CCSM

Community Climate System Model

Proposal for CSL Resources – Development

12/01/2007 – 05/31/2009

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Overview

Project Title
Community Climate System Model: Development

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Current CSL Allocation
130 KGAU/month

Request in this Proposal:

Working Group	Dec. 07 – Nov. 08	Dec. 08 – May 09
AMWG, OMWG, BGCWG	20 KGAU/month	50 KGAU/month
LMWG, PCWG, ChemWG, SEWG	16 KGAU/month	40 KGAU/month
PaleoWG, CCWG	4 KGAU/month	10 KGAU/month
Total	**132 KGAU/month**	**330 KGAU/month**

Thus, the total request is for 3564 KGAU over 18 months.

Introduction

The recent accomplishments of the CCSM project are more fully described in the accompanying report. Over the first half of 2007, an interim version called CCSM 3.5 has been assembled. This uses the new finite volume dynamical core in the atmosphere component, the updated POP 2 code for the ocean component, the latest CICE 4 version for the sea ice component, and a much updated version of the land component compared to the CCSM 3. There have also been significant parameterization improvements in all the components. Probably the most significant improvement in CCSM 3.5 is in its simulation of the El Nino – Southern Oscillation (ENSO) in the tropical Pacific Ocean. All previous versions of the CCSM, and most other climate models, had a peak in the ENSO frequency near 2 years, which is much shorter than in reality. This problem has now been corrected in CCSM 3.5, which shows a frequency peak between 3-6 years. These improvements were documented and shown at the CCSM Workshop in June 2007.

Further development of the CCSM is planned over the next year, with the CCSM Implementation Plan suggesting that the model will be defined during 2008, and the model code, and some standard control runs, to be released and made available to the whole community by the CCSM Workshop in June 2009. Over this time period, there will also be significant development in the carbon cycle to be released with the CCSM 4, and in the atmospheric chemistry component that is being developed for CCSM 4.

This plan for the development and release of CCSM 4 cannot be accomplished without CSL computer resources, which are the lifeblood of the CCSM project. Indeed, the CCSM project has used almost all of the CSL computer resources awarded to it in the past. These resources are actively managed across the project based on the priorities set by the Science Steering Committee. The CSL resources are the glue that keeps the CCSM functioning as a community project. The remainder of this proposal contains the requests from the CCSM Working Groups that describe the proposed scientific use of the CSL resources for development runs.

Atmosphere Model Working Group (AMWG)

1. Research Plan

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

- understanding Earth's climate using the Community Atmosphere Model (CAM) and other CCSM model components.
- understanding the behavior of our current model and the processes controlling that behavior.
- improving the representation of processes that are poorly represented in CAM.
- adding new capabilities to CAM important for understanding chemistry, aerosols, and climate.

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

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

Category Two of the research agenda is designed to further our understanding of atmospheric processes and the ways that they interact with other components of the climate system. For example, we are working on major revisions to the model cloud and aerosol microphysics Our revisions to the cloud microphysical parameterization include explicit prediction of the mass and number of liquid and ice phase condensate and their interactions with aerosol. These revisions allow us to study aerosol direct and indirect effects much more realistically than CAM3 parameterizations. Such a complex scheme may prove too costly for the final production version of CAM4, but we believe that exploratory studies will help to identify where compromises can be made. We are also exploring revisions to the formulation of cloud fraction, cloud overlap, and the inhomogeneities in water substances to explicitly acknowledge the subgrid-scale nature of these fields via a statistical (probability distribution function, PDF) approach. The PDF approach to cloud properties is intimately tied to the formulation of the cloud microphysics and radiative transfer, and an investigation of these interactions will also take place over the next year through a microphysics task team that we have recently formed.

The improvements to the microphysics of clouds are intimately connected to the representation of aerosols. We have completed (in collaboration with the BGCWG and Chemistry-Climate WG) a bulk aerosol module that produces predicted concentrations of four sizes of sea salt and dust and carbonaceous aerosols, in addition to the sulfate aerosol module released with CAM3. Although this is a significant improvement over CAM3 aerosol representations, we hope to replace this formulation with a modal representation for aerosols developed by Ghan and Liu at PNNL in collaboration with the AMWG, BGC, and Climate-Chemistry WG. Adding to our understanding of cloud and aerosol processes in the atmosphere provides a natural prelude to the studies of climate sensitivity that have formed as a continuing area of focus to members of the AMWG over the last 10 years. We have also begun explorations of the role of various types of turbulent mountain stress and form drag that have not been represented in earlier versions of CAM. These new representations substantially change the stationary wave pattern in the Northern Hemisphere and may have an effect on the “excessive sea ice problem” seen in our current coupled CCSM simulations.

Finally, we continue to explore the sensitivity of the model simulations to variations in vertical and horizontal resolution and to the numerical methods used to solve atmospheric dynamics and transport. We are now exploring changes to the vertical layering that increase resolution near the surface by as much as a factor of 5 (to approximately 20m thick layers near the surface. We make simulations with both comprehensive physical parameterizations and using simplified representations for physical processes (for example, “waterworld” and Held-Suarez type simulations).

2. Scientific Objectives

A. Certainly one of our primary goals is to produce a state-of-the-art general circulation model for the research community. Our interim CAM3.5 model has already substantially reduced the biases present in CAM3. Preliminary versions of the University of Washington shallow cloud and PBL parameterizations show additional improvements. We also are working to produce a model that provides new functionality designed to allow the CCSM to deal with new classes of problems in chemistry-climate interactions and biogeochemical cycles.

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

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

3. Computational Requirements

We have formulated our proposal in the context of a series of runs with the FV model. Our baseline model is assumed to be a 30-level 2x2.5-resolution configuration. The baseline model will cost about 70 GAUs per year. The table below lists a set of 10-year runs that span the spectrum of projects discussed previously. We have found that a 10-year run is the minimum length required to allow the land-atmosphere system to approach an equilibrium, and this length run reduces the interannual variability of the system sufficiently that a first look at the atmospheric climate is viable.

