# Report on the DOE/BERAC Workshop

# Identifying Outstanding Grand Challenges in Climate Change Research: Guiding DOE's Strategic Planning

**September 5, 2008**

## Preface

Efforts to reduce greenhouse gas emissions, the bulk of which are from energy-related activities, will add to the challenges facing the nation and the world in meeting the energy needs of the 21st Century. As Secretary of Energy Samuel Bodman recently stated, "By 2030, global energy consumption is expected to grow by over 50 percent. . . . . U.S. electricity demand is projected to increase by about 50 percent by 2030, with global demand nearly doubling. . . . We must recognize the realities of global climate change and work to develop cleaner sources of energy that at the very least do not worsen—and hopefully can improve—the health of the environment."

Much has been learned about climate from research conducted by the Department of Energy (DOE), other agencies under the Climate Change Science Program (CCSP) and its predecessors, and by the international scientific community. Current understanding about climate forcing, climate response, and consequences of climate change is outlined in recent reports by the Intergovernmental Panel on Climate Change (IPCC).

In recognition of the need to develop further research directions, Dr. Raymond L. Orbach, DOE Under Secretary for Science, charged DOE's Biological and Environmental Research Advisory Committee with conducting a workshop identifying the "Outstanding Grand Challenges in Climate Change Research."

In response to this charge, a workshop was held in Crystal City, Arlington, Virginia, March 25-27, 2008, co-chaired by Drs. Robert E. Dickinson and Gerald A. Meehl. Workshop participants included many of the leading U.S. experts in climate change science from academia, other federal agencies, and DOE national laboratories. The workshop consisted of plenary lectures and breakout sessions on several Grand Challenge areas delineated by Dr. Orbach. Participants in the breakout sessions discussed the key challenges in three areas and the research, observational, and computational capabilities needed to meet the identified Grand Challenges.

The outstanding Grand Challenges in climate research proposed by this workshop should guide DOE in its strategic planning activities to meet the energy needs of the nation, while minimizing environmental damage caused by use of this energy.

## Executive Summary

The workshop identified three Outstanding Grand Challenges in climate change science. These challenges are consistent with research priorities identified by other national and international bodies after the IPCC Fourth Assessment Report (AR4). Meeting them would provide a major advance in the Nation's capacity to address the climate issue.

**1. *Characterize the Earth's current climate, and its evolution over the last century to its present state*.**

The ability to predict future climate accurately requires a clear understanding of what has caused climate change over the recent past. The simulation of this observable time period contributes an important validation of the models used to project into the future and provides a better description of the current state that also benefits future projections. Advancing our understanding will require novel approaches to atmospheric reanalysis, combining models and observations to characterize changes to the Earth System to account for cloud and aerosol interactions and cloud feedbacks. These new approaches need high resolution models, depending on computational and computing advances, to greatly extend the past methodology of reanalyses to assimilate many further sets of measurements about the physical state of the atmosphere, ocean, ice-sheet, and land systems into comprehensive data sets. Such datasets provide a fundamental basis for evaluating climate simulations and learning more about the mechanisms and processes that characterize the global coupled climate system.

***2.* Predict regional climate change for the next several decades.**

Predictions over decades at fine enough spatial resolutions are needed to support the decisions being made about adapting to future climate change. Such predictions require the use of high-resolution climate models and improved observations of the current climate to begin model integrations (*i.e.*, Challenge 1). The decadal evolution of the climate state includes climate change to which we already are committed, the change from natural modes of variability, and additional changes resulting from future greenhouse gases, aerosols, and land cover. Providing such predictions on the decadal time scale (*e.g.*, for the next two to three decades) and with regional fidelity is a new challenge for the climate science community.

***3. Simulate Earth System changes and their consequences over centuries.***

Current climate model simulations summarized in the IPCC report do not adequately include feedbacks that contribute to overall Earth

System changes on century-long time scales (*e.g.*, carbon-cycle feedback). Grand Challenge 3 is to develop and integrate important long-term components of the Earth System, such as large ice sheets and the natural and managed components of the carbon cycle. Earth System models would be developed and used to address the character and magnitude of climate changes for the next century and beyond, when large climate change and subsequent forcing feedbacks are expected. This information should allow decision makers to formulate "midcourse corrections" as to the optimum mitigation and adaptation measures needed. Grand Challenge 3 relates directly to the economic, technological, and environmental choices that future generations may need to make in response to climate consequences.

