CCSM

Community Climate System Model

Proposal for CSL Resources – Science

6/1/09 – 11/30/10

Table of Contents

Overview

Project Title
Community Climate System Model: Science

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Current CSL Allocation
CCSM (Development and Production) + WACCM – 880 KGAU/month

Request in this Proposal:

Working Group	June 09 – Nov. 10	Total
WAWG	70K GAU/month	1260K GAU
PALEOWG, OMWG	60K GAU/month	1080K GAU
BGCWG, CHEMWG, AMWG	50K GAU/month	900K GAU
CVWG, LMWG, PCWG	40K GAU/month	720K GAU
CCWG, SEWG	20K GAU/month	360K GAU
Total	**500K GAU/month**	**9,000K GAU**

Introduction

The CCSM project is in the middle of assembling the next version of the coupled model, CCSM4. The new versions of the atmosphere, ocean, land, and sea ice have been delivered, and the first coupled runs are underway. In order for the CCSM4 to be defined, there needs to be both an 1870 control run that has an acceptable top of the atmosphere balance near zero, and a 20th Century run that reproduces well the observed climate over the past century. This will require tuning of all the four components, and especially the new feature of CCSM4, which includes for the first time the indirect effects of aerosols. Once this is completed, then the additional components of the CCSM4 will also have to be defined. These are the carbon cycle component, chemistry component, and the Whole Atmosphere component, all of which up to now have been based on the intermediate version of the model, CCSM3.5.

Once the CCSM4 is finalized, then it will immediately start to be used to make the runs that are required for submission to the IPCC AR5. The CCSM project is planning to do a complete set of lower resolution carbon cycle runs on CSL resources, and a companion proposal to this one has also been submitted. However, there are a myriad of important science questions that require separate runs from the IPCC set. The science questions and required runs from the various CCSM Working Groups are contained in this proposal. Note that the Whole Atmosphere WG is now a part of the CCSM, and so its proposal is included here, and is not a separate request, as it was in the last round of CSL requests.

Thus, the focus of the CCSM project will switch somewhat from model development to model use from June 2009 for the next 18 months. However, a number of model developments will proceed, especially in the atmosphere component. One of these is the requirement to use a different horizontal grid that is not based on latitude/longitude, which is required so that the component parallelizes over many thousands of processors. Thus, this proposal also requests computational resources for model development over the 18 months from June 2009. CSL computer resources are the lifeblood of the CCSM project, are actively managed based on the priorities set by the Science Steering Committee, and are the glue that keeps the CCSM functioning as a community project.

Atmosphere Model Working Group (AMWG)

Research Plan and Science Objectives

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 the 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. One of the main activities for the next year will be to understand the integrated behavior of CAM4. Much attention last year was paid to the development of the component parts. We anticipate an opportunity to explore the model results with all the improvements coupled to each other.

There are a variety of issues that we were not able to address during the development of CAM4, and remaining biases that provide important opportunities for progress in atmospheric models. These are:

1. To explore the model behavior when coupled to alternate dynamical cores that are much better suited to massively parallel computer platforms, e.g. the HOMME core, and the cubed sphere, finite volume core from Lin and Putman. At present, CAM4 only parallelizes well across a few thousand processors at most for high resolution simulations. These new cores will enable it to parallelize over tens of thousands of processors, as the other CCSM components do at present.

2. 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 will make simulations with both comprehensive physical parameterizations and using simplified representations for physical processes (for example, “waterworld” simulations and Held-Suarez type simulations).

3. Aerosol/cloud interactions are one of the critical controlling sets of processes in Earth’s climate system. While we made an important step forward in improving the CAM’s representation of aerosols, many issues remain to be improved. For example, a) the formation of secondary organic aerosols; b) cloud drop activation in convective (deep and shallow) updrafts; and c) ice nucleation; 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.

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

5. There were also certain processes that we know how to represent better, that are candidates for improvement. Among them are: a) the subcloud distributions of water and temperature (e.g. the use of PDFs to describe the variation of these fields and their interaction with clouds); b) subcolumn formulations for cloud and microphysics that acknowledge the issues of cloud overlap (e.g. Klein and Jacobs); and c) the use of correlation length scales in characterizing cloud overlap.

Computational Requirements

CAM4 is substantially more expensive to run than CAM3. At an equivalent horizontal resolution, but 30 vertical layers, with all optional processes turned on (for example predicting the approximately 30 aerosol and gaseous chemical species) it will cost 3-4 times the cost of CAM3. CAM4 also uses the FV dynamical core, rather than the spectral core used as the workhorse configuration for CAM3. The FV core needs about 60% more gridpoints than the spectral core for the equivalent accuracy (there are other benefits to the FV dynamics that outweigh the formal numerical accuracy), and Williamson (2008) has shown that baroclinic wave features are not well resolved at either 1.9x2.5 deg or T42 resolution, so we are recommending that most simulations be done at 0.9x1.25 deg, with occasional excursions to higher horizontal resolutions. We also anticipate running at higher vertical resolution.

We have formulated our proposal in the context of a series of runs with the FV model. Much of the rest of this CSL proposal is calibrated using an anticipated cost of 140 GAU/yr, a cost appropriate for a version of CAM4 run without the higher vertical resolution, and configured to run with prescribed aerosols, rather than the prognostic aerosol distributions appropriate for many studies in which cloud aerosol interactions are important. The more expensive and flexible configuration with fewer compromises costs 200 GAU/yr. We describe runs that use both the cheaper and more expensive configurations in the Table below. 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 changes in parameterization on the climate and to explore new climate interactions (e.g., aerosol/cloud indirect effects). The runs labeled “Alternate Dynamics” will allow exploratory simulations using the HOMME and cubed sphere dynamical cores. They might vary in cost depending on the precise configuration, but we have used the 200 GAU/yr cost for them. The runs labeled “Simpler Formulations” will use the prescribed aerosol formulation or Held-Suarez type forcings. Those labeled “Full aerosol/Clouds” and “resolution” will use the prognostic aerosol formulation. It is, of course, impossible to provide a really precise description of all the runs and configurations that we will explore over the 18 months of this award. The estimates in the Table are based on a reasonable mix of explorations of the topics described above.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Alternate Dynamics	New Dycores	50	3	200	30
Simpler Formulations	FV 1.9x2.5	50	10	140	70
Full Aerosol/Cloud	FV1.9x2.5	100	10	200	200
Vertical resolution (50L)	FV1.9x2.5	100	10	400	400
Horizontal resolution	FV0.9x1.25	25	10	800	200
TOTAL					900

Ocean Model Working Group (OMWG)

Research Plan and Broad Science Objectives

Support of specific science objectives of the CCSM and maintaining a state-of-the-art ocean component for the CCSM as well as conducting related, but curiosity-driven, research leading to new contributions to the CCSM community are the primary goals of the OMWG. The former goals ensure that our working group (through CCSM) fully contributes to science. The latter is absolutely necessary to keep the CCSM at the leading edge of ocean climate models. This, of course, requires continuous high level of effort and support. As always, an overall objective is to be at the fore-front of new model developments and to deliver an improved ocean model to the CCSM community beyond the CCSM4 time frame. Following the recent delivery of the ocean component to be used in the CCSM4, we wish to focus on some longer term developments that will address some of the limitations of our current model during this proposal cycle. For these efforts, the science objective is to understand the behavior of various model developments, both individually and as they interact with the others. These interactions are often surprising and must be investigated before a new model is adopted.

In addition, the OMWG will be actively participating in the IPCC-related science part of the CCSM CSL proposal. Here, we wish to propose three additional research paths: climate impacts of the North Atlantic and Antarctic gravity current overflows as part of our CLIVAR Climate Process Team (CPT) activities; multi-decadal variability seen in many CCSM coupled simulations as depicted in the Atlantic Meridional Overturning Circulation (AMOC), its climate impacts, and potential predictability; and evaluation of new model physics using Transient Tracer Distributions (TTDs). We detail the specific scientific objectives for each of these proposed studies below. We also note that all the proposed ocean-only and ocean—sea-ice coupled experiments will be done using the gx1v5 resolution version of the ocean model. Similarly, the proposed coupled simulations will use the fv1.9x2.5_gx1v5 version of the CCSM4.

Proposed Experiments and Science

1. Model Developments

Implementation and testing of Langmuir mixing parameterization: Preliminary integrations have shown that there is a potentially important role for Langmuir mixing in the near-surface ocean. These tests were carried out with a very rough parameterization to determine whether further investigation was warranted. This rough scheme has shown significant promise, reducing biases in the model chlorofluorocarbon (CFC) distributions in better agreement with observations. We propose to reserve time for simulations with the next generation of the Langmuir mixing parameterization that will be more robust and physically-based than the current version. We plan to conduct 6 ocean—sea-ice coupled simulations, followed by 1 fully coupled integration with our final configuration of the parameterization. Because the model CFC distributions will be the primary metric for these simulations, the integrations will be for 100 years each, with CFCs added after the first 30 years. We note that the computational cost increases by about 20 GAUs / yr when the model simulations include CFCs.

Exploration of new surface forcing methods and role of fine vertical resolution at depth: Bulk forcing experiments using the Coordinated Ocean-ice Reference Experiments (COREs) atmospheric data sets together with a prognostic sea-ice model show notable improvements in the North Atlantic circulation of our ocean model when compared to an equivalent simulation with prescribed sea-ice cover, i.e., an ocean-only case. High latitude surface fluxes in winter-time are highly sensitive to the treatment of sea-ice. Enhanced surface production of dense Labrador Sea water in ocean—sea-ice coupled simulations results in stronger western boundary currents, a more vigorous Northern Recirculation Gyre, a stronger North Atlantic Current (NAC), and temperature and salinity bias reduction east of the Grand Banks. We believe that the treatment of surface fluxes is more physical with a prognostic sea-ice model. However, comparisons with observed fluxes show that both ocean-only and ocean—sea-ice experiments are characterized by excessive surface water mass transformation associated with warm, salty subpolar conditions. Surface salinity restoring reduces high latitude model biases in temperature, salinity, and sea-ice edge, but eliminates the improvements in the North Atlantic circulation. Here, we wish to revisit some of our previous surface flux method choices and explore some new alternatives for surface fluxes that also involve re-consideration of natural flux boundary conditions, i.e., using true freshwater fluxes instead of the virtual salt flux approach. We realize that the latter requires us to deal with sea-ice pressure issues and possibility of vanishing surface layers. We view these issues as part of our long-term model development strategy and now is the time to start addressing some of these issues. The immediate benefit of these studies will be realized in the ocean-only and ocean—sea-ice coupled simulations first. Because the NAC path settles relatively quickly, 20-year integrations will be sufficient. However, we will need many such integrations. Here, we request time for only 35 ocean—sea-ice coupled simulations.

Another avenue that we would like to pursue is to investigate the roles of fine vertical resolution at depth and of bottom topography in affecting the path of the model NAC. We plan to perform two 20-year, ocean—sea-ice coupled sensitivity experiments using a 500-level model in the vertical with about 10 m resolution in the deep ocean. Assuming that the model time step does not change, we estimate the model cost to be 1100 GAUs / yr.