These runs are designed to explore the effect of improved processes (convection, cloud properties, momentum transport, etc.) on the climate and to explore new climate interactions (e.g., aerosol/cloud indirect effects). The runs labeled “revised physics” will include some combination of alternate convection, shallow convection, turbulent mountain stresses, boundary layer parameterizations, and cloud fraction parameterizations. They are grouped together because they all cost approximately the same amount. The runs labeled IPA are runs employing the independent pixel approximation. These runs can vary widely in cost, depending on the precise configuration. It is, of course, impossible to provide a precise description of the runs and configurations that we will explore. These estimates are based on a reasonable mix of explorations of the topics described above.

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
Revised physics	FV2x2.5	150	10	70	105
Aerosols	FV2x2.5	10	10	140	14
Modal Aerosols	FV2x2.5	10	10	200	20
New cloud microphysics	FV2x2.5	15	10	100	15
IPA	FV2x2.5	10	10	210	21
Vertical resolution	FV2x2.5	90	10	140	126
Horizontal resolution	FV1x1.25	30	10	420	126
Horizontal resolution	FV3x4	30	10	30	9
Horizontal resolution	FV0.5x0.5	4	10	2400	96
Slab Ocean Model (SOM)	FV1x1.25	12	10	70	8
TOTAL					540

Ocean Model Working Group (OMWG)

1. Research Plan

Historically, ocean model development comes in two flavors; support of specific science objectives and maintaining a state-of-the-art ocean component for CCSM. The former ensures that CCSM fully contributes to science especially that described in the OWG Production proposal. Activities under the latter are motivated by the necessity to keep CCSM at the forefront of ocean climate models, and involve a continual high level of effort and support. The proposal as written, assumes very optimistic expectations, which by the very nature of model development will likely not always be achieved. Therefore, model integrations have been prioritized, so if high priority efforts get bogged down, there will be some scope for providing more computing resources at the expense of lower priority work.

2. Science Objectives

The overall objective remains the delivery of a package of documented ocean model improvements to the CCSM community and specifically targeted on the science outlined in the production proposal. The science objective is to understand the behavior of the various model developments both individually and as they interact with the others, both in forced (uncoupled) and fully coupled modes. Such interactions are often surprising, and must be investigated before a new model is adopted. It is the increased computational resources that now permit thorough exploration within a fully coupled CCSM.

The most important science objective of the development effort is to reduce biases in the fully coupled CCSM. The most difficult bias to assess is ENSO variability, because of the inherent non-stationarity. However, the OWG is now proposing much longer coupled integrations (200 to 250 years), so that robust ENSO statistics can be determined and compared between cases.

3. Proposed Experiments and their Computational Requirements

The accompanying Table summarizes the proposed experiments and their computational requirements. Each class of experiments is justified in one of the following sub-sections.

Ocean Model Physics

a) *Vertical Resolution*
Preliminary studies of the effects of modifying the POP vertical grid in ocean-alone runs have shown dramatic improvements in upper ocean biases associated with reducing the near-surface grid thickness from ~10m to ~6m. Further ocean or ocean/ice experiments at 1 degree resolution are needed to establish the convergence of upper ocean solutions as vertical resolution is enhanced and/or redistributed in depth (5 twenty year experiments = 100 simulation years). The results of the above experiments will guide the design of 2 coupled FV2_x1 integrations, to be run for 100 years each with the only difference being ocean vertical grid. The choice of an optimal vertical grid can then be based on intercomparisons of ocean-alone and fully coupled solutions.

b) *Vertical Mixing*
Two different proposed hypotheses for the sink of internal wave energy: first at 30N/S through subharmonic instability, second at the continental margins where the energy gets trapped and eventually dissipated. These hypotheses lead to very different spatial and temporal distributions of vertical diffusivity. Initial experiments suggest that the distribution of vertical mixing can radically change the precipitation and wind pattern, and that the equilibration timescale is on the order of decades. Thus, we plan two 200 year fully coupled FV2_x1 runs: enhanced mixing at 30N/S; enhanced mixing along steep topographic ridges.

c) *Parameterized Ocean Sub-meso-scale*

The latest theoretical and process study discovery of the CLIVAR CPT on Ocean Eddy Mixed-Layer Interaction is a parameterization of the sub-meso-scale (1 km) ocean flow. Suspected impacts include more physical restratification of the ocean following deep convection, or strong wind-driven mixing. Verification data are available from the Labrador Sea and hurricanes, respectively. The proposed development experiments are designed to explore the sensitivity of the model solutions to the range of parameters of this new sub-meso-scale scheme. The OWG plans to conduct a number (approximately 7) of relatively long experiments (300 years), so that some deep convection signals can emerge. Following successful past practice, the coarse resolution version of the ocean model (3 degrees) will be used, so that only 10 GAUs per simulated year are needed. We will also investigate if the other related parameterizations need to be retuned when the submesoscale scheme is active.

CCSM Eddy Resolved Ocean Models

d) *Global eddying resolving model*

Recent experience gained with a global eddy-resolving (0.1 degree) version of POP indicates rather different sensitivities of the tropical circulation system to forcing, numerics, and dissipation choices. In particular, the Equatorial Undercurrent strength and structure in the high resolution model are rather insensitive to the choice of lateral viscosity, and quite sensitive to the choice of tracer advection scheme. Both of these results are contrary to the sensitivities exposed in the CCSM x1 ocean component, indicating that the tropical dynamics in the less dissipative, high resolution model are in a distinct regime from the CCSM model. However, due to the high cost of the eddy-resolving global model, a number of overlapping sensitivities to individual model choices could not be distinguished. In preparation for anticipated progress toward a version of CCSM with a global eddy resolving ocean, we propose three experiments, to be compared to an existing Control, which will uncover the sensitivity of the tropical Pacific circulation in a 0.1 degree tropical Pacific basin model extracted from the global domain. Each experiment is integrated for 10 years, starting from rest. The cost of the 40 level 0.1 degree Pacific basin model is 3600 GAUs per simulated year. The first differs from the Control in that stress will be dependent on surface current, as in CCSM. The second will use flux limited Lax-Wendroff tracer advection instead of centered advection. The third will be like the more promising of the first two, but will use a high-order spatial interpolation of winds from the atmosphere to the ocean grid.

