

# CCSM

**Community Climate System Model**



**Proposal for Increased CSL Resources**

06/01/2007 - 11/31/2007

# Table of Contents

<b>OVERVIEW .....</b>	<b>3</b>
<b>BIOGEOCHEMISTRY WORKING GROUP (BGCWG) .....</b>	<b>4</b>
<b>ATMOSPHERE MODEL WORKING GROUP (AMWG) .....</b>	<b>6</b>
<b>OCEAN MODEL WORKING GROUP (OMWG) .....</b>	<b>8</b>
<b>POLAR CLIMATE WORKING GROUP (PCWG) .....</b>	<b>10</b>
<b>LAND MODEL WORKING GROUP (LMWG).....</b>	<b>11</b>
<b>CHEMISTRY CLIMATE WORKING GROUP (CHEMWG).....</b>	<b>13</b>
<b>PALEOCLIMATE WORKING GROUP (PALEOWG) .....</b>	<b>15</b>
<b>CLIMATE VARIABILITY WORKING GROUP (CVWG).....</b>	<b>16</b>
<b>CLIMATE CHANGE WORKING GROUP (CCWG) .....</b>	<b>17</b>
<b>SOFTWARE ENGINEERING WORKING GROUP (SEWG) .....</b>	<b>18</b>
<b>ESTIMATE OF CCSM 3.5 GAU COSTS ON BLUEICE .....</b>	<b>21</b>

## Overview

### Project Title

Community Climate System Model: Development and Production

### PI

Peter R. Gent, NCAR

### Current CSL Allocation

Development, 50 KGAU/month; Production, 88.9 KGAU/month

### Total Additional GAU Requested

The additional GAU requested under this proposal are split between the 10 CCSM Working Groups as follows:

Working Group	Development (in KGAU)	Production (in KGAU)
BGCWG	90	300
AMWG	90	108
OMWG	90	108
PCWG	60	72
LMWG	60	72
ChemWG	30	72
PaleoWG	0	138
CVWG	0	108
CCWG	0	102
SEWG	60	0
<b>Total</b>	<b>480 KGAU</b>	<b>1080 KGAU</b>

Thus, the total CCSM request is 80 KGAU/month for Development and 180 KGAU/month for Production. The distribution among the various Working Groups reflects the new efforts that the CCSM enterprise can accomplish between June – November 2007. The first of these is the new spin up required for the CCSM 3.5 version with a full carbon cycle, which has not been done before. The new CCSM 3.5 will be ready to start these in a couple of months, and we estimate that it will take about six months to complete. Thus, this important new activity can be accomplished during the period of this additional CSL allocation. In addition, there will be further development of the component models for the definition of CCSM 4, which should occur in early 2008, and further use of the CCSM 3 to study important scientific questions in Paleoclimate, climate variability, and climate change.

## Biogeochemistry Working Group (BGCWG)

Currently the Biogeochemistry working group is working on several developments for the next phase of the carbon cycle simulations. The development runs required are:

1. **Improvements to the Land Biogeochemistry (Development):** (3750 years at 8 GAU/year = 30 KGAU). Continued evaluation of tundra and boreal forest carbon cycle simulations will be done and compared against observations. Extensive evaluation against forthcoming FluxNet synthesis datasets (hundred sites across all major vegetation types), and the integration of CLM-CN with the dynamic vegetation model.
2. **Improvements to the Ocean Biogeochemistry (Development):** (130 years at 230 GAU/year = 30 KGAU). We will investigate, and evaluate acceleration schemes that will potentially shorten spin up integrations. We will evaluate in the high resolution ocean component (x1) new iron cycle parameterizations that have been developed in the low resolution version (x3).
3. **Improvements to the Fire Algorithm in the Model (Development):** This work includes the impact of fire on the carbon cycle, aerosols and chemistry and feedbacks back onto the carbon cycle. This work will require simulations of the CLM-CN offline (250 years at 8 GAU/year = 2 KGAU) and coupled to the CAM (200 years at 40 GAU/year = 8 KGAU), and some development within the fully coupled model (10 years at 300 GAU/year = 3 KGAU).
4. **Improvements to the Dust Cycle in the Model (Development):** (200 years at 40 GAU/year = 8 KGAU). This work includes tuning the model to work optimally with the new offline driver capability (NCEP winds) and including the new sandblasting code. In addition, we will link in the capability of predicting soluble iron (25 years at 40 GAU/year = 1 KGAU).
5. **Improvements to our Ability to Evaluate Land and Ocean Carbon Elements (Development):** This work will be done by simulating carbon dioxide and other biogeochemically active species in offline models and comparing to available observations (200 years at 40 GAU/year = 8 KGAU).

The main effort of the BGC increment will be the spin-up of the CCSM3.5 model to test the new BGC components in the new physical model components. We assume here that spin up of the physical model has occurred. The BGCWG production runs needed are:

1. **Run 1 (Production):** Fully coupled carbon cycle simulation: 100 years fully coupled (300 GAU/year = 30 KGAU). The purposes of this simulation are to get the climate model past initial transients, get the short timescale BGC components spun up (ocean chlorophyll, land LAI) and get the surface forcing for the next run. This simulation will be for the preindustrial, and will include

already spun up land carbon elements, and start from best guess of ocean carbon initial conditions. The physical climate is assumed to be spun up. We will save the atmosphere fields at hourly intervals for the last 20 years for ocean spin up (Run 2).

