forcing data sets, including NCEP, ERA40, and Large-Yeager. Additionally, we will run simulations in which model parameters are varied within acceptable ranges. In particular, we will target uncertainties in the ridging parameterizations (which are not particularly well constrained by observations) and in the albedo parameterization (which is much better constrained but to which the model is very sensitive). The comparison of these integrations will provide insight into how to assess better future modifications to sea ice physics and, as such, will aid in future development efforts.

Additional hindcast simulations of the ice ocean coupled system forced with atmospheric observations will also be performed. This will allow us to assess the ocean’s role in the simulation uncertainty when compared to observations. Simulations with multiple forcing data sets will be performed to isolate the role of forcing uncertainty in the ice/ocean system on sea ice model behavior.

Experiment	**# of runs**	**Model Config**	**# of Years**	**GAU/ year**	**Total GAUs**	**Priority**
Melt Pond						
Active-ice-only	4	AIO	45	16	2,900	High
Coupled	1	T42_gx1v3	50	70	3,500	High
Melt Pond w/New SW						
Active-ice-only	4	AIO	45	25	4,500	High
Coupled	1	T42_gx1v3	50	80	4,000	High
Ridging Parameterization						
Active-ice-only	4	AIO	45	16	2,900	Medium
Coupled	1	T42_gx1v3	50	70	3,500	Medium
Validation studies						
Forcing Sensitivity	4	AIO	45	16	2,900	High
Parameter Sensitivity	6	AIO	45	16	4,320	High
Ice-Ocean Integrations	8	gx1POP+CSIM	50	47	18,800	High
Other developments						
CICE/CSIM comparison						
Active-ice-only	1	AIO	45	16	720	High
Coupled	1	T42_gx1v3	50	70	3,500	High
Snow Model Physics	1	AIO	45	16	720	High
Active-ice-only						
Coupled	2	T42_gx1v3	50	70	7,000	High
Tripole Grid						
Active-ice-only	1	AIO	45	16	720	High
Ice-Ocean	1	gx1POP+CSIM	45	47	2,120	High
Coupled	1	T42_gx1v3	50	70	3,500	High
Additional Developments						
Active-ice-only	4	AIO	45	16	2,900	High
Coupled	1	T42_gx1v3	50	70	3,500	High
Total					72,000	

G. Paleoclimate Working Group (PaleoWG)

The goal of the PaleoWG is to improve our understanding of past climates and to improve our ability to predict climate change by developing a better fundamental understanding of the physical, chemical, and biogeochemical components of Earth's system. The PaleoWG has four main themes (listed below) and the innovative applications of, or extensions to, CCSM in these themes are the focus of our development proposal.

1. How much climate variability is due to insolation and volcanic variations?

Scientific rationale. Insolation variations occur on all timescales and help drive climate variations. On long timescales insolation variability is driven by predicable orbital parameter changes, and such forcing is evident in the geologic record throughout Earth's history. It is not currently computationally possible to run CCSM through even the shortest cycles (precessional, 19-23 kyr), a weakness that hampers further improvements in our understanding of climate on long timescales. Recent work has shown that the "orbital year" may be accelerated by large factors (~30) allowing reasonable simulations of orbital scale climate change to be performed within hundreds rather than tens of thousands of years of computation. We aim to test this acceleration in CCSM by comparing an accelerated run against the long transient Holocene simulation currently being carried out. On shorter timescales, variations in the solar "constant" and volcanic forcing drive insolation variations. The current implementation of natural external (i.e., insolation and volcanic) forcing is oversimplified.

Experimental framework**.** To accelerate orbitally-driven solar variations, we will accelerate the orbital year by a factor of 30 (building on improvements to the handling of time varying orbital years derived from previous CSL development time), branching off from the beginning of the long transient Holocene simulation. We will conduct a 6,000-year simulation in 200 accelerated years. Provided that this accelerated simulation bears a good resemblance to the unaccelerated run, this method might be used during any time interval where orbital variability is important. Our proposed effort to revise the solar forcing implementation will better represent heat anomalies in the lower stratosphere tied to the response of ozone to changes in the ultraviolet component of solar irradiance. The goal is to document how far such a "patch" can improve the simulations compared to a vertically more extensive model.

