CESM

Community Earth System Model

Statement to NSF for FY10 – FY12

COMMUNITY EARTH SYSTEM MODEL

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Executive Summary

- Over the past five years the Community Climate System Model (CCSM) has increased in scope to a Community Earth System Model (CESM) by including an interactive carbon cycle component, an interactive chemistry component, a whole atmosphere component (dynamics and chemistry of the stratosphere and mesosphere), and a new land-ice component. Three new working groups have been formed to develop the chemistry, whole atmosphere and land-ice components. The project also works continuously to improve the simulations of the basic physical model, because reduced biases are required when these new components are added.

- Over the past five years, the CCSM/CESM very strongly contributed to the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report, which was jointly awarded the 2007 Nobel Peace Prize. CCSM contributed more runs than any other center, and several CCSM scientists were authors on this report. Many research papers based on the CCSM were referenced in the AR4, and were the meat of several chapters. The CESM project will also contribute strongly to the IPCC 5th Assessment Report, which is scheduled for publication in early 2013.

- Over the past five years, funding for the CCSM/CESM project at NCAR has been flat, which is a 20% decrease in the effective budget. Scientist, software engineering, and the CCSM coordinator positions have been lost. In the same period, computing resources, both at NCAR and DOE laboratories, have increased significantly.

- The CESM project needs to have significantly increased computational resources and data access and storage available from both NSF and DOE centers. It needs a large percentage of the CSL time available on the NCAR Tier II computer, time on at least one of the NSF Tier I centers, and computational and data resources at a number of DOE laboratories.

- The availability of young, well-trained climate modelers is woefully low. A greatly enhanced post-doctoral program is needed to provide the future intellectual leadership for the conceptualization, implementation and application of future series of Community Earth System Models. With additional resources, much more could be done on educational outreach both in terms of summer courses on earth system modeling and web-based information and access.

- The CESM project needs a sustained, NSF base budget increase of up to $4M per year, if it is to fulfill its tremendous potential to answer fundamental questions across a wide spectrum of earth system science. This increase is also required if the CESM project is to develop the capability to produce reliable decadal forecasts of future climate change in the USA.

I. Brief History

The first version of the Climate System Model, CSM1, was released to the community in June 1996, and a special issue of the *Journal of Climate* devoted to results from the CSM1 was published in June 1998. The most significant result was that the CSM1 was the first climate model ever to maintain a stable simulation of the present climate without the use of flux corrections. At this time it was recognized that further development of the model would require input from scientists at Universities, Department of Energy (DOE) laboratories, and other government and private laboratories. The DOE became a formal co-sponsor of the project, which was renamed the Community Climate System Model.

The second version of the model, CCSM2, was released in May 2002, and contained completely new ocean, sea ice, and land components. Further development in all components produced the third version, CCSM3, which was released in June 2004. Again, this version was documented in a special issue of the *Journal of Climate*, published in June 2006, and in a special issue of the *Journal of High Performance Computing Applications* that appeared in the fall of 2005. The CCSM project submitted more results to the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report than any other climate center. In addition, several CCSM scientists were contributing lead authors on a number of chapters in this report, and several chapters cited numerous individual research papers that were based on results from the CCSM. The 4th Assessment Report was published in February 2007 to great acclaim and singular influence, worldwide.

Over the past few years, much further development of the CCSM physical components has occurred, and the next version, CCSM4, will be finalized by June 2009, and released soon thereafter. In addition, several new components are in various stages of development: carbon cycle (building on prototypes in CSM1 and CCSM3), atmospheric aerosols and reactive chemistry, whole atmosphere community climate model (WACCM), and a new land ice component. These will be released later, sometime in early 2010, and at that point the model will become the Community Earth System Model, CESM1. Results from this model will be submitted to the forthcoming IPCC 5th Assessment Report.