2. **Run 2 (Production):** Spin up the ocean biogeochemistry within the ocean model, ~500 years at 230 GAU/year = 115 KGAU (based on BGC doubling the cost of the ocean/ice model). Using initial conditions for the ocean and boundary conditions from Run1, we will spin up the ocean biogeochemistry to be equilibrated at a level of 0.05 PgC/year (or tighter). There will be active ocean and ice, but data atmosphere and land. The longer this run goes, the more likely it is that Run 3 will be shorter.
3. **Run 3 (Production):** Fully coupled carbon/climate model with active biogeochemistry elements, ~280 years (300 GAU/year = 84 KGAU). The purpose of this run is to equilibrate the ocean biogeochemistry with interactive atmosphere and atmospheric CO<sub>2</sub>. We also will get the forcing for Run 4 (land model spin up). Initial conditions come from Run 1, except for ocean, which comes from Run 2. All components of the biogeochemistry and physics are active. For the biogeochemistry elements, the ocean biogeochemistry will see the atmospheric tracer that advects around the ocean fluxes of carbon dioxide, but the land biogeochemistry will see a different carbon dioxide from the land fluxes. In order to keep the two close together, but allow for the land rectifier effect, we will restore the atmospheric tracer for the land carbon dioxide to the ocean carbon dioxide tracer at high altitudes. This will be run long enough to get the ocean into equilibrium with the atmosphere carbon dioxide. We will save hourly atmosphere fields for the last 50 years to force Run 4.
4. **Run 4 (Production):** Offline land BGC spin up ~2000 years, (8 GAU/year = 16 KGAU). The purpose is to get the land BGC equilibrated with the high frequency atmospheric data from Run 3, including the carbon dioxide levels that the ocean is equilibrating to. Goal is to get the ATM-LND CO<sub>2</sub> flux below ~0.02 PgC/year. All acceleration techniques will be used.
5. **Run 5 (Production):** Fully coupled spin up with biogeochemistry and physics active, but radiative carbon dioxide fixed, biogeochemically active CO<sub>2</sub> interactive with both ocean and land carbon cycle. 80 years (300 GAU/year = 24 KGAU). The purpose is to equilibrate the BGC components to each other. The initial conditions come from Run 3, except for the land carbon, which comes from Run 4. We need to run this until the net land and net ocean carbon fluxes are below ~0.02 PgC/year.
6. **Run 6 (Production):** Control run with biogeochemistry ~100 years (300 GAU/year = 30 KGAU). This run is a continuation of Run 5, but with the carbon dioxide interactive with the radiation as well as the biogeochemistry.

## Atmosphere Model Working Group (AMWG)

The AMWG is in a development phase with CAM. This means most of both the development and production allocations will be spent in understanding new parameterizations in the model and their role in the climate system. Generally, these explorations should help us in understanding scientific questions like:

1. What controls the climate sensitivity of CAM, the CCSM, and the earth system?
2. What controls the amplitude and period of ENSO in our model?
3. What is the amplitude of the anthropogenic component of aerosol forcing in our model? How much of it is attributable to indirect versus direct forcing?

The goal of the AMWG is to produce a state of the art climate model capable of answering these questions, and presently most of our resources are going into achieving this goal. There is now a new set of physical parameterizations in our model that can be turned on as options within the CCSM 3.5 framework. These are: a more elaborate and sophisticated bulk aerosol formulation, and a new cloud microphysics formulation. We also have a couple of alternate convection parameterizations (Emanuel and Tiedtke parameterizations) and continue to explore variations on the Zhang-McFarlane deep convection scheme. We anticipate that the cloud microphysics and UW physics module (shallow convection and PBL) will become standard model components for CAM 4, and it is quite likely that the deep convection scheme will continue to evolve as well. The model aerosol formulations developed by Ghan will receive more attention. These parameterizations each produce credible simulations in CAM, but we have very little experience in how they will interact with each other, how they will behave in the coupled CCSM framework, or what they will produce in the way of climate sensitivity. Numerous runs will be made to explore these variations in physical parameterizations. Some simulations include increased computational requirements needed to deal with resolution changes and with the additional resource requirements for the aerosol and cloud microphysics parameterizations. Short, CAM alone runs will be made under the development allocation for initial exploration of the model and tuning. Longer, more expensive and fully coupled CCSM runs will be performed in the production queue. The AMWG plans to explore the sensitivity of the model simulations to variations in vertical (doubling or tripling) and horizontal (doubling or quadrupling) resolution.

**Planned Runs (Development):** Our baseline model is assumed to be a 30 level 2 x 2.5 resolution FV configuration of the model. The baseline model will cost about 45 GAU/year. There will be mostly sets of 10 year runs that span the spectrum of projects discussed previously. Experience has shown that a ten year run is the minimum length required to allow the land/atmosphere system to approach an equilibrium and this length run reduces the inter-annual variability of the system sufficiently that a first look at that atmospheric climate is viable. The exploratory high resolution runs are shorter. 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.

