CCSM

Community Climate System Model

CSL Accomplishments Report
(12/1/2007 – 11/30/2008)

Table of Contents

Introduction

Most of the Development and much of the Production allocations over the past year have been used to produce the new components for the next version of the model, CCSM 4. The deadline for delivery of the new atmosphere, ocean, land, and sea ice components was 1 October. The components were delivered by mid-October, although development of the atmosphere component is still continuing. The first coupled run of a possible CCSM 4 configuration was completed by mid-November after several software and scientific problems had been resolved. Development work on the new carbon cycle, chemistry, and WACCM components has continued over the last year, based on the interim version CCSM 3.5. They will be moved into CCSM 4 when it is completed.

Some highlights using the Production allocation by various WGs include simulations of the Mexico City outflow plume by the Chemistry WG. The Whole Atmosphere WG has completed 20^{th} Century runs using WACCM, and the Paleoclimate WG has completed simulations of several past epochs. The Climate Variability WG completed drought modeling simulations for the US CLIVAR program, and the Climate Change WG completed several runs to simulate effects of partial melting of the Greenland Ice Sheet.

Atmosphere Model Working Group (AMWG)

The Atmosphere Working Group spent essentially all of its CSL computer resources over the last year in developing the next version of the atmosphere component, CAM 4. The Working Group tried to address quite a large number of parameterization improvements to the model, but in the end time constraints limited the development to the following parameterizations of modules for the CAM:

- The new cloud microphysics parameterization of Hugh Morrison and Andrew Gettelman. This scheme predicts both the number concentrations and mixing ratios of cloud water and ice. The liquid to ice fraction is determined by microphysical processes, rather than a simple function of temperature. It is coupled to an aerosol scheme by treating both droplet and ice nucleation, and uses a mapping from aerosol mass to number. The scheme provides a self-consistent treatment of sub-grid cloud water, see Morrison et al. (2005).

- The new RRTMG radiation package that was originally developed by Mike Iacono and colleagues at Atmospheric and Environmental Research Inc., but was implemented into CAM by Bill Collins and Andrew Conley. This radiation package is state-of-the-art for general circulation models, and is considerably more accurate than the CAM 3 package across the entire spectrum.

- The new macrophysics package implemented by Sungsu Park and Phil Rasch. This involves a reordering of the entire physics package in CAM, so that quantities such as the cloud fraction are calculated and applied at the correct times during the iteration loop of the physics timestep. Previously, some of the physics routines were using the cloud fraction calculated before all the quantities used had been updated for the current timestep.

- The new boundary layer and low cloud parameterization of Chris Bretherton and Sungsu Park. These new parameterizations were developed some time ago at the University of Washington, but had never become a standard part of the CAM. In the last year, considerable work has been put in to refine them so that they work better in the CAM context. They result in a much improved amount and location of the low cloud distribution, and for stratus clouds in particular. This is very important in the upwelling regions of the world, which is where the CCSM has always had too warm sea surface temperatures. The new parameterization also allows more vertical layers to be added to CAM, whereas the old scheme was very sensitive to the layer distributions in the vertical. This new scheme is usually run with 30 layers, with the 4 additional layers compared to CAM 3 put in to resolve better the top of the boundary layer.

- The modal aerosol model (MAM) developed by Steve Ghan and Xiaohong Liu at the Pacific Northwest Laboratory of the DOE. This model predicts the size distribution of aerosols, as well as the number of droplets, and so is much more scientifically defensible than the scheme used in CAM 3. It is also considerably more expensive computationally, although its cost has been reduced markedly over the past year by going from a seven mode scheme to a three mode scheme. An important reason to include this aerosol scheme is that, in combination with the Morrison and Gettelman microphysics, it can be used to evaluate the indirect effects of aerosols. This is the first version of the CCSM that has this capability.

- Revisions to the formulation of the surface exchange between the atmosphere and lower components, and an optional 'super-simple photochemistry' developed by members of the Chemistry WG.

- Substantial changes to the software infrastructure, which substantially improves the scalability of the model to more than 1000 processors on massively parallel machines, and interactions with other CCSM components.

The vast majority of the AMWG runs under the Production proposal have been used to run versions of the coupled CCSM using atmosphere components with various combinations of the parameterizations listed above. The AMWG realizes that the CAM has to be evaluated in coupled mode, as well as in stand alone mode. For example, the ENSO characteristics of the CCSM can only be evaluated by running with an active, full-depth ocean, and the characteristics are quite strongly dependent on some of the changes listed above, especially the boundary layer and low cloud scheme, and the macrophysics. In addition, the land and sea ice simulations depend very strongly on the forcings they receive from the atmosphere component. A version of the CAM 4 that has been positively evaluated by the AMWG was delivered at the end of the period, so that it could be incorporated and evaluated in the CCSM 4 currently being assembled.

Ocean Model Working Group (OMWG)

The development, implementation, and testing of several ocean physics and numerical improvements to be used in the CCSM4 ocean component have been the major development activities in 2008. The ocean model contains the following new features:

- Increased number of vertical levels from 40 to 60 and changes in the bottom topography.

- Modified anisotropic horizontal viscosity scheme in which the shear dependent, i.e., Smagorinsky, component is eliminated. The resulting improvements in coupled simulations – documented in Jochum et al. (2008b) – include reduced sea-ice cover in the Labrador and Bering Seas, and stronger tropical instability wave activity, both in better agreement with observations.

- Near-surface eddy flux parameterization that eliminates any ad-hoc near-surface tapering of the mixing coefficients. The resulting improvements include the elimination of the spurious near-surface eddy-induced circulation and a better heat transport profile in agreement with results from eddy-resolving models (Danabasoglu et al. 2008a). This development is part of our Climate Process Team (CPT) on eddy—mixed layer interactions (EMILIE).

- Vertically varying isopycnal and thickness diffusivities, resulting in an improved representation of the vertical structure and transport of the eddy-induced velocity and reduction in the global mean warm bias (Danabasoglu and Marshall 2007). This activity is part of our CPT EMILIE contributions.

