REQUEST FOR
CLIMATE SIMULATION LABORATORY
COMPUTATIONAL RESOURCES - Production

February 1, 2006 – July 31, 2007

CCSM Proposal for Production/Control 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

Some of the previous CSL production time was used to complete the entire suite of CCSM3 runs for the IPCC AR4. These include 1990 control, 1%/year increasing CO_2, and 20^{th} and 21^{st} century scenarios, especially using the lower resolution versions, T42x1 and T31x3, of the CCSM3. In some cases, ensembles of runs were made to complement the same runs previously made with the T85x1 version of the CCSM3. Results from these runs have been sent to the IPCC archive at the Program for Climate Model Diagnosis and Intercomparison (PCMDI), and more data is archived there from the CCSM than any other climate model. This data has been used extensively by many university investigators to produce comparison studies across several of the climate models contributing to the AR4.

Members of all the CCSM working groups have extensively analyzed the CCSM3 control and scenario runs. This has resulted in 26 papers being accepted for publication in a special issue of the *Journal of Climate* dedicated to CCSM3. This will be published in 2006, but copies of all the papers can be freely downloaded from the CCSM website: http://www.ccsm.ucar.edu/publications/jclim04/Papers_JCL04.html. In addition, Volume 19, Number 3, fall 2005 issue of the *International Journal of High Performance Computing Applications* contained 13 papers on various aspects of CCSM software engineering, scalability, and portability. It also documented the latest version of the CCSM coupler, and it can be downloaded from the website: http://hpc.sagepub.com.

Members of the Paleoclimate and Polar Climate Working Groups used a significant amount of CSL resources, in particular those awarded for studies in the category of Abrupt Climate Change. These included fresh water events into the North Atlantic Ocean during the

Last Glacial Maximum (LGM), the Younger Dryas cold event 12.8 thousand years ago, and the warm event transition 8.2 thousand years ago.

The Climate Variability Working Group used CSL resources to perform Atmosphere Model Intercomparison Project (AMIP) type integrations using the CCSM atmosphere and land components, using both sea surface temperature (SST) data and coupled to an ocean mixed-layer model. These runs are used to study the variability of the atmosphere and land components and to compare with the variability of the fully coupled CCSM. They are also used to study the climate sensitivity of the CCSM, which is defined as the equilibrium surface temperature response to a doubling of carbon dioxide in the ocean mixed-layer configuration.

The Ocean Model Working Group used CSL resources to run ocean-alone and ocean plus sea ice components forced by the latest version of observed atmospheric forcing over 1958-2000. These runs are used to document the natural variability in the ocean and sea ice components, which is the equivalent of the AMIP-type integrations for the atmosphere and land components. Again, the variability is compared to that of the fully coupled CCSM.

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 production purposes. These resources are actively managed across the entire project based on the priorities for completion of jobs as determined by the Scientific Steering Committee (SSC) and as the science evolves. The CSL resources are the glue that keeps the project functioning as a community project. The total request for CCSM Production is 1,800K GAUs, or 100K GAUs per month over the 18 months. The remainder of this document contains input from the CCSM Working Groups that describes the proposed scientific use of CSL resources for production runs.

III. Requests from the Working Groups

A. Atmosphere Model Working Group (AMWG)

1. Research Plan

Our production proposal is closely tied to the work done using our model development allocation. We will not repeat the rationale for our work plan again here, but refer the reader to the discussion in our development proposal. Much of the distinction comes from minor variations in our mode of work: a) we plan to make longer simulations in the production category; b) we plan to make more of the most expensive simulations in the production category; and c) we plan to make all coupled model simulations in the production category.

As an example of this kind of work, we expect that when the shorter model simulations performed using development resources suggest that changes to the Community Atmosphere Model (CAM) physical parameterizations will result in significant reductions in the double intertropical convergence zone (ITCZ) problems, we will perform coupled model simulations to identify the impact in CCSM.

We will also make costly simulations using these resources that are designed to reveal model sensitivities. For example, we will conduct the coupled experiments devised by the

Tropical Variability Task Team (TVTT) and those experiments suggested by the Correcting Tropical Biases (CTB) workshop team using the production allocation. These experiments are not designed to examine the response of the model to a particular improvement in a parameterization, but rather may reveal model sensitivities that point us to areas to focus on. The CTB workshop team designed seven planned experiments of which four require multiple coupled model simulations of intermediate length (order 20 years). These experiments explore the sensitivity of El Niño-Southern Oscillation (ENSO) to variations in vertical resolution, to evaporation of rainfall, to suppression of convection in specific geographic areas, and to enhanced heat sources in particular geographic regions. We anticipate about 20 coupled, 20-year experiments associated with this project.

Similarly, as we become confident of the new cloud water microphysics and aerosol branches, we will make coupled (or slab ocean model, SOM) simulations with and without anthropogenic aerosols to characterize the various aerosol direct and indirect effects, and the changes in climate sensitivity in the presence of these new aerosol cloud feedbacks.

2. Scientific Objectives

The objectives are also discussed more fully in our development proposal, but briefly, our scientific goals are to:

a) Produce a state-of-the-art general circulation model for the research community that substantially reduces the biases present in CAM3. We believe those biases 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 finite volume (FV) dynamical core. We are also working on a model that provides new functionality designed to improve the ability of CCSM to deal with new classes of problems in chemistry-climate interactions and biogeochemical cycles.

b) Contributes to an understanding of the processes that control aerosol distributions in the atmosphere, improving the representation of aerosols, and to examine their direct and indirect effect on Earth's climate.

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), and biases in the ITCZ features. We will do this by working with the Ocean Model Working Group (OMWG), the TVTT, and CTB efforts.

3. Computational Requirements

We have picked a number of runs directed to make progress on above goals during the time period of this proposal. 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. We assume that three kinds of runs will be made in the production queues: AMIP runs, SOM runs, and coupled runs.

A 20-year AMIP-type run is the minimum required to be confident of the climate of a stand-alone model and to look at responses of the climate system to variations in (surface) forcing. For example, explorations of the response of cloud and radiative properties to ENSO need such a run. The timescales associated with interactions between the oceans and atmosphere require that much longer runs be made whenever these two components are coupled. Thus, we have chosen to use 50-year SOM simulations for our first exploration of atmosphere-ocean interactions, and to identify the climate sensitivity of alternate model configurations. Finally, five FV coupled model runs are proposed to evaluate the most promising future configurations. Each of these runs will be used to confirm that the model climate is stable and provides a good enough simulation that the model is acceptable.

Experiment	**# of Runs**	**Model Config**	**# of Years**	**GAU/ yr**	**Total GAUs**	**Priority**
Revised physics	12	FV2x2.5	20 (AMIP)	35	8,500	High
Revised physics	6	FV2x2.5	50 (SOM)	35	10,500	Medium
Aerosols	4	FV2x2.5	20 (AMIP)	70	5,700	High
Aerosols	4	FV2x2.5	50 (SOM)	70	14,000	Medium
New cloud microphysics	10	FV2x2.5	20 (AMIP)	105	21,000	High
IPA	10	FV2x2.5	20 (AMIP)	210	42,000	Medium
Vertical resolution	5	FV2x2.5	20 (AMIP)	70	7,000	High
Vertical resolution	4	FV2x2.5	50 (SOM)	70	14,000	Medium
Horizontal resolution	4	FV1x1.25	20 (AMIP)	140	11,300	Medium
Horizontal resolution	4	FV1x1.25	50 (SOM)	140	28,000	Low
FV coupled candidates	4	FV2x2.5	100 (coupled)	90	36,000	Medium
Total					198,000	

B. Chemistry-Climate Working Group (ChemWG)

1. Scientific Background

Recently, a ChemWG has been formed to include the effects of atmospheric chemistry in the CCSM (see http://www.ccsm.ucar.edu/working_groups/Chemistry/index.html). The formation of this group stems from the recognition that the atmospheric circulation and hydrological cycle are impacted by changes in atmospheric composition through changes in the atmospheric radiative forcing, the modification of cloud processes, and the impact on the land surface. The composition and photochemistry of Earth's atmosphere has been profoundly changed by anthropogenic activities through emissions of trace gases and aerosols.