Addressing some numerical shortcomings: As stated in the CCSM OMWG Accomplishments Report, the OMWG has delivered the ocean model to be used in the CCSM4 simulations. With the completion of this task, we plan to focus on addressing some long-standing shortcomings of the ocean model. These include: The elimination of the linearity assumption in the barotropic equation solver procedure to allow fine, i.e., order 1 m, near-surface resolution; and changing the model time stepping algorithm to eliminate the Leap-Frog scheme to facilitate high frequency coupling, i.e., order 1 h, desirable for some science applications. The latter is currently possible to do; however, it is computationally rather expensive because a time-averaging time-step must be included during a coupling interval to preserve tracer budgets. Before engaging into a full-scale change of related algorithms, we plan to first explore the scope of these modifications. In addition, we wish to incorporate new tracer diagnostics to quantify separately the physical and numerically-induced mixing in the ocean model. Obviously, these efforts will require more person time than computer time. We envision about 50 ocean-only simulations integrated for about 5 years each.

Lateral variations of the near-surface mesoscale eddy diffusivity: Estimates of the magnitude of the eddy diffusivity can be deduced from observations. These observations also tell us that the eddy diffusivity is not constant but exhibits considerable variability in space and time. We have tried several global prescriptions for the computation of spatial dependencies of the diffusivities during the last several years (see also the OMWG Accomplishment Report). Here, we would like to take a local approach, focusing on the spatial variability of the tracer diffusivities in the Equatorial Pacific thermocline. This local prescription will be based on very recent observational estimates (Kelvin Richards, personal communication). Since the equatorial response is rather fast, we plan to conduct only 20-year experiments. We anticipate about 6 ocean-only cases, followed by 2 fully coupled simulations.

Climate Impacts of the North Atlantic and Antarctic Overflows

The OMWG has been involved with two CLIVAR Climate Process Teams (CPTs): Eddy-mixed layer interaction (EMILIE) and gravity current entrainment (GCE). These two successful CPTs have been extended one additional year to complete some remaining climate impact studies and to document the new open-ocean overflow parameterization. All the climate impact simulations have been completed for the CPT EMILIE. We have implemented and extensively tested the overflow parameterization for the Denmark Strait and Faroe Bank Channel overflows in short ocean-only and coupled simulations. These initial results were very promising, indicating significant reduction of the long-standing deep warm bias in the Atlantic Basin. We request computer time to apply and test this new parameterization for the Weddell and Ross Sea overflows off the Antarctic coast. Based on our experience with the North Atlantic overflows, we will need about ten 20-year, ocean-only integrations. After the verification of the correct implementation of the scheme for these overflows, we plan to conduct four 200-year ocean-only and ocean—sea-ice coupled (2 each) to assess the behavior of the ocean model solution by itself. The 200-year integration length is a minimum due to the slow deep ocean time scales. Each set will consist of a control simulation and one with the overflows. We note that these separate control integrations (than otherwise may be available) are necessary because we anticipate changes of the bottom topography to incorporate paths for these overflows to follow after their injection in the abyssal ocean. Finally, we wish to conduct four 300-year, fully coupled simulations to document any resulting climate impacts due to overflows, paying particular attention to such measures as air-sea fluxes and atmospheric circulation. The cases are a control case with the same topographic changes, a case with only the North Atlantic Overflows, a case with both the North Atlantic and Antarctic overflows, and a case to be determined considering only the impacts of the most dominant overflow. In all of the long simulations, CFCs will be added during the last 70 years.

Multi-decadal variability and its potential predictability

The Atlantic Meridional Overturning Circulation (AMOC) is a singular feature of the ocean general circulation thought to play a major role in maintaining the climate of the planet. Many coupled general circulation models, including the CCSM3, exhibit multi-decadal variability in their AMOC. Such variability is also present in many other ocean fields in the North Atlantic, including the SSTs and northward heat transport (NHT) – two of the climatically most important ocean fields. The interest in AMOC has been steadily growing over the years because of i) its association with variations in NHT, North Atlantic SSTs, and other climatic variables such as air temperature, precipitation, drought, and severe weather events such as hurricanes, ii) its potential predictability, and iii) it's possible role in abrupt climate change particularly in response to anthropogenic forcing. Despite numerous studies on the subject, many fundamental questions still remain largely unanswered. These include the driving mechanism of this variability, its climate impacts, and its potential predictability. As stated, the previous version of the CCSM revealed multi-decadal oscillations in its AMOC. We anticipate that such behavior will also be present in the new CCSM4. Here, we propose to analyze and conduct additional experiments to address some of the unanswered questions. In particular, to investigate the driving mechanism and time-scale questions, we propose to carry out a set of ocean-only experiments driven by heat, salt, and momentum fluxes extracted from a fully coupled simulation that exhibits multi-decadal variability in its AMOC. In these experiments, these fluxes are imposed sequentially, one by one, while keeping others at their climatological seasonal cycles. These four experiments plus a control ocean-only simulation will then be analyzed. Given the multi-decadal nature of this anticipated variability, each simulation will be carried out for 200 years.

The CCSM will be participating in the Decadal Prediction Experiments coordinated by WCRP and IGBP for the AR5. These experiments will be done on machines provided by the DOE using the fv0.47x0.63_gx1v5 resolution version of the model. Here, we propose to perform a preliminary investigation of short-term, decadal predictability associated with the AMOC using the fv1.9x2.5_gx1v5 resolution version. The intent is to address ocean initialization and robustness-across-resolutions issues. We plan to have a limited set of experiments integrated for 30 years each. We will conduct three sets of 3-member ensemble integrations starting at year 2000. In each ensemble, the atmospheric initial conditions will differ slightly. In each set, the ocean model will be initialized using data from hindcast simulations and a couple of assimilation data products (GFDL and MIT ECCO). The initial 8-9 years will be used as "hindcasts" and various AMOC measures will be compared with data from assimilation integrations and RAPID array products. The later parts of these integrations will serve as forecasts. We hope to use other available 20^{th} Century simulations as the control cases.

Evaluation of new model physics using Transient Tracer Distributions

TTD tracers provide a conceptual framework for evaluating and interpreting the advective-diffusive transport properties of geophysical flows. We wish to perform an experiment with TTDs to evaluate these transport properties in our ocean model with all our recent parameterizations. The experiment will be compared to previous experiments that were performed with parameterizations from CCSM3, and CCSM3.5 as well as with an eddy resolving model. We propose one 210-year ocean-only experiment forced with CORE normal-year data sets. After a 60-year spin-up, both CFCs and TTDs will be introduced. While the CFCs will be simulated only for 73 years, TTDs will be continued till year 210, for a total of 150 years.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
1a) Langmuir	gx1v5 POP/CICE	6	100	140	84
Langmuir	CCSM4 Fully Coupled	1	100	280	28
CFC Surcharge		7	70	20	10
1b) Surface forcing	gx1v5 POP/CICE	35	20	140	98
500-levels	gx1v5 POP/CICE	2	20	1100	44
1c) New development	gx1v5 POP stand-alone	50	5	130	32.5
1d) Lateral diffusivity	gx1v5 POP stand-alone	6	20	130	16
Lateral diffusivity	CCSM4 Fully Coupled	2	20	280	11
2. Overflow Tests	gx1v5 POP stand-alone	10	20	130	26
Ocean Sensitivity	gx1v5 POP stand-alone	2	200	130	52
Ocean Sensitivity	gx1v5 POP/CICE	2	200	140	56
Climate Sensitivity	CCSM4 Fully Coupled	4	300	280	336
CFC Surcharge		8	70	20	11
3. AMOC mechanism	gx1v5 POP stand-alone	5	200	130	130
AMOC Predictability	CCSM4 Fully Coupled	9	30	280	76
4. TTDs	gx1v5 POP stand-alone	1	60	130	8
	gx1v5 POP stand-alone	1	75	420	31.5
	gx1v5 POP stand-alone	1	75	400	30
TOTAL					1080

Land Model Working Group (LMWG)

Over the next several years, the goal of the LMWG is to continue to advance the state of the art in modeling Earth's land surface, its ecosystems, watersheds, and socioeconomic drivers of global environmental change, and to provide a comprehensive understanding of the interactions among physical, chemical, biological, and socioeconomic processes by which people and ecosystems affect, adapt to, and mitigate global environmental change. CLM4, which is in the final stages of development, will be a comprehensive tool that can be used to study the natural and anthropogenic forcings and feedbacks of climate change. The bulk of the LMWG CSL resources for the June 2009 – November 2010 period will be devoted to applying CLM and CCSM to a variety of scientific studies proposed by both NCAR and university members of the LMWG.

Computational resources requested for the LMWG cover six primary projects: 1) irrigation and crop modeling; 2) seasonal changes in the Arctic and the terrestrial system response; 3) urbanization and climate; 4) dynamic wetland and methane emission modeling; 5) carbon, water, and energy cycling change due to insect outbreaks; and 6) sub-grid scale surface elevation variations. Experiments are proposed for each of these projects. Many of these projects will leverage off the fully coupled CCSM4 IPCC simulations. Resources are also requested for general model development and evaluation.

1. Irrigation and crop modeling

This project is a continuation of prior collaborative efforts with scientists at the University of Wisconsin to incorporate irrigation and an active crop cycle representation into CLM. 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. A crop/irrigation model 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 has till now not been exploited. Water will be conserved by removing irrigation water from rivers and aquifers and irrigation demand will evolve as climate and agricultural practices change over time. Work has been completed on a beta version of a CLM crop model. This model is currently being expanded from its present emphasis on mid-latitude crops to global crops. Much of the testing can be completed in offline mode with additional simulations in CAM4/CLM4 also anticipated.

2. Seasonal changes in the Arctic

Due to the potential vulnerability of the large stocks of carbon stored in permafrost-affected soils and the possibly substantial reduction in surface albedo associated with a shorter snow season and concomitant ‘greening’ of the Arctic, there is concern that the integrated Arctic terrestrial response to climate change will be a strong positive feedback that will exacerbate Arctic, and potentially global, climate change. Arctic ecosystems are already displaying a propensity for sudden change with recent observations indicating thawing permafrost, earlier melting of snow, increasing shrubbiness, lengthening growing seasons, advancing treelines, shifting migratory bird ranges, and declining caribou herd health. Models indicate that much more change is expected with large-scale permafrost degradation and widespread changes in snow depth and snow season length likely. Alterations to the surface energy, water, and biogeochemical fluxes, therefore, will reflect the combined surface hydrology, snow, and vegetation transitions.