- Tidally driven mixing scheme representing the dynamics of the mixing in the abyssal ocean arising from the breaking of internal waves generated by the tides flowing over rough topography. This scheme eliminates the ad-hoc enhancement of vertical diffusivity and viscosity with depth and it is energetically consistent with the known constraints on the ocean energy budget (Jayne 2008).

- Submesoscale parameterization representing the mixed layer stratification associated with frontal instabilities and frontogenesis. Some preliminary results, showing the shallowing of the mixed layer depth in better agreement with observations, are presented in Fox-Kemper et al. (2008). This development is part of our CPT EMILIE activities.

- Spatially varying internal wave breaking, i.e., background vertical diffusivity and viscosity, based on currently available theoretical and observational evidence. The coupled model sensitivities that include the improvement of the summer precipitation in the Banda Sea and changes to the Gulf Stream path are documented in Jochum and Potemra (2008) and Jochum (2008).

- A new, open-ocean overflow parameterization to represent the Denmark Strait and Faroe Bank Channel gravity current overflows. Both ocean-only and coupled simulations show the elimination / reduction of long standing deep ocean warm biases in the Atlantic basin. This development is part of our CPT on Gravity Current Entrainment (GCE) activities.

- A new option to use a flux limited advection scheme (Lax-Wendroff) for active and passive tracers.

- Modification of the parameterized diurnal cycle of short-wave radiation to include zenith angle dependency.

Many of the long integrations that were necessary to assess the sensitivity of the model solutions to some of the above listed developments have been done under the CCSM production allocation.

A series of ocean-only and ocean—sea-ice coupled experiments with the Common Ocean-ice Reference Experiments (CORE) normal-year and inter-annual atmospheric forcing data sets to explore and understand the behavior of the ocean model under these forcings were completed. This effort is part of a coordinated, international activity aiming to document the behavior of various ocean and sea-ice models under common surface forcing. The results are presented in Griffies et al. (2008) and Yeager and Jochum (2008).

The CORE forcing data sets were also used in four additional ocean-only experiments to investigate the sensitivity of the oceanic chlorofluorocarbon (CFC) uptake to both surface dynamical forcing (heat and salt fluxes and wind stress) and physical initial conditions (Danabasoglu et al. 2008b). This study shows that the CFC uptake is not significantly affected by either the surface forcing or the initial conditions considered here and that model-observation differences remain large in all simulations.

Another set of coarse resolution ocean-only experiments were conducted to document the effects of spatial variation of the isopycnal and thickness diffusivities (Eden et al. 2008). For this purpose, three different closures were considered. The results show that although the effects of changing diffusivities are small in general and all solutions remain biased compared to observations, there are some local sensitivities affecting the Antarctic Circumpolar Current strength and the depth of the equatorial thermocline.

A couple of long equilibrium coupled integrations were carried out using the low resolution version of the CCSM3 to show that the standard practice of using a slab ocean model in estimating the equilibrium climate sensitivity of a coupled model does indeed give a good estimate of the equilibrium climate sensitivity of the coupled system that uses a full depth ocean model (Danabasoglu and Gent 2008).

The low resolution version of the CCSM3 was also used in another study (Jochum et al. 2008a), investigating the hypothesis that during Pliocene times tectonic changes in the Indonesian Seas modified the Indo-Pacific heat transport, thus increased the zonal sea surface temperature gradient in the equatorial Pacific to its large, current magnitude. Based on the model results, this hypothesis was rejected.

Using the intermediate version of the new CCSM, i.e., version 3.5, four fully coupled cases were integrated for 170 years each to document the climate impacts of the new parameterizations that are incorporated into the ocean model as part of our CPT EMILIE activities. These simulations use the nominal 2^o and 1^o resolution versions of the atmospheric and ocean model components, respectively. The ocean model also carries CFCs during the last 70 years of the integrations. The analysis of these cases is ongoing.

Land Model Working Group (LMWG)

Most of the LMWG CSL resources used during the period December 2007 to November 2008 have been in support of development of CLM4. Development and testing has covered a wide range of major and minor problems. Five main areas are listed below.

Hydrology: Improvements include a more self-consistent treatment of the bottom boundary condition, a revised calculation of the Richards equation, and more realistic treatment of soil evaporation resistance. Together, these changes improve soil moisture variability and surface flux partitioning.

Snow model: A number of changes to the snow model have been incorporated into CLM including revised parameterizations for snow cover fraction and snow burial fraction. The SNICAR model developed by Mark Flanner and Charlie Zender of UCI has been included, which includes vertically resolved snowpack heating, revised snow ageing, and aerosol deposition onto snow. With these changes, the snow cover fraction is much closer to that observed by satellite and the model now can represent the climate forcing due to black carbon or dust deposition onto snow.

Surface dataset and vegetation parameters: The surface dataset has been revised and albedos (NIR, VIS) for grasses have been adjusted based on new observed data. These changes substantially reduce modeled surface albedo biases and permit a more realistic land cover change forcing from potential to current day forcing. The changes to the surface dataset also pave the way for development of a consistent and smooth transient land cover change time series from 1870 to 2100.

Urban model: Work continues to expand the urban model into global simulations.

Other development projects: Splitting runoff into liquid and ice streams to eliminate an energy imbalance due to snow capping; new forcing height calculation to permit thin lowest atmospheric layer; deep soil converted to bedrock; consistent sparse/dense canopy aerodynamic resistance; shrub plant functional type in the Dynamic Global Vegetation Model.

CSL resources have also been used for a range of scientific studies.

Land cover/land use change: A series of land cover change simulations have been completed which will represent the CCSM contribution to an international land use change intercomparison project (LUCID). Initial results are currently being analyzed, and in some cases the simulations are being re-run with CLM4.

Accelerated Arctic warming and permafrost degradation: The impact of a period of accelerated Arctic terrestrial warming on permafrost is assessed through a series of idealized offline experiments. Accelerated warming associated with sea ice loss is found to cause a significant adverse impact on permafrost health.

Prescribed snow: A series of experiments were conducted to investigate how projected trends in snow properties (snow season length, snow depth, snowfall) affect simulated soil temperature trends.

Leaf phenology data assimilation: A pilot study to examine whether the leaf phenology scheme can be constrained through assimilation of satellite leaf area index data.