2. Research Plan

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. This document addresses these goals through a series of longer simulations. To date, the impacts of chemistry have been highly parameterized or neglected within the CCSM. Recently, CAM has been modified to simulate both tropospheric and stratospheric chemistry. In addition, a new bulk aerosol scheme is now available that 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 and document its immediate goals through a series of control simulations.

a) The radiative impact of ozone. After carbon dioxide and methane, the increase in tropospheric ozone has been estimated to provide the third largest increase in radiative forcing since pre-industrial times. The largest climate response to ozone occurs near the tropopause, where both stratospheric and tropospheric processes control its concentration. CAM, in its present configuration, does not adequately represent the stratosphere. We propose to run control simulations to document the importance of including interactive chemistry in the current version of CAM, vis-à-vis importing offline ozone fields into the model and running CAM in a middle atmospheric configuration (i.e., Whole Atmosphere Community Climate Model, or WACCM) where chemistry is explicitly resolved in the stratosphere.

b) Air quality. The effect of climate change and future emissions on air quality is an important consideration in assessing the impact of global change. Predicting air quality is difficult. It is both a regional problem and sensitive to nonlinearities in the chemistry. A proposal for examining air quality can be found at http://www.csm.ucar.edu/working_groups/Chemistry/index.html. We propose to run simulations to assess CAM as a tool for simulating future air-quality on both a regional and hemispheric scale. We intend to run these simulations at different resolutions to determine the impact of resolution in simulating air quality. Ultimately, we propose to run parallel simulations in CAM and in the Weather Research Forecast model with chemistry (WRF-chem), so as to simulate selected regions at very high resolution. We will also explore the resolution dependence of surface ozone change, i.e., the dependence on resolution of the difference in future minus present surface ozone.

c) The effect of aerosols on climate. Understanding the impacts of changing aerosol distributions on observed climate change needs to be assessed to more accurately predict future climate change. We propose to run control simulations to document the response of CAM to an aerosol model that treats a modest number of aerosols, each composed of an internal mixture of multiple aerosol components, with the mass and number of each component predicted; respond to the changing oxidant fields produced by the chemistry; and simulate the indirect effect.

d) Simulations of 1900-2100. Guided by the results from our sensitivity tests, we plan to construct a model of intermediate complexity to simulate the pre-industrial to 2100 time period in a fully coupled context. These simulations are likely to include the following components: full chemistry, an intermediate approach to aerosols, a parameterization of the indirect effect of aerosols, and coupling with the Community Land Model/Carbon Nitrogen (CLM/CN) model. These runs will allow us to explore the interaction between chemistry and climate over the measured record and projected into the future.

The first two series of control runs are in some sense prêt-a-porter and, thus, ready for production runs in the coming year. The last two areas require significant model development, and thus will be deferred toward the end of the budgeted period.

3. Resources Requested

In all cases we intend to run in the FV 2x2.5 version of the CAM stand-alone model. The FV version of CAM is the version most suitable for chemistry. The future climate will include projected emissions for 2100 in all relevant species. Initially 20-year control simulations will be run in CAM under pre-industrial, present, and future conditions. A 20-year run is the minimum required to be confident of the climate response in the stand-alone CAM model due to variations in meteorology. The stratospheric version of the model requires approximately twice as many vertical levels and twice as many chemical tracers. It is budgeted at 2.5 times that of CAM with chemistry. We have budgeted sufficient resources to run WRF-chem for four summers when air quality is usually at its worst.

We propose two 200-year fully coupled simulations to document the response of a fully coupled chemistry/climate/aerosol model to historical and projected forcing. We think that two such runs are necessary due to uncertainties in historical emissions (particularly biomass burning) and possible sensitivities to the representation of aerosols and clouds. While we realize that the FV version of CAM is currently not suitable for long-term climate simulations, we intend to run these simulations toward the end of the budgeted period, after initial model development and sensitivity tests are complete. If at that time the FV version is still not adequate for the proposed coupled simulations, we will run multiple timeslice experiments using the SOM.

Experiment	# of Runs	Model Config	# of Years	GAU/ yr	Total GAUs	Priority
A1) Tropospheric chemistry	3	FV2x2.5	20	150	9,000	High
A2) Tropospheric and stratospheric chemistry	3	FV2x2.5	20	375	22,500	High
B1) High-resolution chemistry	2	FV1x1.25	5	1600	16,000	Medium
B2) Low-resolution chemistry	2	FV2x2.5	5	30	300	Medium
B3) WRF-chem	4	30 km	.25	3400	3,400	Medium
C1) Modal aerosols and chemistry	3	FV2x2.5	20	180	10,800	High
D1) Fully coupled runs of chemistry and aerosols	2	FV2x2.5	200	250	100,000	High
Total					162,000	

C. Ocean Model Working Group (OMWG)

1. Research Plan

There are three main streams in the OMWG research plan for the 18 months starting February 2006. One is full participation in the Coordinated Ocean-Ice Research Experiments (CORE). Another is full collaboration as partners in the Climate Variability and Predictability program (CLIVAR) Climate Process Teams (CPTs) on ocean mixing. The third is the reduction of long standing biases in the fully coupled CCSM. The plan assumes that ocean model developments over the past two years will lead to a new and improved version of the ocean model under the proposed OMWG development strategy. Here a number of production experiments are proposed that span the fully coupled CCSM, coupled ocean ice, and uncoupled forced ocean configurations. In general, an experiment will be useful for more that one purpose and this utility, in addition to perceived scientific merit, dictates the assigned priority.

2. Science Objectives

a) CORE. These experiments are being proposed as a tool for researchers to explore the behavior of global coupled ocean ice models under common surface forcing. The science objective is an understanding of coupled ocean sea ice behavior as a subsystem in the more complete and complex system involving the atmosphere. As part of a coordinated, international activity, peculiarities of the CCSM ocean and sea ice model, as well as their similarities compared to other models, will be revealed. Applications of the CORE results will include studying the interactions between the ocean and sea ice, exploring a greater region of parameter space, manipulating the forcing to understand the mechanisms responsible for generating variability at select time and space scales, exposing deficiencies in model representations of physical processes compared to other models of the same class, assessing various ocean reanalysis and observational data sets in terms of their implications to ocean climate, and testing tools and methods that are ultimately aimed at the fully coupled system. CORE has been developed along three avenues. CORE I will utilize a climatological Normal Year Forcing that will be repeatedly applied for 500 years. CORE II will be forced with a 47-year (1958-2004) cycle of interannually varying forcing that will be repeated ~10 times to achieve solutions directly comparable to CORE I but with interannual variability that can be analyzed for ocean processes and compared to observations. The design of specific CORE III experiments has been collaborative and includes dam-break and Greenland melt experiments. The signals of greatest interest will be ocean climate variability on interannual-to-decadal timescales, tropical variability from daily-to-interannual, and how this variability changes over the 500 years of the integrations. Comparison to existing ocean only runs will allow some sea ice induced variability to be identified.

b) CPTs. The OMWG is involved in the two ocean mixing CPTs, Gravity Current Entrainment (GCE) and Eddy-Mixed Layer Interaction (EMILIE). The CPT science that most naturally falls to the OMWG is the climate impact assessment of CPT ocean model developments. These developments began two years ago, and they will continue at least one and possibly three more years, pending a renewal process now under way. Regardless of the duration, developments under both CPTs have been implemented in the CCSM ocean model and tested in the low-resolution (3 degree) forced ocean (x3ocn) and the low-resolution coupled configuration (T31x3). These resolutions are no longer state-of-art and the developments are to be transitioned to the nominal 1-degree ocean (x1ocn) under proposed OMWG development. The production integrations being proposed here are designed to assess the climate impact of the individual developments. The specific science objectives are to determine the climate sensitivity individually to the parameterization of deep ocean overflows, such as Denmark Strait and Faroe Bank, and the associated GCE, and to the parameterization of eddy mixing within the well-mixed upper ocean. One focus will be on the ocean climate and another on the coupled climate as indicated by such measures as air-sea fluxes and atmospheric circulation. However, an important first step is to validate parameterized eddy behavior with that of resolved eddies in a 1/10 degree global ocean model.

c) Reducing CCSM3 biases. Advisory bodies to both CCSM and to NCAR's Climate and Global Dynamics Division have recommended that long-standing biases, such as the "double" ITCZ in the South Pacific, must be substantially reduced before embarking on the next IPCC assessment. This has struck a cord with the OMWG, which seeks to improve the biases within the ocean model and its atmospheric coupling to make the forced and coupled models more useful in tackling a wider range of science problems. High priority ocean problems include a deep ocean cooling trend, excessively warm surface temperatures along the eastern boundaries of the subtropical gyres, an excessively cold equatorial cold tongue, and a poor representation of the annual cycle of SST in the eastern equatorial Pacific.

