The Use of the Climate-Science Computational End Station (CCES) Development and Grand Challenge Team for the Next IPCC Assessment: An Operational Plan

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The Climate Science Computational End Station[1] is focused on The Grand Challenge of Climate Change Science, which is to predict future climates based on scenarios of anthropogenic emissions and other changes resulting from options in energy and development policies. Addressing this challenge requires a Climate Science Computational End Station (CCES) consisting of a sustained climate model research, development and application program combined with world-class DOE leadership computing resources to enable advanced computational simulation of the Earth System. This proposal provides the primary computer allocations for the DOE SciDAC and Climate Change Prediction Program (CCPP). It builds on the successful interagency collaboration of the National Science Foundation (NSF) and the U.S. Department of Energy (DOE) in developing and applying the Community Climate System Model (CCSM) for climate change science. It also includes collaboration with the National Aeronautics and Space Administration (NASA) in carbon data assimilation and university partners with expertise in high end computational climate research.

In it's fourth year, the CCES advances climate science through both an aggressive model development activity and an extensive suite of climate model application simulations. Subproject allocations are subject to external scientific review of specific proposed computational experiments. The required computing resources and the scientific goals of the proposed CCES are compatible and consistent with the DOE Office of Science (DOE-SC) Strategic Plan, the Federal Climate Change Science Program (CCSP) Strategic Plan, and the CCSM Strategic Business Plan for 2004-2008 and with the CCSM Science Plan.[2]

This multi-year project includes an ambitious simulation plan emphasizing model application with an ongoing, core model development that envisions future needs and scales the CCSM for use on petascale computer systems. The CCSM3 is the current state-of-the-science model that accurately simulates global to continental aspects of the physical climate system. Extensive simulations with higher resolution versions of the current model are under investigation to identify and correct bias errors that are unacceptable for future simulations that require sub-continental and smaller scale accuracy. Using high resolution ocean and ice models, the future simulation schedule also includes studies of abrupt climate change, in which large global scale changes occur within a few decades. The CCSM3 requires the specification of changes to many factors that determine climate change, such as the atmospheric

[1] The creation of Computational End Stations provides the scientific applications software and world-class computational resources needed for researchers in various areas of science.
[2] These are available online at (http://www.ccsm.ucar.edu).

concentrations of greenhouse gases, atmospheric aerosols, and the distribution of vegetation types on the land surface. In the Earth system version of CCSM, these factors result from dynamic physical, chemical and biological processes. These are currently being added to the current CCSM4 as part of this project, and will be used in future versions to realistically predict future climates. Significant "biogeochemical" cycles influencing climate change involve carbon, sulfur and nitrogen cycles. Of particular importance to U.S. energy policy is the correct simulation of the global carbon cycle and its feedbacks to the climate system, including its variability and modulation by ocean and land ecosystems. This continuing model development and extensive testing of the CCSM system to include recent new knowledge about these processes is at the cutting edge of climate science research and is a principal focus of the CCES. We are planning to develop CCSM4 in time for the fifth IPCC assessment. An operational time-line will be shown later in this summary of activities.

The CCES *predicts future climates using emissions scenarios and other changes resulting from energy policies options*. We deliver simulations improving the scientific basis, accuracy and fidelity of climate models and perform climate change simulations that directly inform national and international science policy, thereby contributing to the DOE, NSF, and NASA science missions.

Resources

The Computational Climate End Station manages resources on the three primary systems that fall under the INCITE program: Cray XT4 Jaguar at NCCS, the Cray XT4 Franklin at NERSC, and the IBM BlueGene-P at ANL. The Climate End Station seeks to provide a single source version of the CCSM that runs on all these platforms and that can be used for applied research in climate change. Development time for model extension, validation and verification, as well as software scalability forms a significant part of the requested allocation on each platform. The experiments/simulations outlined in our research plan utilize all these machines demonstrating production on cutting edge High Performance Computer (HPC) platforms and taking advantage of the unprecedented computational power for more comprehensive, high resolution climate prediction results. The Earth System Grid infrastructure links climate simulation data and analysis capabilities across the DOE laboratories and NCAR.

