CCSM

Community Climate System Model

Proposal for CSL Resources - Production

12/01/2007 – 05/31/2009

Table of Contents

Overview

Project Title
Community Climate System Model: Production

PI
Peter R. Gent, NCAR

Current CSL Allocation
268.89 KGAU/month

Request in this Proposal:

Working Group	Dec. 07 – Nov. 08	Dec. 08 – May 09
Paleo WG	36 KGAU/month	90 KGAU/month
AMWG, OMWG, BGCWG, CVWG, CCWG	32 KGAU/month	80 KGAU/month
LMWG, PCWG, ChemWG	24 KGAU/month	60 KGAU/month
Total	**268 KGAU/month**	**670 KGAU/month**

Thus, the total request is for 7236 KGAU over 18 months.

Introduction

The accomplishments of the CCSM project using CSL resources are contained in the accompanying report. The Production runs over the 18 months of this request fall into two broad categories. The first are those coupled runs necessary for the development of CCSM4, including the carbon/nitrogen cycle and the atmospheric chemistry component. These come from the model development Working Groups – Atmosphere, Ocean, Land, Polar Climate, Biogeochemistry, and Chemistry. The second are production runs of earlier versions of the CCSM required to address scientific questions requiring a comprehensive climate model. These come mostly from the Paleoclimate, Climate Variability, and Climate Change Working Groups, but the model development WGs also have production runs in this category.

Atmosphere Model Working Group (AMWG)

1. Research Plan

Our production proposal is closely tied to the work done using our model development allocation. We will not repeat the rationale for our work plan again here, but refer the reader to the discussion in our development proposal. Much of the distinction comes from minor variations in our mode of work:

- We plan to make longer simulations in the production category.
- We plan to make more of the most expensive simulations in the production category.
- We plan to make all coupled model simulations in the production category.

As an example of this kind of work, we expect that when the shorter model simulations performed using development resources suggest that changes to the Community Atmosphere Model (CAM) physical parameterizations will result in significant reductions in the double intertropical convergence zone (ITCZ) problems, we will perform coupled model simulations to identify the impact in CCSM. Likewise, it is very clear that the new formulations for shallow convection and PBL processes devised by Bretherton and Park make very significant changes to the surface fluxes of energy and momentum. These are expected to have a substantial impact on ocean circulations. The PBL, shallow convection, cloud microphysics, and interactions between aerosols, and clouds (the indirect effect) are expected to have strong impacts on the models climate sensitivity (temperature response to CO2 doubling). These effects can only be explored in CAM simulations that are coupled to an interactive ocean (either a slab ocean or a fully coupled dynamic ocean model).

2. Scientific Objectives

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

A) Produce a state-of-the-art general circulation model for the research community that substantially reduces the biases present in CAM3. We believe those biases are associated with physical processes like convection, boundary layer turbulence, clouds, etc. The next generation model must be able to run in fully coupled mode without the sea ice problem in the North Atlantic that is present in CCSM3 with the finite volume (FV) dynamical core. We also are working on a model that provides new functionality designed to improve the ability of CCSM to deal with new classes of problems in chemistry-climate interactions and biogeochemical cycles.

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

C) Understanding the interaction between the processes controlling the hydrologic cycle and the other components of the general circulation. In particular, we will continue to focus on transient features of precipitation (the diurnal variation of precipitation, the biases in the sub-diurnal timescale episodic nature of convection in our model), and biases in the ITCZ features in our model. We will do this by working with the Ocean Model Working Group (OMWG), the TVTT, and CTB efforts.

3. Computational Requirements

We have picked a number of runs directed to make progress on the above goals during the time period of this proposal. We have formulated our proposal in the context of a series of runs with the FV model. Our baseline model is assumed to be a 30-level, 2x2.5 resolution configuration. The baseline CAM/CLM model will cost about 70 GAUs per year. We have assumed that three kinds of runs will be made in the production queues: AMIP runs, SOM runs, and coupled runs.

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

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Revised physics	FV2x2.5	24	20 (AMIP)	70	33
Revised physics	FV2x2.5	24	50 (SOM)	70	84
Bulk Aerosols	FV2x2.5	4	20 (AMIP)	140	11
Bulk Aerosols	FV2x2.5	4	50 (SOM)	140	28
Modal Aerosols	FV2x2.5	4	20 (AMIP)	200	16
Modal Aerosols	FV2x2.5	9	50 (SOM)	200	90
IPA	FV2x2.5	10	20 (AMIP)	210	42
Vertical resolution	FV2x2.5	12	20 (AMIP)	140	33
Vertical resolution	FV2x2.5	12	50 (SOM)	140	84
Horizontal resolution	FV1x1.25	8	20 (AMIP)	420	67
Horizontal resolution	FV1x1.25	8	50 (SOM)	420	168
FV coupled candidates	FV2x2.5	8	130 (coupled)	200	208
TOTAL					864

Ocean Model Working Group (OMWG)

1. Research Plan

There are four main streams in the OMWG research plan for the 18 months starting December 2007. One is full participation in the second and third phases of the Coordinated Ocean-Ice Research Experiments. Another is completion of the collaboration as partners in the CLIVAR Climate Process Teams on ocean mixing. A new theme is the ocean's evolution over the past few millennia. Finally, there is a lead role in CCSM's new priority of short-term climate projections. The proposed “production” runs will utilize existing models, as developed over the past 18 months. They include both fully coupled CCSM and coupled ocean-ice configurations. In general, each experiment will be useful for more than one purpose, and this utility in addition to perceived scientific merit dictates the assigned priority.

2. OMWG Science Objectives

Coordinated Ocean-Ice Research Experiments

Coordinated Ocean-Ice Research Experiments (CORE) have been proposed as a vehicle for ocean modeling groups around the world to explore the behavior of global coupled ocean-ice models under common surface forcing. The science objective is an understanding of coupled ocean sea-ice behavior as a sub-system in the more complete and complex system involving the atmosphere. As part of a coordinated, international activity, the peculiarities of the CCSM ocean and sea-ice model, as well as its similarities, compared to other models will be revealed. Applications of the CORE results will include, studying the interactions between the ocean and sea-ice, exploring a greater region of model parameter space, manipulating the forcing in order to understand the mechanisms responsible for generating variability at select time and space scales, exposing deficiencies in model representation of physical processes compared to other models of the same class, assessing various ocean reanalysis and observational data sets in terms of their implications to ocean climate, and testing tools and methods that are ultimately aimed at analyzing the fully coupled system.

CORE has developed along three avenues, with the first, CORE I, recently completed. It is characterized by a climatological “Normal Year” forcing that was repeated for 500 years. Now being proposed are CORE II and CORE III integrations. Core II runs will be forced with a repeat cycle of interannually varying forcing that is long enough to spin up the upper and intermediate ocean depths, as with CORE I. The interannual variability can be analyzed for ocean processes and compared to observations. Particular foci will be ocean climate variability on interannual to decadal timescales, tropical variability from daily to interannual, and how this variability changes over the 500 years. The robustness of these signals as quantified by their differences over a variety of models is the critical, unique aspect of CORE.

The design of specific CORE III experiments has been collaborative and includes dam-break and Greenland melt experiments, the design for which will be finalized by the end of 2007. The former mimics the sudden outflow of glacial melt waters from North America, while the latter will prescribe a continuous melting of Greenland that accelerates from current levels over about 800 years. The signals of greatest interest will be the ocean response and how this varies between the different models.

Climate Process Teams

The two CLIVAR Climate Process Teams (CPTs) on ocean mixing are Eddy-Mixed Layer Interaction (EMILIE) and Gravity Current Entrainment (GCE). Both were recently renewed for year four and five funding, that will begin in October 2008. Therefore, the related production runs will receive full attention and highest priority over the first year. The CPT science that most naturally falls to the OWG is the climate impact assessment of CPT ocean model developments. One focus will be on the ocean climate and another on the coupled climate as indicated by such measures as air-sea fluxes and atmospheric circulation. Therefore, the specific science objectives are: to determine the climate sensitivity to the parameterization of individual deep ocean overflows, such as Denmark Strait and Faroe Bank; to the parameterization of eddy mixing within the well mixed upper ocean; to the depth distribution of eddy mixing coefficients; and to a recently developed parameterization of the sub-meso-scale.