e) *Nested Regional*

The software engineering associated with nesting a high resolution (20 km) Regional Ocean Modeling System (ROMS) within the CCSM POP ocean model should be completed within a month. The nesting about doubles the computation cost of the coupled system. Three coupled experiments are proposed; one with a

ROMS nest off the coast of California, another with a nest off the coast of Peru/Chile, and finally one with a nest off the coast of Southwest Africa. These are locations of the largest sea surface temperature biases in CCSM3, and the improved upwelling physics of the nested ROMS is expected to have large scale remote positive impacts on the simulated climate. 40 year integrations are proposed, so that at least a preliminary assessment of ENSO influences can be determined.

Coupled Modeling

f) *ENSO Amplitude*

Over the last couple of years we were able to understand and fix the frequency characteristics of ENSO; but not its amplitude. Thus, we are regularly surprised at the impact that seemingly unconnected model changes have on the ENSO amplitude. To guide model development and to understand how ENSO will change in a warming world, we need to know what determines the amplitude in the model. Theory and idealized studies suggest a whole range of possibilities. They will first be verified by analyzing CCSM3.5 output, and then we will do 3 experiments of 250 years to develop the most promising hypotheses (not known currently).

g) *Tropical Seasonal Cycles*

Despite the improvements in ENSO frequency, and in addition to the above questions regarding ENSO amplitude, outstanding biases remain in the tropics of CCSM. One of the most prominent and long standing of these biases is the seasonal cycle in the eastern tropical Pacific. It is to be addressed, by forming a CCSM wide Tropical Seasonal-cycle Task Team (TSTT). A similar approach with a Tropical Variability Task Team (TVTT), contributed to the latest improvements to ENSO. First, hypotheses will be put forward and their testing will require an estimated 10 fully coupled experiments, which fortunately need be only for about 10 years, because the seasonal biases develop quickly in both the atmosphere and ocean.

h) *Decadal Projections/Predictions*

The new high priority focus for CCSM is short term (approximately 30 years) climate projections, but the methodology needs to be developed. This work was begun in June 2007, following the increase in CSL resources at that time, but will continue for years, and include numerous partnerships. Actual “projections” are being proposed in the “OWG production proposal,” but associated development activities are included here. The specific model integrations are short (10 years) coupled model runs to test various initialization techniques.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Ocean Model Physics					
a) Vertical Resolution	xlocn / ice	5	20	125	13
	FV2_x1(120)	2	100	400	80
b) Vertical Viscosity	FV2_x1	2	200	200	80
c) Parameterized Ocean Submesoscale	x3ocn	7	300	10	21
CCSM Eddy Resolved Ocean Models					
d) Global	Pacific .1	3	10	3600	108
e) Nested Regional	POP / ROMS	3	40	400	48
Coupled Modeling					
f) ENSO Amplitude	FV2_x1	3	250	200	150
g) Tropical Seasonal Cycles	FV2_x1	10	10	200	20
h) Decadal Projections / Predictions	FV2_x1	10	10	200	20
TOTAL					540

Land Model Working Group (LMWG)

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

Model development to be conducted over the period December 2007 – May 2009, under the auspices of the LMWG, falls into six main areas: a) improving biogeophysical and hydrological parameterizations to correct biases or deficiencies in the model; b) continuing efforts to improve the representation of the terrestrial carbon, water, and energy cycles and to couple the carbon cycle and vegetation dynamics in the model; c) improving the representation of sub-grid scale permafrost processes in the model, especially with respect to soil subsidence and wetlands; d) adding an irrigation capability to the model; e) continuing development of downscaling algorithms for the high-resolution version of CLM, and (f) contributing to the integration of a dynamic Greenland ice sheet model into CCSM. Our general development strategy will be to conduct preliminary development work offline. However, more effort will be made to evaluate the model in a coupled framework (e.g. CAM-CLM) early on in the development process. This strategy is reflected in the proposed simulations catalog in which most projects include both offline and coupled simulations.

1. Surface Biogeophysics and Hydrology

The LMWG completed the Community Hydrology Project in the spring of 2007, the result of which is a much improved model (CLM3.5). More recent efforts in this area have focused on correcting what appears to be a systematically weak top 1-m soil moisture variability. The concern is that weak upper level soil moisture variability contributes to weak variability in plant water stress seen in the model which, in turn, has an impact on the simulation of the variability of the water and energy cycles. A broad variety of solutions have been suggested by members of the LMWG to reduce this low variability bias.

A longer term goal (which may also contribute to the reduction of this bias) is to incorporate geographical information about the depth to bedrock. The thickness of soil above the underlying bedrock varies considerably over the terrestrial land-surface, ranging from very thick in places like the Amazon rain forest to very thin in the northeastern United States. The thickness of the soil has a strong influence on its water holding capacity and consequently on the timing and extent of runoff The idea is to use depth-to-bedrock data, provided by the Global Soil Data Task, to derive a new layered soil (and rock) texture dataset for use in CLM. Thermal and hydrologic properties of rock will be assigned to the rock layers while properties for the soil layers will be determined as before.

The LMWG is also developing and testing new formulations for within canopy turbulence. A prognostic canopy air space formulation is being added to CLM so that heat, moisture, and CO_2 within the canopy can be simulated. This is expected to improve the simulated diurnal cycle, the numerical stability of the model, and the trace gas fluxes of the model.

2. Carbon Cycle and Vegetation Dynamics

Recent developments in CLM allow for the simulation of both the terrestrial carbon cycle and vegetation dynamics. Work will continue to merge the terrestrial carbon cycle model (CLM-CN) with the vegetation dynamics model (CLM-DGVM) to create a consistent model of terrestrial ecosystems that can simulate both changes in vegetation structure and vegetation biogeography.