3. Proposed Experiments

a) A complete annual cycle of a 1/10-degree global ocean configuration is the minimum integration that will contribute to research objectives and the most that can be hoped to achieve. The science will utilize the solution for guidance and as a baseline "truth" for improved eddy mixing parameterizations developed through the EMILIE CPT. This run will also provide the high horizontal resolution behavior of eastern boundary upwelling and of the equatorial ocean for investigations into biases in these regions.

b) A set of three (CORE I, CORE II, and the Greenland Melt CORE III) is to be conducted. A new 1-degree ocean will be coupled to the CCSM sea ice model (x1ocn-ice) configuration with only an Ideal Age tracer, and it will become our standard reference for comparison with similar integrations that are being performed by nearly all the world's ocean climate modeling groups. The new model will incorporate the most promising suite of ocean model developments, as established under CCSM OMWG development activities. All these integrations will use forcings developed at NCAR, so we can use existing infrastructure. The CORE protocol calls for 500-year coupled ocean ice integrations.

c) The extensive development work on the CCSM ocean model and air-sea coupling will be transferred from the low-resolution T31x3 testbed to the T85x1 configuration that dominated CCSM's contribution to IPCC AR4. An important component of tropical variability is ENSO, and to obtain a robust characterization, a 150-year integration is needed to get past the transient spin up and allow for subsequent regime shifts.

d) The timescale of deep ocean drift has been found to be order 1000 years, but its character is largely established after 500 years. Therefore, one experiment of such duration is proposed, and to keep the computational requirements manageable, a T42x1 configuration will be utilized. Two chlorofluorocarbon (CFC) tracers will be included in this run, because their penetration into the deep ocean is the primary measure by which deep ocean connections with the surface are quantified and compared. The new ocean model will be utilized, and these results will become the baseline control by which to assess the coupled climate impacts of the new developments and future model improvements. Comparison with c) will provide an updated resolution sensitivity of tropical variability in the new model.

e) A climate impact assessment for each of the two ocean CPT developments is to be conducted at T42x1 resolution. The primary question in both cases will be the response of the coupled atmosphere, making near surface processes paramount, and 200-year integrations sufficient. Since both GCE and eddy mixing are expected to affect the deep ocean too, two CFC tracers will be included. In the event that a CPT development is included in the new model, the 200-year assessment run will have the development excluded. If the CPT development is not included, it will be added. In either case comparison with the d) baseline run will be clean.

4. Computational Requirements

a) At the current throughput of one simulated day per calendar day, it is expected that 0.2 years will be completed under the present allocation. Completion of the required full year will use 15,000 GAUs and take nearly nine months.

b) The CORE protocol specifies 500-year coupled ocean ice experiments. Participation in all three CORE streams requires 70,000 GAUs with no flexibility beyond running with no passive tracers, as proposed.

c) The present computational limits will permit only one T85x1 fully coupled integration and the 150 years needed to characterize tropical variability will require 41,000 GAUs.

d) To achieve the minimum 500-year integration needed for deep ocean drift studies, the T42x1 configuration will be used but with two tracers. 40,000 GAUs are still required.

e) The cost of the two CPT impact integrations, each of 200 years with two CFC tracers will be 32,000 GAUs.

Experiment	**# of Runs**	**Model Config**	**# of Years**	**GAU/ yr**	**Total GAUs**	**Priority**
a) Eddy resolved ocean	1	1/10 ocean	0.8	19,000	15,000	High
b) CORE	3	x1ocn-ice	500	47	70,000	High/ Medium
c) Tropical variability	1	T85x1	150	275	41,000	High
d) Deep ocean drift	1	T42x1+2tracer	500	80	40,000	Medium
e) CPT impacts	2	T42x1+2tracer	200	80	32,000	High
Total					198,000	

D. Land Model Working Group (LMWG)

The overall goal of the LMWG is to improve our understanding of the role of land surface processes in the climate system. Of particular interest to the LMWG are the effects of changes in land cover and land use on climate; the contribution of land surface processes to climate sensitivity; permafrost; and the importance of representing the land surface at a high spatial resolution. Experiments are proposed to address each of these areas of research.

1. Land Cover and Land Use Change

The LMWG has initiated two projects to provide a land use forcing to complement the greenhouse gases, aerosols, solar variability, and other forcings used in climate simulations of the 19th, 20th, and 21st centuries. The first is a set of three experiments to examine the impact of urbanization on climate using data sets of urban land cover for pre-industrial (1870), present-day, and 2100 A2. The latter experiment for 2100 uses population scenarios of the SRES A2 emission scenario. The second is a set of nine experiments to examine the impact of land cover change using data sets of potential vegetation, 1700, 1870, 1930, present-day, 2100 A2, and 2100 B1. The latter two experiments use land cover scenarios for 2100 with the SRES A2 and B1 emission scenarios. The LMWG is revising and improving the hydrology of the CLM. Two of these simulations (potential vegetation, present-day vegetation) will be repeated to compare the impacts of hydrology parameterizations on the land use forcing. These simulations will utilize the T85 CAM/CLM to capture high-resolution land cover change. This model configuration will also complement previous land cover change simulations performed by the LMWG under previous CSL allocations.

2. Climate Sensitivity

The climate sensitivity of CAM is defined by performing experiments using the slab ocean model (CAM/CLM/SOM) in which atmospheric CO_2 is instantaneously doubled or is increased at a rate of 1% per year. The LMWG proposes a series of experiments to examine the importance of vegetation and surface physics in determining climate sensitivity. Simulations with the improved dynamic global vegetation model (CLM-DGVM) will examine the role of dynamic vegetation (changes in community composition and ecosystem structure) as a climate feedback. Two experiments (control and $2xCO_2$) will examine the vegetation response to an instantaneous doubling of CO_2. These experiments will be 300 years in length due to the long timescale at which vegetation responds to climate perturbations. Another two experiments will examine the transient response with a 1% per year increase in CO_2.

3. Permafrost

Near-surface permafrost is projected by CCSM to degrade rapidly as atmospheric greenhouse gas concentrations continue to rise. A set of five 150-year experiments using CAM/CLM/SOM, predicated on development of permafrost-related processes in CLM, will examine the climate sensitivity to permafrost degradation. The series of experiments will evaluate the transient response of permafrost to 1% increase in CO_2 per year and related feedbacks on hydrology, carbon cycling, and climate associated with a deeper soil column, dynamic wetland area, interactive soil carbon, and dynamic vegetation.

4. High-resolution CLM

The LMWG has initiated a project to develop a high-resolution version of CLM that allows the land model to operate at a spatial grid independent of the atmosphere model. A series of experiments will be performed to document the impact of the high-resolution CLM on simulated climate. These experiments will utilize the FV CAM/CLM to be consistent with ongoing model development in the AMWG. We will use CAM resolutions of 2x2.5 and 1x1.25 degrees and CLM resolutions of 0.5 and 0.25 degrees. Two experiments will be performed at each CAM and CLM resolution. An additional two experiments, using the SOM, will examine the behavior of the model with a transient 1% per year increase in CO_2.

Experiment	# of Runs	Model Config	# of Years	GAU/ yr	Total GAUs	Priority
Urban	3	T85 CAM/CLM	25	140	10,500	Medium
Land cover change	9	T85 CAM/CLM	25	140	31,500	Medium
DGVM (2xCO_2)	2	FV2x2.5 CAM/CLM/SOM	300	40	24,000	High
DGVM (1% transient CO_2)	2	FV2x2.5 CAM/CLM/SOM	150	40	12,000	High
Permafrost (1% transient CO_2)	5	FV2x2.5 CAM/CLM/SOM	150	40	30,000	High
High-resolution land model (0.5^o)	2	FV2x2.5 CAM/CLM	50	85	8,500	High
High-resolution land model (0.25^o)	2	FV2x2.5 CAM/CLM	50	265	26,500	High
High-resolution land model (0.5^o)	2	FV1x1.25 CAM/CLM	50	90	9,000	High
High-resolution land model (0.25^o)	2	FV1x1.25 CAM/CLM	50	175	17,500	High
High-resolution land model (0.5^o) (1% transient CO_2)	2	FV2x2.5 CAM/CLM/SOM	150	95	28,500	High
Total					198,000	

E. Biogeochemistry Working Group (BGCWG)

The overall goal of the BGCWG is to improve our understanding of the interactions and feedbacks between the physical and biogeochemical climate systems under past, present, and future climates. Accurate projections of future climate change and its impact on society and the natural environment hinge on two key questions: how will radiatively active trace gas and aerosol concentrations in the atmosphere evolve in the future and how sensitive is the climate system to these changes in forcing? The questions are not independent because many of the chemical species of interest have natural biological sources and sinks that respond to climate variations. Also, researchers have become much more aware of how variable the natural climate can be from studies of the history of phenomena, such as El Niño and longer-term paleorecords. The past several centuries appear to have been unusually stable, but dramatic oscillations in climate and atmospheric composition have been observed in the paleorecord with timescales as short as a few decades (e.g., Petit et al., 1999). Thus, future human-induced changes must be understood against this background of an inherently variable natural system.