Perturbed land parameters: Exploratory simulations have been conducted to assess the impact of varying poorly constrained land model parameters such as vcmax, roughness length, snow ageing, water table decay factor in preparation for a large perturbed CLM physics ensemble.

Polar Climate Working Group (PCWG)

Over the past year, the PCWG has done a number of simulations to elucidate various aspects of the polar climate. Additionally, we have done numerous integrations for the development and testing of the new sea ice model for CCSM4. These studies and resulting publications are detailed below.

Sea ice model developments. New model physics has been incorporated into the sea ice component for use in CCSM4 integrations. During the last year this has included software engineering enhancements, further development of a surface melt pond parameterization and the capability to deposit and cycle aerosols within the sea ice component. Taken together, these (and earlier) improvements to the new sea ice component that will be used in CCSM4 represent a much improved and more general treatment of the surface albedo. Numerous simulations have been performed to test these parameterizations in ice-only and coupled configurations. Coupled climate change integrations have also been performed in order to assess the influence of these improvements on the sea ice albedo feedback for future climate conditions. A manuscript is in preparation on these improvements and their influence on climate simulations (Bailey et al., in preparation).

Arctic freshwater studies. We have implemented a number of new freshwater tracers into the CCSM ocean model in order to assess the changing pathways of freshwater in the Arctic system. In particular, tracers from river runoff into different shelf seas, from sea ice melt, precipitation, and Bering Strait inflow have been included. This required numerous code modifications and testing. Initial simulations have been performed in fully coupled integrations to assess behavior in control integrations and changes into the 21st century. These runs are currently being analyzed and will be included as a primary component of a graduate student thesis (being performed by Alexandra Jahn at McGill University, Montreal).

Arctic sea ice predictability studies. Rapidly changing sea ice conditions in the Arctic have led to a considerable interest in the possibility of forecasting sea ice conditions on seasonal to decadal timescales. This assumes that “memory” in the sea ice and ocean conditions and potential pre-conditioning of the system could influence the progression of subsequent sea ice conditions. However, there is considerable uncertainty on the timescales and limits of sea ice predictability. We have performed numerous simulations to assess the role of pre-conditioning versus intrinsic short-term variability for sea ice predictability on seasonal to decadal timescales. These integrations are the subject of a number of presentations that will occur at the fall American Geophysical Union meeting and will be assessed in a number of future planned publications.

Stability of an ice free Arctic. Numerous multi-century integrations have been performed in order to assess the climate dynamics that determine the stability of an ice free Arctic in high greenhouse gas concentration scenarios, and the process of sea ice recovery as these high greenhouse gas concentrations are reduced. These simulations are currently being analyzed and will be the subject of future publications.

Arctic tipping points. There has been much speculation that observed and simulated rapid sea ice loss represents a tipping point in the climate system in which a threshold is crossed such that rapid and irreversible sea ice loss occurs. In order to assess whether rapid ice loss simulated in CCSM3 21^{st} century integrations is reversible, we have performed a number of commitment simulations (with fixed atmospheric CO2 concentrations) started just prior to or in the midst of a simulated rapid ice loss event. By assessing the sea ice behavior in the absence of continued rises in greenhouse gases, we find evidence that the simulated events are not indicative of "tipping point" behavior. A manuscript discussing these simulations in currently in preparation (Bitz et al., in preparation).

Biogeochemistry Working Group (BGCWG)

Biogeochemistry development is focused on improving our simulations of the carbon cycle and other biogeochemical cycles and introducing more interactions between biogeochemical cycles in the model and other components. Ocean model improvements have focused on techniques for accelerating the ocean model's approach to equilibrium to reduce spinup time. Other ocean model development included: investigating the impact of interactive dust iron on the ocean ecosystem; and the impact of a parameterized diurnal cycle on ocean ecosystems. Many multi-authored papers by BGCWG members are listed in the CCSM publications.

Land carbon cycle model development included: the representation of natural and anthropogenic fire dynamics and fire effects; development of models of agroecosystems and vegetation dynamics for use with the carbon model; investigation of nitrogen feedbacks on the carbon cycle; and introduction of phosphorus as a nutrient limiting plant growth. The existing carbon cycle parameterizations were found to produce a poor simulation of the annual cycle of atmospheric CO_2. Extensive model sensitivity experiments were performed to identify the causes for this deficiency and to identify possible solutions.

Additional model simulations examined the interactions of the carbon cycle with natural aerosols which are produced by the land system (e.g. fire aerosols or dust), and their impacts on the carbon cycle through their direct and indirect radiative forcing, as well as their nutrients.

Chemistry Climate Working Group (CHCWG)

The CSL allocation was used to tackle the following topics:

Development and analysis of the modal aerosol model

The CSL allocation was used to perform development and production simulations for the Modal Aerosol Model (MAM) developed by Xiaohong Liu and Steve Ghan from PNNL. A variety of aerosol schemes (with a number of modes ranging from 3 to 11) were developed and tested, with the ultimate purpose of defining a minimal set that would fulfill the needs for interaction with chemistry and cloud microphysics. The 3-mode version will most likely be used in the IPCC AR5 simulations.

Development and analysis of the troposphere/stratosphere chemistry package

The CSL allocation was used to perform additional simulations in support of a version of CAM in which tropospheric and stratospheric chemistry is represented, including Polar Stratospheric Clouds. This version will be used for the off-line simulations in support of IPCC-AR5.

Development and analysis of secondary-organic aerosol formation

The CSL allocation was used to perform additional simulations in support of a version of CAM in which biogenic emissions of volatile organic compounds (VOCs) are explicitly represented in CLM and used in CAM to affect ozone and secondary-organic aerosol formation.

Development and analysis of a fast chemistry package in support of IPCC AR5

The CSL allocation was used to perform additional simulations in support of a version of CAM in which a very reduced set of chemical equations and associated tracers are used to represent the main feedbacks between changes in climate and changes in precursor emissions (through the methane lifetime for example). This package is being developed primarily by P. Cameron-Smith (Lawrence Livermore National Laboratory), with help from M. Prather (University of California, Irvine) in the representation of ozone chemistry in the stratosphere. We expect that this version of the chemistry (at a small additional cost of less than 50%) will be used for some of the long-term simulations in support of IPCC AR5

High-resolution simulations of Mexico City outflow

The CSL allocation was used to perform additional simulations in support of a version of CAM in which the meteorology was input (from NCEP) in order to represent the actual meteorology valid for the MIRAGE field campaign. A set of simulations at high-resolution (0.5°) was performed to analyze the ability of the model to reproduce observed concentrations of chemical species and aerosols. Estimates of the radiative forcing were also performed.