1. **Revised Physics Explorations:** Around 80 runs of 10-year length FV2 x 2.5 at 45 GAU/year = 36 KGAU
2. **Aerosols Formulation:** Around 8 aerosol runs of 10-year length FV2 x 2.5 at 90 GAU/year = 7 KGAU
3. **Modal Aerosols:** 5 runs of 10-year length FV2 x 2.5 at 110 GAU/year = 5 KGAU
4. **New Cloud Microphysics:** 15 runs of 10 year length FV2 x 2.5 at 55 GAU/year = 8 KGAU
5. **Vertical Resolution:** 10 runs of 10-year length FV2 x 2.5 at 90 GAU/year = 9 KGAU
6. **Horizontal Resolution:** 4 runs of 10-year length FV 1 x 1.25 at 270 GAU/year = 11 KGAU
7. **Horizontal Resolution:** 4 runs of 1-year length FV.5 x .5 at 1600 GAU/year = 6 KGAU
8. **SOM:** 5 runs of 30 years of FV1x1.25 at 50 GAU/year = 8 KGAU

The computational cost of the planned development work is 90 KGAU.

**Planned Runs (Production):** The baseline model is assumed to be the 30 level 2 x 2.5 resolution CCSM configuration of the model, which costs about 165 GAU/year. Three kinds of runs will be made in the production queues: AMIP runs, SOM runs, and coupled runs. A 20-year AMIP like run is the minimum required to be confident of the climate of a standalone 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 time scales associated with interactions between the oceans and atmosphere require that much longer runs be made whenever these two components are coupled. The AMWG has thus 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, coupled model runs with the UW physics package, the cloud water, and new aerosol formulations are proposed to evaluate the most promising configurations for a future FV coupled model.

1. **Revised Physics:** 12 amip runs of 20 years at FV2 x 2.5 at 45 GAU/year = 11 KGAU

2. **Revised Physics:** 2 SOM runs of 50 years FV2 x 2.5 at 45 GAU/year = 5 KGAU
3. **Aerosols:** 2 amip runs of 20 years with FV2 x 2.5 at 90 GAU/year = 3 KGAU
4. **Aerosols:** 2 SOM runs of 50 years with FV2 x 2.5 at 90 GAU/year = 9 KGAU
5. **New Cloud Microphysics:** 5 amip runs of 20 years with FV2 x 2.5 at 50 GAU/year = 5 KGAU
6. **Vertical Resolution:** 4 amip runs of 20 years with FV2 x 2.5 at 90 GAU/year = 7 KGAU
7. **Vertical Resolution:** 2 SOM runs of 50 years with FV2 x 2.5 at 90 GAU/year = 9 KGAU
8. **Horizontal Resolution:** 2 amip runs of 20 years at FV1 x 1.25 at 270 GAU/year = 11KGAU
9. **Coupled Candidates:** 3 100-year coupled runs FV2 x 2.5 at 165 GAU/year = 48 KGAU

The computational cost of this production work is 108 KGAU.

## Ocean Model Working Group (OMWG)

The OMWG proposes to use additional CSL computing resources over the 6 month period, 1 June - 30 Nov, 2007 to conduct the following numerical experiments. These represent opportunities that have arisen in the wake of discoveries since the current CSL proposal was written.

1. **Short Term Climate Projections (Development):** The new high priority focus for CCSM is short term (~ 30 year) climate projections, but the methodology needs to be developed. A promising path forward is to pursue the development in the context of “projections” of observed climate changes over the past few decades. To this end, the OMWG is proposing a series of 14 10-year projections beginning in January of every second year from 1970 through 1996. The initial states will come from either the existing CCSM3 20th century integration, or a new CCSM3.5 20th century integration, or the global ocean analyses produced by GFDL (ocean), NCAR/NCEP reanalysis (atmosphere), AMIP simulations (land), 20th century integration (sea-ice). The major metrics will be the predictability/forecast ability of the '70s Pacific regime transition as well as an examination of the predictability of the modulation of ENSO periodicity and amplitude that occurred in the mid 1980's through to 1997. Importantly, this will mark the first attempt to answer the question: how far in

advance might one be able to predict significant decadal events by utilizing the above known changes of the past? This effort will require 140 years of fully coupled integrations of fv1.9x2.5gx1v5 (60 ocean levels) at 190 GAU/year, for a total cost of 26 KGAU.

2. **Testing the CCSM Ocean Component with Tracers (Development):** It has frequently been asserted, and in a few instances demonstrated, that passive tracers can provide a useful test of ocean models. We propose 2 100 year experiments first to test the CCSM3.5 ocean component against observed tracer distributions, and second to test the hypothesis that transit time distributions (TTD) can be used as a metric for testing and tuning parameterizations of ocean mixing processes in the development of CCSM3.5 and beyond. The first test involves simulations of the CFC-11 and CFC-12 transients from the 1930s and the second test involves an additional 14 passive tracers to define regional TTDs. Both CCSM3.0 and CCSM3.5 will be run for 100 years with 16 tracers, which increases the computational cost by a factor of 2.6, (100 yr x 2.6 x 85 GAU/yr) and (100 yr x 2.6 x 110 GAU/yr), respectively for a total of 50 KGAU. Note, an experiment with a global 0.1 version of POP is underway that will provide a metric of “truth”.
3. **Improving the Indian Ocean Region (Development):** Observed trends in Indian Ocean SSTs make this region a new focus of climate research, and hence the OMWG proposes to address biases in the CCSM3 simulations in this region. Two prominent biases are the precipitation in the Bay of Bengal, and the representation of the Findlater jet. The hypotheses are that the ocean barrier layer affects the former, while the orography of the Ethiopian highlands influences the latter. At this time we are proposing 10 short 10-year fully coupled integrations (145 GAU/ year) as initial tests of these hypotheses and to provide guidelines on how to proceed. The computational cost is 14 KGAU.
4. **Perfect Initialization Experiments (Production):** An ensemble of experiments will be performed to estimate whether decadal scale predictability exists in CCSM3. They will be an essential ingredient of a recently formed collaboration with GFDL. The hypothesis is that decadal predictability may arise from deterministic oceanic variability present in the latest CCSM3, and hence the work is an extension of ongoing studies of ocean variability. In these “perfect” initialization experiments, only the atmospheric initial conditions are perturbed, so the degree to which ensemble members diverge from the control is a measure of the potential predictability of the coupled system. Starting at a specified date from the CCSM3 (T85x1) present day control, a 5 member ensemble will be integrated for 20 years each. The total computational cost at 275 GAU/year is 27.5 KGAU.
5. **Ocean-Ice “Equilibrium” Integration (Production):** The OMWG and PCWG wish to obtain the first ocean-ice coupled equilibrium solution at x1 degree resolution, so that long term effects of new parameterizations and