Observations reveal a distinctly seasonal character to the Arctic land response to climate change. Increased and earlier spring plant growth has been reported. Snow is melting earlier, but the date of snow onset remains essentially unchanged. Models suggest, however, that in the future the strongest warming will occur in the autumn and winter, in response to sea ice loss, and that the date of snow onset will retreat faster than the snow melt date will advance. In this project we propose to investigate how a shift in seasonality associated with sea ice loss, both within and outside the context of GHG-related warming, affects vegetation, permafrost, and snow. This resource request supports the terrestrial component of a larger proposed CCSM4 project (“The seasonal response of the Arctic and global climate system to projected sea ice loss within the context of GHG-induced climate change” submitted for consideration to NSF Arctic System Science Program by Clara Deser, Marika Holland, David Lawrence, and Bob Tomas (NCAR) and Andrew Slater (CIRES)). Computer resources for two specific experiment sets (out of a suite of roughly 8 CCSM experiment sets) are requested here. The first experiment set (Prescribed Future sea ice, Nitrogen fixed present-day) is a CAM4/CLM4 experiment in which fixed terrestrial nitrogen pools, taken from a present-day simulation, are fixed in a run with prescribed future sea ice**.** Comparison of this experiment with an active nitrogen experiment will isolate the vegetation response to autumn/early winter mineralization of nitrogen by microbial activity (2x60y, CAM4/CLM4). The second experiment set (Prescribed future sea ice, vegetation fixed present day) tests the impact of dynamical vegetation feedbacks on the coupled atmosphere-terrestrial response to Arctic sea ice change. Note that in all other experiments vegetation is dynamic in the sense that vegetation biogeography and seasonal phenology (e.g. earlier leaf out or delayed senescence) are allowed to evolve in accord with the simulated climate (2x60y, CAM4/CLM4). These experiments will complement ongoing studies with CCSM and CLM that are aimed at evaluating how changes in Arctic snow conditions feedback onto atmospheric and ground climate.

3. Urbanization and climate

CLM4 includes a new urban parameterization. The city representation is based upon the “urban canyon” concept in which the canyon geometry is described by building height to width ratio. The canyon system consists of roofs, walls, and canyon floor. Walls are further divided into shaded and sunlit components. The canyon floor is divided into pervious (e.g., residential lawns, parks) and impervious (e.g., roads, parking lots, sidewalks) fractions. We propose to use this model to address the following questions.

1. What are the effects of including urban landcover in a climate model on present day climate?
2. What are the characteristics of the urban heat island under various conditions?
3. What are the effects of 2030 and 2100 urban landcover compared to present day urbanization?
4. What are the effects of current anthropogenic heat sources on present day climate?
5. What are the effects of 2030 and 2100 anthropogenic heat sources on climate?
6. How sensitive is the urban climate to different representations of urban structure and future growth?

We will focus on impacts of the various forms of urbanization on near-surface air temperature and humidity as well as derived quantities such as diurnal temperature range (minimum and maximum daily temperatures), extremes, and heat indices. This study requires a series of CAM4/CLM4 simulations with present day, 2030, and 2100 SSTs/sea ice. SSTs/sea ice for 2030 and 2100 will be taken from CCSM transient climate change runs.

A. Present day climate without urban landcover - 30 years
B. Present day climate with present day urban landcover - 30 years
C. Present day climate with present day urban landcover plus anthropogenic heat sources – 30 years
D. 2030 and 2100 climate with 2030 and 2100 urban landcover - 60 years total
E. 2030 and 2100 climate with 2030 and 2100 urban landcover plus anthropogenic heat sources - 60 years total
F. Three simulations exploring sensitivity of urban climate to urban structure and future growth scenarios - 90 years total

4. Dynamic wetlands and methane emissions

This project is a joint effort between NCAR, LLNL, UC Berkeley, and Cornell University scientists. The goal is to implement a global natural methane emissions model, merged with an anthropogenic methane emissions dataset to simulate terrestrial methane emissions. Since natural methane emissions are strongly dependent on the global wetland distribution, this project also requires the development of a dynamic wetland (or surface water) module for CLM which can capture how changes in both the surface water balance and small-scale topographic features (e.g. thermokarst in permafrost zones) affect wetland distribution. Both the methane emissions model and dynamic wetlands model development projects are underway. This proposal assumes that by the date of this CSL allocation that both models will be quasi-operational. Resources are requested for testing of the new schemes (CAM4/CLM4) and for a series of experiments that evaluate feedbacks between climate change, tropical and boreal wetland distribution and methane emissions changes, and atmospheric methane concentrations in the fully coupled model (CCSM4). The fully coupled model experiments will be setup to be comparable to the relevant IPCC 1.9x2.5 degree carbon cycle simulations.

5. Insect Outbreaks in an Earth System Model

Recent climate change has influenced insect outbreaks affecting millions of ha of forests in North America. In turn, outbreaks may influence future climate change through altered carbon and energy cycling between the atmosphere and biosphere. Climate is an important driver of outbreaks through temperature effects on insects as well as drought effects on host trees. The long-term goal is to improve the understanding of the drivers, extent, and effects of insect outbreaks. The central hypothesis of this work is that bark beetle infestations cause significant impacts to regional forest carbon cycling in the western United States because of their large areal extent and tree-killing behavior. The strong influence of climate on these outbreaks and projected warming in the coming decades will modify future forest carbon, energy, and water cycling in these regions.

In this project, we will work to implement insect disturbances into CLM. Insect disturbances will be incorporated using an observational database of past outbreaks and existing outbreak models where available. Prognostic modeling of future mountain pine beetle outbreaks will consider separate processes of outbreak initiation, beetle population increase and spread, and collapse. To estimate the impact of historical outbreaks on the carbon budget of the western United States, CLM will be driven with observations of insect-caused tree mortality. Future carbon cycle effects will be estimated offline using a climate projection taken from a transient CCSM4 simulation. Offline CLM model runs will be performed with historical driving data (climate and land use). This resource request is in support of a funded DOE NICCR project ("Climate Change, Insect Outbreaks, and Carbon Fluxes: Using an Earth System Model to Study Interactions in the Western United States") led by Jeff Hicke from the University of Idaho and in collaboration with Peter Thornton of Oak Ridge National Laboratory and NCAR TSS staff.

6. Sub grid scale surface elevation variations

Use CAM4/CLM4 to evaluate surface elevation impact on skin temperature, albedo, and roughness length where sub-grid scale variations in elevation are large. In this experiment, we will continue to examine how to best represent surface elevation information in CLM. Specifically, we will investigate how the effective roughness of steep coastal regions such as Greenland or mountainous regions be represented more realistically within the context of the existing land model framework. We will also investigate how albedo can be modified to include the slope effect. This project requires minimal computational resources, estimated at about 20x5-yr CAM4/CLM4 integrations. The lead scientist on this project is Menglin Jin of San Jose State University

7. Model development and evaluation

This is a more general resource request for computer time to address a range of foreseen and mostly unforeseen model development and evaluation projects. An example of a known smaller model development task not covered by the projects above 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. There is also general interest across the LMWG to revisit the canopy radiation treatment to correct known deficiencies in the current scheme for sparse vegetation environments.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Urbanization	FV1.9x2.5 CAM4/CLM4	10	30	140	42
Seasonal Arctic Change	FV1.9x2.5 CAM4/CLM4	4	60	140	34
Irrigation / Crop Model	FV1.9x2.5 CAM/CLM4	10	30	140	42
Irrigation / Crop Model	FV1.9x2.5 CCSM4 carbon	1	230	560	129
Dynamic wetlands / methane emissions	FV1.9x2.5 CAM4/CLM4 with CHEM	5	30	450	68
Dynamic wetlands / methane emissions	FV1.9x2.5 CCSM4 with CHEM	2	230	600	276
Insect Outbreak	0.25x0.25 (NorthAmerica) CLM4 carbon	10	50	90 (est)	45
Surface elevation	FV1.9x2.5 CAM4/CLM4	10	10	140	14
Model development and evaluation	FV1.9x2.5 CAM4/CLM4	20	25	140	70
TOTAL					720

Polar Climate Working Group (PCWG)

The primary goal of the PCWG is to improve our understanding of the role of the Polar Regions in global climate. Toward this end, we seek to better understand and model important aspects of the coupled polar climate system, including ice/ocean/atmosphere/land interactions, sea ice processes and coupled feedbacks. We also plan to explicitly examine the influence of polar climate processes on the global climate system through sensitivity simulations of the CCSM. The individual studies and the computer simulations required for these studies are detailed below.

1. The Arctic freshwater cycle in a changing climate

Substantial changes in the freshwater budget of the Arctic Ocean are expected in the future with potential implications for downstream conditions and large-scale ocean circulation. In order to assess how these changes influence Arctic-North Atlantic freshwater (FW) exchange, we have implemented FW tracers into the CCSM ocean component. This allows us to track the fate of FW from river runoff into different shelf seas, from sea ice melt, from precipitation, and from Bering Strait inflow. Using transient simulations for the 20th and 21st century, we will assess the effect of transient changes in the FW budget on the pathways of FW in the Arctic, and investigate how atmospheric conditions modify the FW pathways under changing conditions. We are especially interested in analyzing changes in the FW distribution and export during times of rapid sea ice decline in the 21st century (see Holland et al., 2006). Since these rapid sea ice reductions occur at different times in the CCSM ensemble simulations of the 21st century, we plan to perform several ensemble simulations for 2000 to 2050 in addition to one 1900-2100 simulation to analyze the common changes during these events. A hindcast experiment from 1948-2008 will also be performed, to compare the simulated FW export and storage variability from CCSM with results obtained from other models. This will help to understand better the simulated variability, and highlight possible differences in the CCSM simulation of the Arctic FW system compared to other models.

In addition, we will assess the net effect of changing sea ice melt and growth on the freshwater budgets of the Arctic Ocean and potential downstream effects. In particular, we propose a transient future scenario run that will prescribe the ice-ocean freshwater exchange to remain fixed at the present day annual cycle. The difference between this simulation and the standard CCSM4 future scenario run will isolate the role of changing seasonality in sea ice freshwater exchange on ocean conditions and its influence on climate.

2. The role of seasonal sea ice loss on the climate system

Arctic sea ice loss has a strong seasonal signature, with the largest changes present in September at the end of the melt season. This seasonal ice loss has an important influence on ice-ocean-atmosphere heat and freshwater exchange with potential implications for the Arctic and Global climate. However, in future climate projections the direct influence of sea ice loss is intertwined with the influence of rising greenhouse gases. We propose to assess and isolate the impact of future Arctic sea ice changes on the coupled system by fixing greenhouse gas levels at late 20th century values and forcing near seasonally ice-free conditions by lowering the sea ice albedos. This will result in sea ice conditions that are similar to those obtained in future climate scenarios but in the absence of GHG changes. By comparison to standard future scenario runs, this will isolate the impact of future Arctic sea ice loss on the climate system.

3. The impact of black carbon on sea ice change

CCSM4 will include the capability to deposit and cycle aerosols within the sea ice component. Recent improvements in the radiative transfer of the CCSM sea ice model allow for a more complete treatment of the effect of included particulates and the sea ice aerosol implementation that is now included within CCSM is considerably more complex than that used in previous studies. As such, we will build on previous work and assess the climate forcing from changing black carbon deposition in 20th century simulations that use historical forcing. Future projections will also be performed with changing black carbon emission scenarios to provide an estimate of future effects. These simulations will be compared to model runs that do not incorporate changing black carbon deposition. The integrations will be assessed to determine how black carbon deposition modifies seasonal transitions in the sea ice cover, influences the sea ice mass budgets, and impacts the strength of the surface albedo feedback. Additional studies will be performed to assess the role that increased shipping and local black carbon emissions within the Arctic may play in future Arctic sea ice loss.