Ocean Evolution

The latest version of T31x3 is able produce a realistic ENSO, on par with the FV2x2 ENSO. Thus, it opens up the opportunity to explore long term decadal and centennial climate variability as well as timescales of ocean adjustment over thousands of years, so that the deep ocean can finally be equilibrated in a coupled model. The scientific questions of interest include: How different is the ocean in this evolving spin-up from the ocean spun-up using present day conditions throughout? How did ENSO change over the last 4000 years under the influence of greenhouse forcing, volcanic forcing and orbital forcing? Is either our current ocean or our ocean from 1870 in equilibrium, or are we still seeing the effects of events from past millennia? What is the effect of ocean BioGeoChemistry (BGC) on climate variability on times scales up to millennia? The BGC results will also provide experience needed to build the infrastructure for a future Earth System Model.

Short-term Climate Projections

The science objective here is to produce short term (approximately 30 year) climate projections, using the most promising methodology from the development proposal. In order to have some means of validation, the proposed runs are in the context of “projections” of observed climate changes over the past few decades. The major metrics will be the predictability/forecast ability of the 1970s Pacific regime transition as well as an examination of the predictability of the modulation of ENSO periodicity and amplitude that occurred in the mid 1980s through to 1997. Importantly, this will mark the first attempt to answer the question as to how far in advance might one be able to predict significant decadal events, by utilizing the above known changes of the past.

3) Proposed Numerical Experiments and Resource Requirements

Coordinated Ocean-Ice Research Experiments

a) *Interannually Forced Historical*

Coupled ocean-ice experiments forced with a prescribed historical atmospheric state, require about 125 GAUs per simulated year. In order to match the 500 years CORE I, there will be 10 repeat cycles of 50 year forcing (1955 - 2006), which is sufficient to spin-up the upper and intermediate ocean depths.

b) *Greenland Melt*

An 800 year melting scenario prescribed for Greenland will modulate the forcing of coupled ocean-ice models, at a cost of 125 GAUs per simulated year or total of 100 KGAUs.

Climate Process Teams

c) *EMILIE*

We plan to assess the climate impacts of three extensions of the eddy parameterization that have been produced by CPT EMILIE; namely, the near-surface eddy flux scheme, the surface enhancement of the diffusivity coefficients and the submesoscale parameterization. Each of the three assessments will need to allow deep ocean signals time to develop, so 300 year integrations are required. With this duration, good ENSO statistics will be available for analysis.

d) *GCE*

We plan to assess the climate impacts of the parameterized Faroe Bank Channel and Denmark Strait overflows. For the reasons noted above for EMILIE (long term behavior of the deeper ocean, ENSO statistics), two 300 year integrations are proposed. The first will incorporate both overflows. The second will parameterize only one, which will be chosen based on results from the first.

e) *Past Ocean Evolution*

At a minimum, a 3000 year run is needed to spin up the deep ocean. With the new atmosphere and ocean physics of CCSM3.5, the estimated cost is 30 GAUs per simulated year. This run will also be a control for a run where ocean BGC interacts with the physics through solar absorption by chlorophyll from the BGC model. With the addition of BGC, the estimated cost increases to about 50 GAUs per simulated year.

f) *Short-term Climate Projections*

Each projection will be run for 25 years in the fully coupled CCSM. We are proposing to utilize two initialization procedures; one with ocean re-analyses (from development) and the other with the “true” ocean state from a model. For both cases there will be 16 projections. These will be started on January first of 1960, and every second year thereafter through to 1990.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
CORE					
a) Interannually forced historical	x1ocn / ice	1	500	125	64
b) Greenland melt	x1ocn / ice	1	800	125	100
CPT Climate Impacts					
c) Mixed-layer Eddy parameterizations	FV2_x1	3	300	200	180
d) Gravity current overflows	FV2_x1	2	300	200	120
e) Past Ocean Evolution	T31x3 T31x3 (bgc)	1 1	3000 3000	30 50	90 150
f) Decadal Projections / Predictions	FV2_x1	32	25	200	160
TOTAL					864

Land Model Working Group (LMWG)

One of the main priorities of the LMWG is to improve our understanding of the role of land surface processes and feedbacks in the climate system. Of particular interest to the LMWG are the effects of changes in land cover and land use on climate including the effects of urbanization. Additionally, the LMWG is interested in the biophysical feedbacks associated with changes in vegetation distribution, particularly in the northern high-latitudes which are already experiencing considerable change. Lastly, the LMWG is interested in the sensitivity of climate-change induced alterations of the water cycle to the simulated land-atmosphere coupling strength. Experiments are proposed to address each of these areas of research.

1. Land cover change/land use change including urban

A large portion of the CSL production resources requested by the LMWG are devoted to research on the impact of land cover and land use change. The LMWG is participating in an international land cover/use change intercomparison project in which a number of major climate modeling groups are participating; deNoblet and Pitman, 2007: Land-use and climate identification of robust impacts (LUCID) project. A suite of simulations are proposed with 1870, present-day, and a number of future scenario land cover/land use conditions, forced with SSTs and sea-ice taken from a transient CCSM simulation. Multiple ensemble members will be run for each time slice experiment. These simulations will take advantage of the new urban parameterization in CLM to assess the impact of urbanization on climate and to evaluate how changes in regional climate will impact the climate of cities. The urban forcing datasets will be derived in collaboration with Johann Feddema (U. Kansas) and Paty Romero Lankao (ISSE). Simulations will be run with FV1x1.25 CAM/CLM.

CO2	Vegetation and urban map	Prescribed SSTs	Number ensembles per simulation
280 ppm	1870	1870-1900	5
375 ppm	1992	1972-2002	5
280 ppm	1992	1870-1900	5
375 ppm	1870	1972-2002	5
560 ppm	1992	2070-2100	5
560 ppm	2100	2070-2100	5

2. Change in northern high-latitude ecosystems

The climate of the northern high-latitudes is changing more rapidly than elsewhere around the world. Warming of up to 3°C has been observed in some regions. Ecosystems are responding noticeably to this warming with tundra ecosystems being converted to shrubland ecosystems, forest boundaries slowly migrating northward, and larch forests being replaced by coniferous forests. With each of these changes, there are potentially significant associated changes to the albedo - changes which can be amplified by the snow-vegetation-albedo feedback. The CLM-DGVM is being updated to include a boreal shrub plant functional type into CLM, which will permit a more realistic evaluation of the evolution of high-latitude ecosystems. A series of experiments will be conducted to assess the potential ecosystem changes under climate change and to evaluate to what extent the changes in ecosystem structure feedback onto ecosystem evolution itself. This work will be conducted in collaboration with university partners Hank Shugart (U. Virginia) and Xubin Zeng (U. Arizona). The proposed experiments will be CAM/CLM-DGVM/SOM simulations with and without increasing atmospheric CO_2 concentrations.

3. Land-atmosphere interaction and drought

The Global Land-Atmosphere Coupling Experiment (GLACE, Koster et al. 2004) showed that AGCMs characterize the degree of interaction between the land and the atmosphere very differently. This raises important questions with respect to results from climate models on the impact of land cover change on climate and on changes in the water cycle, particularly drought. The family of CCSM models (CAM3-CAM3.5/CLM3-CLM3.5) is interesting in that different combinations exhibit very disparate land-atmosphere coupling strengths. The high coupling strength in CAM3/CLM3, for example, puts it among the strongest of the 12 AGCMs evaluated in GLACE, while the very weak coupling strength in CAM3.5/CLM3.5 puts it among the weakest of the GLACE AGCMs. A series of experiments using various configurations of CAM/CLM is proposed that will take advantage of the differences in coupling strength across the versions of CAM/CLM. They will assess the impact on the frequency, amplitude, and duration of simulated present-day droughts and, more importantly, on the sensitivity of climate-change induced evolution in drought characteristics to land-atmosphere coupling strength. Drought statistics will be obtained from 5-member ensembles of 25-year CAM/CLM simulations forced with SSTs from CCSM simulations for 1975-1999 and 2075-2099 climates. The model configurations will be CAM3-CLM3, CAM3.5-CLM3, CAM3-CLM3.5, and CAM3.5-CLM3.5. CAM4 and CLM4 versions may be used instead of CAM3.5 and CLM3.5, if they are available by the start of this project.