parameter choices can be determined. From past experience at low resolution, order 1000 years of integration will be needed, and the OMWG share will be 70% at 115 GAU per year, giving a total of 80.5 KGAU.

## Polar Climate Working Group (PCWG)

The Polar Climate Working Group proposes to use additional computing resources over the 6 month period, June - November, 2007 to conduct the following numerical experiments. This will complement simulations being performed under our existing CSL allocation.

1. **CICE4.0 Studies (Development):** Under existing CSL resources, a new sea ice model (CICE4.0) has been incorporated into the CCSM model framework. This model contains improved physical parameterizations for radiative transfer, snow properties, surface flux parameterizations, and ridging among others. While each new physical parameterization works well in isolation, the interactions among the different parameterizations have not been adequately explored and initial tests suggest some incompatibility among them. We propose to investigate the interactions among these parameterizations and make improvements or modifications where needed based on simulations of both the stand-alone sea ice model and fully-coupled model. We anticipate that this will require 5 integrations of 50 years length in fully coupled simulations (36 KGAU) and 6 integrations in stand-alone sea ice runs (9 KGAU), for a total cost of 45 KGAU.
2. **New Model Parameterizations (Development):** Snow model developments for the terrestrial system that are being examined within the context of the Community Land Model have shown some promise for inclusion into the sea ice component. For example, parameterizations for snow aging and its influence on radiative transfer may easily translate into improved treatments in the sea ice system. We propose to explore these improvements using stand alone ice model integrations. This will require numerous (10) short integrations of 25 years in length, requiring 7.5 KGAU of development resources. Additionally, a simulation in a coupled configuration of 50 years in length (7.5 KGAU) will be performed to obtain an initial estimate of the climate impact of such a parameterization.
3. **Ocean-Ice Equilibrium Integration (Production):** In collaboration with the Ocean Working Group (OMWG), we propose to obtain equilibrium solutions of ice-ocean coupled integrations at the x1 degree resolution. This will allow the long term effects of new parameterizations and parameter changes to be investigated. It will also allow for studies of the mechanisms driving sea ice changes over the observed record. Based on low-resolution studies, integrations of order 1000 years in length are needed to reach equilibrium conditions. The PCWG share of this will be 30% or 300 years, at 115 GAU per year this

amounts to 34.5 KGAU of production time.

4. **Influence of Ocean History on Future Ice Projections (Production):** In CCSM3 integrations, simulated low-frequency variability in the ocean circulation is important for driving changes in ocean heat transport to the Arctic with consequent impacts on the Arctic ice cover. We intend to further explore these interactions using new simulations of the CCSM3 model initialized with late-20<sup>th</sup> century conditions from existing integrations. In particular, we are interested in the influence of the ocean history on the timescale and character of near-future ice retreat. We propose to do 5 simulations of 25-30 years in duration which are initialized with different ocean states obtained from the sample of 8 ensemble members that are available. This will use the T85-gx1 resolution (at 275 GAU/yr) and amount to 37.5 KGAU of production time.

## Land Model Working Group (LMWG)

Proposed model development and production activities that are not covered in the original CSL resource request, to be conducted over the next 6 months in preparation for CLM4, fall into five areas: improving biogeophysical and hydrological parameterizations to correct biases or deficiencies in the model, installing new snow parameterizations, evaluating the impact of new versions of CAM and CLM on vegetation simulations, investigating land-atmosphere interactions in the new versions of CAM/CLM, participating in an international land cover change model intercomparison project, and evaluating a new soil nitrogen parameterization.