The workshop identified the following research initiatives that could extend areas in which DOE has particular program strengths to meet the Grand Challenges:

**a. Characterization of impacts of radiatively active atmospheric constituents, especially aerosols and clouds, on climate and air quality through their interactions with precipitation, moist convection, and atmospheric chemical processes, as these change with climate change.**

**b. Interactions between ecosystem processes and changes and the climate system.**

**c. Determination of interactions between changing climate, hydrological systems, and their management.**

**d. Incorporation of knowledge gained from observational and modeling process studies into multiple generations of Earth System models; such models will contain more complexity, improved parameterizations, and better initialization procedures that are validated through observational experimental and focused modeling activities.**

**e. Determination of the implications of climate change for energy systems, including a focus on supporting strategies for mitigation actions that affect climate change and influencing selection of adaptation choices.**

The workshop demonstrated that although climate change science intersects a broad range of physical, biological, and social sciences, the science community concurs on the major cross-disciplinary issues that need to be addressed through enhanced research. Individual research conducted along disciplinary lines is a requisite component of the challenges, but the workshop stressed that such research must now connect across disciplinary boundaries in a more integrated approach and more explicitly include human dimension components to address the

Grand Challenges involving the entire global Earth System.

Incorporation of the advances outlined in this report will require accelerated investments in new observational and experimental research for developing complex models, but also investments in highly sophisticated software and in the nation’s most advanced computational capabilities, and in the training of new scientists to develop and use these capabilities.  Meeting these challenges will require an energized research community with strong contributions from new generations of young scientists.  This effort will require tackling many science issues not in isolation but in the context of how each contributes to modeling and understanding of the overall system.

## 1. The Grand Challenges

The IPCC AR4 stated that climate already has changed much in the past few decades and that it can be expected to continue to change (cf. Appendix A for more details). Recent observations have indicated that at least some important aspects of climate, *e.g.*, arctic sea-ice and the Greenland ice sheet, are changing more rapidly than anticipated by the IPCC. Additional recent workshops (cf. Appendix A for more details) have recommended that research be more directed to the need to begin adaptation measures for climate change. Mitigation measures need to be implemented soon, if not now, and can be adjusted in the future on the basis of improved scientific understanding of future climate changes. However, whatever mitigation can and will be done may fall far short of what is needed to prevent serious consequences from climate change.

The Grand Challenges for climate change reported by the Crystal City workshop describe the science needed to enable the nation's best response to the possibly dire changes in the climate system that could occur in its future. DOE is expected to provide leadership, but it can contribute only part of the needed research. Contributions from other agencies in the U.S. CCSP and international partners will also be needed to address the Grand Challenges laid down by the workshop. Descriptions follow.

**a. Characterize the Earth's current climate and its evolution over the last century to its present state.**

We do not sufficiently understand many of the processes and mechanisms inherent in producing weather and climate variability to be able to model with adequate certainty how they will affect future environmental conditions. These deficiencies are, in part, a consequence of inadequate availability and use of observational data and in part from a lack of adequate understanding of cloud-aerosol interactions, cloud feedbacks, land surface characteristics, oceanic mixing, and sea ice dynamics within the climate system. A better quantification of the response of the climate system to external forcing requires improved observations and model representations of the nature and variation in time and space of various types of aerosols coupled to clouds, and of the dynamics of large ice sheets.

Climate datasets for the atmospheric component of the climate system have been provided by agencies responsible for numerical weather prediction (NWP). Weather forecasting depends on combining observations of the present with model forecasts started at some previous time. This combination is referred to as "analysis." The derivation of historical climate data by running a current NWP model assimilating weather data over many years is referred to as "reanalysis." This concept is reviewed in an article titled "Bridging the Gap between Weather and Climate" in the spring 2008 issue of DOE's SciDAC Review. Datasets obtained by such reanalyses, which enable the filling of gaps in the details of the historical record, are used widely by climate researchers for studies of regional contemporary climate change and interactions within the Earth System.