The first generation of NCAR coupled carbon cycle simulations has been completed (Fung et al., 2005; Doney et al., 2006), and the simulations of the coupled behavior of the second-generation coupled simulations within the CCSM3 model are under way. These are being done as a part of the Coupled-Carbon Cycle Climate Modeling Intercomparison Project (C4MIP) (Friedlingstein et al., 2006). CCSM simulations for Phase 1 of this experiment are well under way, using just the atmosphere and land couplings. Next we plan to conduct simulations for Phase 2, which includes ocean biogeochemistry feedbacks and the fully coupled climate system.

In addition, better understanding of the response of the ocean and terrestrial ecosystem models to important forcings is required to understand how the coupled system is behaving. Beginning with the spun up runs from the C4MIP Phase 2 simulations, we will look at each potential forcing mechanism separately to see the relative impact on the carbon cycle. We plan the following eight experiments:

1. Transient simulations–fixed radiative CO_2. 300-year simulations (1800-2100), land and ocean respond to prognostic atmospheric CO_2 from transported fluxes, but atmospheric radiative CO_2 is held constant circa 1800.

a) Prescribed fossil fuel emissions. Historical drivers through 2005, future emissions for 2005-2100 from SRES A2 scenario.

b) Prescribed nitrogen (N) deposition. Historical and future N deposition from offline simulation with CAM-chemistry coupling (Lamarque et al., 2006).

c) Prescribed land cover change, constant dust. Historical period from synthesis of satellite and agricultural data sets (from Johannes Feddema and Peter Lawrence). Future period land cover based on SRES A2 scenario (from Johannes Feddema).

d) Prescribed land cover change, prognostic dust. As 1c, but allowing dust to respond to land cover change, with ocean biogeochemistry responding to dust deposition.

2. Transient simulations–fully coupled CO_2. 300-year simulations (1800-2100), atmospheric radiation budget, land, and ocean all responding to prognostic atmospheric CO_2 from transported fluxes. All other details for drivers as in corresponding components of experiment 1 above.

a) Prescribed fossil fuel emissions. Historical drivers through 2005, future emissions for 2005-2100 from SRES A2 scenario.

b) Prescribed N deposition. Historical and future N deposition from offline simulation with CAM-chemistry coupling.

c) Prescribed land cover change, constant dust. Historical period from synthesis of satellite and agricultural data sets. Future period land cover based on SRES A2.

d) Prescribed land cover change, prognostic dust. As 2c, but allowing dust to respond to land cover change with ocean biogeochemistry responding to dust deposition.

In addition, using the first generation coupled carbon cycle, we plan a simulation of the LGM with the Paleoclimate Working Group (PaleoWG). These simulations will require ocean and land spin up, both alone and coupled, along with a long simulation with the coupled system in the LGM. These simulations will be done as part of an international intercomparison project linked to the C4MIP and Paleoclimate Model Intercomparison Project (as yet unnamed).

Finally, simulations of biogeochemically important aerosols and gases will be undertaken to understand how they interact with the carbon cycle. These will include simulations of mineral aerosols, which provide open ocean iron to ocean biota, as well as carbon dioxide simulations from land and ocean model simulations to evaluate the ability of the models to capture observed variability.

3. Research Plan and Computational Requirements

a) Coupled carbon simulations (C4MIP) Phase 1 and Phase 2 using existing second generation carbon models. These simulations will be continued to finish the simulations and submit them to the C4MIP protocol. These simulations include experiments, such as the impact of carbon dioxide changes on climate and feedbacks onto the carbon cycle.

b) Testing of carbon cycle components to better understand the response of the carbon cycle to various driving mechanisms. Experiments described in more detail above.

c) LGM coupled carbon cycle simulations (similar to C4MIP Phase 1 and Phase 2, but for the LGM) in collaboration with the PaleoWG, using the first generation model (CSM1.4).

d) Simulations using the biogeochemically active aerosol code will take place to show the impact of coupled carbon simulations under different climate simulations on the aerosols and the resulting climate impacts and biogeochemical impacts. Also included in this part of the production budget are simulations of atmospheric transport of carbon dioxide fluxes for diagnostics of the carbon fluxes.

Experiment	# of Runs	Model Config	# of Years	GAU/ yr	Total GAUs	Priority
C4MIP Phase 1	1	CLM, T31, C/N	2000	1	2,000	High
	1	CAM-CLM, T31, C/N	2000	22	44,000	High
C4MIP Phase 2: coupled spin up	1	Fully Coupled, T31-x3, C/N, ECO	500	25	12,500	High
C4MIP Phase 2: control and historical	1	Fully Coupled, T31-x3, C/N, ECO	1600	25	40,000	High
C4MIP Phase 2: future	1	Fully Coupled, T31-x3, C/N, ECO	800	25	20,000	High
Coupled sensitivity studies	8	Fully Coupled, T31-x3, C/N, ECO	300	25	60,000	Medium
LGM carbon cycle (CSM1.4): Ocean spin up	1	CSM1.4: x3 OCMIP'	500	5	2,500	Medium
LGM carbon cycle (CSM1.4): Land spin up	1	CSM1.4: LSM +CASA'	500	1	500	Medium
LGM carbon cycle (CSM1.4): Land/Atmosphere spin up	1	CSM1.4: T31 CAM/LSM+CASA'	200	5	1,000	Medium
LGM carbon cycle (CSM1.4): Full system spin up	1	CSM1.4: T31x3: CASA', OCMIP'	100	10	1,000	Medium
LGM carbon cycle (CSM1.4): Simulation	1	CSM1.4: T31x3: CASA',OCMIP'	1000	10	10,000	Medium
Aerosol/tracer biogeochemistry	1	CAM+aerosols/tracers, T42	180	25	4,500	High
Total					198,000	

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. Toward this end, we seek to understand better important aspects of the coupled polar climate system, including ice/ocean/atmosphere/land interactions and coupled feedbacks. Additionally, we plan to explicitly examine the influence of polar climate processes on the global climate system through sensitivity simulations of the CCSM. This work involves studies related to past, present, and future climate variability and change. The individual studies and the computer simulations required for these studies are detailed below.

1. Polar Climate Feedbacks

Feedbacks at high latitudes make the Polar Regions a particularly sensitive component of the global climate system. However, many of these feedbacks and their global influences are poorly known. A number of studies are designed to examine the simulation of different high latitude feedback processes and their role in the global climate system.

Cloud processes in the Polar Regions are often poorly represented in climate models, making feedbacks associated with clouds in future climate scenarios quite uncertain. Previous work has examined an alternative cloud fraction parameterization that improves the bias in the Arctic cold season low cloudiness in the CCSM3. In particular, a substantial decrease in winter low clouds is present with the new parameterization, providing a better comparison to available observations. While this parameterization has improved simulations of the present-day climate conditions, its influence on cloud feedbacks in the model has not yet been investigated. We propose to perform a coupled simulation with 1% increasing CO_2 per year. The simulation will be run to $2XCO_2$ levels, and the cloud response and the influence on the climate system will be analyzed. This will be compared to analogous simulations from the CCSM3 with the original cloud parameterization.

Recent studies have highlighted large vegetation changes in the high northern latitudes. These include an expansion of shrub and tree cover (e.g., Sturm et al., 2001**)** that modify the surface albedo and contribute to the observed terrestrial summer warming in the Arctic in recent years (e.g., Chapin et al., 2005). These effects are typically not included in climate model simulations, but observational studies suggest that the continuation of trends in shrub and tree expansion have the potential to amplify the regional terrestrial atmospheric warming by two to seven times. Using the dynamic vegetation component of the land surface model, we propose to examine the effects of changing Arctic vegetation on future climate model projections. We will perform two simulations of the coupled model with 1% increasing CO_2 levels per year. These will be branched from a present-day control integration that includes the dynamic vegetation model. The increasing CO_2 runs will include interactive dynamic vegetation globally, but in one case the interactive vegetation will be disabled in high northern latitudes. The comparison of these simulations will allow us to isolate the vegetation feedbacks in high latitudes and their role in polar amplification and global climate change.