4. The importance of changing snow conditions for Arctic sea ice mass budgets

The role of changing snow conditions for Arctic sea ice change is highly uncertain. Because snow has competing effects on sea ice mass budgets, it is unclear whether changing snow conditions will act to stabilize or accelerate Arctic sea ice loss. This topic will be addressed in a number of experiments that broadly include (a) sensitivity studies of the effects of changes in precipitation patterns on growth and melt of sea ice, and (b) tests of revised parameterizations of snow properties and snowfall redistribution in CCSM4. Numerous active-ice-only integrations will be performed to comprehensively assess the influence of changing magnitude, seasonality, intensity and location of snowfall on the ice cover. These will be complemented by fully coupled and atmosphere-sea ice-slab ocean model integrations in both present-day and perturbed climates in order to assess the feedbacks that arise with snowfall on sea ice changes. Additionally, new parameterizations of snow processes will be assessed in both ice-only and coupled integrations that should lead to an improved representation of snow processes in CCSM.

5. The importance of sea ice transport of bio-available iron for the marine ecosystem

Sea ice may be an important vector for transporting iron within the Arctic (from both atmospheric aerosol and sedimentary sources) supporting phytoplankton production in deeper basin areas without direct sedimentary sources. Shelf areas of the Arctic are likely iron-replete due to the strong sedimentary iron source. However, in offshore areas over deeper basins that will increasingly become ice-free during future summers, iron is likely to become the limiting nutrient for phytoplankton growth, since iron in surface waters is rapidly removed through particle scavenging and biological uptake. Sea ice may accumulate iron through aerosol deposition, from both mineral dust and combustion iron, and through incorporation of sediments in shelf regions. It has been suggested for the Antarctic, that this iron-rich ice formed in shallow regions may support phytoplankton blooms far offshore where the ice melts. Satellite observations show more frequent phytoplankton blooms along these ice-advection pathways.

New capabilities in the sea ice component of CCSM4 allow for the deposition and cycling of aerosols, including bio-available iron. This capability will be used to test the influence of the sea ice transport of iron for Arctic and Southern Ocean marine ecosystems. Of particular interest will be how relationships are modified under changing climate conditions. In particular, we propose to perform fully coupled integrations for the 21st century that include the marine ecosystem component and allow for iron deposition, transport, and cycling within the sea ice system.

6. Arctic predictability studies

Predicting future Arctic sea ice conditions on seasonal to interannual timescales is an important societal need. However, there has been little basic research regarding the limits of sea ice predictability. We propose a two-pronged study to assess the predictability of Arctic sea ice conditions. This includes an idealized component that assumes a perfect forecast model and perfect initial conditions. This will initialize the model with conditions from an existing CCSM integration, with slight perturbations to the atmospheric state, and then run forward to produce a forecast. Forecast simulations will be assessed in the context of the rapidly changing Arctic climate. Additionally, a retrospective forecasting component will be performed that initializes CCSM with an ocean-sea ice reanalysis product (ECCO) from conditions over the last 20-years and then integrates forward. To assess the importance of pre-conditioning of the system and the timescales of predictability, and to obtain robust statistics, numerous integrations will be performed starting with initial conditions from different times of year.

7. Changing seasonality in the Arctic system

Seasonal changes that have occurred and are projected to continue in the Arctic have important implications for the functioning of the climate system. This study will address changes in seasonality in the sea ice system, with a particular focus on changing shortwave budgets. Sea ice-slab ocean model integrations forced with atmospheric conditions will be used to address the direct effect of changes in the timing of specific forcing (e.g., the timing and magnitude of snowfall, the timing of solar insolation anomalies) on sea ice mass budgets, melt onset, and shortwave radiation partitioning. By comparison to the results obtained within the fully coupled model, we will determine how resulting feedbacks modify the sea ice response.

Additionally, the net effect of the surface albedo feedback for 21st century climate will be examined with a fully-coupled future scenario model integration in which the surface albedo feedback is disabled. More specifically, we will run a future climate projection within the fully active system, but with a prescribed surface albedo from 20th century conditions. Through comparison to a standard future projection run, we will be able to quantify the surface albedo feedback and its role in Arctic amplification, sea ice mass budgets, ecosystem behavior and changing seasonality in the Arctic system. With the new capabilities present in CCSM4, this will expand on previous work that has quantified the surface albedo feedback and specifically address the importance of changes in timing and seasonality of specific triggers on surface albedo change and amplifying feedbacks and the repercussions for large-scale climate, ecosystems, and global linkages.

8. Influence of local versus remote forcing on Arctic clouds

Future scenario projections indicate important changes in Arctic cloud cover and properties. In order to assess the remote versus local forcing of sea ice reductions on Arctic cloud conditions, we propose to perform three atmosphere model experiments. These include: 1) a simulation with specified reduced Arctic sea ice coverage obtained from a fully coupled greenhouse run but with specified modern SSTs, 2) a simulation with both the reduced Arctic sea ice coverage and the higher simulated SSTs specified from a fully coupled greenhouse run, and 3) a run that specifies the modern, observed Arctic sea ice coverage but the simulated SSTs obtained from a fully coupled greenhouse run. Comparison of these integrations will allow the remote vs. local forcing of sea ice reductions on changing cloud conditions to be determined. These simulations will be complemented by similar runs done under the Climate Variability Working Group request. However, we will use modified cloud parameterizations to assess the robustness of the simulated cloud response and the influence of specific cloud formulations.

9. Stability of seasonally ice-free Arctic conditions

Many model simulations project that summer ice-free conditions may be reached within the 21^{st} century. However, the stability of this seasonally ice-free state is uncertain. Here we will assess the forcing and timescales required to recover the Arctic perennial ice cover. These simulations will be initialized using conditions obtained at the end of a 21^{st} century projection integration. The atmospheric CO2 concentrations will then be decreased at varying rates and the timescales and dynamics that determine the possible re-establishment of the perennial ice cover will be examined.

10. General ice model developments

We anticipate that during the time of this proposal we will need to test numerous new sea ice model parameterizations and code enhancements that are proposed by the broader scientific community. This will necessitate numerous active-ice-only simulations and several fully coupled integrations in order to assess the impacts on the CCSM climate and feedbacks.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Arctic freshwater cycle					
2000 – 2050	Fv1.9x2.5_gx1v5	4	50	280	56
20th century	Fv1.9x2.5_gx1v5	1	100	280	28
21st century	Fv1.9x2.5_gx1v5	1	100	280	28
Ice-Only Hindcast	gx1v5 POP/ICE	1	60	140	8.4
Seasonal ice loss					
Reduced ice albedo	Fv1.9x2.5_gx1v5	1	100	280	28
Black Carbon					
20th – 21st Century	Fv1.9x2.5_gx1v5	1	200	280	56
Arctic shipping	Fv1.9x2.5_gx1v5	4	40	280	44.8
Snow Sensitivity					
Ice-only sensitivity	gx1v5 CICE	30	60	25	45
Atm-ice coupled	Fv1.9x2.5	2	50	140	14
Fully coupled	Fv1.9x2.5_gx1v5	1	200	280	56
Bio-available iron	Fv1.9x2.5_gx1v5 (with ocn eco)	2	560	100	112
Arctic Predictability					
Idealized runs	Fv1.9x2.5_gx1v5	75	2	280	42
Retrospective runs	Fv1.9x2.5_gx1v5	75	2	280	42
Seasonality Study					
Ice-only runs	gx1v5 CICE	20	60	25	30
Albedo feedback	Fv1.9x2.5_gx1v5	1	100	280	28
Cloud Study	Fv1.9x2.5	3	40	140	16.8
Seasonally ice-free Arctic	Fv1.9x2.5_gx1v5	4	50	280	56
General Model Development					
Ice-only	gx1v5 CICE	20	20	25	10
Fully coupled	Fv1.9x2.5_gx1v5	4	17	280	19
TOTAL					720

Biogeochemistry Working Group (BGCWG)

The goal of the biogeochemistry working group is to produce a state-of-the-art climate model for the research community that includes biogeochemistry and to apply this model to explore biogeochemical feedbacks in the earth system. 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 land carbon cycle model requires further development and evaluation to become a community modeling resource. Emphasis is on development and evaluation of the present-day carbon cycle, its interactions with nitrogen and phosphorus biogeochemical cycles, its modification from disturbances by wildfire and land use, and the overall carbon cycle feedback in the climate system. These parameterizations can be developed and evaluated in offline CLM simulations, uncoupled from CCSM and forced with observed climatological atmospheric datasets. Such simulations require approximately 300 model years each for the terrestrial carbon system to come into equilibrium. We request a total of 16 x 300 = 4,800 years simulation at a cost of approximately 10 GAU per year (48 KGAU).

The land carbon cycle model can also be evaluated in CAM/CLM simulations with prescribed sea surface temperatures (SST) and sea ice. These SST and sea ice datasets are available for the period 1870-2100 from prior CCSM transient climate change experiments. This provides an important model configuration with which to test land carbon cycle sensitivity to climate change. We request a total of 4 x 230 = 920 years simulation at a cost of approximately 140 GAU per year (129 KGAU).

The ocean carbon cycle model has been previously developed with a coarse, ~3°, resolution configuration. In order to obtain optimal solutions, some of the model parameters have had to be set to overcome biases in the physical solution, biases that are reduced in the higher, ~1°, resolution configuration used for IPCC simulations. So it will be necessary to perform sensitivity experiments in the 1° configuration to evaluate model parameters. We request a total of 10 10-year experiments to evaluate parameters determining short-time scale behavior and 3 60-year experiments to evaluate some longer time-scale parameters. The total cost of these experiments is (10 x 10 + 3 x 60) x 280 GAU per year = 78 KGAU.

In order for us to be better prepared for IPCC AR5 simulations with CCSM4, we propose a suite of sensitivity experiments in the lower resolution fully coupled CCSM3.1 model that has an interactive carbon cycle. This model configuration costs 60 GAU per year. The experiments will be used to test the sensitivity of the model to interactive dust, aerosols and the new IPCC protocols. We request 7 simulations, each 230 years in length, for a total of 7 x 230 x 60 = 97 KGAU.

The land and ocean carbon cycle models must be spunup to an initial 1870 state for the CCSM transient climate change simulations described in the CSL proposal for IPCC AR5. This can be accomplished with the component land and ocean models only. We estimate that this requires approximately 1000 years for CLM with its carbon cycle model at a cost of approximately 10 GAU per year (10 KGAU). The ocean model with its ecosystem model requires approximately 1000 years at a cost of 280 GAU per year (280 KGAU).