Long-term datasets describing the evolution of clouds and aerosols would challenge models to provide an accurate description of their evolution and their inclusion in reanalyses. Long-term datasets of the time-evolving, three dimensional structure of the ocean, which rely on high-quality ocean reanalyses, are needed to establish the nature and predictability of decadal time-scale variability. In addition, a better long-term data and process description for the cryospheric and terrestrial system and their connections to the atmosphere is needed, as are data sets for various human dimension aspects of climate change.

A 2006 forum held by the National Research Council (NRC) and its Climate Research Committee (CRC), "Development of Integrated Earth System Analysis Capability," summed up the issue of Challenge 1: "Climate analyses and reanalyses are obtained by synthesizing numerous, disparate observations obtained from in situ and remote platforms within a climate model to provide a comprehensive, temporally continuous, and physically consistent quantitative depiction of the climate system."

The workshop emphasized the need for providing, through observational constraints and reanalysis, regionally specific characterizations of current aerosol forcing and cloud feedbacks and of their evolution over the past several decades. Such characterizations will provide a basis for assessing the accuracy by which climate models can project change on decadal and century time scales. The processes and initial state of large ice sheets also needs to be characterized.

The workshop recognized that regional-scale observational field programs are essential for establishing process and other benchmark information for evaluating and improving climate models.

**b. Predict regional climate change for the next several decades.**

The IPCC AR4 established that additional global warming on the order of 0.5 to 1.0 K over the next several decades is likely. The predictability of the manifestations of this global change at spatial scales important for practical planning, decisions, and adaptation has not yet been established nor have the data needed for practical predictions.

Climate change over the next several decades is unlikely to be greatly affected by human decisions that impact emissions of long-lived greenhouse gases. The climate effects of those decisions will be manifested mostly in the second half of the 21st Century and beyond. However, the changes in the next few decades may have large consequences for society. Decadal regional forecasts of natural variability, climate change commitment, and the response to additional greenhouse gas and aerosol forcing would advance practical planning of adaptation and mitigation options and improve models through regular testing against emerging data.

Detection and prediction of changes in the hydrological cycle, especially weather and climate extremes, need to be addressed on the decadal time scale. Decadal regional information is immediately relevant to decisions about water resources and the production and use of energy that will be made to adapt to climate change.

Prediction of extreme climate conditions, particularly those related to precipitation has been shown to benefit from enhanced spatial resolution. Multiple simulations at high-resolution would quantify uncertainties and sensitivity to initial conditions and would provide much better quantification of the likelihood of changes in the occurrence and intensity of extreme conditions and their consequences.

Models with adequate resolution to quantify future regional impacts of climate change are needed to determine optimal adaptation options. Implementing such models as a prediction system could provide early warning of possible thresholds or tipping points related to abrupt climate changes.

Since the requirements for climate model simulations of much higher spatial resolution are being driven by user needs, model prediction data, including uncertainty information, must be available in forms relevant to diverse user communities. Management of terrestrial ecosystems and other land-use shifts, population changes, and possible adaptation measures will affect climate change on regional spatial scales.

Some aspects of climate change on a regional time scale can be affected by mitigation or manipulation of short-lived species contributing to global radiative balance. Reducing black carbon or methane concentrations and enhancing stratospheric aerosols have been suggested as possible such measures. The latter measure is controversial and should be contemplated as useful only under the direst circumstances because of the large uncertainties about its negative and possibly unintended impacts. The effects of such measures, positive or detrimental, would be assessed on a decadal time scale and thus would require decadal prediction models to evaluate the impacts in detail.

**c. Simulate Earth System change over centuries**

Current projections from climate models as summarized by IPCC indicate very large climate changes on century time scales. The likelihood of changes even more extreme than those modeled cannot be quantified yet but should not be disregarded.

Nations must make choices about the means and extent of mitigation measures. More explicit quantification of future climate change dangers and environmental damage that might be avoided through various mitigation and adaptation strategies will guide the selection of the midcourse corrections to these choices.

The characterization of human drivers of net carbon emissions is a major source of uncertainty on century time scales, as are the feedbacks that operate on longer time scales. At what rates will future energy use be decarbonized by technological advances alone in the absence of mitigation efforts? Human drivers of emissions need to be rigorously included and better integrated with physical system modeling.