4. High-resolution CLM

A high-resolution, or fine mesh version, of CLM and associated downscaling algorithms have been developed and coded into CLM over the last couple of years. In this version of CLM, atmospheric data, whether from CAM or an offline forcing dataset, is downscaled from its coarse resolution to a finer CLM resolution. Although the initial downscaling parameterizations appear promising, additional developments are required including work on slope aspect information, radiation downscaling, and more refined precipitation downscaling over mountainous terrain. This model will continue to be developed by David Gochis and Andrea Hahmann in RAL. Here, we will conduct some preliminary simulations to evaluate the utility of the high-resolution land data for use in impacts assessment work. The motivation is to complete some sample simulations prior to the next round of IPCC coupled CCSM simulations to evaluate whether or not the LMWG should propose some high-resolution land simulations for the IPCC effort. These preliminary experiments will consist of two sets of two simulations (CAM-CLM simulations at FV1.9x2.5 and at FV1.9x2.5 with 0.25° land for 1970-2000 and 2070-2100 forced with CCSM SSTs from a transient simulation and associated greenhouse gas concentrations).

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Land cover/land use change	FV1x1.25 CAM/CLM	30	30	420	378
High-latitude DGVM	1%CO_2 FV1.9x2.5 CAM/CLM/SOM	5	200	100	100
Land-atmosphere drought	FV1.9x2.5 CAM/CLM	40	30	75	90
High-resolution land for impact assessment	FV1x1.25 1x1.25° CLM	2	30	420	26
High-resolution land (2)	FV1x1.25 0.25° CLM	2	30	900	54
TOTAL					648

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

1. Fresh water pathways in the Arctic Ocean

Changes in the high latitude hydrological cycle, including increased river discharge and freshwater transport to lower latitudes can have a potentially important influence on the global ocean circulation. Here we seek to identify the pathways of freshwater from different sources in the Arctic Ocean, and to investigate the mechanisms that lead to changes in the freshwater distribution and storage in the Arctic Ocean. We will use the results of the simulations to quantify the contribution of rivers, sea ice melt, Bering Strait inflow and net-precipitation to the freshwater fluxes out of the Arctic. Additionally, we will assess the changes in the spatial distribution of freshwater resulting from different sources in the Arctic in response to varying atmospheric forcing. As the freshwater export from the Arctic is intimately linked with the heat exchange between the North Atlantic and the Arctic Ocean, results from these model realizations will also improve our understanding of oceanic heat transport variability and change.

The proposed experiments will use freshwater tracers in the Arctic to provide constraints on the model simulations of present-day climate and investigate variability and change in the Arctic freshwater pathways. Model results will be compared with the delta O18 data from the environmental working group at Lamont-Doherty-Earth Observatory. By better constraining the present day simulation of the Arctic Ocean, these tracer studies will contribute to improved simulations of the future state of the Arctic, and make projections of Arctic Ocean conditions in the future more reliable. Simulations are proposed for both fully-coupled 20th-21st century integrations and ice-ocean coupled runs forced with historical atmospheric observations. Additional ice-ocean runs using the 60-level ocean model will be performed to assess the improvement gained with this model for Arctic Ocean conditions.

2. Stability of an ice-free Arctic

Future projections of climate change indicate a drastic reduction of Arctic sea-ice within this century, which strongly enhances the surface warming at boreal high latitudes. Here we plan to investigate the stability of a year-round ice-free Arctic state and explore the existence of thresholds at which the Arctic climate system would switch between an ice-free and ice-covered state. This will provide insight into future

Arctic climate conditions and elucidate processes at work in past climates. For example, during the mid-Pliocene, atmospheric CO2 levels and the continental configuration were similar to today (Raymo et al. 1996), but the Arctic was ice-free during summer and had a relatively small winter ice cover relative to present (Dowsett et al. 1999).

We propose a number of simulations to investigate the stability and threshold behavior of the ice cover in this context. First, a control simulation with elevated CO2 levels will be performed to obtain a climate in which a year-round ice-free Arctic state is stable. In the T85-gx1 CCSM3 configuration, this occurs in model runs with 4xCO2 levels (Winton, 2006), although higher levels appear necessary for the T42-gx1 configuration. The stability of this state would be investigated in branch simulations where CO2 concentrations are instantaneously and gradually reduced.

It has been hypothesized that a shut-off of Bering Strait inflow and the freshwater transport that this represents could result in considerable reductions in sea ice (Aagaard and Carmack, 1994; Stigebrandt, 1981). To investigate this, additional simulations are proposed to explore the importance of Bering Strait inflow on these stability properties of the Arctic ice cover.

3. Polar amplification experiments

In late-21st century simulations, CCSM3 exhibits an anomalously large Arctic amplification signal as compared to other models participating in the IPCC-AR4. The reasons for this remain unclear, but are likely related to important, and probably interacting, changes in Arctic sea ice, clouds, and poleward heat transport. We propose a number of experiments with CCSM3 to disentangle and assess various processes affecting polar amplification. This will include studies to examine 1) the role of the surface ice-albedo feedback, 2) the importance of coupled cloud-sea ice interactions for future Arctic change, and 3) the role of changes in ocean heat transport at elevated atmospheric CO2 levels. Additional experiments with the CCSM3.5 and CCSM4 models will be performed to examine polar amplification in the context of those models with comparison to CCSM3 simulations.

3.1 Albedo feedback studies

The importance of the surface ice-albedo feedback in CCSM3 polar amplification will be assessed in simulations with 1% increasing CO2 levels that fix the ice surface albedo at present day values. The comparison of these simulations with existing 1% increasing CO2 runs will allow us to diagnose the impact of surface sea ice albedo change on the simulated polar amplification. The role of changing cloud and poleward heat transports on the Arctic climate will be assessed in the absence of the surface albedo feedback, providing insight into their effects.

3.2 Cloud sensitivity simulations

Work under previous CSL proposals has investigated alternative cloud parameterizations that modify the simulation of Arctic cloud conditions. The polar amplification signal that occurs in increasing CO2 simulations with alternative cloud parameterizations will be analyzed. The importance of the initial cloud conditions for these simulations will be assessed, and the mechanisms driving cloud changes will be investigated. This will require increasing CO2 simulations of the fully coupled model.

Additionally, a series of atmosphere-only simulations will be performed to examine the importance of ice/SST boundary conditions and greenhouse gas (GHG) changes for polar cloud change. These will isolate the influence of changing GHGs versus changing surface conditions on the resulting cloud conditions.

3.3 Ocean heat transport

Ocean heat transport to the Arctic increases in CCSM3 simulations with increased CO2 levels even while the North Atlantic meridional overturning circulation decreases (e.g. Bitz et al., 2006). This appears to play an important role in sea ice change and consequent polar amplification. We will explore these effects in simulations with active atmosphere, sea ice, land, slab ocean model components which apply a specified ocean heat flux convergence ("qflux"). These runs will isolate the influence of changing ocean heat transport versus changing GHGs on the Arctic ice cover and climate. This will elucidate the importance of ocean heat transport changes present in the CCSM3 integrations for changing sea ice and Arctic amplification.

4. Short term integrations in a rapidly changing Arctic environment

Rapid Arctic summer ice loss is present in CCSM3 21st century integrations and in one case the September Arctic goes from conditions similar to present-day to near ice-free conditions in a decade. Associated with this abrupt ice loss are rapid increases in Arctic cloud cover and pulse-like increases in ocean heat transport to the Arctic. The interaction (cause and effect) of these changes is not entirely clear however. Additionally, the predictability of these events and the importance of ocean memory for triggering these events is uncertain. Here we plan to investigate the physical mechanisms and feedbacks contributing to these events and examine their predictability in short-term climate forecasts. These will use multiple short (50 year) integrations, including sensitivity simulations to examine the effects of clouds and ocean changes and simulations with various initial conditions to explore predictability issues.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Arctic freshwater system				(w/tracers)	
20th-21st century	T85-gx1	2	200	300	120
Ice-Only Hindcast	gx1	2	60	75	9
	gx1v5-60	2	60	175	21

Stability of an ice-free Arctic					
Control Run	T42-gx1	1	500	70	35
Instant CO2 change	T42-gx1	1	100	70	7
Gradual CO2 change	T42-gx1	1	500	70	35
Bering Sensitivity	T42-gx1	1	500	70	35
Polar Amplification					
Albedo feedback	T85_gx1v3	1	140	275	39
Cloud cover	T85-gx1	2	70	275	39
	T85-atm	3	50	140	21
OHT sensitivity	T85-SOM	4	100	165	66
CCSM3.5	fv1.9x2.5gx1v5	1	140	200	28
CCSM4	fv1.9x2.5gx1v5	2	140	200	56
Rapidly changing Arctic	T85_gx1v3	10	50	275	137
TOTAL					648

Biogeochemistry Working Group (BGCWG)

For our production runs, we propose to do the spinup with the CCSM4 simulations that are specific for the BGC. Spinning up the BGC requires many years, since the equilibrium time of carbon in the deep ocean or soil layers (when soil nitrogen is interactive) is thousands of years. Thus, the BGC working group will have to take a spun up physical model and spin up the biogeochemistry. The specific methods for the spin up for the biogeochemistry has been proposed in a separate document http://www.ccsm.ucar.edu/working_groups/presentations/2007/022607lindsay-spinup-bgc.pdf, which we do not repeat in its entirety here for the sake of brevity. The idea is to ensure that different components are as close to equilibrium with the final system as possible, before we couple to reduce coupling shocks and the time it takes to equilibrate the system. For the CCSM4 spinup, the SSC proposes that we spinup for the preindustrial climate and then do transient runs for the historical period through 2100.