The albedo feedback plays a critical role in the polar amplification of global warming. Changes in the sea ice cover and sea ice surface albedo are an important component of this feedback. As such, the parameterization of the surface albedo can modify the simulated feedback. A new melt pond parameterization will add more realism to the albedo parameterization and may considerably influence the evolution of the surface albedo in increasing greenhouse gas scenario simulations. The effect of this new melt pond parameterization on the albedo feedback will be examined in coupled 1% increasing CO_2 simulations that are run to $2XCO_2$ levels. Simulations that use the new melt pond parameterization coupled to a new sea ice shortwave radiation parameterization that was developed under previous work will also be performed to investigate the influence of the improved shortwave physics on the simulated feedbacks. These simulations will be compared to existing CCSM3 runs to assess the effect on high latitude polar amplification and the strength of the albedo feedback.

Snow cover in high latitudes has a considerable climate impact through its high albedo and effect on surface fluxes. Work under our previous CSL allocation has examined the influence of snow cover on Arctic air mass incursions to middle latitudes and found a considerable effect. We propose to continue these studies to isolate the effect of changes in

Arctic snow cover versus changes in snow cover at midlatitudes. This will be examined in simulations that remove snow cover regionally and analyze the climate response. This will require integrations of the fully coupled model.

2. Diagnosing Abrupt Transitions in the Future Ice Cover

CCSM3 future climate projections exhibit abrupt transitions in the summer Arctic sea ice cover, with the most extreme case showing a decrease in the Arctic Ocean September sea ice from 80% coverage to 20% coverage in approximately 10 years. The mechanisms involved in these abrupt transitions have been examined in different ensemble members, and three factors appear to be important for the rapid ice cover reductions. They are thinning of the ice cover to a point where increases in ice melt rates are more efficient at producing open water, positive surface albedo feedback that accelerates the summer melting as the ice cover retreats, and increases in ocean heat transport to the Arctic that occur as the ice thins.

Sensitivity studies are planned to elucidate these mechanisms and their role in driving abrupt transitions in the future Arctic sea ice. In particular, we will perform model runs that isolate these different factors and compare their effects in isolation and combination on the future Arctic sea ice trajectory. For example, we will perform experiments branched from the scenario runs just prior to an abrupt transition with an atmosphere/sea ice/SOM configuration. These simulations will hold the ocean heat transport to the Arctic region fixed, allowing us to assess whether the increasing ocean heat transport is critical in driving the abrupt transition. We also propose experiments that use idealized forcing that have an abrupt increase in atmospheric CO_2 levels. The use of these forcing scenarios with different initial sea ice conditions will elucidate the role of abrupt forcing changes versus the role of the sea ice state in contributing to potential abrupt changes in the future summer sea ice.

3. The Role of High Latitudes in Ocean Heat Uptake

Changes in the Southern Ocean ventilation appear to play a critical role in future simulated changes in ocean heat uptake. Many of these ventilation changes are related to the changing sea ice cover. We propose a number of studies to further examine the mechanisms at work in the high southern latitudes that contribute to the ocean heat uptake changes. In particular, we propose experiments to examine the role of fresh water forcing in the regions of Southern Ocean convection by applying ocean fresh water perturbations in present-day simulations in regions that have reduced convection in 21st century runs. A number of these hosing runs will be performed with perturbations applied in different regions. These simulations will help elucidate the role of changing fresh water fluxes (which is largely related to ice-ocean exchange) in modifying the Southern Ocean heat uptake. Additionally, we will examine the role of changing surface heat fluxes due to ice retreat in modifying the Southern Ocean heat uptake. In these simulations, additional light will be passed through the sea ice in a present-day run. This will mimic the effects of sea ice retreat on the ocean shortwave fluxes.

Bitz et al. (2006) suggest that changes in ice growth rates and consequent brine rejection in a warming climate modify the ocean ventilation within the Arctic basin. This affects the ocean circulation, driving an increased inflow from the North Atlantic and leading to an increased ocean heat uptake within the Arctic. To further investigate these effects, we propose a sensitivity simulation run with 1% increasing CO_2 in which the ice is allowed to evolve, but the ice ocean fresh water exchange remains at present-day conditions. This will allow us to determine how changes in the ice ocean fresh water flux affect ocean circulation changes in future climate simulations and modify the ocean heat uptake in both hemispheres. The influence of brine rejection on the ocean circulation will be modified by changes in Arctic river inflow, which increases in a warming climate. To diagnose these interactions, we propose an additional 1% CO_2 simulation in which the rivers are fixed at present-day values.

4. Consequences of a Seasonally Ice Free Arctic Ocean

Future climate model projections suggest that the Arctic may be seasonally ice free within the 21st century. This could have far reaching effects, and some idealized studies show an impact on water resources within the western United States (e.g., Sewall and Sloan, 2004). We plan to examine the consequences of a seasonally ice free Arctic Ocean on these and other remote effects using atmospheric model simulations forced with modified surface sea ice conditions. A number of ensemble members will be performed to obtain robust statistics on the climate consequences of a seasonally ice free Arctic Ocean.

Experiment	**# of Runs**	**Model Config**	**# of Years**	**GAUs/yr**	**Total GAUs**	**Priority**
Cloud feedback	1	T42_gx1v3	80	70	5,600	High
Vegetation feedback						
Control integration	1	T42_gx1v3	100	70	7,000	High
1% CO_2 runs	2	T42_gx1v3	80	70	11,200	High
Snow cover feedback	1	T42_gx1v3	50	70	3,500	Medium
Albedo feedback	2	T42_gx1v3	80	70	11,200	Medium
Ocean heat uptake						
Southern ocean hosing	3	T42_gx1v3	100	70	21,000	High
Increased SW thru ice	1	T42_gx1v3	100	70	7,000	High
Fixed ice-ocn fw flux	1	T42_gx1v3	80	70	5,600	High
Fixed river runoff	1	T42_gx1v3	80	70	5,600	High
Ice cover transitions						
Sensitivity to OHT						
Sensitivity to ice	4	T85_SOM	30	168	20,200	High
thickness	4	T85_gx1v3	30	275	33,000	High
Rapid forcing changes	3	T85_gx1v3	30	275	24,800	High
Consequences of a seasonally ice free Arctic	6	T42 CAM/CLM	50	21	6,300	Medium
Total					162,000	

G. Climate Variability Working Group (CVWG)

The research focus of the CVWG is the analysis of natural and anthropogenically-induced patterns of climate variability and their mechanisms in CCSM3 and its component models, as a means of furthering our understanding of the observed climate system. The CVWG proposes a series of production runs that will be made available to the research community. These include simulations with CAM3 in uncoupled and coupled mode (CAM3 coupled to an ocean mixed-layer model) to examine the relative impact of SST forcing versus the combined effect of SST, greenhouse gas, aerosol, volcanic, and solar forcing on climate variability during the 20th century. Some of the integrations proposed in this cycle are motivated by community interest in investigating drought genesis and maintenance, especially over North America. These integrations will be closely coordinated with other modeling centers (NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), NASA/Global Modeling and Assimilation Office, Lamont-Doherty Earth Observatory, and NOAA/Climate Diagnostics Center) to ascertain the robustness of key findings and to focus on novel aspects of the problem.

1. Scientific Goals

a) What are the relative impacts of SST forcing versus the combined effect of SST and greenhouse gas, aerosol, volcanic, and solar forcing upon climate variability during the 20th century? What role do tropical Pacific SSTs play in particular, and what is the impact of air-sea feedbacks outside of the tropical Pacific upon climate variability?

b) How are droughts and pluvials generated over North America? What is the contribution of concurrent/antecedent SST anomalies and soil-moisture states in drought genesis and maintenance? Are both Pacific and Atlantic basin SSTs important? And above all, what are the mechanisms by which SSTs influence North American hydroclimate?

2. Standard AMIP Integrations

We propose to expand the current set of ensembles of CAM3 AMIP integrations to include the period before 1950 to encompass the full range of variability during the late 19th and 20th centuries; currently available AMIP integrations begin in 1950. We propose a three-member ensemble of CAM3 at T85 resolution for the period 1856-1949, complementing the existing five-member ensemble that begins in 1950. We also propose to extend the latter through the present as it currently ends in 2001. The start year for the integrations (1856) is determined by the availability of SST forcing data. High-resolution (T85) simulations are necessary for Great Plains drought and pluvial studies, in view of the need to resolve the Great Plains low-level jet that transports copious amounts of moisture from the Gulf of Mexico into the continental interior during late spring and summer. The T85 version of CAM3 also exhibits more realistic ENSO teleconnection patterns than the T42 version.