Two other projects related to the carbon cycle and vegetation dynamics are also planned. The first is to integrate the soil organic matter thermal and hydrologic parameterizations that have been developed to improve the simulation of soil temperature dynamics with the prognostic soil carbon content calculated in CLM-CN. This will result in a more dynamic representation of soil conditions in CLM-CN. The other project is to incorporate shrubs into the DGVM. At present, the DGVM only simulates the biogeography of a variety of tree and grass plant functional types. Recent work by the group at the University of Arizona has focused on the addition of semi-arid and boreal shrubs into the DGVM. The new DGVM shrub version needs to be incorporated into the latest configuration of CLM-CN-DGVM, and tested globally.

3. Permafrost and wetlands

Permafrost degradation may initiate a number of feedbacks to the hydrological and biogeochemical cycles that are of global relevance. Recent improvements to CLM (a representation of the thermal and hydrologic properties of organic soil that can be applied globally and an extension of the soil column to ~50m) have significantly improved soil temperature and hydrology dynamics in icy soils and have demonstrated that permafrost can be represented within the framework of a climate model. Further improvements are being developed, including a sub-grid scale representation of thermokarst (soil subsidence as ice melts) and associated changes in wetland and or lake area. This will require the incorporation and development of dynamic wetland and lake parameterizations. This is a longer term project, and is not likely to be part of CLM4.

4. Irrigation

The contribution of irrigation to seasonal evaporation fluxes is considerable in regions where irrigation is integral to agricultural practices. The inclusion of irrigation into CLM is desirable, therefore, from the perspective of the water cycle. It would also provide a more direct representation of the human influence on climate and facilitate the analysis of the vulnerability of agricultural practices in a future climate. To this end, initial efforts to implement an irrigation scheme into CLM have been initiated. Irrigation fluxes are derived from a gridded data set of present-day irrigation. In order to model irrigation more realistically, crops need to exist on their own soil column, which is a software feature of CLM that until now has not been exploited. Water will be conserved by removing irrigation water from rivers and aquifers. Other proposed activities include development and testing with a historical data set of irrigation (there is a group at the University of Frankfurt that is nearing completion on such a data set), and allowing irrigation demand to evolve as climate and agricultural practices change over time. Much of the testing can be completed in offline mode with additional simulations in CAM-CLM also anticipated.

5. Greenland ice-sheet model

The LWMG is working with Bill Lipscomb at the Los Alamos National Laboratory to couple a dynamic ice sheet model (GLIMMER) to CCSM. Initial experiments with a positive degree day scheme for the coupling proved to be highly unstable. At the June CCSM meeting, we decided to move forward with an energy balance approach. The implementation of the energy balance solution requires an intricate interfacing with CLM as well as improvements to the glacier physics that are currently used in CLM. The computer resources requested under the CSL allocation are only for testing and development of the software engineering and energy and water balance aspects of this project. Full simulations of the ice sheet will require larger computing resources due to the long timescales involved. These resources have already been secured through DOE supercomputer allocations to the Climate Change WG.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Hydrology	FV1.9x2.5 CAM/CLM	10	25	75	19
	CLM Offline	20 5	50 500	15	52
Carbon cycle – DGVM	CLM-CN-DGVM	10	150	30	45
Permafrost and wetlands	FV1.9x2.5 CAM/CLM	10	25	75	19
	CLM Offline	20 5	50 500	15	52
Irrigation	FV1.9x2.5 CAM/CLM	10	25	75	19
	CLM offline	20	50	15	15
Ice sheet model	FV1x1.25 CAM/CLM	5	25	450	56
	CLM offline 1x1.25	15	50	100	75
	CCSM 1x1.25	8	10	1000	80
TOTAL					432

Polar Climate Working Group (PCWG)

The primary goal of the Polar Climate Working Group (PCWG) is to improve our understanding of the role of the polar regions in global climate. Towards this end, we seek to better simulate important aspects of the coupled polar climate system, including individual component systems, ice/ocean/atmosphere/land interactions and coupled feedbacks. As discussed below, there are a number of sea ice model developments underway.

1. Snow model improvements

Many processes, such as snow aging effects and blowing snow cover are not included in the current version of the sea ice model. These can substantially modify the surface albedo and albedo feedback under changing climate conditions. Here we propose to improve numerous aspects of the snow model formulation over sea ice. This will include a representation of snow metamorphosis (aging, etc) and its influence on the surface albedo among others. Numerous ice-only simulations are proposed for this development. Additionally, a number of coupled model integrations are proposed to investigate the climate influence and effects on the sea ice albedo feedback with these model improvements.

2. Frazil and Pancake ice parameterization

Frazil ice and pancakes form in sea water that supercools by heat loss at the surface, which is common around Antarctica in the presence of strong ocean turbulence. Presently CCSM permits no ocean supercooling, thus sea ice freeze-up is earlier than actually occurs in nature, which in turn causes errors in the timing of freshwater and heat exchange between the atmosphere and ocean. We propose to develop frazil ice and pancake formation parameterizations appropriate for CCSM and investigate their consequences in CCSM3.5. The model development and climate effects of this parameterization will be assessed in ice-ocean and fully coupled integrations.

3. Improved melt pond formulations

Using previous CSL resources, a parameterization has been developed to simulate the influence of melt ponds on the surface albedo. However, many aspects of pond formation, development, and latent heating effects are not included in this formulation. These aspects of melt ponds can have important climate impacts as the ponds delay fall freeze up and can modify the sea ice annual cycle and mass budget. We propose to further investigate and improve these aspects of the melt pond parameterization using ice-only model simulations. Additional fully coupled integrations are proposed to assess the climate impact of these improvements.

4. Sea ice impurities (algae, dust, soot, etc)

The development of a new sea ice radiative transfer under previous CSL allocations allows for the general and consistent inclusion of impurities in the sea ice and snow cover, including soot, algae, and dust. Previous studies using other climate models have suggested that this may influence the surface albedo feedback associated with sea ice change with implications for Arctic climate system change. Additionally, it can influence the ocean biogeochemistry (BGC), which currently assumes that all dust (and the iron associated with it) is immediately passed to the ocean even in the presence of sea ice cover. A more realistic representation of the dust deposition in the presence of sea ice will likely influence the timing and magnitude of the spring phytoplankton bloom in high latitudes.