Explosive volcanic eruptions. These eruptions have a large effect on the radiative balance of the planet. The current implementation of volcanic forcing simply prescribes the mass of sulfuric aerosol with a fixed size distribution. Local heating rates are somewhat overestimated compared to observations, particularly in the initial aerosol cloud when real world aerosols are still very small. Additionally, the limitation of the single aerosol size approach is apparent in simulations of very large volcanic eruptions with sulfuric aerosol mass larger than 30 terra grams. It is important to represent the large eruptions more accurately as they are affecting not only the transient surface climate but also the ocean heat content, which has much more extensive timescales associated with it.

Experimental framework. Sensitivity tests with a new implementation of evolving aerosol distributions provide means to find an acceptable solution for this issue and also build a base for some basic research in volcanic aerosol evolution. Some limited experiments focusing on mega eruptions (~100x Pinatubo) are proposed to study the handling of such large forcings in the radiation code (which is built on assumptions of optically thin aerosol perturbations), as well as the effect in the fully coupled system (dynamic vegetation).

2. What are the mechanisms that drive abrupt climate?

Scientific rationale**.** As described in the production proposal, we propose to conduct a series of simulations looking at the Bolling-Allerod (BA) and Younger Dryas (YD) period. The BA period is of interest because of the strong warming recorded in the Greenland ice cores. A strong meltwater pulse (MWP-1a), identified as a 20m sea level rise from coral records, precedes the BA warm interval. One proposal is that MWP-1a was from Antarctica, leading to an increase in the thermohaline circulation (THC) and a warming of the North Atlantic. The proposed experiments on BA warming in the CSL PaleoWG production proposal require a better understanding of the response of the climate system to climate forcing of different timescales. Because of much longer response timescales of the Southern Ocean than the North Atlantic Ocean, the North Atlantic may play a dominant role at decadal-centennial timescales, while the Southern Ocean becomes dominant at centennial-millennial timescales. This may be important to our understanding of the BA experiment and YD events.

Experimental framework**.** As a first test to complement the BA coupled experiment, we propose to first perform ocean-alone experiments with the ocean component of the CCSM3-T31x3. We will examine the response of the ocean model to two climate forcings of the same magnitude (such as a global uniform warming), but with different timescales; one lasts only for 100 years, and the other for 1,000 years. We expect the first experiment to be dominated by the North Atlantic response and the second by the Southern Ocean response. In the future, we hope to test this in the coupled model. We will use the ocean acceleration scheme in the coupled model developed in the last CSL development, which can accelerate the transient millennial-scale simulation by five times. Then, we can use this accelerated coupled model to test the fully coupled climate response to climate forcing of different timescales.

3. How do hydrologic, biogeochemical, and cryospheric processes feedback onto climate change?

Scientific rationale**.** Cryospheric feedbacks represent some of the strongest and most pervasive processes in climate. Whereas snow and sea ice dynamics are now reasonably well represented in models such as CCSM, interactive land ice is not currently included. Key climate change questions, such as glacial-interglacial cycles and the initiation of Northern and Southern Hemisphere glaciation (and, of course, the future evolution of climate), cannot be addressed without adding dynamical interactions with this fundamental component of Earth's system.

Experimental framework**.** We propose to couple a state-of-the-art ice sheet model to CCSM, in collaboration with the Climate Change Working Group (CCWG), to allow century and millennial scale simulations of ice sheet growth and decay and of the resulting feedbacks on climate and the carbon cycle. The ice sheet model is Genie Land-Ice Model with Multiply-Enabled Regions (GLIMMER), developed by A. Payne at the University of Bristol. Computer time is requested for the implementation of GLIMMER into CCSM3, which is being done by Bill Lipscomb (LANL).