Whole Atmosphere Working Group (WAWG)

The following summarizes work carried out with WACCM using CSL resources during the period December 2007–November 2008. The topic headings and numbering correspond to the resource requests in the WACCM CSL proposal of 7 September 2007.

Historical simulations of the climate of the 20th century (C20C)

We have completed development of a new version of WACCM (WACCM-3.5.48) based upon the Community Atmosphere Model, version 3.5.48. This version incorporates all of the improvements included in CAM3.5.48, as well as a new parameterization of mesoscale gravity waves wherein the source spectra are determined from fields calculated by the model (convective heating for tropical and summer hemisphere sources, and a frontogenesis parameter for waves excited by extratropical fronts; see Beres et al, 2005; Charron and Mancini, 2002). The use of the new gravity wave parameterization improves the mean middle atmospheric climate and stratospheric variability with respect to the previous version of WACCM (Richter et al., 2008). WACCM-3.5.48 also includes a new specification of solar variability based on the work of Lean (Lean et al, 2005), and has the ability to run coupled with the CCSM ocean model.

Testing of WACCM-3.5.48 as a stand-alone model (with specified SST) has been completed, and the model is currently being used in simulations that do not require coupling with the ocean. Tuning and testing of the ocean-coupled model has been delayed due to the loss of Project Scientist F. Sassi in last summer's round of NCAR budget cuts. Testing of the coupled model has been taken over by other members of the WCCM team, led by D. Marsh (ACD), and we expect it to be completed in January-February, 2009. We project that the C20C simulation will be completed before June 2009.

Response of the middle atmosphere to natural and anthropogenic perturbations

WACCM-3.5.48 is being used to run simulations REF0 (reference climate for 2000 conditions) and REF1 (climate over 1950-2007) in support of the CCM Validation (CCMVal) project of SPARC (Stratospheric Processes and their Role in Climate). We will deliver ensembles of REF0 and REF1 simulations to the CCMVal repository by January, 2009. All of these simulations will be carried out at relatively high horizontal resolution (2°) and will be compared with results of prior CSL-supported work carried out at coarser (4°) resolution (e.g., Garcia et al., 2007; Marsh and Garcia, 2007; Garcia and Randel, 2008).

We also proposed to deliver a simulation of climate change and ozone recovery for the 21st century (REF2), building on the results of the C20C simulation discussed above. Due to the delay in completing the C20C simulation, we do not envisage delivery of the REF2 results before June of 2009. Of particular interest will be whether these ocean-coupled runs reproduce or modify the impact of ozone recovery on the Southern Hemisphere tropospheric jet found in previous CSL-supported simulations (Son et al., 2008).

The impact of Br chemistry on O_3 in the troposphere and lower stratosphere

This works examines the impact of including bromine chemistry in WACCM, in particular the impact of very short-lived (VSL) organic Br compounds on ozone chemistry in the troposphere and lower stratosphere. The CSL proposal outlined several model development tasks and specified five WACCM simulations. Model development tasks (incorporating enhanced bromine tropospheric and stratospheric chemistry in WACCM) have been completed. A reference simulation, the "no VSL" run including only long-lived organic Br source gases, has been completed. This simulation was run with both fully interactive dynamics and with dynamics specified from the NASA/GSFC GEOS5.1 data assimilation system. Results are currently being compared to data collected by the NASA Aura Satellite instruments and data collected using the Whole Air Sampler (WAS) taken during the Stratosphere-Troposphere Analysis of Regional Transport (START-08) aircraft campaign. The "VSL reference" simulation along with the "no-recycling simulation" will be run next. The "Future Climate" simulation will be completed in spring 2009.

Ozone depletion from asteroid impacts

Preliminary work has been carried out to define the initial distribution of impact products lofted into the stratosphere and mesosphere (Cl, Br, H_2O, NO, etc.) by asteroids impacting the oceans. We are collaborating on this issue with Drs. Elizabeth Pierazzo (Planetary Science Institute, Tucson, AZ) and Jay Melosh (U. of Arizona, Tucson), who have done detailed modeling of impact ejecta (e.g., Pierazzo and Melosh, 2000). Simulations using these initial conditions will be carried during winter 2008, and the results prepared for publication by summer 2009.

Study of climate variability in the thermosphere.

We have completed three 1-year simulations of the whole atmosphere (ground to upper thermosphere, at 500km) under solar maximum, mean, and minimum conditions using the extended version of WACCM (WACCM-X). The winds, temperature, and composition in the middle and upper atmosphere are in good agreement with those obtained from TIME-GCM and MSIS/HWM. WACCM-X successfully reproduced the semi-annual variation of the O/N_2 ratio, with both the magnitude and phase in good agreement with the MSIS climatology. The migrating and non-migrating tides and their seasonal variability resolved by the model are in good agreement with those derived from NASA's TIMED/SABER and TIDI observations. The thermospheric tides from the model also show strong and quite realistic short-term variability. This is the first time that the wind, temperature and compositional structures are resolved from the ground to the upper thermosphere self-consistently in a seamless model (Liu et al, 2008a). WACCM has also been used to study error growth in the whole atmosphere system (Liu et al., 2008b).

Paleoclimate Working Group (PAWG)

Pre-Quaternary Report

Paleocene-Ecocene Thermal Maximum (PETM) Simulations

Prof. Cindy Shellito (U. Northern Colo.) carried out a series of coupled PETM simulations to study the effects of both CO_2 levels and paleogeography on Arctic surface temperatures. The findings of these studies are being submitted to Geophys. Res. Letters. The most intriguing result from these simulations is the role of opening the Bering Strait on Arctic temperatures. Opening of a shallow straight led to a substantial warming in this region, which brings the model closer to paleoproxy estimates of Arctic surface temperatures. Prof. Arne Winguth (U. Texas, Arlington) completed a series of PETM simulations where he has begun to couple in the effects of ocean biogeochemistry.