We propose to further develop the capabilities associated with sea ice impurities in the model, and allow them to interface with the biogeochemistry and dust transport components in the atmosphere and ocean systems. Additionally, we propose to assess the climate and biogeochemistry consequences associated with these various sea ice impurities. This will require multiple sea ice simulations for development, ice-ocean (with BGC) integrations with a specified dust deposition to investigate and develop the interaction of the sea ice and ocean BGC, and a fully coupled simulation (with interactive dust module) to investigate the climate and BGC consequences.

5. Ice-ocean spin-up experiments

Intercomparisons of model simulations are complicated by the fact that no standard initial conditions exist. However, it is unclear to what extent this influences the transient or equilibrium model behavior. A standard initial condition for sea ice has been developed which is solely based on the observed ice concentration from satellite data. All remaining variables needed for initialization (e.g. ice thickness, temperature profile, etc.) are obtained as functions of this ice concentration data. This provides a simple and consistent means to initialize the ice model component of ice-ocean or fully-coupled integrations. Here, we propose multiple integrations to test the effects of these (and other) sea ice initial conditions on the behavior of ice-ocean and fully coupled integrations. This will provide insight into the influence that the sea ice initial conditions have on model behavior, and give guidance for model intercomparison projects that are being proposed.

6. Other miscellaneous model/software engineering improvements

Other miscellaneous improvements are underway for the sea ice model component. Included among these are modifications to the surface flux parameterizations and software engineering enhancements. We request a number of ice-only simulations for the development and testing of these improvements. Additionally, fully coupled simulations are requested to assess the climate impact of these additional model improvements.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Frazil and Pancake	POP+CICE4	4	50	125	25
	fv1.9×2.5g×1v5	1	200	200	40
	CICE4	10	50	30	15
Improved melt ponds	fv1.9×2.5g×1v5	1	200	200	40
	CICE4	10	50	30	15
Improved snow	fv1.9×2.5g×1v5	1	200	200	40

Sea ice impurities	CICE4	10	50	30	15
	POP(eco) +CICE	4	50	300	60
	fv1.9×2.5g×1v5 w/carbon cycle	1	200	375	75
Ice-ocn spinup	POP+CICE4	4	100	125	50
	fv1.9×2.5g×1v5	2	100	200	40
Miscellaneous	CICE4	3	20	30	2
	fv1.9×2.5g×1v5	3	25	200	15
TOTAL					432

Biogeochemistry Working Group (BGCWG)

Biogeochemistry development is focused on improving our simulations of the carbon cycle and introducing more interactions between the carbon cycle in the model and other components. The following development approaches can be grouped into ones directly coupling the carbon cycle, and ones which will enhance our ability to simulate couplings in the future.

Improvements in the ocean carbon cycle include several approaches. First of all, we will investigate techniques for accelerating the ocean model's approach to equilibrium to reduce spinup time, a large cost (experiment 1). We request 500 years of the ocean only with the ecosystem model in the low resolution x3 model. The second improvement in the ocean model (experiment 2) is to investigate the impact of interactive dust iron on the ocean ecosystem. We request 200 years using the fully coupled+BGC, x1-fv1.9x2.5. We will use existing dust simulations and/or interactive dust for these experiments. A third improvement in the ocean model (experiment 3) will be to investigate methods for making CaCO3 formation and dissolution dependent on local carbonate chemistry. This will allow us to investigate the impacts of anthropogenic activity on ocean acidification. We propose 200 years of the ocean only+ecosystem, x1. We will also investigate the impact of a parameterized diurnal cycle on ocean ecosystems (experiment 4), using the current parameterization that is independent of zenith angle and a “to be developed” zenith angle dependent parameterization. We propose 200 years of simulation in the ocean only+ecosystem, x1.

For improvements in the land carbon cycle model we will investigate: 1) the sensitivity of carbon and nitrogen fluxes to land use change; 2) the representation of natural and anthropogenic fire dynamics and fire effects; 3) the speciation of fluxes of reactive nitrogen; and 4) the introduction of phosphorus as a nutrient limiting plant growth and microbial activity. We request a total of 2000 years of land-only (1x1) simulation for these combined sensitivity tests (experiment 5), and an additional 1000 years of coupled CAM/CLM-CN (FV 2x2.5) to explore the associated carbon-climate feedbacks (experiment 6)

In addition, we propose to improve the interactions of the carbon cycle with natural aerosols which are produced by the land system (e.g. fire aerosols or dust), and their impacts on the carbon cycle through their direct and indirect radiative forcing, as well as their nutrients. For development we need to improve both fire and dust production mechanisms in the model, as well as their transport and deposition in the atmosphere. Finally, we need to improve their interactions with the direct radiation and cloud properties in the atmospheric component of the model. For these experiments, we request 800 years for the fire experiments (experiment 7) and 800 years for the dust experiments (experiment 8).

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
1: Ocean spinup	Ocean only, x3	1	500	15	8
2: Ocean/dust	Full model FV2x2.5, x1	1	200	375	75
3: Ocean/CaCO3	Ocean only, x1	1	200	275	55
4: Ocean zenith angle	Ocean only, x1	1	200	275	55
5: Land	Land only, x1	8	250	16	32
6: Land/atmosphere	CAM/CLM-CN, FV2x2.5	4	250	75	75
7: Fires/carbon cycle	CAM/CLM-CN, FV2x2.5	1	800	150	120
8: Dust/carbon cycle	CAM/CLM-CN, FV2x2.5	1	800	150	120
TOTAL					540

Chemistry Climate Working Group (ChemWG)

1. Scientific Background

The composition and photochemistry of the Earth’s atmosphere has been profoundly changed by anthropogenic activities through the emissions of trace gases and aerosols. The associated changes in near-surface air quality have had significant impacts on human health. In addition, the change in composition and photochemistry of the atmosphere has impacted the climate, atmospheric circulation and hydrological cycle through changes in atmospheric radiative forcing and the modification of cloud processes. Chemistry also impacts ecosystems, and thus the surface energy balance, by influencing light and water availability, influencing nutrient cycling, and damaging plant tissue at high concentrations of oxidants and acids. The Chemistry-Climate Working Group (ChemWG) has been formed to address these issues.