1. **Surface Biogeophysics and Hydrology (Development):** The LMWG recently completed the Community Hydrology Project, the result of which is a dramatically improved model (CLM3.5). However, a number of outstanding hydrology-related issues remain including addressing a weak top 1-m soil moisture variability bias, incorporating the physical properties of organic soil matter and assessing its impact on climate simulations, and introducing a deeper soil column to account for the thermal and hydrologic inertia provided by deep ground layers. Changes to hydrologic parameterizations can be tested and documented in 15 to 25-year AMIP style simulations of FV CAM/CLM at 1.9x2.5 degree resolution. Spin up timescales for the new hydrology scheme with and without a deeper soil column are not well understood. Long offline simulations will be conducted to evaluate the spin up timescales of the new model, with a total GAU estimate for the series of development simulations = 15K GAU.
2. **Improved Snow Parameterizations (Development):** The LMWG has initiated a project to evaluate and integrate a number of improvements to the snow model based on research by LMWG members over the last few years. This project is termed the Community Snow Project and is a collaborative effort. Improvements that are under consideration include explicit treatment of

vertically distributed radiative heating, a seasonally dependent snow cover fraction parameterization, more realistic snow burial fraction over short vegetation, and improved snow ageing parameterization that is based on dynamic snow grain size. Taken together, these changes are likely to result in improved simulations of snow albedo and snow water equivalents as well as an improved representation of snow-albedo-climate feedbacks. Total GAU estimate for series of CAM/CLM development simulations and two CAM/CLM/SOM 1% CO<sub>2</sub> simulations = 25 KGAU.

3. **Soil Nitrogen Parameterization (Development):** A new detailed and empirically-based soil nitrogen parameterization has been developed and requires testing for 1) gaseous NO<sub>x</sub> and N<sub>2</sub>O fluxes out of the soil and 2) the soil nitrogen balance. Gaseous NO<sub>x</sub> emissions from soil affect atmospheric oxidation chemistry. N<sub>2</sub>O is a radiatively important species. Soil N cycling has feedbacks into soil carbon cycling. The BGCWG and ACWG groups have identified better representation of soil-derived NO<sub>x</sub> and N<sub>2</sub>O fluxes as a priority need for CCSM4. In order to complete the testing, the new model needs to be spun up offline with CLM-CN (8GAU/yr) for 2000 - 3000 years, with a total GAU estimate = 20 KGAU.
4. **Dynamic Vegetation in CAM3.5/CLM3.5 (Production):** Preliminary analysis indicates that the improvements to the land and atmosphere models for CCSM3.5 will result in improved simulations of vegetation biogeography in CLM-DGVM. A series of experiments are proposed (CLM3.5-DGVM and CAM3.0/CLM3.5-DGVM and CAM3.5/CLM3.5-DGVM) that will isolate the impact of CLM improvements in hydrology and biogeophysics and CAM3.5 changes on vegetation biogeography. Total GAU estimate = 30 KGAU.
5. **Land-atmosphere Interaction (Production):** Recent changes to the land (CLM3.5) and atmosphere (CAM3.5) contribute to a strong reduction in land-atmosphere coupling strength (soil moisture-precipitation feedback). Land-atmosphere coupling strength in CAM3/CLM3 was high compared to other comparable GCMs while coupling strength in CAM3.5/CLM3.5 is low. A series of experiments using various versions of CAM/CLM will be run that will be used to explore the impact of land-atmosphere coupling on convectively-coupled waves (e.g. African easterly waves) and the frequency, amplitude, and duration of simulated droughts. Total GAU estimate for series of AMIP-style sensitivity experiments = 12 KGAU.
6. **Land Cover and Land Use Change (Production):** As part of an international comparison among major climate modeling groups, we will perform the following suite of simulations to assess the land use forcing of climate. This involves up to 20 30-year CAM/CLM simulations with prescribed SSTs and sea ice. Total GAU estimate = 30 KGAU.

## Chemistry Climate Working Group (ChemWG)

The Chemistry-Climate Working group proposes to use additional computing resources over the period June - November, 2007 to conduct the following numerical experiments. This will complement simulations being performed under our existing CSL allocation.

1. **Emissions (Development):** The “Pioneer Agriculture Revolution” occurred during the late 1800s when a large fraction of the forested land over the U.S. was cleared. There is convincing evidence for a sustained anthropogenic biomass burning event during this time. We propose to simulate possible scenarios of biomass burning emissions in the late 1800s and their ramifications for atmospheric chemistry and climate. We propose 5 sensitivity studies of 10 years each during the late 1800s using CAM FV 1.9 x 2.5. The total computational cost at 200 GAU/year is 10 KGAU.
2. **Photolysis and Cloud Overlap (Development):** The photolysis of chemical constituents and the modification of the photolysis rate by clouds and aerosols are important drivers for atmospheric chemistry. We propose to incorporate the Prather Fast-j parameterization with the Neu formulation of cloud overlap into CAM-MZ4. We propose 10 simulations of 1 year each with CAM FV 1.9 x 2.5 to develop this scheme. The total computational cost at 200 GAU/year is 2 KGAU.
3. **Aerosol Direct Effect (Development):** Xiahong Liu and Steve Ghan are developing a modal aerosol scheme for CAM-MZ4 which allows for a more accurate representation of aerosols than has been possible to date. This scheme will allow for internally mixed aerosols as well as prognostic number and mass calculations. We propose GAU three benchmark simulations of 10 years each using different versions of this aerosol scheme. Using CAM FV 1.9 x 2.5 the computational cost is at 400/200/100 GAU/year (depending on the aerosol scheme used) is 7 KGAU. We also propose to investigate the impact of adding ammonia to the CAM-MZ4 aerosol scheme for comparison with the Barth/Rasch sulfate scheme with input oxidants. This would require 5 five year simulations with chemistry and 5 five year simulations without chemistry. Using CAM FV 1.9 x 2.5 the total computational cost at 220/64 GAU/year is 7 KGAU.
4. **Chemistry and Physical Parameterizations (Development):** The physical parameterizations within CAM are in a state of flux. The current convective scheme will be replaced in CAM3.5, with possible future changes to other transport parameterizations. We propose 4 simulations of 5 years each to test impact of the new physical parameterizations on chemistry and evaluate this impact against chemical measurements. Using CAM FV 1.9 x 2.5 the total computational cost at 200 GAU/year is 4 KGAU.