After the physical fully coupled model (Step 1) (Step 2, part 1—see above document), the ocean carbon cycle needs to be spunup for 1000 years (step 2, part 2) for CCSM4 spinup (ocean only+ecosystem, x1).

Next the land, ocean and atmosphere are coupled together, but the biogeochemical and radiative carbon are not fully interactive in order to further equilibrate the ocean system. In order to reduce spinup time, we reset the land CO2 tracer to the ocean CO2 tracer high in the atmosphere to prevent drift, but allow for spatial inhomogenieties due to the land rectifier effect (step 2, part 3). We propose 300 years fully coupled+BGC, x1-fv1.9x2.5.

Next we spinup the land model, using forcing fields from Step 2, part 3, in offline CLM-CN simulations (step 2, part 4). We propose 1600 years.

Using the spunup separate components from step 2 parts 3 (ocean) and 4 (land), we begin the coupling of the full model (100 years). Carbon for biogeochemistry and radiation is still not coupled together, but rather radiative carbon dioxide is set at 280 ppm, but used to diagnose the systems. (step 2, part 5)

Once this is in equilibrium, we allow the biogeochemical carbon and radiative carbon to evolve together. This becomes the CCSM4 control, and is run for 1000 years (control). The control run will be done using other computational resources, and therefore we include only 100 years of sensitivity study to test the sensitivity of this control to land/ocean processes.

CCSM4 historical runs are run for 130 years which will be conducted by the Climate Change Working Group. We propose 520 years of sensitivity experiments to look at the relative importance of the land use change, land carbon uptake and ocean carbon uptake on the system.

CCSM4 future runs (A2 scenario simulations) will be made by the Climate Change Working Group. We propose another 480 years of simulations of sensitivity studies, to look at the relative importance of land use change, land carbon uptake and ocean carbon uptake on the system.

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
1: Ocean only spinup (step 2, part 2)	Ocean only, x1	1	1000	275	275
2: Full model, ocean spinup (step 2, part 3)	Full model FV2x2.5, x1	1	300	375	113
3: Land only spinup (step 2, part 4)	Land only, x1	1	1600	15	25
4: Full model, ocean and land spinup (step 2, part 5)	Full model FV2x2.5, x1	1	100	375	38
5: Control/sensitivity experiments	Full model FV2x2.5, x1	1	100	375	38
6: Historical runs – sensitivity	Full model FV2x2.5, x1	4	130	375	195
7: Future runs – sensitivity	Full model FV2x2.5, x1	4	120	375	180
TOTAL					864

Chemistry Climate Working Group (ChemWG)

1. Research Goals and Developments

The research goals and developments are set out under the ChemWG part of the CCSM Development proposal. To accomplish these goals the ChemWG has:

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

ii) Investigated methodologies for incorporating the effects of chemistry and aerosols into the CCSM under the operational constraints of a climate model. CAM3.5 makes use of a number of these formulations.

2. Proposed Simulations

Proposed production simulations addressing group deliverables are given below. All proposed simulations will include an aerosol package.

A) Time-slice runs: These simulations are intended to provide the time-varying ozone, oxidants and nitrogen fields so as to run the CCSM4 using offline chemistry. The 2300 horizon is now mentioned quite regularly, with approximately 4 scenarios for the future. Assuming time slices every 20 years from post-industrial to present gives 7 simulations. From the present to 2300 results in another 15 simulations for each scenario. For our request, we are assuming we will run 4 different scenarios resulting in a total of 67 simulations. Each simulation should be 10 years in length to create a stable ozone distribution.

B) Aerosols: Xiahong Liu and Steve Ghan (PNNL) are developing a modal aerosol scheme for CAM-MZ4 which allows for a more accurate representation of aerosols than has been possible to date. This scheme will allow for internally mixed aerosols as well as prognostic number and mass calculations. We are requesting gaus for a number of production runs to examine the sensitivity of the climate using these new aerosol schemes. These runs will include simulations in which the aerosols are coupled with the cloud microphysics. Some of these simulations will use online chemistry, others will only include input oxidant fields.

C) Secondary Organic Aerosols (SOA): Recent calculations and measurements suggest that the source of secondary organic aerosols (SOA) is underestimated by an order of magnitude in model calculations. Colette Heald (Colorado State University) has recently implemented a biogenic emission scheme (MEGAN: Model of Emissions of Gases and Aerosols from Nature) into the CLM with an associated update to the secondary aerosol scheme currently in CAM. We are requesting gaus for a present day and future production simulations to investigate the impact of SOA on chemistry and climate.

D) **Hemispheric Transport of Air Pollution (HTAP):** There is increasing evidence that many air pollutants are transported on a hemispheric or global scale. To develop a fuller understanding of this growing body of scientific evidence, the Executive Body of the UNECE (United Nations Economic Commission for Europe) Convention on Long-range Transboundary Air Pollution has established a Task Force on Hemispheric Transport of Air Pollution (HTAP). CAM with chemistry is one of the models which participated in the 2007 interim report of transboundary air pollution. We are requesting additional gaus to participate in the 2009 assessment report. Additional simulations will focus on transboundary air pollution in a future climate.

E) **Data Assimilation:** An ensemble Kalman filter has been implemented into a version of CAM-MZ4 with simplified chemistry through DART (Data Assimilation Research Testbed). This system, as currently implemented, is designed to assimilate meteorology and satellite derived CO. We are requesting gaus for production runs using DART covering two different field campaigns: 1) INTEX-B (Intercontinental Transport Experiment) in Spring 2006, and 2) PACDEX (Pacific Dust Experiment) in Spring 2007. We will use the ensemble-based data assimilation system, DART/CAM-Chem, to integrate additional observational constraints from satellite retrievals of MOPITT CO and MODIS AOD (Aerosol Optical Depth) into CAM-Chem during these two periods. In conjunction with the satellite retrievals, observations of aerosol species during the two campaigns provide an opportunity to systematically compare distributions of modeled aerosols with observations. In addition, the proposed data assimilation system, which was previously evaluated for CO, can potentially provide insights on model errors through post-analysis of assimilation residuals. We plan to run three sets of experiments (i.e. no assimilation, assimilation of AOD, and assimilation of CO and AOD) for each campaign using 40-member ensembles.

F) **Hindcast experiments:** Over the last 25 years, considerable changes in chemical and aerosol emissions have occurred along with important changes in climate. In addition, during this period atmospheric chemical measurements have become increasingly numerous. We are requesting gaus for a series of 20-year hindcast simulations to examine this comparatively data-rich period and understand the specific role of various emissions and forcings. These hindcast simulations are aligned with the objectives of the Atmospheric Chemistry and Climate Initiative (AC&C) endorsed as a joint effort of WCRP and IGBP.

G) **20th Century Forcing**: The atmospheric chemistry group has simulated the radiative forcing of aerosols during the 20th century using a version of CAM chemistry with input oxidants and the Barth/Rasch sulfate aerosol parameterization. Output from this run is used as forcing for the spinup of CCSM3.5. We are requesting additional gaus to repeat this run using interactive chemistry, a more sophisticated aerosol parameterization (including ammonia nitrate), and a new inventory of surface emissions from 1870-2000 (developed by Claire Granier, NOAA/Boulder). In addition, we will incorporate land-use change distributions for this period developed by Johan Feddema (University of Kansas), allowing emissions of hydrocarbons from the vegetation to evolve over the 20th century. These simulations will use the full coupled CCSM, where we are requesting three ensemble members. In addition, we have requested one CCSM simulation where we have coupled the chemistry and carbon cycles, and one where we use a simple chemistry package already tested in short-term simulations.