Brief Summaries of Subprojects:

The Climate Science Computational End Station is the primary allocation that develops and deploys the Community Climate System Model (CCSM) for use in DOE and NSF climate change simulation experiments. The CCSM is our primary computational instrument. We provide the capability tools and simulation frameworks needed to advance climate-change science and carry out leading climate-science research program in conjunction with our partners and sponsoring agency programs. We execute the high-priority simulations for the DOE that require the high end computational capability of scalable high performance computers; and provide outreach to the larger research community through simulation products and analysis of model results and workshops.

Climate Change (NCAR/LLNL)

The Climate Change working Group (*Washington(NCAR)/Meehl(NCAR)/Santer(LLNL)/Buja(NCAR)*) and the climate modeling community has initiated an experimental design process for the next round of coordinated climate change experiments that will involve AOGCMs and Earth System Models (ESMs) for assessment in the upcoming IPCC Fifth Assessment Report in 2013. In consultation with the Integrated Assessment Modeling community that formulates scenarios, a set of climate change experiments and scenarios is proposed that will address short-term climate change (out to about 2030) with high resolution coupled models (0.5-1.0 degrees horizontal resolution in the atmosphere) to look at regional climate change and processes involved with producing changes of weather and climate extremes; and long-term climate change (out to 2300) with medium resolution coupled models (about 1.5-2.0 degrees horizontal resolution in the atmosphere) to quantify feedbacks involved with carbon cycle, and assess climate change adaptation in mitigation scenario experiments. We are planning future climate change simulations to the year 2300, short term high resolution climate predictions, coupled ice sheet simulations, and 1000 year biogeochemistry simulations. The simulation data is freely and openly provided to the international climate science community via the Earth System Grid.

SciDAC Biogeochemistry (LLNL/PNNL/ORNL/NCAR/LANL)

The SciDAC Biogeochemistry sub-project of *Jim Randerson and Forrest Hoffman (ORNL)* will look at the impacts of land use change and dynamic global vegetation on the climate system. This is a follow on, second phase, to the Carbon-Land Model Intercomparison Project (C-LAMP) and the C4MIP model analysis and evaluation projects. It is hoped that this will be instrumental in defining the biogeochemical/carbon experiments for the IPCC AR5. This will assess the performance using observational datasets of the CLM-CN, CASA' and IBIS models in the CCSM framework to gauge the strength of the feedback between the carbon cycle and the climate system.

SciDAC Earth System Model with Sulfur (NASA/ORNL)

As part of the SciDAC CCSM Consortium project a groundbreaking Earth System Model simulation (and model development) is being carried out by *Philip Cameron-Smith (LLNL), Steve Ghan (PNNL), Scott Elliott, Dave Erickson (ORNL), Jean-Francois Lamarque (NCAR), Matt Maltrud (LANL), and Phil Jones (LANL).* The SciDAC Earth System Model focuses on dimethyl sulfide (DMS) interactions to extend and augment the current plans of the CCSM Biogeochemistry working group by focusing on the sulfur cycle and aerosol feedbacks. The simulations will also be used as a testbed for atmospheric chemistry, particularly new aerosol indirect effects.

NASA Carbon Assimilation (ORNL)

Our NASA team is pursuing the Simulation and Assimilation of Atmospheric Carbon Species. The proposers are *Donald Anderson, Steven Pawson, and Mike Seablom (NASA).* Carbon modeling and use of observational data is considered key to the long term success of the End Station's modeling thrust. This project is performing multi-year data assimilation simulations of atmospheric carbon species at 0.5-degree spatial resolution using the GEOS-5 atmospheric general circulation model (AGCM). The runs will use specified emission boundary fluxes for CO and CO2.