Cretaceous Simulations

Prof. Chris Poulsen (U. Mich) in collaboration with NCAR scientists has completed three simulations of the mid-Cretaceous (100Ma) that include two levels of CO_2 and the presence of dynamic vegetation. These simulations indicate that the CCSM cannot reproduce the extreme warm polar temperatures as deduced from paleoproxy data. Thus, the CCSM like all other climate models seems to be missing a fundamental process operative in warm greenhouse climates.

Mid-Permian Climate Simulations

A Permian simulation with $1XCO_2$ levels was completed. This simulation is the first of a series of simulations that are a part of a collaborative project involving Prof. Lynn Soreghan (U. Oklahoma) and Prof. Natalie Mahowald (Cornell U.). Results from this simulation show good agreement with paleoproxy data for tropical surface wind patterns. This is encouraging since the model winds will be used by Prof. Mahowald to drive a dust transport model for this time period.

High Resolution Latest Permian Simulation

Jeff Kiehl and Christine Shields completed a T170 (~70 km) CAM3 simulation of the Latest Permian. The sea surface temperatures were taken from a low resolution CCSM3 $13XCO_2$ simulation and interpolated to the CAM3 high resolution model. The results from this simulation have been shown at the Fall 2007 AGU conference and generated considerable excitement among the paleo community. The simulations show the existence of large intense hurricanes in the tropics. These storms propagate to fairly high latitudes and there is an implication that they may play an important role in poleward heat transport. It is proposed for the next CSL allocation to carry out a fully coupled simulation to see if this is indeed the case. If so, these storms may be the missing process for warm greenhouse climate simulations.

Coupled Climate Simulation of the Late Ordovician

Significant effort was put into creating a Late Ordovician version of the paleo CCSM3. Christine Shields worked with members of the NCAR Oceanography section to configure the CCSM to run with a rotated ocean grid. This was required to avoid placing a false pole over the North pole, since there was no land in the high northern latitudes at this time period (445 Ma). Shields was successful in creating this version of the CCSM3, and it is now the first such configuration for this time period. Preliminary simulations for two levels of CO_2 (4X and 15X) indicate that conditions were right for the growth of a major ice sheet over Gondwana, which was situated over the southern polar regions. Prof. Chris Scotese (U. Texas, Arlington) is a collaborator on this project, and has recently provided a more realistic bathymetry data set for the simulations. Future simulations will employ this bathymetry.

Quaternary Report

The CSL allocation was used to simulate the mid-Pliocene (~3 million years ago), a period when the land-ocean geography was similar to present, atmospheric carbon dioxide concentrations are estimated to be about 400 ppmv, and the polar ice sheets were much reduced from their present extents (Otto-Bliesner and Rosenbloom). These simulations are part of a series of model-model and model-data comparisons for the PlioMIP project. The first step was to perform CAM3-CLM3 simulations with PRISM2 sea surface temperatures, sea ice, and land surface conditions. A simulation with dynamic vegetation was also performed. These simulations are being compared to simulations with the HadCM and GISS models.

High-resolution (T85x1) CCSM3 simulations were started to simulate the Last Interglacial (~130 thousand years ago (Otto-Bliesner, Brady, and Rosenbloom). A version of the ocean grid was developed that removes the West Antarctic Ice Sheet (WAIS). This grid can be used for future scenarios of disintegration of the WAIS. These simulations will be evaluated to understand the impact of the presence of the WAIS on the Southern Hemisphere climate, past and future.

Climate Variability Working Group (CVWG)

Since January 2008, the CVWG has completed a 5-member T42 ensemble forced by tropical (20N-20S) time-varying SSTs taken from the CCSM3 Climate of the 20th Century 8-member ensemble mean during the period 1950-1999. This set of simulations is aimed at attribution of atmospheric circulation and climate variability to the anthropogenic component of SST variability during 1950-1999, as given by the CCSM3 ensemble mean. All model output are available to the community through the CVWG web page.

The CVWG has also completed a 30- member set of IPCC A1B scenario runs with CCSM3 at T42 resolution in conjunction with the Climate Change Working Group (CCWG), a project begun in 2005. The purpose of these experiments is to provide a large ensemble (30 members) of integrations driven by a fixed, standard "business-as-usual" climate change scenario during 2000-2061. Such a large ensemble will allow an assessment of uncertainties in climate projections resulting from intrinsic system variations, as well as the evolving properties of interannual variability. The ensemble members all begin from the same ocean/land/sea ice conditions taken from the last year of the 1870-1999 historical runs, with different atmospheric initial conditions. These runs are available to the community through the CVWG web page.

A major accomplishment of CVWG this past year was leading NCAR's participation in the US CLIVAR Drought Modeling program. CVWG with the help of Adam Phillips (NCAR) and Alfredo Ruiz-Barradas (University of Maryland) executed a dozen 50-year atmospheric model integrations following the experiment design advocated by the Drought Working Group. The experiments involved running the CAM3.5 model with seasonally invariant SST anomaly patterns specified on top of the monthly varying SST climatology in various ocean basins (Pacific/Atlantic, tropical/global). In addition to individual basin experiments, simulations were produced with multi-basin specifications as well (e.g., cold Pacific and warm Atlantic). The simulation archives consist of a large number of surface, upper-air, and thermodynamic fields, including 3D diabatic heating components. The drought simulation data sets are archived at NCAR's MSS (/ASPHILLI/csm/cam3_3_17_t85_dwg*), and are served from the NASA/GSFC Global Modeling and Assimilation Office (GMAO) ftp site and the University of Maryland's Department of Atmospheric & Oceanic Science data server. The community is currently intercomparing the CAM3.5 drought simulations with those produced at other national modeling centers (NASA/NSIPP, NCEP/CFS, GFDL/AM2.1, and LDEO/CCM3).

Climate Change Working Group (CCWG)

For 2008, the Climate Change Working Group proposed a Greenland sheet melting development run, and production runs in the areas of CCSP low emissions scenarios, studies investigating hurricane mixing, the effect of Bering Strait on climate stability, as well as some geoengineering recovery runs. For the development run, despite continuous interaction with the ice sheet developers at LANL, the scientific code for this was not ready and only initial attempts at starting control runs were possible.