In addition to the global AMIP integrations described above, we also propose a three-member ensemble of tropical AMIP integrations in which only the evolving tropical SSTs are used to force CAM3. SSTs elsewhere are held fixed at their climatological monthly values. These runs will be performed for the same time periods as the global AMIP runs, and they will complement the existing five-member tropical SST forced ensemble of CAM3 for the period 1950-2000. These runs will be used to assess the influence of tropical SSTs on the global climate system, and in comparison with the global AMIP runs, will afford an assessment of the additional influence of extratropical SSTs.

3. CAM3 Coupled to an Ocean Mixed-Layer Model

We propose a set of integrations in which CAM3 is coupled to an entraining ocean mixed-layer model outside of the region affected by dynamical ocean processes associated with ENSO (e.g., the Tropical Indo-Pacific Ocean). Two sets of atmospheric general circulation model (AGCM) experiments will be run with different ocean configurations to examine how air-sea interaction in various ocean basins influences the atmospheric bridge. In all of the experiments, SSTs are prescribed to evolve according to observations in the 1856-present period in the tropical Pacific Ocean (15°S-15°N). The experiments differ in their treatment of the ocean outside of this region. In the "control" experiment, climatological SSTs, which repeat the same seasonal cycle each year, are specified at all ocean grid points outside of the tropical Pacific region. This experiment design is referred to as the "Pacific Ocean Global Atmosphere" or "POGA." In the mixed-layer model (MLM) experiment, a grid of column ocean models is coupled to the atmosphere at each AGCM grid point over the ocean outside the tropical Pacific region. Both experiments will consist of an ensemble of three simulations where the individual members are initiated from different atmospheric states obtained from a CAM3 simulation. For these experiments, CAM3 will be run at T85 resolution. Comparison of the control POGA runs with the AMIP runs forced by global (tropical) SSTs will allow an assessment of the role of tropical Pacific versus global (tropical) SSTs in climate variability. Comparison of the MLM POGA runs with the control POGA runs will allow an assessment of the contribution of air-sea feedbacks outside of the tropical Pacific to climate variability.

4. "Soil Moisture" Integrations

The current "control" runs of CAM3 (100 years duration for T85 and 200 years duration for T85) in which the lower boundary conditions are held fixed at their climatological mean monthly values include interactive soil moisture and snow cover. To isolate the intrinsic atmospheric variability, we propose to duplicate these control runs but keep the land cover and snow cover fixed at their climatological monthly mean values. We are also proposing two special integrations to advance understanding of the dynamic and thermodynamic influence of the land surface in initiation and maintenance of North American droughts. In the first, soil-moisture over North America will vary only climatologically, allowing investigation of the role of land surface as a delayed moisture source and of its influence on column thermodynamics. Intercomparisons with the standard GOGA-IPCC run will provide a quantitative appraisal of the relative importance of local and remote forcing of North American droughts and pluvial. The other experiment involves modification of North American orography. Orographic features play an important role in shaping Great Plains hydroclimate, by influencing the formation of the Great Plains low-level jet in boreal summer months. The significance of this interaction will be investigated from modeling experiments where some orographic features are modified.

5. "Climate of the 21st Century" IPCC Scenario Integrations with CCSM3

The CVWG has begun a set of IPCC scenario runs with CCSM3 at T42 resolution in conjunction with the Climate Change Working Group (CCWG). The purpose of these experiments is to provide a large ensemble (~30 members) of integrations driven by a fixed, standard "business-as-usual" climate change scenario during 1990-2050. Such a large ensemble will allow an assessment of uncertainties in climate projections resulting from intrinsic system variations, as well as the evolving properties of interannual variability. This project will also include a large ensemble (~40 members) of short (~10-year duration) integrations of CAM3 driven by the surface boundary conditions from years 2041-2050 of the CCSM3 climate change scenario integrations. This set of integrations will be used to assess the change in the likelihood of extreme events, for which a large ensemble is crucial. These integrations are being coordinated with GFDL, who are performing similar runs with their coupled model.

Experiment	**# of Runs**	**Model Config**	**# of Years**	**GAU/ yr**	**Total GAUs**	**Priority**
AMIP (SST only)	3	CAM3 T85	55 1900-1949 2001-2005	140	23,100	High
AMIP (SST only) TOGA (Tropical SSTs Only, CLIM elsewhere	3	CAM3 T85	55 1900-1949 2001-2005	140	23,100	High
Control (Fixed SST, fixed land surface and snow cover)	1	CAM3 T85	100	140	14,000	High
AMIP (GOGA-IPCC) Drought exp: Pres soil moist	1	CAM3 T85	106 1900-2005	140	14,850	High
AMIP (GOGA-IPCC) Drought Exp: Mod Orography	1	CAM3 T85	106 1900-2005	140	14,850	High
AMIP (POGA/MLM): OBS SSTs in Trop Pac; Ocean Mixed Layer elsewhere CCSM3 T42 Climate of the 21st century AMIP T42 Climate of the 21st century	3 13 38	CAM3/MLM T85 CCSM3 T42 CAM3 T42	106 1900-2005 61 1990-2050 10 2041-2050	140 70 21	44,550 55,550 8,000	High High High
Total					198,000	

H. Paleoclimate Working Group

The PaleoWG has developed a scientific plan that focuses on testing and evaluating CCSM sensitivities while addressing “big” scientific questions, including:

- How much climate variability is due to insolation variations and volcanic activity?
- What are the mechanisms that drive abrupt climate change?
- How do hydrologic, biogeochemical, and cryospheric processes feedback onto climate change?
- What are the relative roles of greenhouse gases and heat transport in the maintenance of “greenhouse” climates?

1. Mid-to-late Holocene Transient Simulation

a) Scientific rationale. Natural climate variability of the Holocene offers opportunities to calibrate the climate response to key natural forcings, such as the sun and volcanoes, while many other potential forcing factors are essentially fixed, and data records give a relatively accurate depiction of past climate change. For this reason, the PaleoWG has embarked (in the last CSL allocation period) on a long transient Holocene simulation covering the period from 8 ky BP (before present) to 3.5 ky BP. Whereas almost all numerical efforts to understand mid-Holocene climate have focused on timeslice experiments at 6 ka, the PaleoWG is studying the response of the climate system to transient mid-Holocene variations in climate forcing with time-dependent irradiance, greenhouse gases, and with fully dynamic vegetation, utilizing the most recent dynamic vegetation improvements. This long transient integration will help to test nonlinearities in the climate system induced by century to millennial scale transient changes in external forcing of mid-Holocene climate variations.

b) Experimental framework. For this CSL allocation, we propose to extend this transient Holocene simulation to the modern era to provide a bridge between the Holocene and the Anthropocene. Thus, we are proposing a simulation of the last three millennia, both as an extension of the long transient Holocene simulation that the PaleoWG has embarked upon and also because of its own intrinsic importance as the transition to the modern age. We propose to do this in two stages. First, we will simply extend the existing transient simulation 1500 to 2000 years BP. Second, we will incorporate some code and boundary condition improvements that are more appropriate to the latter half of this period because of better constraints on boundary forcing conditions and a better proxy framework for model-data intercomparison, and run an additional 2000 years.

In addition to these experiments, we will also conduct some sensitivity studies on tropical-extratropical teleconnections during this interval. One of the significant questions with regard to natural climate variability of the past century and millennia remains the variability in the low latitudes. In particular, changes in the mean state of the Pacific basin are only poorly reproduced. In fact, the low-frequency changes in models seem to be almost opposite of what proxy records suggest, although a link to the forcings is debated. To augment the fully coupled simulations, a set of sensitivity experiments to evaluate the effect of a different mean state in the tropical ocean’s east-west temperature gradient is proposed. This should help to evaluate teleconnection patterns (and their stability) as they are currently used in the data community.