We will then test the response of the Greenland Ice Sheet (GIS) to the forcings of the Last Interglacial, a period when ice core and other paleoclimate proxy evidence indicates a smaller and steeper GIS and its contribution to sea level rise of 3-4m. We will also test the response of the Laurentide and Fennoscandian ice sheets through the deglacial period from the Last Glacial Maximum (LGM). GLIMMER will be asynchronously coupled to the T31x3 CCSM3 starting from an existing LGM simulation and stepping forward in time at 2,000 year intervals from 21 to 15 ky BP when the ice sheet and sea level changes were small and at 1,000 year intervals from 15 to 10 ky BP. The intervening T31x3 CCSM3 simulations will be coupled to the dynamic vegetation module to include feedbacks with new growth of vegetation in regions where land ice has retreated. A scheme for handling ice melt into the ocean will be developed.

Scientific rationale. A challenge for paleoclimate science is to understand the causes and consequences of changes in the atmospheric composition over the glacial-interglacial cycles of the last million years as recorded in the polar ice cores and in the carbon cycle over longer timescales. This understanding of the natural system is important if we are to model the responses to future anthropogenic emissions and to understand the functioning of the biologically-mediated feedbacks in Earth's system. We propose to study biogeochemistry/atmospheric chemistry-climate interactions within the Holocene, glacial-interglacial cycles, and also in the deeper past (Paleocene-Eocene Thermal Maximum (PETM) and Permian).

Experimental framework**.** As a first step for CCSM, we propose to simulate the climate-carbon cycle for the latest Holocene in collaboration with the BGCWG and CCWG to leverage even further on CCSM's Earth system modeling capability. We have coordinated a potential collaboration and cost-sharing with the working groups to run a parallel transient experiment covering the past 1,500 years with a fully coupled carbon cycle interactive in the simulation. The insights into the transient model behavior, when exposed to full external forcing, while the carbon cycle is interactive and the deviations from the more traditional simulation framework will provide valuable information about this model framework. It is a candidate for the next generation coupled model. The fullness of the implementation of biogeochemical cycles that will be added to the last millennia depends to a degree on progress within and collaborations with other working groups (BGCWG, CCWG), as well as further discussion within the PaleoWG. We are requesting time for the spin up initial part of the simulation.

4. What are the roles of greenhouse gases and heat transport in "greenhouse"?

Scientific rationale**.** The nature of the Cretaceous climate (144-66.4 my BP) has posed fundamental questions about how the climate system works under extreme greenhouse conditions. The causes and character of the extreme warmth, low meridional thermal gradient, warm continental interiors, accumulation of widespread organic-rich sediments, and the terminal mass extinction remain largely unresolved despite decades of study. Progress in our understanding of these problems over the last 25 years can be linked to the evolution of climate modeling, from the early version of NCAR's Community Climate Model. With the ongoing development of the CCSM as an Earth System Model, the opportunity exists to make scientific breakthroughs in many long-standing problems.

Experimental framework**.** Based on prior Cretaceous simulations performed at NCAR (with CSM1.4 and CCSM2) and elsewhere, there are several areas that we can anticipate needing to perform sensitivity studies at the beginning of the experiments and near their conclusion. We will need to develop appropriate initial conditions and river routing frameworks—these will be based on work done earlier with CCSM2, but the paleogeography (and other boundary/initial conditions) for the late Cretaceous are somewhat different and we believe that some initial, relatively short runs will be necessary to achieve an optimal beginning to the simulations. For example, the initial deep ocean temperature profile will need to be tuned for the specified carbon dioxide concentration. Because of the uncertainty and potential importance of fresh water runoff on the Cretaceous deep ocean circulation, we plan to develop a scheme for calculating and implementing end-member runoff conditions and their potential for influencing the deep-ocean circulation. This development will provide an important tool for creating sensitivity experiments to evaluate the influence of uncertainties in the placement of runoff on the deep ocean circulation and the Cretaceous coupled climate.