The runs investigating the effect of hurricanes on the meridional overturning circulation were carried out. By prescribing Atlantic hurricanes in a global coupled climate model to show that, climatically, the strong hurricane winds can strengthen the Atlantic meridional overturning circulation (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. This paper is undergoing revision

The Greenland ice sheet melting experiment shows that an ice sheet melting with a rate up to 0.03 Sv would not alter 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. This paper is in preparation and nearing completion.

The runs investigating the Bering Strait effect on global sea level rise were able to reproduce observed oscillations of global mean sea level seen at the beginning of the last glacial. This effect results from cycles in ocean temperature, salinity and albedo that affect the strength of the ocean circulation and impact the degree of net melt water. This paper is in preparation.

The CCSP low emissions scenarios were carried out during a friendly user opportunity at another center, freeing up time for CCSM4 development. WGCM emissions scenarios and the geoengineering recovery runs were not carried out.

The sensitivity runs for the climate change detection and attribution experiment were carried out via a perturbed physics ensemble. The CAM ensemble is an 81 member perturbed physics experiment comprising slab ocean model experiments, each of which are simulated for 45 years in total, breaking down into 3x15 year experiments for calibration of q-flux, pre-industrial control and instantaneous carbon dioxide doubling from which the climate sensitivity may be inferred. The simulation set was so large that the runs were made both on Blueice at NCAR and on Jaguar at ORNL. The data is being used for several papers in preparation; firstly, we wish to explore the relationships between feedback mechanisms and model parameters in the CAM, and compare those relationships to those determined from other perturbed physics ensembles. Also, we intend to use the ensemble results to improve current estimates of climate sensitivity by adopting a non-linear emulation technique to find optimal configurations of CAM as judged by various observational metrics, and use the differences to estimate the likelihood of various values of climate sensitivity.

Software Engineering Working Group (SEWG)

Under the CSL development allocation, the SEWG working group has focused on infrastructure improvement efforts in order to produce a scalable, efficient and easily extensible and portable model system. The SEWG has also worked to improve CCSM robustness by continued expansion of the CCSM scripts and testing framework and by also providing both expert and non-expert users with "user-friendly" scripts and timing utilities.

The SEWG produced a completely new CCSM4 coupling architecture, cpl7, which addresses both new CCSM4 scientific requirements as well as anticipated petascale architecture requirements. CCSM3 coupling architecture, cpl6, operated as a multiple executable system where all models ran as separate binary executables on non-overlapping processor sets. The exchange of boundary data between components was accomplished via exchange with a central coupler and met the scientific requirements of the system while maximizing the amount of concurrency between components. There was no concept of a top-level driver. This approach had not fundamentally changed in CCSM since the development of CSM1 in the mid-1990s.

The development of cpl7 has introduced a completely new approach to the high-level architecture and design of the system. The CCSM4/cpl7 system is a single executable system that now provides new flexibility in running model components sequentially, concurrently, or in a mixed sequential/concurrent mode. To achieve this additional flexibility, a new driver has been introduced in the cpl7 system. This driver runs on all the processors of a model simulation and controls the time sequencing, processor concurrency, and exchange of boundary data between components. In the cpl7 architecture all model components can run on subsets of all the processors and the component processor layouts can be determined at run time from simple user editable files. This design permits the model system to have greatly increased flexibility in setting up an appropriate component layout to optimize the performance of a model simulation for a given model resolution and scientific complexity. In particular, component layouts are now supported where all components run concurrently on non-overlapping processor sets, where all components run sequentially on the same processor set, or where components run in a "hybrid" sequential/concurrent layout. Furthermore, the new design guarantees that the results of a given simulation are *bit-for-bit* regardless of the component processor layouts chosen.

New scientific parameterizations and resolutions associated with CCSM4 developments indicate that more frequent component coupling is necessary for a subset of the components (i.e. land, ice and atmosphere). This latter requirement can only be met without a significant performance cost within a framework that permits coupling of these components in a more sequential manner. The new cpl7 architecture addresses these requirements in a way that the CCSM3/cpl6 architecture could not meet.

The cpl7 architecture has also ensured that key capabilities required of the CCSM system are maintained. In particular, the design provides "plug and play" capability of data and active components and produces the same climate as the CCSM3/cpl6 system. The resulting new system, however, also permits extensive code reuse and removes the existence of stand-alone component configurations that have a different code base than those used in coupled simulations. This has resulted in decreased code maintenance, consistent science across components and increased system robustness. All current CCSM4 development efforts are utilizing the cpl7 architecture. In addition, the DOE Grand-Challenge simulation is also utilizing the cpl7 coupling architecture. This simulation will be the first ever U.S. multi-decadal global climate simulation with an eddy resolving ocean and high resolution atmosphere (0.25° atmosphere/land and 0.1° ocean/ice).

The SEWG CSL development allocation was extensively utilized to test and validate the new CCSM4 coupling architecture. The allocation was also used to carry out a variety of performance tests of the system. Numerous load balancing tests were carried out in order to determine the optimal processor layout for various experimental configurations. CCSM4 performance, load balance, and scalability are strongly dependent on the individual component resolutions and component complexity. Within the system, each component has its own scaling characteristics that are often dependent on internal load balance, decomposition capabilities, communication patterns, and cache usage.

Finally, the CSL development allocation was utilized to routinely test the functionality of the evolving model system as new CCMS4 science was incorporated in each component. This testing was critical in the creation of the CCSM4 model and will permit new multi-century control simulations to be carried out starting in early December of 2008.

Publications of the CCSM Project: Dec. 07 – Nov. 08

Danabasoglu, G., and P. R. Gent, 2008: Equilibrium climate sensitivity: Is it accurate to use a slab ocean model? *J. Climate*, accepted.

Danabasoglu, G., and J. Marshall, 2007: Effects of vertical variations of thickness diffusivity in an ocean general circulation model. *Ocean Modelling*, **18**, 122-141, doi:10.1016/j.ocemod.2007.03.006.