Over the past five years, three new Working Groups have been formed: the Chemistry Climate WG, the WACCM WG in 2008, and the Land Ice WG in 2009. This now makes a total of 12 Working Groups; see Figure 1. Each Working Group has a NCAR and external Co-Chair(s), and meets both at the Annual Workshop and one other time during the year. Thirteen Annual Workshops have now been held, most often at Breckenridge, CO in June, with recent attendance of over 300 from across the USA and abroad. This has become one of the premier climate workshops. The CCSM/CESM project is run by the Scientific Steering Committee, which has 12 members; six from NCAR and six from DOE Laboratories, Universities and other laboratories. The CCSM/CESM has an Advisory Board (CAB), which meets annually at the NSF, and at the Annual Workshop.

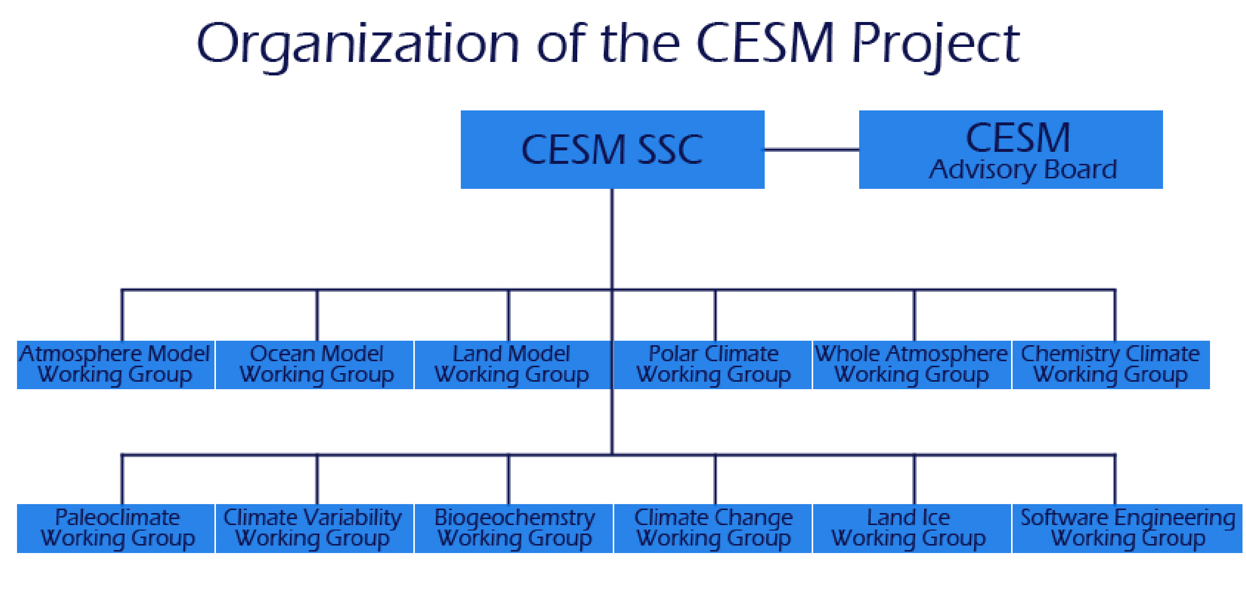

Figure 1

II. Commitments and Plans

The project has a number of commitments:

- Assemble the new version of the CCSM4 by June 2009, and release both 2° and 1/2° atmosphere/land versions soon afterwards.

- Release versions of the interactive carbon cycle, interactive chemistry, WACCM, and a simplified land-ice component, plus a low resolution version of the model for paleoclimate use sometime in early 2010.

- Produce substantial suites of simulations for the IPCC AR5 by the end of 2010. This includes longer runs out to 2100 and beyond with a fully interactive carbon cycle using the 2° atmosphere/land and 1° ocean/sea-ice version. It also includes shorter decadal projections and predictions out to 2030 using the 0.5° atmosphere/land and 1° ocean/sea ice version of the model.

- Produce a version of the CESM atmosphere component that parallelizes to ten thousand processors on massively parallel machines. The ocean, sea-ice, and land components already meet this criterion, but the CESM as a whole does not.

- Participate in the analysis of simulations for, and writing of, the IPCC AR5.