Experiment	**# runs**	**Model Config**	**# of Years**	**GAU/ year**	**Total GAUs**	**Priority**
Latest Holocene BGC	1	T31x3	350+	25	8,750	Medium
Ice sheet modeling	1	T31x3	250	15	3,750	High
Testing for LIG, 130-125 ky BP	4	T42x1	50	70	14,000	Medium
Testing for deglacial period, 21-10 ky BP	5	T31x3	200	15	15,000	Medium
LGM BGC – spin up	1	T31x3	500	10	5,000	High
- sensitivity	1	T31x3	100	10	1,000	Medium
LGM methane	3	MACCM	40	30	3,600	Medium
PETM Chem	4	MACCM	40	30	4,800	High
Latest Permian Chem	4	MACCM	40	30	4,800	High
Latest Permian Transport	5	Paleo Transport		100	500	High
Cretaceous sensitivity studies	4	T31x3	150	15	9,000	Medium
BA abrupt climate change, ocean sensitivity tests	1	x3	1200	6	7,200	High
	1	x3	200	6	1,200	High
SOLAR improvement						
Orbital year acceleration	1	T31x3	200	15	3,000	High
- CAM	6	T31	25	10	1,500	High
- FV with Chem	2	FV2.5 hvR	25	60	3,000	High
Volcanic Multi-bin						
- multi-bin	20	T31	2	10	400	Medium
- Mega eruptions	2	T42x1	25	70	3,500	Medium
TOTAL					90,000	

H. Climate Change Working Group

1. Research Plan

At the 2005 CCSM workshop in Breckenridge, the co-chairs of the CCWG identified a number of topics to be investigated in the coming year, including:

a) Common forcings for 20th century climate.
b) Climate change adaptation/mitigation.
c) Large ensembles and climate change signals.
d) Climate sensitivity.
e) Further analysis of the 20th century and future climate change simulations from CCSM3, as well as the IPCC multi-model ensemble.

The 2006-2007 CCWG CSL development proposal addresses these topics. In addition, the CCWG is collaborating with the PaleoWG to develop and test an interactive ice sheet modeling capability in CCSM with Bill Lipscomb (LANL).

When the CCSM is run in IPCC mode, an increased GAU/yr value is used to reflect the actual charge level we observed while running the IPCC AR4 scenarios.

2. Development Runs

a) Cryospheric processes feedbacks with the PaleoWG. Cryospheric feedbacks represent some of the strongest and most pervasive processes in climate. Snow and sea ice dynamics are now reasonably well represented in models such as CCSM (interactive land-ice is not currently included). Key climate change questions, such as glacial-interglacial cycles and the initiation of Northern and Southern Hemisphere glaciation (and the future evolution of climate), cannot be addressed without adding dynamical interactions with this fundamental component of Earth's system. We propose to couple a state-of-the-art ice sheet model to CCSM, in collaboration with the PaleoWG, to allow century and millennial scale simulations of ice sheet growth and decay and of the resulting feedbacks on climate and the carbon cycle. The ice sheet model is Genie Land-Ice Model with Multiply-Enabled Regions (GLIMMER), developed by A. Payne at the University of Bristol. The runs themselves will involve four T31x3 testing simulations followed by a 200-year T42x1 spin up using 1870 conditions. In parallel, the PaleoWG will test the response of the GIS through the deglacial period from the LGM.

b) Common forcings. While the IPCC scenarios have attempted to define a common set of common forcings for 20th century simulations, considerable variation still exists between the forcings used by the different modeling groups. We propose carrying out a single 1870-2000 historical simulation run with the T85x1 CCSM in IPCC mode to establish a common forcing set to provide to the community. The common scenario will be the basis for coordinating the execution of consistent and comparable climate change projections for use in impact assessments.

c) A relatively modest amount of resources are allocated to the post-processing and analysis of the history data from these experiments.

Experiment	# of runs	Model Config	# of Years	GAU/ year	Total GAUs	Priority
a1. Ice-sheet developments	4	T31	100	15	6,000	Medium
a2. Ice-sheet developments	2	T42	100	70	14,000	Medium
b. Common forcings (20th Cen)	1	T85 IPCC	130	371	48,230	High
c. Data analysis					3,770	High
Total					72,000	

I. 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 modifications in the current coupling software to enable the transfer of new biogechemical fluxes and tracers. New revisions are also arising due to the development of new CCSM data models and the construction of an alternative sequential CCSM using the Earth System Modeling Framework (ESMF). Finally, 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.