H) It is likely that the default resolution of CAM will be increased in the future. This will almost certainly be the case for shorter-term forecast simulations (simulations nominally planned for the period from 1980 and 2030). The atmospheric chemistry working group is requesting additional gaus to examine chemical interactions within high resolution simulations, focusing partly on regional differences. The results will be compared with the lower resolution time-slice simulations (A).

Experiment	**Model Config**	**# of runs**	**# of years**	**GAU / year**	**Total KGAU**
A) Time-slices	fv1.9x2.5/offline chemistry	67	10	350	234
B) Aerosols (1)	fv1.9x2.5/chemistry	5	10	365	18
B) Aerosols (2)	fv1.9x2.5/chemistry	5	10	85	4
C) SOA (1)	fv1.9x2.5/chemistry	10	10	400	40
C) SOA (2)	fv1.9x2.5/chemistry	2	10	365	7
D) HTAP	fv1.9x2.5/chemistry	20	2	365	15
E) Data Assimilation	fv1.9x2.5/chemistry	120	1	220	27
F) Hind-casts	fv1.9x2.5/chemistry	3	20	350	21
G) 20th Century (1)	fv1.9x2.5/chemistry	3	100	470	141
G) 20th Century (2)	fv1.9x2.5/chemistry/carbon	1	100	670	67
G) 20th Century (3)	fv1.9x2.5/simple chemistry	1	100	340	34
H) High resolution	fv1x1.25/chemistry	2	10	2000	40
TOTAL					648

Paleoclimate Working Group (PaleoWG)

1. Quaternary Simulations

Hosing experiments during last deglaciation

With a recent DOE INCITE project (CoPIs: Z. Liu (UW-Madison), B. Otto-Bliesner (NCAR), R. Jacob (ARNL) and D. Erickson (ORNL)), we have been awarded DOE computing time to carry the first synchronously coupled transient ocean-atmosphere-terrestrial ecosystem general circulation simulation in CCSM3 (T31x3) for the past 25,000 years. This transient simulation is important because it will address the role of transient evolution on the sensitivity of the climate system to the change of greenhouse gases and glacial forcing; it makes it possible to study abrupt climate changes of decadal-centennial time scales during the last deglaciation, and it opens a new era of model-data comparison on time series. The setting up of the transient simulation is, however, very challenging. The most uncertain part is the melting water forcing, whose amount and location is still poorly constrained from the proxy evidences. As a result, our transient simulation will be accompanied by many short (~1000 year) sensitivity experiments. At the times of each major melting event, ~3-4 short sensitivity runs will be performed, with each run being forced by a possible scenario of melting water input. The sensitivity run that resembles most the observations will be selected to continue for the transient simulation. Although the DOE INCITE proposal has allocated sufficient CPU for the major transient simulation of 25,000 years, it does not allocate sufficient time for testing short sensitivity runs. Consequently, we would like to apply for some extra CPU for sufficient tests of melting water forcing. Here, we request the time for 6 experiments, mainly to test the melting water scenarios for the two events of H1 and M1A.

Last Interglacial Intercomparison Project

Globally, there was less glacial ice on Earth during the last interglacial, which started about 130,000 years ago, than now. Proxy data indicate that, as compared to today, Arctic summers were up to 5°C warmer, the Greenland ice sheet was reduced to a dome in central and northern Greenland, Arctic sea ice was greatly reduced, and sea level was 4 to 6 meters higher. The primary forcing of this time period is well-constrained – the large increase in Northern Hemisphere spring/summer insolation associated with orbital variations. Atmospheric greenhouse gas concentrations were not significantly different than their preindustrial values. This period is of significant policy relevance because it tests our understanding and modeling of the sensitivity of the Arctic climate system. It also has linkages to the data communities that are developing time series on the magnitudes and rates of change and several other international modeling groups that are doing comparable simulations. We propose to run a transient simulation from 130,000 to 125,000 with CCSM3 coupled to the GLIMMER ice sheet model, which is currently being added to CCSM and will be available in mid-2008. By synchronously coupling a Greenland ice sheet model to a transient LIG simulation, a more realistic understanding of the forcings and feedbacks can be done, providing the next step from the snapshot and offline experimental design used in the published CCSM2 simulation. The orbital cycle forcing will be accelerated by a factor of 10. This acceleration has been shown to give reasonable results in CCSM3 and other global climate models for studying the response of the climate system to forcings such as the Milankovitch orbital variations which change on much longer time scales.

Transient Holocene Simulation

A transient Holocene simulation is important because it will address the role of transient evolution on the sensitivity of the climate system and will be an important benchmark for the data community to use for understanding the spatial and temporal framework of their proxy records. We will run a simulation that will parallel the last 10,000 years of the INCITE project to provide an additional ensemble member. This additional simulation is important to better understand the mechanisms and timing of abrupt changes recorded in the proxy data, such as the drying of the Sahel region and ENSO variability, to the interactions of internal variability and forcing by precessional orbital variations which change on time scales of tens of thousands of years. The orbital cycle forcing will be accelerated by a factor of 10. This acceleration has been shown to be appropriate in CCSM3 and other global climate models for studying the response of the climate system to forcings such as the Milankovitch orbital variations which change on much longer time scales.

Stage 11 Intercomparison Project

The five interglacials of the last 450,000 years were different in multiple aspects; studying interglacials in addition to the Holocene and Last Interglacial will give us a more complete view of the range of natural variability of the Earth System. Stage 11, from approximately 420,000 to 395,000 years ago, is of particular relevance because it was a very long interglacial period with the Earth's orbital configuration similar to today (low orbital eccentricity). In addition, ice core records indicate atmospheric CO_2 concentrations stable at preindustrial values throughout this time period. An international project is being organized to better understand the Stage 11 interglacial, using both data and models. Several modeling groups plan to do a snapshot simulation for ~408ka and, when feasible, a transient simulation for the entire Stage 11 interglacial. Generally the transient simulation will only be done with Earth Models of Intermediate Complexity with their lower resolutions and simplified parameterizations. Employing a factor-of-ten acceleration of the orbital forcing, which has been shown to give reasonable results for the Holocene with CCSM, will allow this transient simulation to also be done with CCSM, a full atmosphere-ocean GCM.

Completion of a 14k simulation

The 14k simulations to date is at year 130 of the planned 630 year length. It is exhibiting many interesting results that would benefit from extending the run. In particular, the thermohaline circulation is weaker than at LGM by about 50% (or about half of the strength at present) , and thus the northern North Atlantic and Greenland surface temperatures are actually colder than at LGM. This is intriguing because there are records that show times in the last glacial that were briefly colder than at LGM. The thermohaline circulation also has greater variance than in the LGM (and modern) run. The characteristic timescale of the variance is about 12 years, which is about half the timescale of modern thermohaline variability, although the length of the run makes this result somewhat uncertain at this time. The 14k thermohaline variance is strongly coupled to the sea ice cover and atmospheric circulation. A longer integration would give us greater confidence in our analysis of the variability and its covariance among model variables.

2. 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 2007 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 reduced Greenland and Antarctic ice sheets configurations.

Paleocene-Eocene Thermal Maximum (PETM) Simulations

The Paleocene-Eocene Thermal Maximum (PETM) at about 55.5 Ma is of climatic interest due to the significant warming that occurred over a relatively short geologic time period. This warming is thought to have occurred in response to a destabilization of marine methane clathrates. The significant warming was accompanied by a negative excursion in carbon isotopes, indicative of a supply of light carbon to the climate system. Polar warming was substantial at this time period, where recent estimates suggest Arctic Ocean surface water temperatures of ~+20°C (growing season). Recent isotopic data also indicate that subtropical SSTs were warmer than present by only ~5°C. This even represents a natural experiment in the response of the climate system to a rapid (<10,000) year greenhouse gas release, and so far, much of the response remains unexplained. Two coupled T31x3 CCSM3 250-year simulations of the PETM will be carried out to investigate the role of elevated CO_2 and/or methane on the climate of this time period (with near modern and elevated greenhouse gas concentrations). Acceleration will be used to make these simulations equivalent to ~1000 ocean years.