We propose two fully coupled CCSM simulations with its carbon cycle to augment the planned IPCC AR5 simulations. One simulation would isolate land cover change as a forcing in the transient simulations. The other would isolate dust feedbacks. We request a total of 2 x 230 = 460 years simulation at a cost of approximately 560 GAU per year (258 KGAU).

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Parameterization development					
Land carbon cycle	CLM/DATM fv1.9x2.5	16	300	10	48
Land carbon cycle	CAM/CLM/CICE(prescribed) / DOM fv1.9x2.5	4	230	140	129
Ocean carbon cycle	gx1v5 POP/CICE and ocean ecosystem	10 3	10 60	280	78
AR5 model spinup					
Land carbon cycle	CLM/DATM fv1.9x2.5	1	1000	10	10
Ocean carbon cycle	gx1v5 POP/CICE and ocean ecosystem	1	1000	280	280
AR5 science					
CCSM3.1 sensitivity	CCSM3.1 T31_gx3v5 with carbon cycle	7	230	60	97
Dust	CCSM4 fv1.9x2.5_gx1v5 with carbon cycle	1	230	560	129
Land cover	CCSM4 fv1.9x2.5_gx1v5 with carbon cycle	1	230	560	129
TOTAL					900

Chemistry Climate Working Group (ChemWG)

The Chemistry-Climate working group is requesting a total of 900K GAUs to 1) further our understanding of chemistry-climate interactions in support of IPCC AR5 and Atmospheric Chemistry and Climate (AC&C) activities 1 and 4; 2) study the role of halogen chemistry in the troposphere, in both polar and global regions, including the role of disappearing sea-ice; and 3) the role and representation of biogenic emissions from land and ocean. The scientific rationale for each item is described in more detail below.

No specific order is attached to the list of research topics, other than the first two represent a commitment we have made to the international community.

1. Hindcast

We expect CCSM4 will have dramatic effects on the simulation of atmospheric chemistry and aerosols in comparison with previous model configurations. In addition to changes in model physics, the inclusion of the new modal aerosol scheme (MAM) will modify the chemistry of the atmosphere and change the impact of the chemistry-aerosol system on the radiative budget. To evaluate these impacts we propose to run a number of hindcast simulations to evaluate not only the chemistry and aerosols as measured during specific field campaigns, but to also evaluate our ability to simulate interannual variability and chemical trends. A number of these hindcasts will be run under the auspices of AC&C (Atmospheric Chemistry and Climate, *A joint initiative of IGBP-IGAC and WCRP-SPARC*). Planned hindcasts include those designed to evaluate the interannual variability of aerosols, ozone, OH and long-lived trace species (e.g., N_2O and CFCs). We will run these hindcasts using: i) analyzed winds, ii) winds generated from CAM using fixed SSTs (AMIP simulations), and iii) winds generated using an interactive mixed layer ocean. While analyzed winds have the greatest fidelity for specific field campaigns, they often do a poor job of capturing observed climate trends. On the other hand while AMIP simulations capture many of the observed climate trends, they do not provide a true test of the coupled model system (e.g., the response of the chemistry to simulated El-Niño events). Thus we also propose hindcasts using the capabilities of the full CCSM.

2. IPCC AR5 sensitivity studies

In support of IPCC AR5, several simulations will be performed to simulate the distribution of radiatively-active gases in the atmosphere. These simulations will be performed online (in CCSM4) and offline (CAM4 driven by fixed sea-surface temperatures). We propose here to extend the scientific role of those simulations by providing additional simulations. In particular, as shown in a recent *JGR* paper (Lamarque et al., 2008), there is considerable information to be gained by performing simulations in which some of the driving factors are kept constant. For example, we can keep the level of ozone-depleting substances to their pre-industrial levels to understand the role of such compounds on atmospheric composition and climate. We propose here to do studies with both CAM and CCSM, as specific studies would be better understood under a CAM framework than CCSM. The simulations will combine both historical and future conditions.

3. Secondary-organic aerosols

This is a continuation of the work conducted by C. Heald (CSU), which lead to the recent *JGR* paper Heald et al., 2008. Recent studies on the dependence of biogenic emissions on the ambient CO_2 levels (with emissions of isoprene decreasing with increasing CO_2, potentially reducing the role of CO_2 fertilization) and biogenic volatile organic compounds (VOCs) chemistry in the canopy indicate the need for additional studies on such emissions, their dependence on climate and their impact on tropospheric chemistry and aerosol formation.

4. OASIS

A field campaign for the understanding of ozone chemistry in the Arctic will take place in the spring of 2009. Our experience with high-resolution simulations of chemistry in support of the MIRAGE campaign has shown the ability of the model in reproducing transport events (when driven by NCEP analysis) and pollution chemistry. This application will enable us to test the model physics and chemistry packages in a very different environment, enabling a model evaluation of halogen chemistry representation using ground-based and airborne measurements.

5. Disappearing sea-ice

An interesting corollary of the previous study is the fact of disappearing sea-ice in the Arctic. Because of the potential role of first-year sea-ice in the formation of bromine explosions (and henceforth on ozone depleting events), there is considerable interest in studying the next few decades in which the gradual disappearance of sea-ice will lead to more widespread availability of first-year sea-ice. It is quite unclear at this point how strong this signal will be, and how large an impact it will have on tropospheric composition; but it is clearly a topic the tropospheric chemistry community will tackle over the next few years.

6. Rainout

Wet deposition is important in the determination of the lifetime of atmospheric species and aerosols. The wet deposition scheme currently implemented in CAM is based on a scheme initially proposed by Giorgi and Chameides over 20 years ago. In collaboration with Jessica Neu (University California at Irvine), we are requesting computer resources to update this scheme to more systematically incorporate cloud overlap effects and model microphysics.

7. Stomatal conductance

Surface deposition is an important regulator of surface ozone concentrations, while stomatal conductance is an important regulator of surface deposition. Ozone impacts stomatal conductance as well as the total carbon intake of plants. These effects have not been adequately incorporated into the CCSM. We propose a number of simulations to incorporate these impacts into the CLM model in collaboration with Jed Sparks and Danica Lombardozzi (Cornell). Ultimately, we will examine the effect of ozone on (i) latent heat flux (through its impact on stomatal conductance); (ii) carbon cycling (through its impact of photosynthesis) and (iii) the feedback between ozone concentrations and its dry deposition.

8. Ocean emissions

Ocean emissions of chemical compounds are some of the main drivers of the chemistry in the marine boundary layer. Some recent collaboration with Los Alamos National Laboratory, Lawrence Livermore National Laboratory and NCAR (under SciDAC funding) has demonstrated the possibility of using simulated ocean biogeochemistry to drive oceanic emissions of dimethylsulfide (DMS), carbon monoxide and a large number of VOCs. This coupling allows us to perform exploratory studies of the potential feedbacks between climate and oceanic emissions and tropospheric chemistry.

In the following Table, various chemistry schemes are used: full, reduced (reduced hydrocarbon chemistry), strat (stratospheric chemistry from WACCM) and halogen (tropospheric halogen chemistry of bromine, chlorine and iodine). Because of the difference in the number of tracers and reactions, the overall cost of each scheme can vary.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Hindcast: 1950-2009	CAM4 1.9x2.5 Full+MAM	10	60	400	240
IPCC AR5 sensitivity studies (1850-2150)	CAM4 1.9x2.5 Reduced+strat+MAM	4	300	350	420
IPCC AR5 sensitivity studies (1850-2150)	CCSM4 1.9x2.5 ocean x1 Reduced+strat+MAM	2	100	500	100
Secondary-organic aerosols	CAM4 1.9x2.5 Full+MAM	1	60	400	24
High-resolution simulation of Arctic chemistry (support for OASIS field campaign)	CAM4 0.47x0.63 Full+halogen+MAM	1	5	8000	40
Impact of disappearing sea-ice on tropospheric chemistry	CAM4 1.9x2.5 Full+halogen+MAM	1	60	500	30
Development of new rainout parameterization	CAM4 1.9x2.5 Full+MAM	1	20	400	8
Development of ozone feedback on stomatal conductance	CAM4 1.9x2.5 Full+MAM	1	20	400	8
Oceanic emissions and climate feedback	CCSM4 1.9x2.5 Ocean x1 Full+halogen+MAM	1	50	600	30
TOTAL					900

Whole Atmosphere Working Group (WAWG)

1. Scientific Background

The Whole Atmosphere Working Group (WAWG) was formed to facilitate continued development of the Whole Atmosphere Community Climate Model (WACCM) as part of CCSM, and to use WACCM to understand the couplings between atmospheric layers, the role of chemical and physical processes in defining these couplings, and the interaction between the Earth's atmosphere and the Sun. The current version of WACCM (see http://waccm.acd.ucar.edu/) spans the range of altitude from the Earth's surface to the lower thermosphere (~140 km) and is based on version 3.5 of the Community Atmospheric Model (CAM). Ongoing studies that utilize WACCM simulations include prediction of the evolution of ozone and other radiatively active species in the middle and upper atmosphere; effects of the stratosphere on tropospheric climate, including the response to increased greenhouse gases; and investigations of upward and downward coupling in a high-top model with an interactive ocean.

2. Development and Research Goals

The goals of the WAWG are to continue development of a state of the art, "high-top" numerical model with coupled chemistry that will serve the needs of the scientific community, and to conduct research on the science areas outlined above. Specifically, we propose to use CSL resources to:

- Update the current version of WACCM to make it consistent with CAM, version 4 (which will be used in the next round of IPCC simulations); and improve the representation of physical processes relevant to the middle atmosphere that are not fully represented in CAM;
- Perform numerical simulations of past and future climate, assess chemical and physical variability, and diagnose whether it is the result of human activities (e.g., GHG increases) or natural processes (e.g., changes in solar and geomagnetic forcing);
- Participate in national and international climate and chemistry assessment activities, including IPCC, the WMO Ozone Assessment, and the WCRP/SPARC Chemistry-Climate Model Validation (CCMVal) project.

3. Model development and non-IPCC science studies

WACCM-4 development

WACCM4: Starting in 2009 CAM, version 4 (CAM4), will become the default version of the CCSM atmosphere model, and will be used in the AR5 round of IPCC simulations. Therefore, it is necessary to update the current version of WACCM, which is based upon CAM3.5, to the code base of CCSM/CAM4. This will require updating code to use the new RRTMG radiative transfer model in CAM4, and retuning the model energy balance and gravity wave parameterizations. We will initially test and tune the low-resolution version of the model (WACCM4-4X), for which we estimate requirements of 100 model years for testing and an additional 50 years to establish a base climatology. We will then proceed to tune the standard resolution version (WACCM4) (approximately 50 years of testing) to produce a 50-year climatology. Finally, we will test WACCM4 coupled to the CCSM ocean model (POP); this version (WACCM4-CCSM) will also be run at standard resolution for 50 years for both pre-industrial and present day conditions.