- Use the CESM to address the very large spectrum of earth system science that is described quite thoroughly in the CESM Science Plan: 2009-2015.

All the component development working groups have plans that are elucidated in the CESM Science Plan. Two important developments are highlighted here.

- The atmosphere model working group has a plan to assess an atmosphere core that can run in both hydrostatic and non-hydrostatic modes, and uses a horizontal grid that will ensure excellent parallelization. This will allow the project to move in the direction of "seamless prediction," where the same component can be used in both weather forecasting and climate prediction mode. This trend is occurring as climate models use higher horizontal resolution and, like weather models, are initialized to make predictions, rather than projections, of the future climate on decadal timescales.

- The land-ice component will be developed so that it can be applied to the Antarctic ice sheet as well as the Greenland ice sheet. This will necessitate the ability of this component to interact with the ocean component, in order to simulate the interaction between the ocean and ice shelves, which form a substantial fraction of the Antarctic ice sheet. Accounting for future changes in both the Greenland and Antarctic ice sheets will enable the CESM to make much more realistic projections of sea level changes over the 21st century than is currently possible.

III. Current Resources

Over the past five years, the CCSM project at NCAR has seen a number of relatively senior scientists depart, especially from the atmosphere group. Byron Boville died, Jim Hack, William Collins, and Phil Rasch have left, and Jeffrey Kiehl moved to the Paleoclimate group. There have also been departures from the biogeochemistry group: Natalie Mahowald and Peter Thornton, and from the chemistry group: Peter Hess. A number of junior scientists have joined the CCSM project over this time. Yaga Richter, Peter Lauritzen, and Sung-Su Park have joined the atmosphere group; Dave Lawrence, funded by a DOE grant, to the terrestrial group; and Synte Peacock to the ocean group. A more senior position in the atmosphere group remains to be filled.

The number of associate scientists working on the CCSM project has remained constant over the past five years. Several act as liaisons for the various model development working groups. However, the number of working groups has increased over the last five years, so that the number of required liaisons has increased. Thus, there is now a shortage of associate scientists to act as liaisons, who are essential help for WG co-chairs and external developers and users of the community models.

The CCSM project received NSF funds in FY08 for two senior software engineers, which has helped enormously over the past two years. However, the number of software engineers specifically assigned to the CCSM project has reduced by three positions over the past five years, which is a 30% decrease. The CCSM coordinator position within the CCSM program office has been lost, and the project now has 70% of an administrative assistant, rather than a full-time administrator. These reductions in the scientific and support staff are the result of a flat CCSM budget over the last six years. Figure 2 shows the NSF base budget for the Climate and Global Dynamics Division (CGD) for the years FY03 through

FY09. The FY09 budget for CGD, in which the CCSM project is embedded, is less than the FY03 budget, which implies at least a 20% budget loss when inflation is taken into account.