Eddy-Resolving POP (LANL/SIO/NCAR)

The Parallel Ocean Program (POP) Ocean model is being used to produce Climate Simulations with an Eddy Resolving Ocean. *Phil Jones (LANL), Matt Maltrud (LANL), Elizabeth Hunke (LANL), Julie McClean (SIO) and Frank Bryan (NCAR)* are studying ocean mesoscale eddies (~20km in size) and small-scale topographic features. These play an important role in determining the structure of important current systems in the ocean and in the eddy transport of heat. Previous simulations have shown that high resolution (0.1ºor less) is required to adequately represent properties of ocean current systems such as that of the Gulf Stream, with its separation at Cape Hatteras and subsequent turn to the northwest near the Grand Banks. At coarser resolutions, it has been impossible to reproduce such features, resulting in significant biases that can strongly distort important feedbacks in the climate system. This version uses a new configuration with a tripole grid and partial bottom cells and also attempts to introduce an improved advection scheme. This high-resolution standalone coupled ocean/ice simulation set the stage a fully-coupled climate simulation with the eddy-resolving ocean as a high priority SciDAC project.

CAM Development (NCAR/LBL/LLNL/PNNL/LANL/ORNL)

High-resolution configurations of the Community Atmosphere Model (CAM3) and prototype CAM4 have been developed to quantify the improvement in simulation fidelity across the wide range of space and time scales observed in the climate system *(Jim Hack (ORNL)).* The development of CAM3 demonstrated a clear break point in simulation quality when horizontal resolution was doubled from a 42-wavenumber truncation (T42) to an 85-wavenumber (T85) truncation. Early results suggest that the large-scale systematic biases in mean climate, which affect the quality of regional performance, are far more related to the parameterized treatment of non-resolvable physics, such as clouds, convection, radiation and boundary layer. Some transient features of the simulation are far more realistic, including the clear presence of tropical storms at the T341 truncation. This project investigates both the spectral Eulerian dynamical core and the prototype CAM4 using the Finite Volume (FV) dynamical core at resolutions as fine as 0.25 deg, which should have solution accuracy equivalent to the T341 spectral model.

CCSM Development (NCAR/LBL/LLNL/LANL/PNNL/ANL/ORNL)
Over the next year, the CCSM Software Engineering Group under the leadership of *Peter Gent (NCAR) and Mariana Vertenstein (NCAR)* will perform CCSM development simulations in four main categories.

1) Model development towards CCSM version 4. CCSM Version 3.5 was assembled in June 2007, which reduced several long-standing biases in CCSM 3. The atmosphere model working group is working on incorporating the following new parameterizations: a) new boundary layer scheme, b) new shallow convection scheme, c) revised vertical coordinate, d) new aerosol microphysics package, and e) revised gravity wave drag scheme. The land, ocean and sea ice components have also been upgraded.

2) It has been demonstrated by scientists at LLNL and NCAR that the simulation quality of the FV atmosphere component improves rapidly with increasing resolution. Thus, the development versions of CCSM will be regularly tested at the higher atmosphere resolution as development is progresses towards CCSM 4.

3) CCSM3.5 with the carbon cycle. The carbon cycle includes a new land component with fully interactive carbon and nitrogen limitation, an ocean ecosystem component, and several extra fields being transported by the atmosphere component.

4) First attempts at short-term simulations using a high resolution version of CCSM 3.5. A novel type of climate change simulation proposed for the next IPCC report is high resolution simulations of the near future with regional climate change information. The integrations are proposed to start in 1980, run to 2005 using observed climate forcings, and then proceed to 2030 in predictive mode. It has been decided to include interactive chemistry in some of these simulations in order to include predictive aerosols. This will enable regional simulations of pollutants near large cities to be made.

WRF Resolution Studies (PNNL)
Ruby Leung(PNNL) and Steve Ghan (PNNL) are assessing the impacts of spatial resolution at cloud-resolving and mesoscale scales using regional to global configurations of the Weather Research and Forecasting (WRF) model. Recent advances in high performance computing have made it possible to run these model configurations at very high spatial resolution down to the cloud resolving scale over relatively large domains and long time periods. This project uses WRF to systematically assess the impacts of spatial resolution, with a focus on the model's ability to simulate cloud processes and their interactions with the local to large scale circulation. Taking advantage of the nesting capability and cloud resolving to global modeling capability in WRF, numerical experiments using WRF configured in regional/global domains are also being performed.