The consequences of various feedbacks that dictate the amplitude of the climate system response remain quite uncertain, and some of these feedbacks are only now being recognized. The feedbacks of the natural science system include those involved with clouds, water vapor, the carbon cycle, snow, sea-ice and ice sheets and determine how the climate system responds to changes in external forcing, such as increasing greenhouse gases. They should be included in new generations of Earth System models developed with more complete and accurate observations of the most important variables. These models will include components capable of accurately simulating the carbon cycle, large ice sheets, atmospheric chemistry, aerosols, and dynamic vegetation. Feedbacks from societal choices of various mitigations and adaptation options that further modify the systems also need inclusion. Such Earth System models are in the early stages of their evolution, but as they mature, they will allow better quantification of expected changes on the longer term.

The technical and scientific challenges of Grand Challenge 3 will be to improve these newly emerging Earth System models to better understand and simulate interactions and feedbacks among the carbon cycle, clouds, atmospheric chemistry, aerosols, large ice sheets, vegetation, and human systems. Such models must be run at higher resolution for centuries in ensemble simulations with multiple mitigation scenarios to quantify the time-evolving aspects of climate change.

Linkages among observational, experimental, and modeling communities of the physical, biological, and human dimension sciences must be strengthened to advance the underlying science within process-level and integrated Earth System models. Connecting climate modeling to scenario-building and mitigation-response activities, as endorsed by the workshop, should strengthen the policy relevance of global coupled climate modeling.

The workshop showed that the global climate modeling community and the integrated assessment modeling community have begun to work together to coordinate the next round of experiments to address near-term and longer-term climate change.

## 2. Research needed to address the Grand Challenges

The workshop described research necessary to successfully address the Grand Challenges identified in this report. Descriptions follow.

**a. Characterization of impacts of radiatively active atmospheric constituents, especially aerosols and clouds, on climate and air quality through their interactions with precipitation, moist convection, and atmospheric chemical processes, as these change with climate change.**

**b. Characterization of impacts from climate change on managed and natural ecosystems.**

**c. Determination of interactions between changing climate, hydrological systems, and their management.**

**d. Incorporation of knowledge gained from the above studies into multiple generations of Earth System models; such models will contain more complexity, improved parameterizations, and better initialization procedures that are validated through observational, experimental, and focused modeling activities.**

**e. Determination of the implications of climate change for energy systems, including a focus on supporting decision strategies for mitigation actions and adaptation choices.**

**Other research questions not discussed in the workshop and not in DOE's current climate**

**research programs are also needed to provide more complete modeling capabilities.**

In short, research topics identified by the workshop are: **(a) Aerosols, clouds, and atmospheric chemistry, (b) Interactions between ecosystems and climate, (c) Interactions between climate change and management of hydrological system, (d) Earth System modeling, and (e) Energy systems and climate change.**

Descriptions follow of how each contributes to the Grand Challenges, identified below as ***(i) Characterize the current climate, (ii) Predict climate over the next several decades, and (iii) Simulate Earth System change over centuries.***

**a. Aerosols, clouds, and atmospheric chemistry**

**i. *Characterize the Earth's current climate.***

- Establish the radiative forcing from present-day aerosols and the attributions of current climate change patterns to aerosols and their impacts on clouds.
- Establish how to analyze and assimilate into models information about the global distribution of aerosol properties.
- Establish the appropriate dimensions in terms of aerosols' size distribution and composition and their effects on clouds.
- Include tropospheric species of intermediate lifetimes (*e.g.*, CO, ozone, and methane) as interactive components in Earth System models.
- Characterize the impact of clouds in climate change at regional scales.

**ii. *Predict climate over the next several decades.***

- Establish what changes are expected in regional distributions of aerosol properties and how they will affect regional climates.
- Characterize the impacts of aerosols on clouds and precipitation.
- Characterize the feedback of clouds for climate change on global and regional scales.
- Clarify the possibilities of large changes in aerosol or methane radiative forcing resulting from either human or natural causes.
- Identify the sources of black carbon and explore approaches to their reduction.

**iii. *Simulate Earth System change over centuries.***

- Establish on a century time scale aerosol, (*e.g.*, organic, sulfate, dust, sea salt, and black carbon), methane, and ozone contributions to radiative forcing of global climate. How might these components change due to either human or natural causes?

- Establish the feedbacks between longer-term climate change, the forcing by aerosols, and their impacts on cloud properties.