WACCM4 for UTLS Studies: To support detailed studies of the upper troposphere and lower stratosphere (UTLS), a version of WACCM4 with enhanced resolution in the UTLS and full tropospheric chemistry (WACCM4-103L-TC) will be tested to ensure that it produces an acceptable climatology in the UTLS and realistic transport of trace species into the middle atmosphere. We expect the testing will require 50 years of simulation (5 runs of 10 yrs each) using WACCM4-103L-TC.

Internal generation of the quasibiennial oscillation (QBO)

Observations and recent model simulations (e.g., Labitzke et al., 2006; Matthes et al., 2008) indicate that the response of the stratosphere to the 11-year solar cycle is modulated by the quasibiennial oscillation (QBO). In addition, the wind regime associated with the QBO in the stratosphere modulates the vertical flux of waves into the upper atmosphere. WACCM does not generate a QBO spontaneously at present. It is generally acknowledged that at least three requirements must be met in order to spontaneously generate this oscillation: (a) vertical resolution in the stratosphere must be high (750-1000 m); (b) the underlying model's convective parameterization must produce significant power at periods in the 1-10 day range; and (c) numerical "hyperdiffusion" used to control the enstrophy cascade must be at least 4^{th} order. (See, e.g., Giorgetta et al., 2002; Ricciardulli and Garcia, 2000; Hourinouchi et al., 2003). In collaboration with L. Ricciardulli (REMSS, Santa Rosa, CA), we have succeeded in implementing the convective parameterization of Tiedtke-Nordeng (used in the successful QBO simulations of Giorgetta et al., 2002) in the current version of WACCM; and efforts to introduce fourth-order hyperdiffusion in the Lin (2004) finite volume advection scheme used in WACCM are underway at NCAR's Climate and Global Dynamics Division (P. Lauritzen, private communication). We will incorporate this work into a version of WACCM4 with sub-kilometer resolution throughout the stratosphere (WACCM4-140L) and attempt to generate a QBO internally. We expect that 25 yrs of simulation will allow us to test the model and an additional 25 yrs will produce ~10 QBO cycles to determine the climatology of the oscillation in WACCM.

Climatology of stratospheric sudden warmings (SSWs)

The frequency of SSWs is thought to be influenced by several factors such as the QBO and ENSO, and models differ widely in their ability to reproduce the evolution and observed occurrence frequency of SSWs (e.g., Charlton et al., 2007). Nevertheless, the behavior of SSWs in high-top models has not been examined systematically. In this study we will attempt to quantify the dependence of SSW frequency on several factors by carrying out and analyzing several 30-year WACCM simulations: i) fixed seasonal sea surface temperatures (SSTs) and no QBO; ii) variable SSTs and no QBO; and iii) variable SSTs and a prescribed QBO. In addition, iv) we will do three 30-yr runs to test the sensitivity of SSWs to the parameterization of mountain drag in WACCM, which is known to affect stratospheric winter variability by altering the generation of planetary Rossby waves that propagate from the troposphere into the stratosphere. Mountain drag parameterizations (see, e.g., Wilson, 2002) are used in low and moderate resolution models to account for the effects of unresolved orography on the atmospheric momentum budget. We will run WACCM with two standard settings of the mountain drag parameterization, and with no mountain drag at all. In addition to assessing the effects of the parameterization on the frequency of SSWs, we will also study to what extent mountain drag improves the climatology of the simulation in the troposphere (e.g., 500 hPa geopotential and sea-level pressure). Simultaneous improvement of the climatology of SSWs and of tropospheric dynamical fields will enhance confidence in the physical plausibility of the results. We note, by the way, that the ability to carry out this experiment does not depend on the success of our experiments to generate a QBO internally in WACCM4 (item 3.1.2), since the current version of the model has the ability to run with tropical winds constrained to existing observations of the QBO.

Studies of the UTLS

The UTLS is a region where dynamics, chemistry, microphysics, and radiation are fundamentally interconnected and climatically important. In the UTLS greenhouse gases, such as water vapor and ozone, are controlled by stratosphere-troposphere exchange, and by chemical processes including multiphase chemistry and cloud microphysics. We propose to use a version of WACCM run with specified dynamics and enhanced vertical resolution (WACCM-SD) to examine whether WACCM can model realistically chemical composition and mixing in the UTLS region. Running WACCM with specified dynamics is an efficient way of comparing the model chemistry and transport against observations for a particular period, as it eliminates the influence of the "natural" variability of the free-running model. The meteorological fields used to constrain WACCM-SD in the troposphere and stratosphere are taken from the NASA GMAO GEOS5.1 data assimilation system. Each SD-WACCM simulation will cover the period 2004–2008 and use an enhanced chemical mechanism (approximately 130 species). This mechanism contains a detailed representation of chemical processes in the troposphere, stratosphere, mesosphere, and lower thermosphere. We will run SD-WACCM at two horizontal resolutions (1.9° x 2.5° and 1° x 1.25°) to ascertain the impact of resolution on the ability to model in detail the distributions of climatically important chemical species in the UTLS. Results from these simulations will be compared to satellite data measured by NASA's Aura High Resolution Dynamics Limb Sounder (HIRDLS), and with results from the Stratosphere-Troposphere Analysis of Regional Transport 2008 (START-08) campaign, which was led by the Atmospheric Chemistry Division of NCAR. Together, these datasets cover the period 2004–2008 and can be directly compared to WACCM-SD results.

In addition to the data/model validation study outlined above, a free-running version of WACCM, with enhanced vertical resolution and full tropospheric chemistry (WACCM-103L-TC) will be used for process studies of the UTLS, focusing on transport and chemistry of Very Short Lived Species (VSLS) that are thought to provide an important contribution to the active Bromine and Chlorine content of the stratosphere. These runs will document the role of convective sources, stratospheric and tropospheric chemistry, and ice microphysics. We will carry out two 20-yr simulations, one with full tropospheric chemistry, and one without contributions from VSLS.

Impacts of aviation on climate

Aircraft cause cirrus clouds to form in the upper troposphere directly from water emissions (contrails), and may significantly impact natural clouds both through the introduction of water and the introduction of soot (black carbon) and particulates. Currently there are large uncertainties in the global and regional impact of aviation on cirrus clouds. Despite this uncertainty, policy makers are considering significant multipliers on aircraft emission taxes with significant economic effects. Further work is urgently needed to understand ice cloud formation and nucleation in the atmosphere, and to constrain the impact of aviation emissions in particular. WACCM4 with high vertical resolution in the UTLS and full tropospheric chemistry (WACCM4-103L-TC) will be used to analyze the impact of aircraft emissions of water vapor and soot on climate and chemistry in the UTLS. Simulations will use CAM4 ice supersaturation physics for a consistent treatment of ice supersaturation and ice nucleation. We will carry out two 10-yr simulations, one with and one without aircraft emissions, to assess the impact of the latter.

Ionospheric and thermospheric variability

Ionospheric electrodynamics plays an important role in ionosphere-thermosphere coupling, as well as coupling with the lower atmosphere. It is also crucial for understanding upper atmosphere variability and space weather processes. We will implement, test and validate ionospheric electrodynamics modules in a version of WACCM4 that has been extended to approximately 500 km (125 levels) and includes ionospheric electrodynamics (WACCM4-X). We will then use the model to study ionospheric and thermospheric variability, ionosphere-thermospheric coupling, and coupling of the ionosphere and thermosphere to the lower atmosphere under different solar conditions. We request computational resources for a 3-yr simulation using WACCM-X with electrodynamics.

Experiment	Model Configuration (see Notes below)	# of runs	# of years	GAU / year	Total (KGAU)
3.1.1 WACCM4 development	WACCM4-4X WACCM4 CCSM/WACCM4 WACCM4-103L-TC	3 2 2 5	50 50 50 10	330 1320 1580 3880	49 132 158 194
3.1.2 QBO generation	WACCM4-140 L	2	25	2640	132
3.1.3 SSW climatology	WACCM4	6	30	1320	238
3.1.4 UTLS studies	WACCM-SD WACCM-SD-1X WACCM4-103L-TC	1 1 2	5 5 20	3320 13,280 3880	16 66 155
3.1.5 Aviation impacts	WACCM4-103L-TC	2	10	3880	78
3.1.6 I/T Variability	WACCM-X	1	3	14,140	42
Total					**1,260**

NOTES: Configuration of various versions of WACCM4 cited in Table 1.

WACCM4: 1.9° x 2.5° (lat x lon); 70 levels
WACCM4-4X: 4° x 5° (lat x lon); 70 levels
WACCM4-103L-TC: 1.9° x 2.5° (lat x lon); 103 levels; full tropospheric chemistry
WACCM4-140L: 1.9° x 2.5° (lat x lon); 140 levels
WACCM4-CCSM: 1.9° x 2.5° (lat x lon); 70 levels; coupled to CCSM POP model
WACCM4-SD: 1.9° x 2.5° (lat x lon); 88 levels; full tropospheric chemistry; driven by GEOS5.1 data (level structure matches GEOS5.1 dataset)
WACCM4-SD-1X: 1° x 1.25° (lat x lon); 88 levels; full tropospheric chemistry; driven by GEOS5.1 data (level structure matches GEOS5.1 dataset)
WACCM-X: 1.9° x 2.5° (lat x lon); 125 levels (top at 500 km); with ionospheric physics and electrodynamics

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Paleoclimate Working Group (PaleoWG)

Quaternary Simulations

New volcanic aerosol implementation with CCSM-4

The new implementation of volcanic aerosol in CCSM-4 includes two major advances over previous versions: (1) it now contains an evolving aerosol size distribution, and (2) the radiative perturbations in CAM/CCSM and CAM/WACCM are now consistent with the chemistry assumptions and processes in WACCM. The new evolving size distribution uses the aerosol mass concentration in each grid box to determine the size of particles, and thus the specification is prognostic if aerosol is transported by CAM, and diagnostic if the aerosol mass field is prescribed. This new treatment promises a more faithful representation of large volcanic eruptions, which were overestimated in previous versions. Additionally, the new consistency between the radiation and chemistry now offers investigations of chemical changes in the stratosphere that might prolong volcanically induced climate changes. To explore the skill of the new implementation we propose three simulations:

- Scale of explosive events from Pinatubo-sized to Toba-type Mega eruptions (event sizes tropical: Pinatubo, Tambora, 1257-event, Toba; and high-latitude: Katmai, Laki, Saksunavattn)
- Aerosol transport and deposition: quantification of polar sulfate flux (deposition) in relation to the size of the event to test ice-core based eruption estimates. (A parallel sensitivity test needs to be done for 10-Beryllium as a solar proxy as well)
- Investigate how volcanic forcing could be prolonged:
    - Effect on stratospheric water vapor and OH concentrations
    - Halogen injection and stratospheric effects

Landuse in CCSM-4

As the IPCC simulations of the last Millennium will include landuse (Pongratz et al. 2008), it is important to understand how regional landuse changes affect the climate independent of other external forcings. A set of sensitivity simulations explores the effect of landuse changes focused on particular regions, as well as for the longterm trend. These simulations are to be executed in the IPCC mode with diagnostic carbon cycle to estimate sources and sink changes due to landuse. One simulation is a branch off an IPCC run with coupled carbon cycle to evaluate if the observed Medieval to LIA fluctuation in atmospheric CO2 can be reproduced (von Hoof et al., 2008).