5. **20<sup>th</sup> Century Forcing (Production):** Currently the atmospheric chemistry group is in the process of simulating the radiative forcing of aerosols during the 20<sup>th</sup> century using a version of CAM-MZ4 (CAM with MOZART-4 chemistry) with input oxidants and the Barth/Rasch sulfate aerosol parameterization. Output from this run will be used as forcing for the spin up of CCSM3.5. We propose additional GAU to repeat this run using interactive chemistry, a more sophisticated aerosol parameterization (including ammonia nitrate) and a new inventory of surface emissions from 1870-2000 (developed by Claire Granier). In addition, we will incorporate land-use change distributions for this period developed by Johan Feddema (University of Kansas), allowing emissions of hydrocarbons from the vegetation to evolve over the 20<sup>th</sup> century. This simulation will be for 130 years (1870-2000) using CAM FV 1.9 x 2.5. The total computational cost at 200 GAU/year is 26 KGAU.
6. **Secondary Organic Oxidants (Production):** Recent calculations and measurements suggest that the source of secondary organic aerosols (SOA) is underestimated by an order of magnitude in model calculations. Colette Heald has recently implemented a biogenic emission scheme (MEGAN: Model of Emissions of Gases and Aerosols from Nature) into the CLM with an associated update to the secondary aerosol scheme currently in CAM. To examine the impact of SOA on chemistry and climate we propose 3 future simulations of 11 years each using CAM FV 1.9 x 2.5 and 6 present day simulations of 2 years. The total computational cost at 200 GAU/year is 10 KGAU.
7. **Data Assimilation (Production):** An ensemble Kalman filter has been implemented into a version of CAM-MZ4 with simplified chemistry through DART (Data Assimilation Test Bed). This system, as currently implemented, is designed to assimilate meteorology and satellite derived CO. We propose two additional runs of this system (consisting of 20 ensemble members each) with full chemistry and the assimilation of CO and ozone. Using CAM FV 1.9 x 2.5 the total computational cost is at 200 GAU/year is 8 KGAU.
8. **Air Quality (Production):** The effect of climate change and future emissions on air quality is an important consideration in assessing the impact of global change. Air quality exceedances often occur on local scales and air quality is sensitive to non-linearities in the chemistry. Global chemistry models are necessary to ascertain changes in air-quality due to the global impact of climate on chemistry as well as changes in transboundary chemical transport. We are requesting two five year simulations with CAM: one using FV 1.9 x 2.5 and the other FV 1 x 1.25. The total computational cost at 200 and 1340 GAU/year is 8 KGAU. We also propose 4 simulations linking WRF-chem to CAM-MZ4 during the summer season (each simulation is 4 months). The total computational cost at 3760 GAU/year 6 KGAU.
9. **Hindcast Experiments (Production):** Over the last 35 years considerable changes in chemical and aerosol emissions have occurred along with important

changes in climate. In addition during this period atmospheric chemical measurements have become increasingly numerous. This hindcast simulation is also aligned with the objectives of the Atmospheric Chemistry and Climate Initiative (AC&C) endorsed as a joint effort of WCRP and IGBP. For a 35 year hindcast simulation using CAM FV 1.9 x 2.5 at 200 GAU/year the total computational cost is 7 KGAU.

10. **Model Evaluation (Production):** In recent years, satellite and aircraft measurements are available for rigorous model evaluation during specific field campaigns. We are requesting 16 simulations of 2 years each using CAM FV 1.9 x 2.5 for targeted comparisons with aircraft campaigns. The total computational cost at 200 GAU/year is 7 KGAU.

## Paleoclimate Working Group (PaleoWG)

1. **Arctic and Antarctic Warmth at the Last Interglacial (Production):** 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). We will 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 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. The total length of integrations is 400 years with a computational cost of 39 KGAU.
2. **Pliocene Warmth – Analog for Future Warming? (Production):** As compared to the Quaternary periods of warmth, which show seasonal and latitudinal warmth but not significant global, annual warmth, the mid-Pliocene (approx. 3.5 my BP) is a period of increased atmospheric CO<sub>2</sub> levels and global warming. Given the relative similarity of boundary conditions to modern, and the fact that carbon dioxide concentrations are reconstructed in the range that Earth will experience within the next 50 years or so (~400ppm), this Pliocene warm period may represent the closest paleoclimate analogue to the future. We will use CCSM3 at T42x1 resolution and coupled to dynamic vegetation for this integration. This relatively high resolution simulation is fitting because it represents the current state of the art for this period and because the nature of the hypothesized crucial interactions during this period requires an excellent treatment of deepwater formation and sea-ice interactions. We will follow this simulation with experiments designed to test the sensitivity of the tropical mean state and the impacts of these tropical states on global climate. The total length

of integrations is 600 years, with a computational cost of 59 KGAU.