2. Abrupt Climate Changes during the late Quaternary

a) Scientific rationale. The Atlantic meridional overturning circulation, or thermohaline circulation (THC), is an important feature of the climate system that may be sensitive to anthropogenic climate change. One way to assess, and possibly reduce, uncertainty about possible future slowdown in the THC is to consider the forcing and response during past climate events. By modeling past abrupt climate changes and working with researchers developing proxy records of paleoclimate, we will evaluate the sensitivity of the CCSM3 THC.

b) Experimental framework. We propose several simulations to look at past time periods where proxy indicators suggest abrupt events that were associated with fresh water added to the North Atlantic. We propose to use more realistic fresh water perturbations to allow a more quantitative comparison to the proxy records. For the 8.2 event, one of the largest abrupt climate changes during the Holocene, the geologic record suggests three sources of fresh water preceding and during the event: a small baseline flow of glacial runoff down the St. Lawrence River, an abrupt and large drainage of Lake Agassiz, and subsequent, more extended collapse of the Laurentide ice sheet. Because this event is fairly recent, well-resolved proxy records, especially in the North Atlantic region, record the climatic responses to this event. The 8.2 event has been identified as an important research opportunity for the CLIVAR/Past Global Changes (PAGES) intersection and proposed for the Paleoclimate Hosing Model Intercomparison Project (PhMIP).

We also propose to do the first in a series of simulations looking at the Bolling-Allerod (BA) and Younger Dryas 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 THC and a warming of the North Atlantic. We propose to do two simulations: an equilibrium simulation with boundary conditions and forcings for the period of the BA, and then a transient simulation where we introduce a fresh water pulse into the Southern Ocean.

3. Arctic and Antarctic Warmth at the Last Interglacial

a) Scientific rationale. Paleoclimate records indicate a much warmer (as much as 5°C increase in temperature) Arctic and Antarctic during the last interglacial period (LIG, ca. 130-116 ky BP). A previous simulation with CCSM2 at T31x1 resolution indicated the importance of Milankovitch solar insolation anomalies in simulating the Arctic warmth but could not reproduce the ice core records of Antarctic warmth. This CCSM2 LIG simulation forcing a Greenland ice sheet model was also able to reproduce the Greenland ice core records of a smaller and steeper Greenland ice sheet and sea level rise of 3-4m at LIG. The CCSM2 simulation did not include the feedbacks with vegetation and ice sheet retreat, making it difficult to determine the rates of change of sea level rise.

b) Experimental framework. We propose to run new LIG simulations with CCSM3 at T42x1 resolution and coupled to the dynamic vegetation model to address these discrepancies. The first simulation will start from the CCSM2 simulation with the same ocean resolution but now with CCSM3 and dynamic vegetation. The second simulation will explore the possibility of the melting of the west Antarctic ice sheet (WAIS) by removing this ice sheet in a sensitivity simulation to determine if this can account for the warm East Antarctic ice core LIG temperatures. The effect of a reduced WAIS is of relevance to future climate change with recent evidence of its thinning over the last decade.

4. Pliocene Warmth–Analog for Future Warming?

a) Scientific rationale. As compared to the Quaternary periods of warmth that show seasonal and latitudinal warmth but not significant global, annual warmth because of the nature of Milankovitch forcings, the mid-Pliocene (~3.5 my BP) is a period of increased atmospheric CO_2 levels and global warming. It is a period recent enough that the land-ocean configuration was not significantly different than present, and a reasonably narrow interval of

CO_2 concentrations is available from the proxy record (~30% above pre-industrial). Despite the similarity between modern and Pliocene boundary conditions, the mean climates of these intervals were substantially different. In comparison to the modern proxy, evidence indicates that the Pliocene had a smaller meridional thermal gradient, a lower sensitivity to Milankovitch forcing, and a reduced tropical SST gradient. In fact, the Pliocene has been characterized as an "El Niño" world.

b) Experimental framework. We propose to do our first Pliocene simulation using CCSM3 at T42x1 resolution and coupled to dynamic vegetation. This relatively high-resolution simulation is fitting because it represents the current state-of-the-art for this period (the Haywood and Valdes (2004) simulations were conducted at this resolution), and because the nature of the hypothesized crucial interactions during this period require an excellent treatment of deepwater formation and sea ice interactions. Haywood and collaborators have expressed an interest in performing a model intercomparison for this interval, so we will follow as closely as possible the specification of boundary initial conditions as delineated in Haywood and Valdes (2004), which includes utilizing the boundary conditions established as part of the PRISM project. We will follow this simulation with short experiments designed to test the sensitivity of the tropical mean state and the impacts of these tropical states on global climate if additional computing time can be found (e.g., by running in the economy queue).

5. Abrupt Greenhouse Gas-Induced Global Warming at the PETM

a) Scientific rationale. The Paleocene-Eocene Thermal Maximum (PETM) at about 55.5 my BP is of climatic interest due to the significant warming that occurred over a relatively short geologic time period. This warming is thought to have occurred in response to a destabilization of marine methane clathrates. The significant warming was accompanied by a negative excursion in carbon isotopes, indicative of a supply of light carbon to the climate system. Polar warming was substantial at this time period, where recent estimates suggest Arctic Ocean surface water temperatures of ~+20°C (growing season). Recent isotopic data also indicate that subtropical SSTs were warmer than present by only ~5°C. This represents a natural experiment in the response of the climate system to a rapid (<10,000) year greenhouse gas release, and so far, much of the response remains unexplained.

b) Experimental framework. Two coupled T31x3 CCSM3 250-year simulations of the PETM will be carried out to investigate the role of elevated CO_2 and/or methane on the climate of this time period, with near modern and elevated greenhouse gas concentrations. Acceleration will be used to make these simulations equivalent to ~1000 ocean years. In addition to the physical climate simulations, a slab ocean paleo Middle Atmosphere Community Climate Model (MACCM) configuration using information from the coupled model simulation will be used to explore the role of elevated methane on the chemical climate state of the PETM as described in the development proposal.

6. Cretaceous Greenhouse Climate

a) 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. With the ongoing development of the CCSM as an Earth System Model, the opportunity exists to make scientific breakthroughs in many long-standing problems. In this context, the PaleoWG has embarked on a large-scale collaborative project involving the Cretaceous research community to investigate the climate of the Late Cretaceous (i.e., pre-impact), an interval selected for its data richness.

b) Experimental framework. We propose a series of Late Cretaceous simulations to be carried out over the next 36 months that will target these outstanding scientific questions. During the first 18 months, the interval of this allocation request, we will develop and run Late Cretaceous simulations that investigate the impact of greenhouse gas concentrations using CCSM3 T31x3 resolution and coupled to dynamic vegetation modified to account for the absence of C4 grasses at this time period. Three simulations will be completed with specified concentrations of CO_2 and CH_4 representing pre-industrial, high ($4xCO_2$), and extreme levels ($10xCO_2$). The coupled simulations will be integrated for 600 years each (with acceleration these will be about 2500 years). These simulations will serve as baseline experiments for the design of future experiments and initial comparisons with proxy data.

Experiment	# of Runs	Model Config	# of Years	GAU/ yr	Total GAUs	Priority
Quaternary						
8.2 ka event	1	T42x1	300	70	21,000	High
LIG Orbital, WAIS sensitivity	2	T42x1	200	70	28,000	High
Deglacial, 14.4 ka, MWP-1a	2	T31x3	500	15	15,000	Medium
Last 2 Millennia						
Trop. state sensitivity	6	T31x1	50	15	4,500	High
Last 2000 years	1	T31x3	2,000	15	30,000	Medium
- sensitivity runs	3	T31x3	45	15	2,000	Medium
Transient Holocene extension	1	T31x3	1,500	15	22,500	High
Pre-Quaternary						
Pliocene	1	T42x1	600	70	42,000	Medium
Latest Cretaceous –	3	T31x3	600(acc)	15	27,000	Medium
PETM	2	T31x3	200 (acc)	15	6,000	High
Total					198,000	

I. Climate Change Working Group

1. Overall CCWG 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. Included in this list were common forcings for 20th century climate; climate change adaptation/mitigation; large ensembles and climate change signals; climate sensitivity; and further analysis of the 20th century and future climate change simulations from CCSM3, as well as the IPCC multi-model ensemble. The CCWG production runs are described below, with the specific resource request appearing in the table at the end. When the CCSM is run in IPCC mode, an increased GAU per year value is used to reflect the actual charge level observed while running the IPCC AR4 scenarios.