Under the development proposal, the SEWG will perform numerous short tests on each new CCSM revision to ensure reliability on CSL production machines. This will primarily encompass Bluesky and Bluevista. In the past, test cases included the verification of exact restart, branch startup, and hybrid startup functionality for a variety of CCSM configurations. Since the CCSM3.0 release, the test parameter space has significantly increased. Current tests have also added regression validation, transfer of intercomponent biogeochemical fluxes and tracers, and tests that turn on atmospheric chemistry within the FV dynamical core. Each test type is often run in more than one resolution and configuration. Additional "debug" tests are also run with compiler trapping turned on. These tests often find subtle problems such as use-before-set and out-of bounds references. Finally, stand-alone versions of CCSM components (such as CAM) now run a restricted set of CCSM tests as part of their development process. The CCSM test suite is run for all CCSM revisions including those submitted by external collaborators, such as DOE's SciDAC project and NASA's ESMF.

Due to resource constraints, test coverage is not nearly as broad as one would like. However, the CCSM test suite has detected many problems before major resources have been expended in long production runs. In the active development phase that CCSM is currently in, running the "expanded" CCSM test suite will permit software problems to be detected early in the development cycle. As new tests are added to cover new scientific or software functionality, the number of configurations and resolutions that are encompassed by these new tests will need to be adjusted. It is important to note that a test is only run one time if it executes successfully the first time. If a test fails, however, one or more additional tests are always required to validate bug fixes to the original failed test.

The SEWG is in a very active phase of model development. The current CCSM data models are being completely rewritten to leverage code reusability among the different data model components, as well as introduce uniform functionality throughout the data models. During this CSL time period, the completion of the data model unification project will require significant testing to ensure that the code base is operating successfully.

Another very active phase of current CCSM model development is the construction of a sequential, single-executable version of CCSM using ESMF. The goal of this project is the creation of a single executable SPMD implementation of the CCSM coupled model system that can run in either sequential or concurrent mode. There are numerous advantages to the creation of such a system:

- Scientific development across all model components (e.g., CAM, CLM, POP, CSIM) will occur in only one model system.

- Code duplication will be greatly reduced.

- Code maintenance and testing will be greatly simplified.

- SPMD is a "sweet spot" for vendor tools. As a result, the creation of a SPMD coupled model will greatly simplify the process of error tracing and portability to new platforms. Performance monitoring will also be improved since performance tools are also normally designed to work with SPMD executables.

Having the capability of running the CCSM system in either a sequential or concurrent mode will improve the efficiency under certain scenarios. In particular, in those scenarios where communication overhead is not too large, and where each component model scales effectively over the processor set chosen, we expect that efficiency should be improved in the sequential system when compared to the concurrent system.

In addition to running the CCSM test suite, the CCSM will have to be ported to Bluevista. Porting of the CCSM model to new platforms currently requires the performance of 100-year "validation" runs. These runs verify that, upon migrating the code to a new platform or operating system, the model climate is statistically the same as a "baseline" climate. Porting the current model to Bluevista will require a T85x1 validation run. In addition, a new "baseline" climate at this resolution will also need to be established on Bluevista as new science is introduced into the model system.

The resources requested in the table below assume that the utilization estimates for the data model and sequential CCSM projects are folded into the equivalent years of the FV2x2.5_x1 estimates.

Experiment	# of runs	Model Config	# Years	GAU/ year	Total GAU	Priority
CCSM Testing	2400	T42_x1 + BGC	0.1	80	19,200	High
CCSM Testing	2400	FV2x2.5_x1	0.1	80	19,200	High
CCSM Testing	800	FV2x2.5_x1 + MOZART	0.1	250	20,000	High
CCSM Testing	130	T85_x1	0.1	275	3,600	High
CCSM Validation	2	T85_x1	100	275	55,000	High
Total					117,000	