3. **Cretaceous Greenhouse Climate (Production):** 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. A series of Late Cretaceous simulations will be carried out. Three simulations will be completed with specified concentrations of CO<sub>2</sub> and CH<sub>4</sub> representing pre-industrial, high (~4 x PAL CO<sub>2</sub>) and extreme levels (~10 x PAL CO<sub>2</sub>). We will use the T31 x 3 version of CCSM3 for these studies. These simulations were strongly requested by the working group community. The total length of integrations is 2000 years, with a computational cost of 40 KGAU.

## Climate Variability Working Group (CVWG)

The Climate Variability Working Group's efforts are broadly focused on analysis of natural and anthropogenically-induced patterns of climate variability and their underlying dynamical and thermodynamical mechanisms in CCSM3 and its component models, as a means of furthering our understanding of the observed climate system. The main scientific goals of the additional runs proposed are: How are droughts and pluvials generated over North America? What is the role 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?

1. **CAM3 integrations to investigate drought genesis and maintenance, especially, over North America (Production):** Integrations will be coordinated with those at other modeling centers. 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. The second integration will involve modification of North American orography. Orographic features, such as the Sierra Madre Oriental, play an important role in shaping Great Plains hydroclimate, by influencing the formation of the Great Plains low-level jet in boreal summer months. Both integrations are viewed as perturbations of the CAM3 "control" integration. The computational cost is 120 years of integration of CAM 3 at 25 GAU/year, which is 3 KGAU.
2. **Climate of the 21st Century IPCC Scenario Integrations with CCSM3 (Production):** CVWG has initiated a set of IPCC scenario runs with CCSM3 at T42 resolution, in conjunction with the Climate Change Working Group. 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. 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 (~50 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. We are proposing to complete these runs during this upcoming CSL allocation period. The computational cost is 10 x 9.5 KGAU for the 21st Century Scenario ensemble runs, and 40 x 10 x 25 GAU for the CAM 3 runs, which is a total computational cost of 105 KGAU.

## Climate Change Working Group (CCWG)

1. **IPCC WG3 Adaptation/Mitigation Scenarios (Production):** The IPCC WG3 has requested a suite of climate change adaptation/mitigation scenarios assuming political intervention and/or technological progress targeting certain GHG stabilization levels to accompany the IPCC SRES scenarios. 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 IPCC Working Group III 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 dataset to WG 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 dataset for those who study impacts of climate change on ecosystems and human society. These simulations were proposed under the CCWG original CSL request, but were dropped due to the cut in our allocation. The total set of runs will require four 100-year T85 CCSM runs: two baseline cases and two intervention scenarios, each covering the period 2000 - 2100. We are proposing to run two of the four members of this experiment under CSL time and acquire the remaining time through divisional and directorate reserves. This will require 2 100-year T85 runs at 360 GAU/yr = 72 KGAU.
2. **Effect of hurricane induced mixing and heat release on THC and MHT in the Atlantic (Production):** Given the nature of the coupled climate model, the effect of hurricanes is normally ignored since the model resolution is too coarse

to resolve the hurricane and even very hard to parameterize the hurricane into the climate models. Recent research indicates that the hurricane may have significant influence on the meridional heat transport in the Atlantic and the strength of the meridional overturning circulation. Here we propose a few runs to test this hypothesis using the T42 version of the CCSM3. Three idealized hurricane paths will be constructed based on observations and the mean number of hurricanes in the Atlantic will be included. This first test run will be branched from the T42 CCSM3 1990 control simulation to include the effect of the hurricane induced mixing and heat exchange between air and sea on THC and MHT. The result will be compared with the standard control run. The length of the run should be 100 to 200 years. Second, the effect of the variation of hurricane intensity on the THC and MHT will be tested by increasing the hurricane intensity without changing the total number of tropical cyclones (100-200 years). And the effect of the variation of hurricane frequency on the THC and MHT will be evaluated by increasing the number of hurricanes without changing their intensity. This work will require 3 150-year T42 runs at 66 GAU/yr = 30 KGAU.

## Software Engineering Working Group (SEWG)

The SEWG is actively involved in all stages of CCSM production and development and 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 scientific and software development, associated with the creation of CCSM3.5, is occurring across all CCSM model components. As a result, new CCSM revisions are being constructed on a weekly basis. CCSM revisions are also created for patches made to the CCSM3.0 release. We project that at least four revisions will normally be created each month.

The SEWG will perform numerous short tests on each new CCSM revision to ensure reliability on CSL production machines. These tests will be performed on Bluevista, Blueice and Lightning. Test cases include the verification of performance throughput, load balance, exact restart, branch startup and hybrid startup functionality for a variety of CCSM configurations and resolution. Since the CCSM3.0 release, the test parameter space has significantly increased resulting in a continually expanding regression validation test suite. We are currently running between 200-250 tests every month. Examples of new tests include validating the transfer of inter-component BGC fluxes and tracers and the incorporation of atmospheric chemistry within the finite volume (FV) dynamical core. Each test type is often run in more than one resolution and configuration. If a test fails, one or more additional tests are required to validate bug fixes to the original failed test. 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 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 failures. The CCSM test suite is run for all CCSM revisions including those submitted by external collaborators such as DOE's SciDAC project. All these additional tests will require an additional 10 KGAU/month under development, for a total of 60 KGAU.