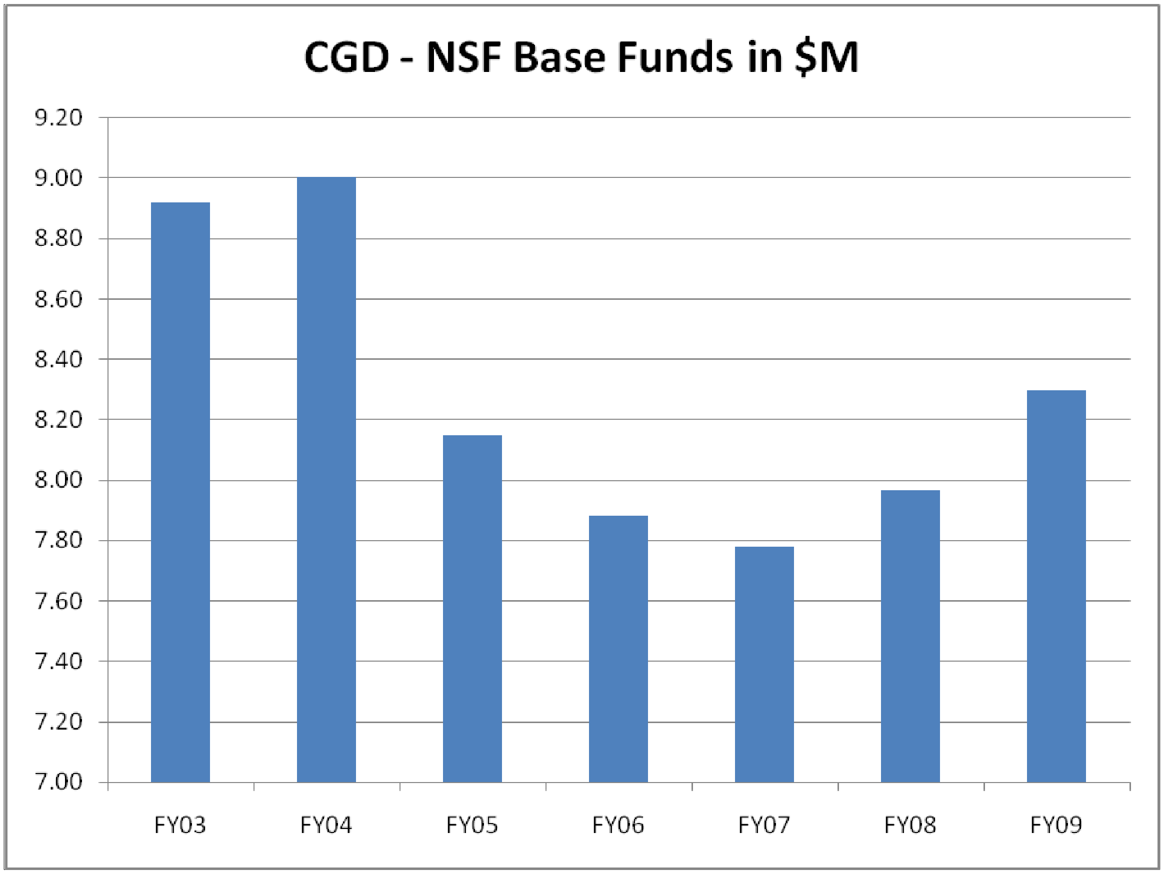

Figure 2

In sharp contrast to people resources, computational resources for the CCSM project have expanded rapidly. These resources come from three places: the NCAR Climate Simulation Laboratory (CSL), CGD allocations, and resources from a number of DOE Laboratories. The CESM project has to compete for CSL resources, but generally has been awarded about 65% of the total resource. The CCSM CSL allocation for 2003 through 2009 is shown in Figure 3, and has increased by a factor of almost 20 over this time. The CGD allocation has also increased by about the same factor since 2003, and CESM has an allocation on the NSF funded machine, Kraken, which is housed at Oak Ridge National Laboratory. The CESM project has allocations on the DOE Jaguar machine at Oak Ridge, the Franklin machine at Lawrence Berkeley National Laboratory, and on the Blue-gene machine at Argonne National Laboratory. Allocations on all these machines have increased quite significantly over the past five years, although efficiently using these resources can be problematic, as these machines are not dedicated only to climate work. The present computational resources are allowing the CESM project to do its carbon cycle IPCC AR5 runs on NCAR's CSL resources, but the higher resolution, decadal projections/forecasts for AR5 will have to be done on DOE resources, especially those at Oak Ridge National Laboratory.