LGM Spin-up and spin-down experiments

Prof. Z. Liu (U. Wisconsin) will test the complete spin-up and spin-down from LGM to preindustrial, to help understand the transient mechanism of the climate system during glacial-interglacial cycle. The spin-up forward experiment will start with the LGM initial condition, but forced by the preindustrial forcing/boundary conditions, while the spin-up backward experiment will start with the pre-industrial initial condition, but forced by the LGM forcing boundary conditions.

Interglacials and Warm Periods: Paleoclimate Modeling Intercomparison Project

Studying interglacials and other past warm periods defines our understanding of the forcings and feedbacks that established and maintained the global and regional patterns of past warmth indicated by proxy data. We propose to do two simulations with the coupled

CCSM4 - 2º atmosphere x 1º ocean. The two simulations will be snapshots at 130 ka at the beginning of the Last Interglacial (LIG) to emphasize insolation forcing of summer Arctic warming and 125 ka during the middle of the LIG to additionally emphasize insolation forcing of the monsoonal circulations. These two LIG simulations, which bracket the strongest May-June-July insolation anomalies at the latitudes of Greenland, can also be used to interpolate atmospheric conditions to force offline ice sheet modeling of the Greenland Ice Sheet.

These simulations are PMIP3 coordinated experiments that were discussed and agreed to at the PMIP Workshop in Estes Park in September 2008. At least 8 international modeling groups have agreed to run these three periods with common forcings and boundary conditions. PMIP is designed to be not only a model-model intercomparison project but also a model-data comparison project, which enhances its contribution to IPCC assessment. We expect the PMIP3 data to be archived in IPCC format, similar to the PMIP2 data, to allow access by the community for analysis for the IPCC AR5, as well as other research interests.

Incorporation of paleo tracers into CCSM (with Paleo, Ocean & Biogeochemistry WGs each supporting one-third of the computing costs)

The paleo record demonstrates rapid and dramatic changes in ocean circulation and climate on timescales from decades to tens of thousands of years. These changes are recorded in ice cores and ocean sediments using tracers that are not currently simulated within the component models of CCSM. In order to gain an understanding of whether the CCSM model is able to replicate such changes, it is essential to be able to simulate the tracers that are recorded in the observational record. Determining whether, and by what mechanisms the model is able to replicate past abrupt changes in climate will also be crucial to our ability and confidence in future prediction of abrupt change events.

The paleo tracers we plan to incorporate into the fully coupled CCSM are • ^{18}O (used for assessing atmospheric temperature, precipitation, and ice-volume changes from water isotopes in polar and tropical ice cores); radiocarbon (which yields information on changes in rates of ocean ventilation); and • ^{13}C (which has been widely used to infer dramatic shifts and re-organizations in ocean circulation). This work will build on efforts incorporating water isotopes into CAM3.0 and CLM3.0 (David Noone, University of Colorado).

Pre-Quaternary Simulations

Pliocene Intercomparison Project

Past warm intervals may provide insight into climatic forcing in the absence of anthropogenic perturbations. Among the many past warm intervals, the Pliocene is of particular interest because continental configurations were very similar to modern configurations and CO_2 concentrations appeared to be both comparable to 2007 values and stable. These boundary conditions provide an ideal testbed for exploring feedback mechanisms that may have contributed to the significantly warmer temperatures, smaller polar ice sheets, and higher sea level of the Pliocene, and will form the basis of a new model-data intercomparison project that is being developed. In addition to CCSM, the HadCM and GISS modeling groups are proposing to work together on simulating the mid-Pliocene (3 million years ago) using a common experimental design, which includes atmosphere-only simulations forced with SSTs reconstructed by the PRISM3 project and a coupled simulation. Standardized multi-model paleoclimate intercomparison projects have become important benchmarks in the IPCC assessments. A session will be held at the AGU Fall Meeting in December 2008 to identify additional interest among paleoclimatologists employing models and proxies from the marine and terrestrial realms. A first coupled simulation with CCSM3 to be completed this fall on the current CSL allocation will provide the basis for these future simulations. It will evaluate the influence of the polar ice sheets on future warming by using present-day geography and greenhouse gas concentrations with Pliocene estimates of the configurations of the reduced Greenland and Antarctic ice sheets.

Impact of changes of orbital forcing on Paleocene Eocene Thermal Maximum climate

Recent studies indicate that orbital changes may have led to climatic change such as changes in temperature and precipitation and may have contributed to the global warming event at the Paleocene-Eocene boundary. Prof. A. Winguth (U. Texas, Arlington) will carry out two PETM coupled simulations for maximum and minimum northern hemisphere insolation to investigate the effect of orbital changes on monsoonal circulations. Results of the simulation will be compared with paleoclimatic data, for example for the Eocene Willwood formation and changes in marine records.

Latest Cretaceous Simulation

The nature of the Cretaceous climate 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. We will carry out a simulation for the Latest Cretaceous (65.5 Ma) time period to establish the state of the climate system just prior to the bolide impact. The Paleoclimate WG also endorsed this simulation, with strong interest in comparing the results of the simulations against a wide range of paleoclimate data. This project is in direct collaboration with Prof. Garland Upchurch (Texas State U.), who will provide paleoproxy data to evaluate the model simulation.

Mid Permian Climate Simulations

The mid Permian time period was a cold Permian state with extensive continental ice formations. Carbon dioxide levels were similar to present day concentrations. This simulation is to support a collaborative effort involving Prof. Lynn Soreghan at the University of Oklahoma and Prof. Natalie Mahowald at Cornell University. Geologic data indicate that the mid-Permian was a time period of heavy atmospheric dust loading.

Two simulations will be carried out for two levels of atmospheric CO_2. The output from these simulations will be used to drive the dust model of Mahowald. Results from the dust simulations will be compared with geologic data from specific regions. The radiative role of the dust on the climate system will also be assessed in this project. Results from these simulations will also be provided to Prof. I. Montanez (U.C. Davis), who has paleoproxy data for the mid-Permian.

High Resolution Latest Permian Coupled Simulation

This simulation will be the first coupled high-resolution climate model for this time period. The motivation for this coupled simulation comes from the results of the uncoupled CAM3 high-resolution simulation carried out under the previous CSL allocation. Results from the CAM hi-res simulation produced a large number of intense tropical and extra-tropical storms. There is an indication that these storms may play an important role in the meridional temperature gradient for warm climate regimes. The only way to test this is to carry out a fully coupled integration for the Latest Permian. Thus, this simulation is a natural extension of the previous uncoupled Permian simulation. The findings of this simulation will be applicable to other periods of geologic time where CO_2 levels were high and the climates were very warm.

Coupled Climate Simulation of the Late Ordovician

The Latest Ordovician (~445 Ma) was a time when Earth experienced the first recorded mass extinction. This was a time where much of the land mass was joined together, and was located in the southern hemisphere. This extinction is attributed to the cold climate regime that Earth entered at this time. The Ordovician is a time of elevated levels of atmospheric carbon dioxide relative to today (~4 to 15 times pre-industrial levels). The solar luminosity was approximately 5% less at this time, which means that the net forcing of the climate system was equivalent to a ~ 1/2 to 2 -fold increase in CO_2. Geologic data indicates that much of the southern hemisphere continent was ice covered at this time. We have completed the development of an Ordovician version of CCSM3. This model uses a novel rotation of the ocean gird to avoid placing a false pole in the northern hemisphere. Now that the Orodovician model is running, we will use it to model the climate of the Late Ordovician. We will carry out simulations assuming two different levels of CO_2: 4X and 15XPAL. We will look at the mechanisms that determine the climate state, in particular the role of ocean energy transport versus atmospheric energy transport. Model output will also be compared with existing geologic data to evaluate the model’s ability to accurately simulate the Late Ordovician climate. This project is being carried out in collaboration with Prof. Chris Scotese (U. Texas, Arlington).

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Quaternary					
Volcanic forcing	fv1.9x2.5_gx1	4	100	280	112
Land use	fv1.9x2.5_gx1-cc	3	50	560	84
LGM spin-up	T31X3	2	2000	34	136
Glacial PMIP	fv1.9x2.5_gx1	2	200	280	112
CCSM tracers	T31X3+Tracers	6	400	40	96
Pre-Quaternary					
Pliocene PMIP	T31X3	1	2000	34	68
PETM Orbital	T31X3	2	1000	34	68
Latest Cretaceous	T31X3	2	2000	34	136
Mid Permian	T31X3	3	1275	34	130
Permian Hi-Res	T170_gx1 CCSM	1	50	1400	70
Latest Ordovician	T31X3	2	1000	34	68
TOTAL					1080

Climate Variability Working Group (CVWG)

Overall Scope

The overall research focus of the CVWG is the analysis of natural and anthropogenically-induced patterns of climate variability and their mechanisms in CCSM and its component models, as a means of furthering our understanding of the observed climate system. The CVWG proposes a series of production runs that will be made available to the broad research community. These simulations are focused in four areas: 1) Decadal Prediction, 2) Drought, 3) Assessing Uncertainty in Future Climate Projections, and 4) Arctic Climate Change. All of the integrations proposed in this cycle are motivated by broad community interest and are being closely coordinated with the CCSM Climate Change and Polar Climate Working Groups. The total GAU request is divided approximately evenly among the 4 topics.

1. Decadal Prediction

i. Background

The WCRP/CLIVAR Working Group on Coupled Modeling (WGCM) and the Analysis, Integration and Modeling of the Earth System (AIMES) project of IGBP have jointly recommended coordinated climate change experiments for modeling groups planning to contribute to the next assessment activity of IPCC. One set of experiments is specifically designed to help address science questions related to regional climate change and the predictability of natural variability. They are centered on the idea of producing 10-30 year coupled model predictions from initialized climate states with relatively high resolution atmospheric model components. Within this set of experiments, modeling groups are encouraged to produce 10-year integrations with start dates every 5 years from

1960 to 2005, and 30-year integrations from start dates of 1960, 1980 and 2005. Each modeling group will ultimately decide how they wish to "initialize" their coupled model, with the only guidance being that the ocean initial conditions be in some way representative of the observed anomalies or full fields for the start date. The modeling groups are also being encouraged to perform ensembles for each start date of order three.

The CCSM community is committed to following this experimental protocol using an atmospheric model resolution of ~50 km. Moreover, several preliminary decadal forecasts using CCSM already exist. The latter were begun from 1980 and 2000 start dates. Several members of CVWG are planning to analyze the planned and existing CCSM hindcast simulations and others as they become available, verifying against the observed evolution of the climate system.

ii. Proposed Experiments

The CVWG proposes additional experiments to better quantify the sources of uncertainty in regional climate change and decadal predictions resulting from chaotic atmospheric variations that yield spread in regional climate responses to specific SST states. In particular, it is of community value for the CVWG to significantly enhance the planned efforts of CCSM by performing much larger ensembles (order 25) using the atmospheric component of CCSM forced with the SST trajectories taken from the hindcast experiments. This approach will allow for more statistically meaningful probabilistic statements of decadal climate change with which to compare to the actual observed evolution over North America.