Danabasoglu, G., R. Ferrari, and J. C. McWilliams, 2008a: Sensitivity of an ocean general circulation model to a parameterization of near-surface eddy fluxes. *J. Climate*, **21**, 1192-1208.

Danabasoglu, G., S. Peacock, K. Lindsay, and D. Tsumune, 2008b: Sensitivity of CFC uptake to physical initial conditions and inter-annually varying surface forcing in a global ocean model. *Ocean Modelling*, submitted.

Deser, C., and A. S. Phillips, 2008: Atmospheric Circulation Trends, 1950-2000: The Relative Roles of Sea Surface Temperature Forcing and Direct Atmospheric Radiative Forcing. *Journal of Climate*, in press.

Doney, S., I. Lima, J. K. Moore, M. Behrenfeld, N. Mahowald, M. Maltrud, D. Glover, D. McGillicuddy, T. Takahashi, 2008: Skill metrics for confronting global upper ocean ecosystem biogeochemistry models against field and remote sensing data. *Journal of Marine Science*, accepted.

Doney, S. C., I. Lima, R. A. Feely, D. M. Glover, K. Lindsay, N. Mahowald, J. K. Moore, and R. Wanninkhof, 2008: Mechanisms Governing Interannual Variability in the Upper Ocean Inorganic Carbon System and Air-Sea CO2 Fluxes. *Deep Sea Research II*, submitted.

Eden, C., M. Jochum, and G. Danabasoglu, 2008: Effects of different closures for thickness diffusivity. *Ocean Modelling*, in press.

Fox-Kemper, B., G. Danabasoglu, R. Ferrari, and R. W. Hallberg, 2008: Parameterizing submesoscale physics in global climate models. *CLIVAR Exchanges*, **13**, 3-5.

Garcia, R.R., D.R. Marsh, D.E. Kinnison, B.A. Boville, and F. Sassi, 2007: Simulation of secular trends in the middle atmosphere, 1950-2003, *J. Geophys. Res.*, **112**, D09301, doi:10.1029/2006JD007485.

Garcia, R.R. and W.J. Randel, 2008: Acceleration of the Brewer-Dobson circulation due to increases in greenhouse gases, *J. Atmos. Sci.*, **65**, 2731-2739.

Gettelman, A., and D. E. Kinnison, 2007: The global impact of supersaturation in a coupled chemistry-climate model. *Atmos. Chem. Phys.*, **7**, 1629-1643.

Gettelman, A., and T. Birner, 2007: Insights on tropical tropopause layer processes using global models. *J. Geophys. Res.*, **112**, D23104, doi:10.1029/2007JD008945.

Gettelman, A., *et al.*, 2008: The tropical tropopause layer 1960-2100. *Atmos. Chem. Phys. Discuss.*, **8**, 1367-1413.

Griffies, S. M., and Coauthors, 2008: Coordinated Ocean-ice Reference Experiments (COREs). *Ocean Modelling*, in press.

Heald, C. L., D. K. Henze, L. W. Horowitz, J. Feddema, J. -F. Lamarque, A. Guenther, P. G. Hess, F. Vitt, J. H. Seinfeld, A. H. Goldstein, and I. Fung, 2008: Predicted change in global secondary organic aerosol concentrations in response to future climate, emissions, and land-use change. *J. Geophys. Res.*, **113**, D05211, doi:10.1029/2007JD009092.

Jackman, C. H., D. R. Marsh, F. M. Vitt, R. R. Garcia, E. L. Fleming, G. J. Labow, C. E. Randall, M. López-Puertas, B. Funke, T. von Clarmann, and G. P. Stiller, 2008: Short- and medium-term atmospheric constituent effects of very large solar proton events. *Atmos. Chem. Phys.*, **8**, 765–785.

Jayne, S. R., 2008: The impact of abyssal mixing parameterizations in an ocean general circulation model. *Ocean Modelling*, in press.

Jochum, M., 2008: Simulated climate impacts of latitudinal variations in diapycnal diffusivity. *J. Geophys. Res.*, in press.

Jochum, M., and J. Potemra, 2008: Sensitivity of tropical rainfall to Banda Sea diffusivity in the Community Climate System Model. *J. Climate*, **21**, 6445-6454.

Jochum, M., B. Fox-Kemper, P. Molnar, and C. Shields, 2008a: Differences in the Indonesian Seaway in a coupled climate model and their relevance for Pliocene climate and El Nino. *Paleoceanography,* submitted.

Jochum, M., G. Danabasoglu, M. Holland, Y. -O. Kwon, and W. G. Large, 2008b: Ocean viscosity and climate. *J. Geophys. Res*., **113**, C06017, doi:10.1029/2007JC004515.

Lamarque, J. -F., D. E. Kinnison, P. G. Hess and F. Vitt, 2008: Simulated lower stratospheric trends between 1970 and 2005: identifying the role of climate and composition changes. *J. Geophys. Res*., **113**, D12301, doi:10.1029/2007JD009277.

Lawrence, D. M., and A. G. Slater, 2008: The contribution of snow condition trends to future ground climate. *Clim. Dyn.,* submitted.

Lawrence, D. M., A. G. Slater, R. A. Tomas, M. M. Holland, and C. Deser, 2008: Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. *Geophys. Res. Lett.*, **35**, L11506, doi:10.1029/2008GL033985.

Lawrence, D. M., A. G. Slater, V. E. Romanovsky, and D. J. Nicolsky, 2008: The sensitivity of a model projection of near-surface permafrost degradation to soil column depth and inclusion of soil organic matter. *J. Geophys. Res.*, **113**, F02011, doi:10.1029/2007JF000883.

Levis, S., G. B. Bonan, and P. J. Lawrence, 2007: Present-day springtime high-latitude surface albedo as a predictor of simulated climate sensitivity. *Geophys. Res. Lett.*, **34**, L17703, doi:10.1029/2007GL030775.

Liu, H.-L., et al., 2008a: Thermospheric structures and variabilities from the extended NCAR Whole Atmosphere Community Climate Model (WACCM-X). *J. Geophys. Res.,* in preparation.