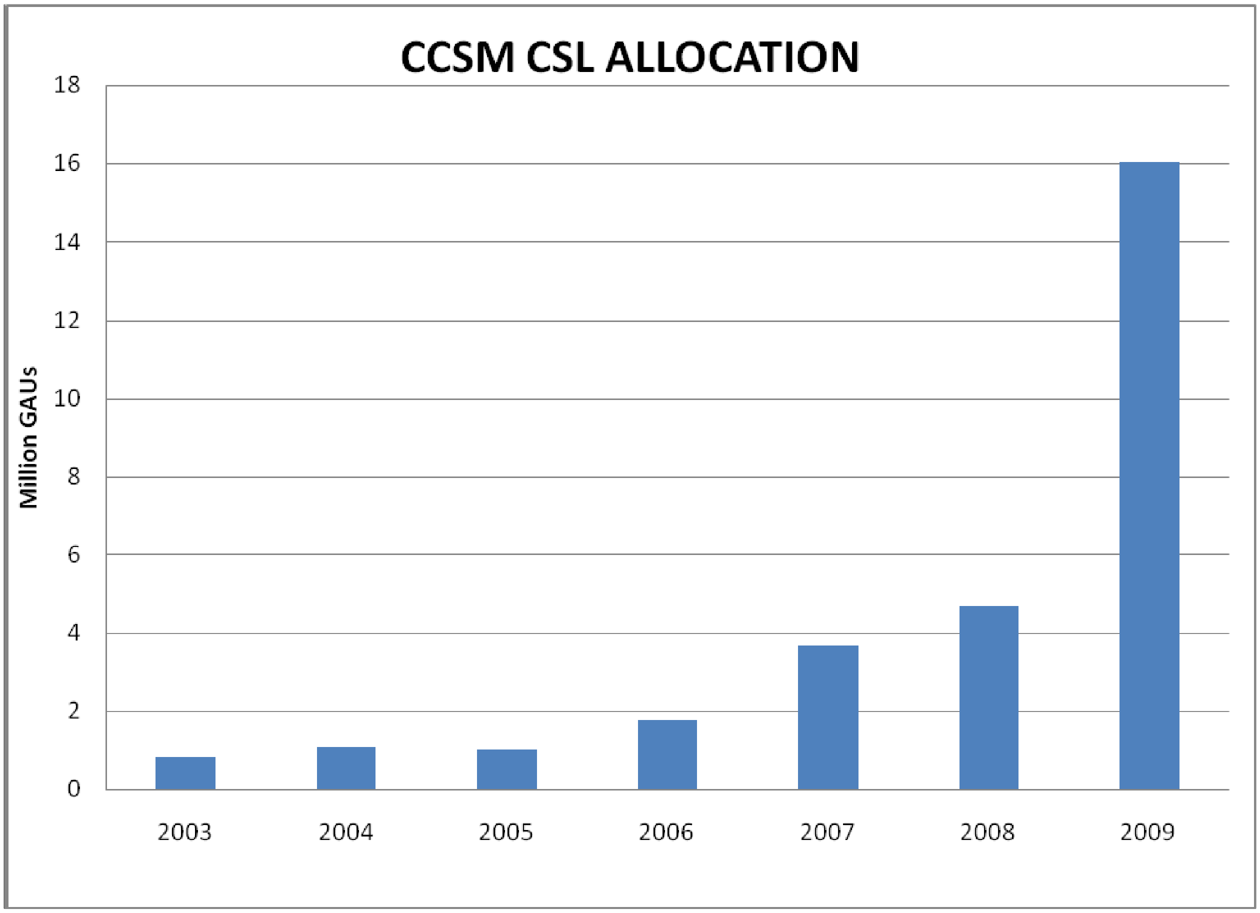

Figure 3

IV. Future Resource Requirements

a) Science Positions

Over the past five years science positions have been lost in the areas of atmosphere modeling, biogeochemistry, and atmospheric chemistry. Several of these positions have been lost because of a flat budget, although the atmosphere group within CGD has recently hired two new scientists. Therefore, the most immediate need is for new positions in both biogeochemistry and chemistry. CGD currently has no scientist positions in either ocean biogeochemistry or in glacial modeling that could interact with the recently formed land-ice working group. It is interesting to note how similar the list of new positions is to that in the 2004-2008 CCSM Strategic Business Plan.

The importance of keeping the current CGD breadth of scientific expertise cannot be overstated. This covers the atmosphere, land, ocean and sea-ice, which are the four basic physical components of a climate model. For example, the current NCAR co-chair of the land working group is entirely funded from a DOE grant, and not from base NSF or CCSM funding. Improving the biases in the physical model becomes even more important as additional components, such as biogeochemistry, dynamic vegetation, and land-ice for example, are included, because these components can be very sensitive to biases in basic physical variables such as temperature and precipitation. The CESM project must not lose its focus on improving the physical model, and considerable success has been achieved towards this goal in developing the CCSM4.