**b. Interactions between ecosystems and climate**

This topic is unique in climate change studies because it requires experimental approaches to predict future changes.

**i. *Characterize the current climate.***

- Define appropriate state variables for ecosystem function, structure, and composition (*e.g.*, disturbance history, seasonal and extreme temperatures, precipitation, and nutrient availability) as components of Earth System models.
- Distinguish natural and managed ecosystem contributions to atmospheric composition.
- Through experimental and observational studies on natural and model systems, develop process-level understanding and quantitative expressions needed to represent interactions between ecosystems and climate and develop spatial datasets needed to represent these processes in coupled Earth System models.
- Establish what changes in vegetation cover, species habitants and their populations have already occurred and how much of these changes can be attributed to climate change.

**ii. *Predict climate over the next several decades*.**

- How does climate change impact ecosystem capacities to provide goods and services?

- Include ecosystem state variables in the Earth System models and develop appropriate tools for their initialization.
- Assess the impacts of climate and air-quality changes on ecosystems at regional scales over the next few decades.
- How will climate change together with shifts in land use and cover modify the character and impact of natural disturbance regimes? How will such changes alter regional climate?
- How might regional changes in large-scale land use contribute to large-scale changes in carbon and nitrogen fluxes and to fluxes of energy and water with the atmosphere?

- Establish the impacts of expected climate change on vegetation cover, habitants and species populations.
- How will economic development, changing food and fiber demands, and potential demand for biofuels affect land use, biogeochemical cycles, and other ecosystem services?

**iii.** ***Simulate Earth System change over centuries.***

- Establish how, on the century time scale, ecosystems will be affected by future climates (as influenced by changing atmospheric composition, especially carbon dioxide; air quality; and other impacts of advertent and inadvertent human activities).
- How will those impacts feed back through the global carbon cycle and terrestrial structural and compositional changes to determine net greenhouse gas flux to the atmosphere, evapotranspiration and sensible heat, and surface albedo changes.
- How will climate-driven changes in the biogeochemical cycling of essential elements such as nitrogen and phosphorus limit future terrestrial carbon storage.

**c. Interactions between climate change and management of hydrological systems**

**i.** ***Characterize the current climate.***

- Provide better information as to the current managed hydrological systems and water use and how they should be described to best benefit from climate model projections.
- How are regional climates affected by land-use and land-cover change and other forcing?
- How can the impacts of climate change be incorporated into strategies for water management?
- Would incorporating future management practices into climate models lead to better predictions of future regional climate?
- Quantify the supply and demand for water resources in developing countries to provide a basis for their projection into the future.

**ii.** ***Predict climate over the next several decades.***

- Through observational and modeling studies, eliminate large errors in simulations of regional precipitation and develop quantitative measures of the ability to predict changes in extreme precipitation probabilities.

- Establish through modeling the regional details of changes in water resources (e.g., winter snow pack) and frequencies and intensities of extreme hydrological events, such as floods and droughts.
- What consequences will managing the biosphere for biofuels and carbon storage have on hydrological resources, and how will these interactions be affected by climate change at regional scales over the next few decades?
- How will small non-polar glaciers change and how will such change affect water resources and occurrence of floods?

**iii. *Simulate Earth System change over centuries*.**

- How will changing land cover and soil moisture impact the anticipated global temperature change over land?
- How will clouds and precipitation respond to changing aerosols and climate and water management practices?
- What will regional water shortages look like at the century scale?

**d. Earth System modeling**

**i. *Characterize the current climate.***

- Plan and develop the next generations of Earth System models. Improve model parameterizations, maintaining and enhancing advances in computational resources.
- Incorporate improved understanding of how clouds and aerosols interact to modify climate.
- Internalize human dimensions as Earth System model processes.
- Establish strong activities in validation of model parameterizations and process descriptions. A multiyear "closure experiment" to combine a field program encompassing a large region of the U.S. (*e.g.*, the Mississippi River Basin) and modeling of all aspects of energy and mass transport should be considered as a major component.
- Develop the procedures needed to initialize the long-memory components of the models. Extend the current approaches of reanalysis to include more Earth System state variables, such as various aerosol and cloud properties and other aspects of atmospheric composition, and various carbon-cycle and ecosystem variables.
- Needed emphases include cloud parameterizations and their evaluations with ARM and satellite data and improved modeling of upper

tropospheric water vapor and its connections to clouds and impacts on atmospheric chemistry.