Priority will be to focus on the 1990 and 2000 start dates, which provide two independent, and the most recent, decades from which we can judge the "success" of the initialized predictions, and also compare them to the regional climate change in uninitialized (C20C) experiments.

Another source of uncertainty in regional climate change is that chaotic coupled ocean-atmosphere variations will produce spread in projected SST changes. It would therefore also be useful to aggregate the simulated decadal SST changes from each of the hindcast ensemble members into an "average" single SST forecast, again initially emphasizing the 1990 and 2000 start dates, and again perform a large ensemble of atmospheric-only simulations. Working within the constraints of the total CVWG GAU allocation, we propose a total of 32 10-yr integrations of CAM4.0 at 1 degree resolution for this component of the CVWG CSL proposal (see "Decadal Prediction" entries in Table).

2. Drought

We propose integrations of the CAM4.0 model to investigate drought genesis and maintenance, especially over North America. The integrations will follow the experiment suite recently executed with the CAM3.5 model to facilitate NCAR's contribution to the US CLIVAR Drought Modeling program. The new integrations are designed to be more revealing of the mechanisms generating North American droughts. They differ from previous experiments, principally, in the introduction of seasonal (and modal) evolution of the specified SST anomaly patterns, and because of focus on inter-basin interactions.

Integrations executed earlier this year closely followed the CLIVAR Drought Modeling Group prescription, which involved specifying seasonally invariant (i.e., perpetual) SST anomaly patterns atop the monthly varying SST climatology in 50-year long integrations. Specification of static SST anomalies is considered unreasonable, especially in context of multi-year droughts over the central United States (e.g., the 1930s 'Dust Bowl') as the SST anomalies in this period exhibited considerable seasonal (and interannual) variation. In this new cycle, CVWG will focus on elucidation of drought mechanisms by executing CAM4.0 integrations with seasonally evolving SST anomalies in the Pacific and Atlantic basins; individually and together. The specified anomalies will also evolve on interannual time scales: For example, the proposed experiments will model the response of a seasonally evolving ENSO rather than just the static, mature-phase ENSO pattern. For starters, AMIP-vanilla (forcing from historical SSTs only) simulations for the 1871-2007 period are proposed with climatological SSTs, observed global SSTs, and SST anomaly specification from both individual and combination of recurrent modes (totaling 11 simulations at 2 degree resolution and 137 years in length each). The proposed experiments are summarized in Table ("Drought" entries).

3. Assessing Uncertainty in Future Climate Projections

The CVWG and CCWG have completed a 30-member ensemble of IPCC A1B scenario runs with CCSM3 at T42 resolution for the period 2000-2061. The unprecedented size of the ensemble allows for the first time a robust assessment of the uncertainties in climate projections. This ensemble is presently being analyzed by a wide variety of researchers. As part of this project, it was proposed to undertake a large ensemble (~50 members) of short (~10-year duration) integrations of CAM3 at higher resolution (T85) driven by the surface boundary conditions from the last 10yrs 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. The CVWG proposes to conduct these experiments in the upcoming CSL cycle (see "Uncertainty" entries in Table).

4. Arctic Climate Change

Arctic sea ice is diminishing at an alarming rate, and model projections indicate the Arctic will be ice-free in summer by the mid-to-late 21st century. The CVWG proposes a set of experiments directed at understanding the role of projected Arctic sea ice loss in the seasonal response of the climate system to increased GHG concentrations. These experiments are motivated by community input from both the CVWG and PCWG. The first experiment using CAM4/CLM4 will prescribe the seasonally varying Arctic sea ice area and thickness from present-day and the late 21st century taken from the CCSM4 historical and A1B integrations. SSTs will be fixed at a seasonally-varying present-day climatology in order to isolate the coupled atmosphere-terrestrial response to Arctic sea ice change in the absence of any oceanic feedbacks. Terrestrial carbon cycle and vegetation dynamics will be active in these experiments. The second experiment will repeat the previous future sea ice simulation, but include an interactive simple slab ocean mixed (SOM) layer model. Comparison of the two sets of future sea ice experiments will isolate the effect of the thermodynamic ocean mixed layer response *via* SST changes on the coupled atmosphere-terrestrial response to Arctic sea ice change. These experiments are listed in Table under "Arctic".

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Drought AMIP (Global time-varying SSTs)	CAM4 (2°)	5	137	140	96
Drought AMIP (Climatological SSTs)	CAM4 (2°)	1	137	140	19
Drought AMIP (Seasonally varying SST anomalies specified from individual/combination of recurrent modes)	CAM4 (2°)	5	137	140	96
Decadal Prediction 1990 start date Individual hindcast SST	CAM4 (1°)	8	10	600	48
Decadal Prediction 2000 start date Individual hindcast SST	CAM4 (1°)	8	10	600	48
Decadal Prediction 1990 start date Ensemble mean SST	CAM4 (1°)	8	10	600	48
Decadal Prediction 2000 start date Ensemble mean SST	CAM4 (1°)	8	10	600	48
Uncertainty 2052-2061 SSTs	CAM3 (T85)	50	10	400	200
Arctic Present-day sea ice Future sea ice	CAM4 (1°)	2	60	600	72
Arctic Future sea ice	CAM4 / SOM (1°)	1	60	750	45
Total					720

Climate Change Working Group (CCWG)

Work begun in 2008 investigating the impact of Greenland ice sheet melting on ocean circulations shows that an ice sheet melting with a rate up to 0.03 Sv would not alter the MOC much in comparison to the simulation without prescribed Greenland Ice Sheet melting. A melting rate exceeding 0.05 Sv would further weaken the MOC by 9-24% by the end of the 21st century. This weakened MOC doesn't make the late 21st century global climate cooler than the late 20th century, but does cause the climate to be a few degrees less warm in the northern high latitudes. However, the additional dynamic sea level rise due to this weakened MOC could potentially aggravate the sea level problem near the northeast North America coast. For 2009, we would like to evaluate the effect of increased river runoff due to melting of the mountain glaciers and ice caps, and combined effect of the Greenland, Antarctic and river runoff on the MOC. This will require 6 two-hundred years of T42 CCSM3 simulations.

1. West Antarctic ice sheet melting via a constant melting rate of 0.004 Sv
2. Same as 1, but with rate of 0.004 Sv increase 1% per year.
3. Same as 1, but with rate of 0.004 Sv increase 3% per year
4. Same as 1, but with rate of 0.004 Sv increase 7% per year
5. Same as 3, but with global runoff increase of 3% per year
6. Same as 5, but adding Greenland melting with 3% increase.

Runs investigating the effect of hurricanes on the MOC were also carried out. By prescribing Atlantic hurricanes in a global coupled climate model to show that, climatically, the strong hurricane winds can strengthen the Atlantic MOC that is responsible for an increased northward meridional heat transport (MHT), and the hurricane rainfall tends to weaken the MOC and to reduce the MHT. The net effect of the hurricanes on the MOC and MHT depends on the outcome of these two competing processes. This result implies that hurricanes may indeed play an important role in the coupled climate system and need to be studied further in high resolution global coupled models. For 2009, we would like to extend this study to evaluate the effect of the Pacific and Indian Ocean tropical cyclones on the MOC

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
Greenland Ice Sheet melting	T42 CCSM3	6	200	200	240
Pacific & Indian Ocean Hurricanes	T42 CCSM3	6	100	200	120
TOTAL					360

Software Engineering Working Group (SEWG)

The SEWG is actively involved in all stages of CCSM production and development. This work involves 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, especially where new component science has been introduced). The creation of CCSM4 has been associated with ambitious new scientific and software development across all CCSM model components. As a result, new CCSM4 related development revisions are being created on a weekly basis. In addition, CCSM revisions are also periodically created for patches made to the CCSM3 release and CCSM3.5 code base. We project that at least four revisions will normally be created each month for these older code bases.

The creation of each CCSM revision involves the performance of numerous short tests to ensure reliability on CSL production machines. These tests will be performed on Bluefire and Lightning. Historically, the CCSM test suite has successfully detected many unanticipated problems *before* major computational and scientific resources have been expended in long production runs. Current test cases include the verification of performance throughput, the determination of memory high water marks, the determination of optimal load balance and functionality tests for exact restart, branch startup and hybrid startup. Each of these tests is often performed for a variety of CCSM configurations and resolutions. Since the CCSM3 release, and with the creation of CCSM4, the test parameter space has continued to expand rapidly and has therefore resulted in a continually growing regression validation test suite. The SEWG is currently running between 300-400 tests every month. Each test type is often run in more than one resolution and with a variety of component configurations. 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 and unexpected performance slow downs that can be remedied before a production run is started.

As CCSM4 science is finalized, additional tests covering new scientific or software functionality will be added and 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 allocation request also includes the need to run various load balancing runs before a production run is undertaken to ensure optimal throughput and efficiency for the given experimental configuration. A CCSM load balancing exercise involves the process of determining the optimal number of MPI tasks and Open-MP threads for each CCSM component for a given CCSM configuration and resolution and targeted processor count. The determination of proper load balancing for a given experimental simulation can result in a dramatic difference in overall CCSM performance and efficiency. The CCSM4 modeling system is accompanied by 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, and that simplifies the determination of optimal load balancing. Furthermore, the CCSM scripts ensure that all CCSM users utilize SMT functionality on Bluefire in CCSM production runs.

The SEWG is requesting 20 KGAU/month in resources over the next 18 months to run CCSM tests, for a total of 360K GAU.

Estimate of CCSM3 and CCSM4 GAU Costs on Bluefire

Runs	GAU / Sim Year	CPU-hrs / Sim Year
CCSM3 coupled integrations		
T42_gx1v3	210	150
T31_gx3v5	34	24
T31_gx3v5 with carbon cycle	42	30
CCSM4 coupled integrations		
fv1.9x2.5_gx1v5	280	200
fv0.47x0.63_gx1v5	3220	2300
fv1.9x2.5_gx1v5 with carbon cycle (ocean ecosystem and clm CN or CASA)	560	400
fv1.9x2.5_gx1v5 with CAM chemistry	600	430
fv1.9x2.5_gx1v5 with WACCM (70 levels)	1580	1130
CCSM4 CAM/CLM/CICE (prescribed) / DOM (F) (CAM3.5 + MG microphysics + RRTMG + prescribed BAM aerosols)		
fv1.9x2.5	140	100
fv0.47x0.63	2675	1910
fv1.9x2.5 with CAM chemistry	470	336
fv1.9x2.5 with WACCM (70 levels)	1320	943
CCSM4 POP/CICE/DATM		
gx1v5 POP stand-alone (C)	130	93
gx1v5 POP/CICE (G)	140	100
gx1v5 POP/CICE and ocean ecosystem	280	200
gx1v5 CICE stand-alone (D)	25	18

GAU estimate based on bluefire charge factor of 1.4

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