Interactions among scientists at many different institutions is a unique and vital aspect of the CESM project, and it is facilitated by each working group having a liaison. Many of the liaisons are project or associate scientists at NCAR. The number of these positions hasn't changed significantly over the past five years, which is encouraging. However, it means that some working groups, such as Climate Variability and Climate Change, do not have a liaison, and others, such as the newer Chemistry and WACCM, have a software engineer in this position. The CESM project would benefit greatly from some additional associate scientists in the future. In particular, the atmosphere working group is the largest, and has to interact with a large number of scientists across the USA. This interaction would be made considerably easier and faster with additional associate scientist positions, and this is also the case for the ocean, land, polar climate, and biogeochemistry working groups.

b) Software Engineer Positions

The CCSM project received two new senior software engineer positions in FY08, but the number of software engineers in the CESM project has decreased over the last five years. In that time, the CESM has grown considerably in complexity with additional biogeochemistry, chemistry, WACCM, and land ice components. The code has more than doubled in length and is now well over one million lines of code. This code has to be tested and made efficient on a variety of computers around the country to which the CESM has access. This is a major task that is the responsibility of the software engineering working group and the software engineers at NCAR. Considerable progress in making the CESM more efficient and easier to use has been made in the past two years by the introduction of version 7 of the coupler, which allows the model to be run in concurrent, as well as parallel, mode. The ocean, land, sea ice, and coupler components now parallelize over at least 30,000 processors when run at 1/10° resolution. However, although the parallelization of the atmosphere component has been considerably improved recently to run well on a few thousand processors, it does not parallelize well over tens of thousands of processors. Rectifying this position is a very high near-term priority for the CESM project.

If the CESM project does not increase the number of software engineers in the immediate future, then there will be two consequences. The first is that the CESM contribution to the IPCC AR5 will be negatively affected. Two SEIIs are needed to facilitate the AR5 runs on the various DOE computers, and to make sure the data from these runs is available from the data archives at the various DOE laboratories. Without these people, the CESM contribution to AR5 will be reduced from what it could be in terms of the number of runs performed. The second is that the longer-term progress in enabling the CESM to be used for the wide variety of earth system science will also be compromised. The present SE staffing level has only slowed down progress marginally; progress has mostly been slowed by the difficulty of the new science itself. However, unless the CESM project expands by three SE III or IVs over the next two to three years, then a stage will be reached where the progress in science across the CESM will be slowed down by a lack of software engineering resources.

c) Computational and Data Resources

The CESM project will need to see a strong increase in computational resources over the next few years if it is to retain its competitive edge and to answer a new range of questions about earth system science. The increased resources would be used to run model versions with both increasing complexity and increasing model resolution. At present, no CESM runs have been done with all the new components switched on together; computational resources have dictated they be switched on one or two at a time. In preparation for the AR5 decadal projection/prediction runs, the CCSM3.5 has been run with 0.5° atmosphere/land resolution. This run shows much smaller sea surface temperature biases, especially in the upwelling regions on the eastern side of ocean basins, compared to the 2° atmosphere/land version. However over the next few years, the CESM needs to explore much finer atmosphere resolution as it heads towards “seamless prediction.” In addition, the question of how much resolving ocean eddies modifies future predictions of climate change has not been adequately answered, although versions of the CESM using 1/10° ocean/sea ice resolution have now been run for model time-periods of a decade or so.

Consequently, the CESM project needs to have increased computational resources available from both NSF and DOE centers. It needs a large percentage of the CSL time available on the NCAR Tier II computer, and time available on at least one of the NSF Tier I centers. It also needs to have a good share of future computational resources at a number of DOE laboratories. It already has time on Jaguar at Oak Ridge, Franklin at NERSC, and Atlas at Lawrence Livermore National Laboratory. The DOE has plans to greatly increase the computational resources for climate at Oak Ridge, and the CCSM needs to be the beneficiary of much of this resource if it is to address the important questions outlined above, and to keep pace with its competitors and colleagues both in the USA and around the world. Just increasing the CESM resolution is not a panacea to ensure excellent results, but it is necessary if the CESM is to provide the best projections and predictions of climate change on a regional basis within the USA over the next few decades.