Cretaceous Simulations

The nature of the Cretaceous climate (144-66.4 Ma) has posed fundamental questions about how the climate system works under extreme greenhouse conditions. The causes and character of the extreme warmth, low meridional thermal gradient, warm continental interiors, accumulation of widespread organic-rich sediments, and the terminal mass extinction remain largely unresolved despite decades of study. Progress in our understanding of these problems over the last 25 years can be linked to the evolution of climate modeling, from the early version of NCAR's CCM. With the ongoing development of the CCSM as an Earth system model, the opportunity exists to make scientific breakthroughs in many long-standing problems. In this context, the deep time subgroup of the CCSM Paleoclimate WG endorsed a large-scale collaborative project involving the Cretaceous research community to investigate the climate of the Latest Cretaceous (i.e. pre-impact), an interval selected for its data richness.

We propose to conduct a series of three production simulations with specific GHG concentrations representing pre-industrial, high (e.g. ~8xCO_2), and extreme (e.g. ~16xCO_2) levels. We will also carry out two simulations (for two levels of GHGs) for the Latest Cretaceous time period (~66 Ma) to establish the state of the climate system just prior to the bolide impact. The Paleoclimate Working Group endorsed these two simulations, with strong interest in comparing the results of the simulations against a wide range of paleoclimate data.

Simulation of the Triassic-Jurassic Boundary

Many scientists now believe that at least three of the major extinction events of the geologic past occurred because of global warming (Permian-Triassic, Triassic-Jurassic, and Paleocene-Eocene Thermal Maximum). The leading hypothesis for these extinctions links global warming to major changes in ocean circulation with impacts to marine species. Currently the CCSM3 has been used to simulate the climate of the Permian-Triassic boundary and the PETM. We propose to now carry out coupled climate model simulations for the Triassic-Jurassic (~200 Ma) time period. Paleo proxy data indicate that this was a time of elevated atmospheric CO_2 (~ 4 to 8 time pre-industrial levels). We will carry out three simulations for differing levels of CO_2 to explore the impact of paleogeography and greenhouse gas levels on the climate of this time period. At present, there is only one other coupled simulation of this time period (Huynh and Poulsen, 2005). These authors argue that the levels of oxygen in the ocean are sensitive to the strength of the overturning circulation. Thus, it will be of great value to apply a different climate model to this time period to see if the implications for mass extinction are similar or different than the study of Huynh and Poulsen. This simulation will also allow us to cross compare three time periods of elevated CO_2 and mass extinction to find general causes for the extinctions. These conclusions will be of great importance in understanding how life will respond to elevated CO_2 levels in the future.

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.

High Resolution Late Permian Atmospheric Simulation

The CCSM3 paleoclimate simulation of the Late Permian (251 Ma) generated great interest in the deep time community. This simulation is the first climate model to agree with a wide range of geological data for high latitudes. The climate of this time period was very warm with a large increase in atmospheric water vapor due to the warm surface. Atmospheric scientists have been intrigued with the weather of this type of warm and moist world would look like. In particular, given the large expanse of the Panthalassic Ocean, the extensive warm sea surface temperatures, and the high specific humidity of the atmosphere, one would expect more intense hurricanes, and the ability of these hurricanes to form and propagate to mid and high latitudes. Emanuel et al. (1995) proposed that the intense systems, or hypercanes, could contribute to global extinction of life. Hack and Caron (NCAR/CGD) have carried out CAM3 T170 simulations for the present day and found that the atmospheric model simulates realistic hurricanes, in terms of intensity and storm tracks. We propose to use the boundary condition information from the coupled CCSM3 Late Permian simulation to construct a CAM3 T170 Late Permian atmospheric model. The CCSM3 topography smoothed the 0.5 degree data provided by David Rowley (U. Chicago). We will use the original 0.5 degree data for the high resolution atmospheric model. We will carry out a ten-year simulation and look at the hurricane (hypercane) statistics from this simulation. We will also look at the role these systems play in altering atmospheric energy transport, and implications for ocean mixing. 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 Late Ordovician (~440 Ma) was a time when Earth experienced a major 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 (~8 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 ~ 4-fold increase in CO_2. Geologic data indicates that much of the southern hemisphere continent was ice covered at this time. Thus, this is an interesting climate regime where a cold state existed in spite of elevated CO_2. Climate modeling studies of this time period include atmosphere only simulations, atmospheric models coupled to slab oceans, an energy balance model coupled to the MOM ocean model, and uncoupled MOM ocean simulations. To date, no fully coupled climate model simulation exists for this time period. We propose to use CCSM3 to model the climate of the Late Ordovician. We will carry out three simulations assuming three different levels of CO_2: 8x, 10x, and 15x. We will look at the mechanisms that determine the climate state, in particular the role of ocean energy transport versus atmospheric energy transport. We also propose to use the glacial ice model being developed at Los Alamos National Laboratory to see if this climate state leads to an extensive glacier on the southern hemisphere continent. Model output will also be compared with existing geologic data to evaluate the models ability to accurately simulate the Late Ordovician climate.

3. Paleo-Chemistry Simulations

Paleo chemistry Under Extreme Conditions

Atmospheric chemistry under extreme climate conditions will be explored. Two different climate states will serve as the basis for the research. There is growing geologic evidence that Earth was completely ice covered in the Proterozoic. During this period (850 to 630 Ma), Earth's hydrologic cycle shut down. WACCM will be configured to study the implications of such a climate state for the chemistry of the atmosphere. As a counter example to this icehouse state, WACCM will be applied to the warm climate of the Paleocene Eocene Thermal Maximum, where isoprene emissions were high.

Constraining the Role of Stratospheric Clouds in the Maintenance of High Latitude Warmth in the Eocene

Sloan and Pollard (1998), Kirk-Davidoff, Schrag and Anderson (2002), and Kirk Davidoff and Lamarque (2007) have discussed the possibility that additional water vapor in the stratosphere could result in optically thick polar stratospheric clouds, which could contribute to the maintenance of high latitude warmth during the Eocene, and other "equable" climate periods. Lamarque et al. (2006) simulated extremely moist stratospheric conditions using WACCM, and found little stratospheric cloud radiative contribution to surface warming. In the latter runs, the CAM3 cloud size parameterization was used, which involves a purely temperature dependent cloud particle size. This results in stratospheric clouds with particle sizes of 20 to 30 microns, so that stratospheric clouds tend to be optically thin, and to lose water rapidly to sedimentation. In these runs, we will impose a high water vapor mixing ratio at the tropical tropopause by adding an arbitrary heat source there, balanced by cooling at mid-latitudes. We will run a series of experiments in which the cloud particle size is varied from the standard CAM3 case down to a minimum of 1 micron. The surface temperature distribution will be adjusted to approximate Eocene conditions. This will enable us to place a clear upper limit on the ability of stratospheric clouds to influence the surface radiative budget in the context of a sophisticated atmospheric model. The simulation will require three experiments (high, medium and low particle size), each run for 30 years with fixed surface temperatures, to achieve adequate statistics, for a total of 90 years.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
Quaternary					
Last Deglaciation Hosing	T31x3	6	1000	20	120
Last Interglacial Intercomparison	T42x1	2	700	100	140
Transient Holocene	T31x3	1	1000	20	20
Stage 11 Intercomparison	T31x3	1	3000	20	60
Extension of 14k	T42x1	1	500	100	50
Pre-Quaternary					
Pliocene Intercomparison	T31x3	1	2000	20	40
Pliocene Intercomparison	T31 CAM	2	100	10	2
PETM	T31x3	4	600	20	48
Cretaceous	T31x3 DVG	3	1000	25	75
Latest Cretaceous	T31x3	2	1000	20	40
Triassic-Jurassic	T31x3	3	1000	20	60
Mid Permian	T31x3	2	1000	20	40
Permian HiRes	T170 CAM	1	25	1880	47
Late Ordovician	T31x3	3	2000	20	120
Paleo-Chem					
PSCs in Eocene	WACCM	3	30	380	34
Chem PETM	WACCM	1	100	380	38
Snowball Earth	WACCM	1	100	380	38
TOTAL					972

Climate Variability Working Group (CVWG)

The overall research focus of the CVWG is the analysis of natural and anthropogenically-induced patterns of climate variability and their mechanisms in CCSM3 and its component models, as a means of furthering our understanding of the observed climate system. The CVWG proposes a series of production runs that will be made available to the broad research community. These include simulations with CAM3 in uncoupled and coupled mode (CAM3 coupled to an ocean mixed-layer model) to examine the relative impact of SST forcing versus the combined effect of SST, greenhouse gas, aerosol, volcanic, and solar forcing upon climate variability during the 20th century. Some of the integrations proposed in this cycle are motivated by community interest in investigating drought genesis and maintenance, especially over North America. These integrations (with CAM3.5) will be closely coordinated with other climate modeling centers (NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), NASA/Global Modeling and Assimilation Office, Lamont-Doherty Earth Observatory, and NOAA/Climate Diagnostics Center) by following the US CLIVAR Drought Working Group recommendations on experiment design. The coordination will allow assessment of the robustness of key findings and help focus on novel aspects of the problem.