2. Research Goals and Developments

The deliverables of the ChemWG to CCSM and the community at large are:

- To produce the radiative forcing from chemically active species and aerosols for CCSM simulations. This includes ozone forcing and nitrogen deposition on a regional basis. This forcing may be input into the CCSM or calculated during run-time.
- To produce fully coupled chemistry-climate biogeochemistry simulations, investigating the importance and strength of the feedbacks between chemistry and the climate system.
- To produce air quality projections for a future climate, as well as to investigate the impact of transboundary pollutant transport on air quality in the present climate.
- To quantify errors in simulating chemistry through chemical hindcasts, forecasts and data assimilation.
- To evaluate and correct various emission scenarios through their chemical ramifications.

To accomplish these goals the ChemWG has:

i. Completed the development of CAM with chemistry. In this model the latest MOZART (Model of Ozone and Related Tracers, version 4) chemical subroutines have been incorporated, blended and tested in CAM3. This model can run interactively within CAM, or in an offline mode where the meteorology is specified.

ii. Investigated methodologies (complexity of chemistry schemes and/or aerosol treatments) and model setups (including vertical and horizontal resolutions and vertical extent) for incorporating the effects of chemistry and aerosols into the CCSM under the operational constraints of a climate model. CAM3.5 makes use of a number of these formulations developed by the ChemWG.

3. Proposed Simulations

Simulations will be made with CAM-MZ4 in either the offline or online mode. The nominal resolution and model configuration will be stand-alone CAM FV 1.9 x 2.5, but higher resolutions will be tested. Except for methane and hydrogen, tropospheric chemistry usually equilibrates after about 1 year, suggesting that 2 year simulations are appropriate. The equilibration time for the stratosphere and troposphere system is considerably longer. We assume 8 year simulations are appropriate for the coupled stratosphere-troposphere system. Simulations where we examine the climate feedback are nominally set at 10 year. The top priority of the ChemWG is to implement and test the new Ghan aerosol parameterization, nominally slated for inclusion in CAM4.

A. **Aerosols:** At present the prognostic bulk aerosol scheme incorporated into CAM specifies only aerosol mass and assumes all aerosol types are externally mixed. The introduction of the Ghan (PNNL) aerosol scheme allows both aerosol number and mass to be specified and aerosols to be mixed internally. This will allow for a more realistic simulation of the direct and indirect aerosol radiative forcing. We are requesting GAUs to incorporate the Ghan aerosol into CAM using either offline and online chemistry, and test the sensitivity of the resulting simulations to the details of the aerosol schemes. Some of the proposed simulations will couple the aerosol and cloud schemes through the indirect effect.

B. **Secondary organic aerosols (SOA):** Recent calculations and measurements suggest that the source of secondary organic aerosols is underestimated by an order of magnitude in model calculations. Colette Heald (Colorado State University) 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. Necessary improvements include: i) further development of the biogenic emission scheme in CLM/CAM to include additional compounds and environmental drivers; ii) further development of the SOA scheme in CAM to incorporate the latest yields and algorithms for SOA formation.

C. **Photolysis and cloud overlap:** The photolysis of chemical constituents and the modification of the photolysis rate by clouds and aerosols are important drivers for atmospheric chemistry. We are requesting additional GAUs for the incorporation of the Prather (UC-Irvine) Fast-j parameterization with the Neu (UC-Irvine) formulation of cloud overlap. The Prather scheme offers considerable advantages over what is currently in CAM-MZ4: it is based on a 4-stream calculation which acts to increase OH concentrations considerably; it is valid at higher heights, an advantage for modeling the upper atmosphere; finally, the cloud overlap scheme is more sophisticated than the scheme currently implemented.

D. **Physical parameterizations:** The physical parameterizations within CAM are in a state of flux. The current convective scheme has been replaced in CAM3.5, with the University of Washington boundary layer scheme also available for incorporation into CAM. Preliminary simulations suggest these changes have large effects on the transport of chemical constituents and on the production of lightning NO_x. We are requesting GAUs to test the impact of the new physical parameterizations on chemistry, to evaluate this impact against chemical measurements and to tune the model chemistry (e.g., the lightning flash rate) in accordance with the new parameterizations.

E. **Emissions:** New chemical emission scenarios are being developed between 1870 and present. These scenarios have a large influence on simulated aerosol distributions and consequently 20th century simulations in CAM. These new scenarios need to be tested within the CAM with chemistry to determine if they are consistent with chemical measurements.

F. **Impact of Ozone on Productivity:** It has been recently reported that ozone can have an important climatic influence through its effects on the land-carbon sink. In order to investigate this effect, the dry deposition scheme in CAM-chem must be updated so that it is influenced by the calculated stomatal resistance within the CLM. We have requested additional GAUs to begin implementing this update and to calculate the impact of ozone on carbon uptake.

G. **Lightning emissions of nitrogen oxides:** Upper tropospheric model chemistry and ozone (and hence its radiative impact) are very sensitive to nitrogen oxides produced from lightning. The current lightning emission parameterization in CAM (Price and Rind) is in need of improvement. We are requesting additional GAUs for the input of a new ice mass flux parameterization being developed in WRF (Weather Research and Forecasting model) with Mary Barth (NCAR) and Christelle Barthe (NCAR), making use of Christelle Barthe's experience with explicit lightning generating models.

H. **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. 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. Here we are requesting additional GAUs to investigate the coupling of the regional WRF-chem model at high resolution to CAM with chemistry. To investigate this coupling we are requesting GAUS for both WRF-chem for about 12 months. Meteorological and chemical boundary conditions for WRF-chem will be taken from the high resolution CAM chemistry simulations (see L below).