Liu, H.-L., F. Sassi, R. R. Garcia, 2008b: Error growth in a whole atmosphere climate model, *J. Atmos. Sci.,* in press.

Luo, C., N. Mahowald, T. Bond, P. Y. Chuang, P. Artaxo, R. Siefert, Y. Chen, and J. Schauer (2008), Combustion iron distribution and deposition, *Global Biogeochem. Cycles*, **22**, GB1012, doi:10.1029/2007GB002964.

Mahowald, N., T. D. Jickells, A. R. Baker, P. Artaxo, C. R.Benitez-Nelson, G. Bergametti,T. C. Bond, Y. Chen, D. D. Cohen, B. Herut, N. Kubilay, R. Losno, C. Luo, W. Maenhaut, K. A. McGee, G. S. Okin, R. L. Siefert, S. Tsukuda, 2008: The global distribution of atmospheric phosphorus deposition and anthropogenic impacts, *Global Change Biology*, accepted.

Mahowald, N., S. Engelstaedter, C. Luo, A. Sealy, P. Artaxo, C. Benitez-Nelson, S. Bonnet, Y. Chen, P. Y. Chuang, D. D. Cohen, F. Dulac, B. Herut, A. M. Johansen, N. Kubilay, R. Losno, W. Maenhaut, A. Paytan, J. M. Prospero, L. M. Shank, R. L. Siefert, 2008: Atmospheric Iron deposition: Global distribution, variability and human perturbations. *Annual Reviews of Marine Sciences*, accepted.

Marsh, D. R. and R. R. Garcia, 2007: Attribution of decadal variability in lower-stratospheric tropical ozone, *Geophys. Res. Lett.*, **34**, L21807, doi:10.1029/2007 GL030935.

Mills, M. J., O. B. Toon, R. Turco, D. E. Kinnison, and R. R. Garcia, 2008: Catastrophic ozone loss following a regional nuclear conflict. *Proc. Nat. Acad. Sci.*, **105**, 5307-5312.

Nevison, C., N. Mahowald, S. Doney, I. Lima, N. Cassar, 2008: The impact of variable air-sea O-2 and CO2 fluxes on atmospheric potential oxygen (APO) and land-ocean carbon sink partitioning. *Biogeosciences*, **5**, 3, 875-889.

Nevison, C. D., N. M. Mahowald, S. C. Doney, I. D. Lima, G. R. van der Werf, J. T. Randerson, D. F. Baker, P. Kasibhatla, and G. A. McKinley, 2008: Contribution of ocean, fossil fuel, land biosphere, and biomass burning carbon fluxes to seasonal and interannual variability in atmospheric CO_2 . *J. Geophys. Res.*, **113**, G01010, doi:10.1029/2007JG000408.

Oleson, K. W., G. -Y. Niu, Z. -L. Yang, D. M. Lawrence, P. E. Thornton, P. J. Lawrence, R. Stöckli, R.E. Dickinson, G. B. Bonan, S. Levis, A. Dai, T. Qian, 2008: Improvements to the Community Land Model and their impact on the hydrological cycle. *J. Geophys. Res.*, **113**, G01021, doi:10.1029/2007JG000563.

Oleson, K. W., G. B. Bonan, J. Feddema, M. Vertenstein, and C. S. B. Grimmond, 2008: An urban parameterization for a global climate model. 1. Formulation and evaluation for two cities, *J. Appl. Meteorol. Clim.*, **47**, 1038-1060.

Oleson, K. W., G. B. Bonan, J. Feddema, and M. Vertenstein, 2008: An urban parameterization for a global climate model. 2. Sensitivity to input parameters and the simulated urban heat island in offline simulations, *J. Appl. Meteorol. Clim.*, **47**, 1061-1076.

Randel, W. J., and R.R. Garcia, 2008: Dynamical balances and tropical stratospheric upwelling. *J. Atmos. Sci.*, **65**, 3584-3595.

Randerson, J. T., F. M. Hoffman, P. E. Thornton, N. M. Mahowald, K. Lindsay, Y. -H. Lee, C. D. Nevison, S. C. Doney, G. Bonan, R. Stöckli, C. Covey, S. W. Running, and I. Y. Fung, 2008: Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models. *Global Change Biology*, submitted.

Richter, J., F. Sassi, R. R. Garcia, K. Matthes, and C. A. Fischer, 2008: Dynamics of the middle atmosphere as simulated by the Whole Atmosphere Community Climate Model, version 3 (WACCM3). *J. Geophys. Res.*, **133**, D08101, doi:10.1029/ 2007JD009269.

Richter, J. R., Sassi, F., and R. R. Garcia, 2008: Towards a source oriented gravity wave parameterization, *J. Geophys. Res.*, in preparation.

Son, S.-W., L. M. Polvani, D. W. Waugh, H. Akiyoshi, R. Garcia, D. Kinnison, S. Pawson, E. Rozanov, T. G. Shepherd, and K. Shibata, 2008: The impact of stratospheric ozone recovery on the Southern Hemisphere westerly jet, *Science*, **320**, 1486-1489, DOI: 10.1126/science.1155939.

Son, S. -W., L. M. Polvani, D. W. Waugh, T. Birner, R. R. Garcia, A. Gettelman, and D. A. Plummer, 2008: The tropopause in the 21st century as simulated by stratosphere-resolving Chemistry-Climate Models. *J. Climate*, in press.

Song, I. -S., H. -Y. Chun, R. R. Garcia and B. A. Boville, 2007: Momentum flux spectrum of convectively forced internal gravity waves and its application to gravity wave drag parameterization. Part II: Impacts in a GCM (WACCM). *J. Atmos. Sci.*, **64**, 2286-2308.

Stöckli, R., D. M. Lawrence, G. -Y. Niu, K. W. Oleson, P. E. Thornton, Z. -L. Yang, G. B. Bonan, A. S. Denning, and S. W. Running, 2008: The use of Fluxnet in the Community Land Model development. *J. Geophys. Res.*, **113**, G01025, doi:10.1029/2007JG000562.

Yeager, S., and M. Jochum, 2008: The nonlinear connection between Labrador Sea buoyancy loss, deep western boundary current strength, and Gulf Stream path in an ocean circulation model. *Ocean Modelling*, submitted.

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