1. Scientific Goals

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

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

2. Standard AMIP Integrations

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

The global AMIP integrations described above will complement the five-member ensemble of tropical AMIP integrations (1871-1949) in which only the evolving tropical SSTs are used to force CAM3; SSTs elsewhere are held fixed at their climatological monthly values. We propose to undertake individual basin versions of the tropical AMIP integrations for the period 1871-2005 in this cycle. The global AMIP runs, in conjunction with the tropical ones, will yield an assessment of the influence of individual basin and tropical/extratropical SSTs on regional and global climate variability.

3. "Climate of the 20th Century" AMIP Integrations

While AMIP simulations provide a benchmark, and are thus necessary, it could be argued that an equally important and, perhaps, even more desirable experiment would be to include not only the observed variations in SST and sea ice, but changes in other external forcing (e.g., changes in greenhouse gas concentrations, aerosols, solar forcing, etc.) as well. These integrations will be referred to as GOGA-IPCC from here on. This data set would be more ideal than the simple AMIP integrations for comparisons with observed climate records, and it should provide a time history of atmospheric responses closer to observations than is likely with a coupled model. We propose a five-member ensemble of CAM3-T85 GOGA-IPCC integrations for the period 1856-1949 and also extend through 2005 the existing five-member GOGA-IPCC integrations that currently end in 2001. Comparison of the standard SST-only AMIP runs and the "Climate of the 20th Century" AMIP runs will allow an evaluation of the impact of SST forcing alone versus the combined impact of SST forcing and changes in greenhouse gas concentrations, aerosols, solar output, and volcanoes upon climate variability.

4. CAM3 Coupled to an Ocean Mixed-Layer Model

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

5. “Climate of the 21st Century:” CAM3 runs with 2041-2050 Boundary Conditions

The CVWG will soon complete a set of IPCC scenario runs with CCSM3 at T42 resolution in conjunction with the Climate Change Working Group (CCWG). These experiments provide a large ensemble (~30 members) of integrations driven by a fixed, standard “business-as-usual” climate change scenario during 1990-2050, allowing assessment of the uncertainties in climate projections.

In this cycle, we propose to undertake a large ensemble (~50 members) of short (~10-year duration) integrations of CAM3 driven by the surface boundary conditions from years 2041-2050 of the CCSM3 climate change scenario integrations. This set of integrations will be used to assess the change in the likelihood of extreme events, for which a large ensemble is crucial. These integrations are being coordinated with GFDL, who are performing similar runs with their coupled model.

6. Drought Integrations with the CAM3.5 model

We propose integrations of the CAM3.5 model to investigate drought genesis and maintenance, especially over North America. Integrations will be coordinated with those at other modeling centers, by following the US CLIVAR Drought Working Group design recommendations. CAM3.5's drought simulation skill, especially, in context of multi-year droughts over the central United States (e.g., the 1930s ‘Dust Bowl’ and another drought in the 1950s) will be first assessed via two suites of AMIP simulations: A 5-member ensemble of AMIP-IPCC (forcing from historical SSTs, greenhouse gas concentrations, volcano, solar, aerosols, etc.) and AMIP-vanilla (forcing from historical SSTs only) simulations for the 1900-2002 period, i.e., a total of 10 simulations, each of approximately 100 years, at T85 resolution. In order to be consistent with the community-driven drought modeling effort, the proposed CAM3.5 simulations will be driven by SSTs and sea ice from the HadISST data set. The assessment will be followed by additional modeling experiments designed by the Drought Working Group to help characterize the contribution of individual ocean basins to North American drought genesis.

Additional drought experiments are being configured with CVWG member input. Two recommended experiments are briefly discussed here. In the first, soil-moisture over North America will vary only climatologically, allowing investigation of the role of land-surface as a delayed moisture source and of its influence on column thermodynamics. Note, in both AMIP-IPCC and AMIP-vanilla integrations, soil moisture and snow cover are fully interactive. We propose to duplicate one of the AMIP suites holding both these variables fixed at their climatological monthly values. Intercomparisons with the corresponding AMIP runs will provide a quantitative appraisal of the relative importance of local and remote forcing of North American droughts and pluvial. The experiment suite will have five ensemble members.

The second experiment will involve modification of North American orography. Orographic features, such as the Sierra Madre Oriental, play an important role in shaping Great Plains hydroclimate, by influencing the formation of the Great Plains low-level jet in boreal summer months. Both integrations are viewed as perturbations of one of the CAM3.5 AMIP integration suites.

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
AMIP-Vanilla (Global SST only)	CAM3 T85	5	1856-1949 2001-2005	140	70
AMIP-Vanilla ATOGA (Atlantic tropical SSTs only) ITOGA (Indian tropical SSTs only) PTOGA (Pacific tropical SSTs elsewhere)	CAM3 T85 CAM3 T85 CAM3 T85	5 5 5	1871-2005 1871-2005 1871-2005	140 140 140	95 95 95
AMIP-IPCC (Global SST + External Forcing)	CAM3 T85	5	1856-1949 2001-2005	140	70
AMIP (POGA/MLM): OBS SSTs in Trop Pac; Ocean Mixed Layer elsewhere	CAM3/MLM T85	5	1871-2005	144	97
AMIP T42 Climate of the 21st century	CAM3 T42	50	2041-2050	20	10
AMIP-IPCC (Global SST + External Forcing)	CAM3.5 T85	5	1900-2005	75	40
AMIP-Vanilla (Global SST only)	CAM3.5 T85	5	1900-2005	75	40
AMIP-Vanilla (Global SST only, but with soil moisture and snow cover held to monthly climatology) AMIP-Vanilla Drought Working Group Basin Experiments (CLIM, CLIM+ EOF patterns)	CAM3.5 T85 CAM3.5 T85	5 25	1900-2005 1900-2005	75 75	40 197
AMIP-Vanilla (CLIMGlobal SST, but with 3 modifications of Central and North American orography)	CAM3.5 T85	4	50	75	15
TOTAL					864

Climate Change Working Group (CCWG)

A. Low Emissions and WGCM Scenarios

The range of climate change scenarios explored over the last decades with general circulation models has generally focused on so-called “non-intervention” scenarios. Those are sometimes also referred to as “business as usual” scenarios, although this may be misleading. These scenarios do, for example, assume some technological progress (e.g., increase in energy efficiency), and they may for example include changes in the energy sector, but only to the extent that this is economically beneficial. However, these scenarios do not include political intervention in the sense that greenhouse gas emissions are regulated in order to avoid or reduce climate change or “disruptive changes” in technology progress through significantly different R&D efforts. The currently most generally accepted set of scenarios was put together by the Intergovernmental Panel of Climate Change (IPCC) SRES. Six of the 35 scenarios of that report are often used as ‘illustrative’ scenarios or storylines, but no likelihood was officially attached to any of the scenarios. Thus, they should be seen as examples of “what-if” cases, not necessarily representative of all the possible outcomes. More recent United States-based scenarios were prepared by a special study of the federal Climate Change Science Program (CCSP). These scenarios come from the use of three integrated assessment (IA) models. The IA models provided a “consistent” no policy scenario, refereed to as “reference” and policy stabilization emission scenarios.   We will run one scenario at NCAR.

One 2000-2100 CCSP scenario, 5-member ensemble T85 CCSM

Similarly, the JCS/CLIVAR Working Group on Coupled Models (WGCM) is working with the IPCC Working Groups I and III to use the WGIII Integrated Assessment Models to develop scenarios for the new class of Carbon/Nitrogen Earth System Models leading up to the IPCC AR5. These scenarios will be released in mid-2008.