An absolutely vital consequence of more computational resources and higher model resolution is that data storage, transfer, and availability keep pace with the computer resources. This requires much larger and quicker mass storage systems at all computer sites mentioned above and improvements in data access systems, such as the Earth System Grid. Without these, the fruits of increased computer resources for the CESM will not be realized. In addition, better visualization and analysis tools for analyzing the more complex and higher resolution simulations are required.

d) Educational Outreach

A high priority concern of the Scientific Steering Committee is the education and training of a new generation of climate system modelers. The availability of young, well trained climate modelers is woefully low. A greatly enhanced post-doctoral program to train future climate scientists is sorely needed. This would allow postdocs to work at a number of climate modeling centers around the country, and enable graduate students to spend time at NCAR and other climate centers to work on a modeling project.

In addition, the CESM needs to enhance the availability of data through web based data portals, and to enhance its web-based outreach. However, inevitably during a period of flat budgets, these aspects are the first to be reduced in scope. A tutorial on how to run the CCSM was held for over 60 participants after the 2002 Annual Workshop, and a two-week course on “The Art of Climate Modeling” was held at NCAR in the summer of 2007, with over 50 participants. The CESM web site (www.ccsm.ucar.edu) was greatly improved and enhanced in 2008, and is regularly updated with news about the project and future meetings. Presentations from the Annual Workshop and working group meetings are also attached to the web site and are available for easy download.

With additional resources, much more could be done on CESM educational outreach. There could be more summer courses on earth system modeling, and a CESM-based curriculum on climate system modeling could be generated. The web-based data portals, and the CESM web site itself, could also be significantly enhanced.

V. Conclusion

This statement to NSF provides a description of the infrastructure needs of the CESM program for the next three years, FY10 - FY12. It shows that the CESM and CGD budgets have been flat between FY03 and FY09. This has resulted in a loss of scientists, especially in the atmosphere and biogeochemistry working groups, of some software engineers, and of the CESM coordinator position. Meanwhile, the scope of the project has broadened considerably by the inclusion of chemistry, WACCM, and land-ice components. The resulting Community Earth System Model is much more complicated than previous CCSM versions, and contains well over a million lines of code. The range of runs required for the IPCC AR5 has also increased over AR4 because both long runs with an interactive carbon cycle and shorter decadal projections/forecasts will be conducted.

Consequently, the CESM project is stretched to the limit, and there is no doubt that progress over the last few years has been slowed down. The problems will only be exacerbated in the future. Therefore, if the CESM project is to continue to serve as a unique national climate research resource, blossom in the future, and fulfill its tremendous potential, then it needs a large sustained increase it its NSF base budget of up to $4M a year. This increase would fund the following new positions in the CESM project:

5 Scientists	1.20M
5 Post Docs	.75M
3 Software Engineers	.60M
6 Associate Scientists	.90M
CCSM Coordinator	.25M
Administrative Assistant	.10M
Education and outreach	.20M
Total	4.00M

Computational and data storage resources for the CESM have increased substantially over the last five years. However, further increases in dedicated computer resources are required if the project is to satisfy pressing national needs for credible, high resolution climate information.

Finally, the National Research Council report on “Restructuring Federal Climate Research to Meet the Challenges of Climate Change” has just been published. One highlighted priority is to "Develop the science base and infrastructure to support a new generation of coupled Earth System Models to improve attribution and prediction of high impact regional weather and climate, to initialize seasonal to decadal climate forecasting, and to provide predictions of impacts affecting adaptive capacities and vulnerabilities of environmental and human systems". The CESM project is very well positioned to do this, but needs the increased funding outlined above to make rapid progress.

CESM gratefully acknowledges our primary sponsors, the National Science Foundation, and the Department of Energy.