I. **MACCM (Middle Atmosphere CCM) development:** The chemistry climate working group is working to finalize the development of a middle atmosphere chemistry-climate model. This model will enable the investigation of tropospheric-stratospheric coupling without the expense of running WACCM. While the pieces of the MACCM are in place, we are requesting additional GAUs to assemble and test MACCM. This version of the model is being discussed for use in high resolution forecast simulations.

J. **Data assimilation:** We are requesting GAUs to help with the development of new capability in the Ensemble Kalman filter using DART (Data Assimilation Research Testbed). This system, as currently implemented, is designed to assimilate meteorology and satellite derived CO. It will be expanded to perform the simultaneous assimilation of aerosol optical depth (AOD) from satellite measurements.

K. **Washout:** Washout is an important determinant in the lifetime and burden of key radiatively active speices. With the incorporation of the new Gettelman-Morrison microphysics within CAM, washout of chemical species and aerosols needs to be updated, both for large scale rainout and for rainout within the parameterized convection scheme.

L. **High and Very-high Resolution runs:** It is likely that the default resolution of CAM will be increased in the future. This will almost certainly be the case for high resolution forecast simulations (simulations nominally to cover the period from 1980 to 2030). The atmospheric chemistry working group is requesting additional GAUs to examine the sensitivity of running these higher resolutions with chemistry.

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
A) Aerosols (1)	fv1.9x2.5/offline chemistry	20	10	100	20
A) Aerosols (2)	fv1.9x2.5/chemistry	2	10	365	7
B) SOA	fv1.9x2.5/chemistry	20	2	400	16
C) Photolysis	fv1.9x2.5/chemistry	20	2	350	14
D) Parameterizations	fv1.9x2.5/chemistry	20	2	350	14
E) Emissions	fv1.9x2.5/chemistry	20	2	350	14
F) Ozone and Productivity	fv1.9x2.5/chemistry	20	2	350	14
G) Lightning emissions	fv1.9x2.5/chemistry	20	2	350	14
H) Air quality	WRF-chem	12	1 month	72000	72
I) MACCM	fv1.9x2.5/MACCM	10	8	1100	88
J) Data assimilation	fv1.9x2.5/chemistry	40	1	220	9
K) Washout	fv1.9x2.5/chemistry	20	2	365	15
L) High resolution (1)	fv1x1.25/chemistry	5	2	2000	20
L) High resolution (2)	fv0.5x0.625/chemistry	5	2	11500	115
TOTAL					432

Paleoclimate Working Group (PaleoWG)

1. Quaternary Simulations

Testing the incorporation of water isotopes into CCSM

With a recent DOE INCITE project, we have been awarded DOE computing time to carry out the first synchronously coupled transient ocean-atmosphere-terrestrial ecosystem general circulation simulation in CCSM3 (T31x3) for the past 25,000 years. This transient simulation is important because it will address the role of transient evolution on the sensitivity of the climate system to prescribed changes in greenhouse gases, ice sheets, and meltwater pulses. Records from the ice cores of Greenland and Antarctica suggest bipolar and abrupt responses of temperature from the Last Glacial Maximum (~21,000 years ago) to the start of the Holocene (~11,000 years ago). These ice core records, though, use oxygen isotopes to infer temperature though this isotopic signature may also be influenced by changes in precipitation, sea ice, and the location and isotopic value of the source regions. We propose to perform an additional simulation for the period from 21,000 to 11,000 years ago to that being done by the INCITE project with a version of CCSM3 with oxygen isotopes that has been developed by David Noone, University of Colorado. This will provide the first test of this model development in simulating the substantial changes of water isotopes that occurred during the deglacial phase of the last glacial-interglacial cycle, thus providing a basis for its possible inclusion as an option in future versions of CCSM. The orbital cycle forcing will be accelerated by a factor of 10.

Testing the coupled carbon climate model with past climate benchmarks

The quantitative and mechanistic explanation of atmospheric carbon dioxide variations over the glacial-interglacial cycles of the last million years remains one of the major unsolved questions in climate research. Simplified models suggest that no single mechanism can be invoked, but rather that physical and biogeochemistry changes in the ocean and over land need to be considered and that the relative importance varies as the climate state changes. We will perform three snapshot simulations – the previous interglacial (~125,000 years ago) and two time periods at ~90,000 and ~15,000 years ago, as the climate system was transitioning into and out of the last glacial maximum and atmospheric CO_2 concentrations were intermediate between their glacial lower and interglacial higher values. The fourth snapshot simulation for full glacial conditions is being done on the current CSL allocation to the Paleo and BGC working groups. The proposed simulations will benefit from the setup strategy that has been developed for this glacial simulation. These simulations will provide an important benchmark for our evaluation of the CCSM3 BGC model that is being used for future projections, but is only currently tested for preindustrial and 20th century changes.

2. Pre-Quaternary Simulations

Testing of Deep Ocean Acceleration for Paleoclimate Simulations

Many paleoclimate applications require understanding the climate state of the deep oceans. Paleo proxy data provide information on near surface and deep ocean circulations. Thus, it is of great value to have steady state solutions of the paleo CCSM. The steady state time scale for the deep oceans is around 3000 years. Carrying out many simulations of CCSM3 for this length of time is prohibitive. To date the longest simulation of CCSM3 is the Permian-Triassic simulation, which is 2700 years in length. Acceleration techniques exist to efficiently make coupled models reach steady state using less computational resource. This project will carry out a series of Permian-Triassic accelerated simulations, which will then be compared to the explicit 2700 simulation to determine if acceleration techniques can be used for paleoclimate research.