One 2000-2100 WGCM scenario, 5-member ensemble, FV2 CCSM3.5
One 2000-2100 WGCM scenario, 5-member, FV2 with carbon cycle

B. Hurricane Mixing

Hurricanes are a significant natural phenomena which can bring tremendous loss to human life and property. Due to the lack of long-term observations, variations of hurricanes in the past and possible changes in the future are not clear. On the other hand, because it is a mesoscale system, the current generation of the climate models cannot resolve it. Here we use specified experiments to assess the effect of the hurricane on the Atlantic meridional overturning circulation and associated meridional heat transport. We also will evaluate the relation of the hurricane and the Atlantic multi-decadal oscillation.

Two 100 yr T42 CCSM3 runs

C. Effect of the Bering Strait status on the thermohaline circulation in the future warmer climate.

The Bering Strait is a shallow and narrow pathway connecting the Pacific and the Arctic. Presently, about 0.8 Sv fresher Pacific water flows into the Arctic and sequentially transported into the North Atlantic, where it affects the strength of the thermohaline circulation. Hu and Meehl (2005) and Hu et al. (2007a, b) have demonstrated the significant influence of the Bering Strait on the response of the thermohaline circulation to freshwater forcing for present day and LGM climate conditions. The question left unanswered is how the Bering Strait would affect the thermohaline circulation and the global climate under future warmer condition? Here we propose two CCSM3 runs that will be compared with the standard present day CCSM3 control run and the 1% CO2 run to assess the effect of the Bering Strait.

One 300-yr T42 CCSM3 run with a closed Bering Strait. This will be branched from the CCSM3 present day control run.
One 1% CO2 T42 CCSM3 run with a closed Bering Strait. Branched from the first run for 150 yrs (quadruple CO2).

D. Geoengineering

The recent IPCC report effectively ended the debate of whether or not human induced climate change is occurring and advanced the discussion to addressing how we should respond to it, and the cost and magnitude of the effort required to survive it. Two of the primary US government responses to the IPCC Summary for Policymakers involved investigating speculative and potentially dangerous geoengineering approaches to mitigating climate change impacts by reducing the incoming solar radiation by either introducing reflective sulfur to the stratosphere or orbiting a reflecting mechanism ("*US answer to global warming: smoke and giant space mirrors"*http://environment.guardian.co.uk/climatechange/story/0,,1999968,00.html. Numerous other groups have recently suggested the sulfur injection approach as well. The science community has made some very strong arguments about why the sulfur approach should be avoided due to potential side effects. We have already carried out a two-member sulfur run and two single-member solar geoengineering runs, one looking at a constant decrease in solar input and another with a variable decrease, using NCAR Director's reserve funds. To complete this study, we will be running two recovery runs to show the timescale of response once the geoengineering forcing is removed.

One 2070-2100 sulfur recovery, T85 CCSM
One 2070-2100 Solar recovery, T85 CCSM

E. Climate Change Detection/attribution

The 11 year solar cycle (Decadal Solar Oscillation or DSO) at its peak strengthens the climatological precipitation maxima in the tropical Pacific during northern winter. However, recent results suggest that this initial fast response may give way to a warm event-like pattern and general warming of the tropics. Ensembles of sensitivity experiments branching from the CCSM3 control will be used to understand the response of the climate system to the DSO, with only variations in the solar forcing included. This suite of experiments will enable a full statistical analysis of the influence of solar forcing to be undertaken.

20 years, T85, 20 ensemble members

Experiment	Model Config	# of runs	# of years	GAU / year	Total KGAU
A. CCSP Low Emissions Scenario	T85	5	100	540	270
A. WGCM Emissions Scenarios	FV2	5	100	185	93
A. WGCM Prognostic Carbon Cycle	FV2CC	5	100	375	188
B. Hurricane mixing	T42	2	100	100	20
C. Bering Strait & climate stability	T42	1	100	450	45
D. Geoengineering recovery runs	T85	2	30	540	32
E. CC detection / attribution	T85	20	20	540	216
TOTAL					864

References

Aagaard, K., and Carmack, 1994: The Arctic Ocean and climate: A perspective. In: *The Polar Oceans and their role in shaping the global environment*. AGU Geophys. Monogr., **85**:5-20.

Bitz, C. M., P. R. Gent, R. A. Woodgate, M. M. Holland, and R. Lindsay, 2006. The influence of sea ice on ocean heat uptake in response to increasing CO2. *J. Climate*, **19**, 2437-2450.

deNoblet, N., and A. Pitman, 2007: Land-use and climate identification of robust impacts (LUCID) project. *GEWEX News*, **17**, 6-7.

Dowsett H. J., Barron, J. A., Poore, R. Z., Thompson, R. S., Cronin, T. M., Ishman, S. E., Willard, D. A. 1999: Middle Pliocene paleoenvironmental reconstruction: PRISM2. USGS Open File Report 99-535, http://pubs.usgs.gov/openfile/of99-535

Emanuel, K. A., K. Speer, R. Rotunno, R. Srivastava, and M. Molina, 1995: Hypercanes: A possible link in global extinction scenarios. *J. Geophys. Res.*, **100**, 13755-13765.

Hu, A., and G. A. Meehl, 2005: Bering Strait throughflow and the thermohaline circulation. *Geophys. Res. Lett.*, **32**, L24610, doi: 10.1029/2005GL024424.

Hu, A., G. A. Meehl, and W. Han, 2007a: Role of the Bering Strait in the thermohaline circulation and abrupt climate change. *Geophys. Res. Lett.*, **34**, L05704, doi:10.1029/2006GL028906.

Hu, A., B. Otto-Bliesner, G. A. Meehl, W. Han, C. Morrill, E. C. Brady, and B. Briegleb, 2007b: Response of thermohaline circulation to freshwater forcing under present day and LGM conditions. *J. Climate*, revised.

Huynh, T. T., and C. J. Poulsen, 2005: Rising atmospheric CO_2 as a possible trigger for the end-Triassic mass extinction. *Paleogeog., Paleoclimat., Paleoecolog.*, **217**, 223-242.

Kirk-Davidoff, D. and J. -F. Lamarque, 2007: Maintenance of polar stratospheric clouds in a moist stratosphere. *Climate of the Past*, submitted.

Kirk-Davidoff, D. B., D. P. Schrag, and J. G. Anderson, 2002: On the feedback of stratospheric clouds on polar climate. *Geophys. Res. Lett.*, **29**, doi:10.1029/2002GL014659.

Koster, R. D., P. A. Dirmeyer, Z. Guo, G. Bonan, E. Chan, P. Cox, C. T. Gordon, S. Kanae, E. Kowalczyk, D. Lawrence, P. Liu, C-H. Lu, S. Malyshev, B. McAvaney, K. Mitchell, D. Mocko, T. Oki, K. Oleson, A. Pitman, Y. C. Sud, C. M. Taylor, D Verseghy, R. Vasic, Y. Xue, and T. Yamada, 2004: Regions of strong coupling between soil moisture and precipitation. *Science,* **305**, 1138-1140.

Lamarque, J.-F., J. T. Kiehl, C. A. Shields, B. A. Boville, and D. E. Kinnison, 2006: Modeling the response to changes in tropospheric methane concentration: Application to the Permian-Triassic boundary. *Paleoceanography*, **21**, PA3006, doi:10.1029/2006PA001276.

Raymo M. E., B. Grant, M. Horowitz, and G. H. Rau, 1996: Mid-Pliocene warmth: Stronger greenhouse and stronger conveyor. *Mar. Micropaleotol.* **27**, 313-326.

Sloan, L. C., and D. Pollard, 1998: Polar stratospheric clouds: A high latitude warming mechanism in an ancient greenhouse world. *Geophys. Res. Lett.*, **25**, 3517-3520.

Stigebrandt, A., 1981. A model for the thickness and salinity of the upper layer in the Arctic Ocean and the relationship between the ice thickness and some external parameters. *J. Phys. Oceanogr.*, **11**, 1407-1422.

Winton, M., 2006: Does sea ice have a tipping point?, *Geophys. Res. Lett.*, **33**, doi:10.1029/2006GL028017.

Estimate of CCSM 3 and CCSM 3.5 GAU Costs on Blueice

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

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