2. CCWG Production Runs

a) IPCC Working Group III (WG3) adaptation/mitigation scenarios. The IPCC WG3 has requested a suite of climate change adaptation/mitigation scenarios assuming political intervention and/or technological progress targeting certain greenhouse gas stabilization levels to accompany the IPCC SRES. The IPCC scenarios considered so far with GCMs were all non-intervention scenarios. The goal of the new proposed mitigation scenario is to study the effect of reductions in greenhouse gas emissions on climate through specified interventions in the form of targeted political initiatives and economic investments. The economists of WG3 are currently generating these new scenarios. These scenarios will allow us to study the climatic response to a range of low emission scenarios that have not been studied with any GCM so far. While traditionally those types of scenarios were only used in simple models, CCSM will provide a unique data set to Working Group I to study the amount of climate change that can be avoided by political intervention, not only in terms of global mean temperature as provided by simple models, but in more relevant properties like precipitation patterns, climate variability, and changes in extreme events. It will also serve as a unique high-resolution data set for those who study impacts of climate change on ecosystems and human society. This is a very late breaking development in the IPCC AR4 process, and we may be the only IPCC modeling group capable of carrying out these runs on such short notice and in time for them to be considered in the Second Order Draft in March 2006. The total set of runs will require four 100-year T85 CCSM runs: two baseline cases and two intervention scenarios, each covering the period of years 2000-2100. We are proposing to run three of the four experiments under CSL time and will acquire the remaining time through divisional and directorate reserves.

b) Large ensembles and climate change signals (with CVWG). One of the outstanding questions from the IPCC simulations is how to quantify the minimum number of ensemble members required to capture the full range of potential climate states. To separate the climatic "signal" from the climatic "noise," the CCWG and CVWG will run a 30-member ensemble experiment with the T42 version of CCSM. The CCWG will carry out 15 of the ensemble members using CSL production. This 30-member ensemble will allow us to investigate the uncertainties in climate projections resulting from intrinsic variations of the climate system to assess the optimum ensemble number for future climate change simulations.

c) Biogeochemistry spin up (with BGCWG and PaleoWG). Prior to the industrial revolution, Earth's climate system did experience significant variations. These were partly due to internal variations, but a significant portion was forced from the outside. Solar irradiance changes, explosive volcanisms, changes in Earth's orbit, and possibly human land use changes are probably the dominant factors directly affecting climate, while feedbacks from the carbon cycle (through greenhouse gas and vegetation) further modulated the response. The coupled climate system with the connected carbon cycle has inherent equilibration timescales of many centuries if not millennia. We propose to simulate the climate of the past 1500 years with full carbon cycle included. One goal is to study the full system when exposed to the best available forcing history over the pre-industrial time and to compare the results with a parallel, but more traditional, coupled experiment that only uses solar irradiance and volcanic eruptions as external forcings but prescribes the observed greenhouse gas histories. It will be important to compare these experiments and to understand the differences with regard to climate and the changes in the carbon cycle reservoirs. An important element in this test transient simulation is to identify the imbalances that are present in the year 1850 or 1870, the "pre-industrial" starting point of the IPCC "historical" equilibrium. Because of the superposition of interests, this experiment is co-sponsored by three CCSM working groups: Paleoclimate, Biogeochemistry, and Climate Change.

d) Climate sensitivity. Stocker and Schmittner (1997) (SS97) suggested that the North Atlantic meridional overturning circulation (MOC) would be more susceptible to catastrophic collapse for faster rates of increase of greenhouse gases. The question of the dependence of the MOC response on the rate of greenhouse gas increase is closely tied to the interplay of timescales of various feedback mechanisms involved in the recovery of the MOC following stabilization. Namely, the penetration of heat and fresh water anomalies into the ocean interior at low latitudes can re-establish the meridional steric height gradient that drives the MOC. How the timescale of that process relates to the timescale of the forcing and the timescale of both local and remote feedbacks affecting the static stability in the deep water formation sites is the intended focus of this study. The CCWG will explore the mechanisms of the recovery of the MOC following stabilization of greenhouse gases and test the SS97 hypothesis concerning the dependence of the response on the rate of forcing using the T42x1 version of CCSM3. As shown by Bryan et al. (2006), the mean MOC and its response to climate forcing in the T42x1 version of CCSM3 are qualitatively similar to those of the T85x1 version, whereas the T31x3 differs in a number of fundamental ways (e.g., the absence of deep water formation in the Nordic Seas). Further, the 1% per year increasing CO_2 integrations have been integrated longer (to approximately 7x) in the T42x1 version than in either of the other two configurations, thereby minimizing the length of integrations required to address problems to be investigated here. Running the experiments to 8x present-day CO_2 allows investigation of the MOC recovery in the interesting regime of an ice free Arctic Ocean.

e) Cryospheric process feedbacks (with PaleoWG). 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. 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 a 250-year continuation of the T42 development control run followed by a 1870-2100 simulation for the IPCC A1B scenario. In parallel, the PaleoWG will test the response of the GIS through the deglacial period from the LGM.

f) Data analysis. 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/yr	Total GAUs	Priority
a. IPCC WG3 mitigation scenarios	3	T85 IPCC	100	371	111,300	High
b. CCWG/CVWG ensembles	15	T42	60	70	63,000	High
c. CO_2 climate sensitivity studies	1	T42	415	70	29,050	Medium
d. CCWG/PaleoWG/BGC spin up	1	T31	500	25	12,500	Low
e1. Ice sheet production 1870-control	1	T42	250	70	17,500	Medium
e2. Ice sheet production 1870-2100	1	T42	230	70	16,100	Medium
f. Data analysis					2,550	High
Total					252,000	

J. Software Engineering Working Group (SEWG)

The SEWG is actively involved in all stages of CCSM production and development work. In particular, in the production account, the SEWG performs key control simulations that span the activities of all working groups. In addition performance tuning of these control runs is achieved via the performance of hundreds of short performance tests at full production resolutions and process configurations. Timing results from these runs are used to tune performance and optimize load balance (assignment of processors to components). Software modifications that accompany new science generally are accompanied by changed performance characteristics. Consequently, rebalancing of load is normally required to tune performance whenever new software changes are introduced into CCSM. Load balancing is done by the SEWG for SEWG specific production runs, as well as other working group production runs. In some cases, improved load balancing has increased CCSM performance by more than 20%. We estimate that 4000 GAUs will be needed in performance tuning activities over this CSL period. The SEWG is also proposing to perform a 400-year control run using the CAM FV dynamical core at FV2x2.5_gx1v3 to establish the stability and validity of this configuration.

Description	# of Runs	Model Config	# of Years	GAU/yr	Total GAUs	Priority
CCSM Control Runs	1	2x2.5_x1	400	80	32,000	High
Performance Tuning	Many	All			4,000	High
Total					36,000	

IV. References

Bitz, C. M., P. R. Gent, R. A. Woodgate, M. M. Holland, and R. Lindsay, 2006: The influence of sea ice on ocean heat uptake in response to increasing CO_2. *J. Climate*, accepted.

Bryan, F. O., G. Danabasoglu, N. Nakashiki, Y. Yoshida, D.-H. Kim, J. Tsutsui, and S. Doney, 2006: Response of the North Atlantic thermohaline circulation and ventilation to increasing CO_2 in CCSM3. *J. Climate*, accepted.

Chapin, F. S., III, et al., 2005: Role of land-surface changes in Arctic summer warming. *Science*, **310**, 657-660.

Doney, S. C., K. Lindsay, I. Fung, and J. John, 2006: Natural variability in a stable 1000 year coupled climate-carbon cycle simulation. *J. Climate*, accepted.

Friedlingstein, P., et al., 2006: Climate-carbon cycle feedback analysis, results from the C4MIP model intercomparison. *J. Climate*, in press.

Fung, I., S. C. Doney, K. Lindsay, and J. John, 2005: Evolution of carbon sinks in a changing climate. *Proc. Nat. Acad. Sci. (USA)*, **102**, 11201-11206, doi:10.1073/pnas.0504949102.

Haywood, A. M., and P. J. Valdes, 2004: Modelling Pliocene warmth: Contribution of atmosphere, oceans and cryosphere. *Earth and Planetary Science Letters*, **218,** 363-377.

Lamarque, J. F., et al., 2006: Assessing future nitrogen deposition and carbon cycle feedback using a multi-model approach. Part 1: Analysis of nitrogen deposition. *J. Geophys. Res*., in press.

Petit, J. R., et al., 1999: Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, **399**, 429-436.

Sewall J. O., and L. C. Sloan, 2004: Disappearing Arctic sea ice reduces available water in the American west. *Geophys. Res. Lett*., **31**, L06209, doi:10.1029/2003GL019133.

Stocker, T. F., and A. Schmittner, 1997: Influence of CO_2 emission rates on the stability of the thermohaline circulation. *Nature*, **388**, 862-865.

Sturm, M., C. Racine, and K. Tape, 2001: Increasing shrub abundance in the Arctic. *Nature*, **411**, 546-547.