University Components (MIT/ORNL and Georgia Institute of Technology)
The magnitude and ubiquity of deforestation in the Amazon basin has become increasingly clear in recent years. Furthermore, there is overwhelming evidence that vegetation is not passively responding to changes in climate and weather, but is dynamically evolving with climate and human and natural disturbances to vegetation. Human disturbance of Amazonian forests over the next several decades is inevitable. The MIT team (Knox//Erickson) is taking the null hypothesis that this disturbance will have no effect on the non-local vegetation structure or the spatio-temporal partitioning of energy in the Amazon basin.

The Georgia Tech team (Dickinson/Shaikh) is developing and testing a systematic subgrid scaling framework for the land component of the CCSM based on four elements: i) a complex vegetation tiling representation; ii) an orographic tiling system; iii) a tiling system to describe a distribution of water table parameters that derives a realistic statistical model of wetland; iv) extension of our current work on precipitation intensity scaling that incorporates statistical estimation of precipitation intensities based on the physics of the CAM convective parameterization.

CCSM Scaling (ANL/Sandia National Laboratory)

Rob Jacobs, Mark Taylor (Sandia National Laboratory) and Ray Loy (ANL) and his team at ANL have completed the first scaling tests with the HOMME version of CCSM CAM dynamical core. Results are very encouraging compared to ANL's Blue Gene/P, which is up to 4 times faster for a model with full physics and high resolution than other Blue Gene systems.

Operational Plan Time Lines for IPCC Fifth Assessment Simulations

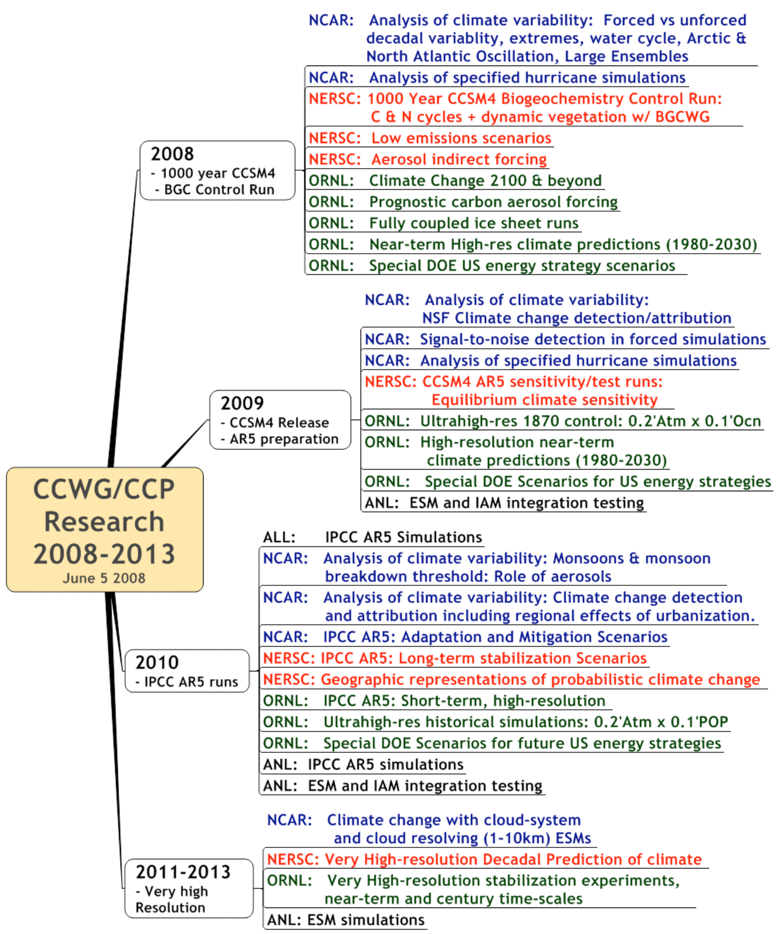

Figure 1. This time line chart that shows the various CCSM4 model developments and production steps required to be prepared for the IPCC fifth assessment simulations (AR5). Also shown are the various organizations where the simulations will take place and the areas of programmatic emphasis with time.