CCSM has made it a very high priority to improve the efficiency of the model system. Concern was raised regarding the performance of CCSM3 on the IBM supercomputers at NCAR, following the presentation of some code efficiency measurements to the CCSM Advisory Board. These measurements indicated that CCSM was less efficient, by about 30%, than other large codes running on these platforms. A detailed CCSM3 performance study was undertaken to address these concerns. The result of this work demonstrated that the individual components in CCSM3 are as efficient as other typical geophysical codes running on the IBM supercomputers, but that the concurrent design has some inherent performance overhead that accounts for the measured efficiency decrease. This overhead was shown to be associated with the concurrent scheduling of multiple components and the blocking associated with the sending or receiving of data between the components and the coupler which resulted in idle processor times during CCSM simulations. This overhead can be quantified as an average percent utilization of processors and its measurement has been incorporated into a new CCSM specific user-friendly performance tool mentioned below. A final document, “CCSM Efficiency and Performance on the NCAR IBM Machines”, was written to summarize these findings and was presented to users and management in several forums.

We have taken various steps to optimize CCSM performance and efficiency. CCSM load balancing involves the process of determining the optimal number of MPI tasks and Open-MP threads for each CCSM component in a given CCSM configuration and resolution. Proper load balancing can result in a dramatic difference in overall CCSM performance and efficiency. We have significantly improved the load-balancing process by developing a user-friendly automated load-balancing utility that provides detailed statistics related to CCSM efficiency and throughput during the entire course of a model run. In addition, we are ensuring that all CCSM users are leveraging SMT functionality in CCSM production runs. To that end, we modified the CCSM scripts to utilize SMT as the standard “out of the box” configuration. We also developed a guide for utilizing SMT in CCSM, <http://www.cisl.ucar.edu/docs/bluevista/ccsm.html>, sent this document to the CCSM user-community and worked with CISE to have it published on the CISE web site.

The table below has been updated from the earlier report to include post-SMT bluevista and blueice efficiency measurements. The CCSM efficiency values have been tallied from recent multi-day verification or production runs. Platform workload averages are quoted from the CISE Hardware Performance Monitor Statistics webpage.

**CCSM 3.5 Efficiency Values (percent of peak)**

<b>Supercomputer</b>	<b>CCSM</b>	<b>Workload Average</b>	<b>“Best” App</b>
bluesky	2.8 %	4.13 %	10 %
bluevista (pre-SMT)	7.0 %	10 %	16 %
bluevista (post-SMT)	7.84 %	8.15 %	-
blueice	7.03 %	7.24 %	-

Values for the “Best” applications are not provided for the additional platforms, and the source of the earlier values is unknown. In general, this table shows that CCSM is running very close to the workload average on each platform. In addition, on bluevista CCSM’s efficiency has increased despite a decrease in that platform’s average from pre-SMT to post-SMT. The results show that the SEWG has successfully adapted CCSM to the SMT environment, increasing its measured efficiency, in terms of percent of peak performance, to be within 4% of the workload average on both bluevista and blueice. In addition, CCSM’s performance on bluevista actually increased despite a significant decrease in that platform’s workload average.

As presented in the earlier report, CCSM is a system of model components and cannot be readily compared to single model codes typically running on the NCAR machines. CCSM performance was previously noted to be approximately 70% that of WRF and CAM. A cursory survey of the CISL HPM job pages shows that WRF and CAM can still both attain higher maximum efficiency than CCSM, where the maximum achieved by CCSM is still 70-75% the maximum of either single model code. However, both CAM and WRF display a wide range of efficiency measurements. This difference in performance was shown to be directly attributable to the overhead of CCSM’s concurrent architecture.

In conclusion, the SEWG has been successful in adapting to the SMT environment of bluevista and blueice. Its efficiency is very close to the workload average on each platform, despite the overhead of its system architecture. In trying to improve the performance of CCSM on Blueice, we are also examining the effects of implementing processor binding, multiple page sizes, and new compiler optimizations. As new science is added to the development CCSM as part of the creation of CCSM3.5, we will continue placing a very high priority on ensuring that our code base runs as efficiently as possible on both Blueice and Bluevista.

## Estimate of CCSM 3.5 GAU Costs on Blueice

<b>Runs</b>	<b>GAU/Sim Year</b>	<b>CPU-hrs/Sim Year</b>
<b>ccsm3_1_beta43 coupled integrations</b>		
fv1.9x2.5gx1v4	145	165
fv1x1.25gx1v3	360	410

<b>ccsm3.5 coupled integrations (estimated)</b>		
fv1.9x2.5gx1v4	165	190
fv1x1.25gx1v3	390	450
fv1.9x2.5gx1v4 w/ carbon cycle	300	342

<b>ccsm3.5 special configurations (estimated)</b>		
1-degree POP standalone (40 levels)	85	96
1-degree POP standalone (60 levels)	110	126
1-degree POP+CICE4 (40 levels)	90	100
1-degree POP+CICE4 (60 levels)	115	133
1-degree CICE4 standalone	30	35

<b>standalone ccsm3.5 components (estimated)</b>		
fv1.9x2.5 CAM+CLM standalone	45	52
fv1x1.25 CAM+CLM standalone	270	312
fv1.9x2.5 CAM + Chemistry standalone	200	230

---

CCSM gratefully acknowledges our primary sponsors,  
The National Science Foundation and  
The Department of Energy