3. Paleo-Chemistry Simulations

Development of Paleo WACCM for Snowball Earth Simulation

Boundary data sets will be developed for Snowball Earth conditions, and these will be tested in the stand-alone version of WACCM. The chemistry module will also be tested for conditions of low temperatures and specific humidity.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Quaternary					
CCSM isotopes	T31x3	1	600	22	13
CCSM+Carbon C	T31x3	2	1000	25	50
Pre-Quaternary					
Deep Time Accel	T31x3	5	300	20	30
Paleo-Chem					
Snowball	WACCM	1	50	300	15
Total					108

Climate Change Working Group (CCWG)

Effect of the Greenland Ice sheet melting on the thermohaline circulation and the global climate

There is a large uncertainty in the IPCC AR4 report sea-level change conclusions due to the lack of knowledge of the possible changes of the Greenland and Antarctic ice sheets. One of the major development thrusts for the CCSM is to address this through the inclusion of an active land ice sheet model. Here we will perform a set of experiment to assess the impact of different ice sheet melting rates on climate in the next 200 years. We are going to run a set of experiments with different rate of the ice sheet melting to cover the possible fast ice sheet melting process which is not understood currently.

1) A1B greenhouse forcing, with a Greenland ice sheet melting rate of 0.01 Sverdrups, constant in time. 215yr, T42x1 CCSM3 run.
2) Same as 1, but with rate of 0.01 Sv increase 1% per year.
3) Same as 2, but with rate of 0.01 Sv increase 2% per year.
4) Same as 1, but with rate of 0.01 Sv increase 7% per year (as observed).
5) Same as 4, but additionally the effect of west Antarctic ice sheet melting will be included via a melting rate of 0.004 Sv with an increase of 3% per year.

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
Greenland Ice Sheet melting	T42x1	5	215	100	108
TOTAL					108

Software Engineering Working Group (SEWG)

1. CCSM Test Suite Coverage

The SEWG is actively involved in all stages of CCSM production and development. The SEWG is responsible for testing each CCSM revision on all production platforms to ensure required functionality (such as exact restart capability), correct results (such as bit-for-bit reproducibility where it is expected) and other key production requirements (such as optimizing performance of new revisions). Currently, ambitious new scientific and software development, associated with the creation of CCSM4, is occurring across all CCSM model components. As a result, new CCSM revisions are being created on a weekly basis. In addition, CCSM revisions are also periodically created for patches made to the CCSM3 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. The CCSM test suite has detected many problems before major resources have been expended in long production runs. 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 release, the test parameter space has significantly increased resulting in a continually expanding regression validation test suite. In addition, the recent creation of CCSM3.5 has expanded this parameter space even further, and we expect that this pattern will continue to occur as the CCSM4 system is constructed. Examples of new tests include the incorporation of atmospheric chemistry within the finite volume (FV) dynamical core, and the addition of new higher resolution component set combinations to the system. The SEWG is currently running between 200-300 tests every month. 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 size of this stand-alone test suite is also increasing as CCSM4 development is accelerating.

In the active development phase that CCSM is currently in, running the continuously expanding CCSM test suite will permit software problems to be detected early in the CCSM4 development cycle. As additional tests covering new scientific or software functionality are added, the number of configurations and resolutions that are encompassed by the CCSM test suite 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.

The SEWG is requesting 16 KGAUs/month in CSL Development resources over the next 18 months to run the CCSM test suite as part of CCSM4 model development.

2. Development of Sequential CCSM4

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 CCSM3 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 CISL to have it published on the CISL web site. The table below includes post-SMT bluevista and blueice efficiency measurements. The CCSM efficiency values have been tallied from multi-day verification or production runs. Platform workload averages are quoted from the CISL Hardware Performance Monitor Statistics webpage.

CCSM 3.5 Efficiency Values (percent of peak)

Supercomputer	CCSM	Workload Average	"Best" App
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 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. This difference in performance was shown to be directly attributable to the overhead of CCSM's concurrent architecture.

The CCSM Software Engineering Group (CSEG) has been aware of the above mentioned issues related to concurrency for a number of years, and is in the process of developing a new inter-component communication architecture for CCSM4 to address this problem. The goal is to create a new single-executable version of CCSM that can be run as either a full sequential system (where all components run sequentially over the same set of processors) or as a hybrid sequential/concurrent system (where some components run sequentially, whereas other components run concurrently). There are numerous advantages to the creation of such a system. First, the ability to run a subset of the CCSM components sequentially is expected to improve the efficiency of the system. Second, scientific development across all model components will occur in only one model system, resulting in simplified code maintenance and testing and decreased code duplication. Third, new scientific parameterizations and resolutions being introduced into the CCSM4 development code seem to indicate that more frequent component coupling might be necessary for a subset of the components. This latter requirement can only be met without a significant performance cost within a sequential framework. Finally, a sequential system will be easier to port to new systems, and the load balancing complexity associated with the fully concurrent system will be eliminated. We are targeting the use of both the ESMF framework, as well as the MCT toolkit currently utilized in CCSM3, for the creation of this new architecture.

The SEWG requests the resources in the table below for validation of the new CCSM4 hybrid sequential/concurrent system.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
CCSM Tests	All	Many			288
CCSM4 Sequential Validation	1.9x2.5_gx1v5 w/carbon cycle	2	100	375	75
CCSM4 Sequential Validation	1.9x2.5_gx1v5	3	115	200	69
Total					432

Estimate of CCSM 3 and CCSM 3.5 GAU Costs on Blueice

Runs	GAU / Sim Year	CPU-hrs / Sim Year
CCSM 3 coupled integrations		
T42_gx1v3	100	115
T31_gx3v5	20	23
T31_gx3v5 with carbon cycle	25	29
CCSM 3.5 coupled integrations		
fv1.9x2.5gx1v5	200	230
fv1x1.25gx1v5 with carbon cycle	375	430
Standalone CAM and CLM 3.5 components		
fv1.9x2.5 CAM+CLM standalone	75	85
fv1x1.25 CAM+CLM standalone	425	490
fv1.9x2.5 CAM + Chemistry standalone	350	400
Standalone POP and CICE 3.5 configurations		
1-degree POP standalone (60 levels)	120	140
1-degree POP+CICE4 (60 levels)	125	145
1-degree POP+CICE4 (60 levels) with the ecosystem component	300	345
1-degree CICE4 standalone	30	35

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