**ii.** ***Predict climate over the next several decades***.

- Develop Earth System models on scales that resolve cloud processes. How must model parameterizations be changed with such resolution?
- Establish the predictability of such models. How much information can be predicted regarding natural modes of variability? What state variables need to be initialized, and how can this be done?
- Include predicted regional details in integrated assessment models that address issues such as the impacts of climate change on and vulnerabilities of human society. What are the consequences for human health? What are the options for adaptation?
- Use models to derive probabilistic descriptions of sea level rise over this period and express in a form useful for coastal development policy.
- Investigate the role of human system feedbacks in the Earth System models —How do Earth System changes, forced by human activity or through natural variability, affect human activities which in turn have feedbacks on biogeochemistry, hydrology, and surface radiation balances?
- Identify appropriate model output statistics that are currently not calculated or saved in user-accessible formats but are needed to address the above questions.

**iii.** ***Simulate Earth System change over centuries.***

- Develop the next generation of carbon emission scenarios, including improved understanding of their human drivers.
- Develop advanced models of the carbon cycle, dynamic vegetation, and land use change.
- Develop dynamic models for large ice sheets and their interaction with the climate system.
- Project on a century time scale and beyond the changes of the coupled climate system. What are the vulnerabilities of various sectors to these changes?

**e. Energy systems and climate change**

i. ***Characterization of the current climate***

- What are the most promising near-term strategies for reducing carbon

emissions through economic incentives and technology development?
- How is the current production of biofuels affecting global food supplies.

**ii*. Predict climate over the next several decades*.**

- What will be the consequences of various mitigation options that might be adopted for food production, water resources, and climate?
- How and to what degree will climate change affect national economies over the next several decades?
- What are the most urgent threats from abrupt climate change and changes in extreme weather events? How can societies be made less vulnerable to such extremes?
- What sectors of human society and economies are most vulnerable to climate change over the next several decades?
- What adaptation strategies can be employed to anticipate extreme weather and climate changes?

**iii. *Simulate Earth System change over centuries.***

- On the century time scale, what are the relative magnitudes of climate change to which human societies will have to adapt based on various decisions made in the next decade or so?
- What sectors of society are the most vulnerable to longer-term changes in, for example, possible large sea-level rise or significant changes in extremes?
- How will ice sheets respond to climate change, and how can we better quantify the speed and extent of sea level rise?

## 3. Directions highlighted by workshop

The workshop discussions led to a rich menu of important physical, biological, and human dimension science issues requiring attention as summarized in Table 1. Research on individual questions, addressed in isolation, cannot meet the needs of informing the nation's energy policy. Rather, at the highest level, the Outstanding Grand Challenges must include the integration and communication of ever-improving scientific knowledge and human dimensions components into an overall assessment of climate change. Such assessments must address not only the basic physical and biological processes of the Earth System but also mitigation and adaptation options. Table 2 provides some examples of policy issues affecting National, State, and local government private industry, and individual citizens that would be guided by the Grand Challenge research.

New research initiatives, (computational, observational, and experimental) are needed to meet these Outstanding Grand Challenges. These initiatives will provide information needed by the United States to better manage its energy resources in the context of climate change. Such efforts also will likely provide many of the scientific underpinnings the nation needs to develop more operational climate services.

The Outstanding Grand Challenges require support for new Earth System reanalysis and observational activities, decadal prediction with high-resolution global coupled climate models, and long-term projections of climate change and associated consequences using new mitigation scenarios with complex Earth System models. To advance these activities, workshops on decadal prediction and Earth System modeling for long-term climate change should be sponsored by DOE in the next year. Activities in these areas are just beginning. Such workshops would facilitate contact among relevant communities involved in these efforts and help inform DOE of the research status in these areas.

All the Outstanding Grand Challenges are directly related to and would be facilitated by enhanced computing capability as well as a better understanding of the physical, biological and human dimensions components of the climate system through observational programs. The former was well described in the ASCAC-BERAC Report. Computing demands for future generations of high-resolution Earth System models will be considerable. The workshop recommends that DOE be well positioned to support these efforts through exascale computing. Computing at this level, along with associated data storage and access, will accelerate Earth System modeling on all time scales. Exascale computing is required for quantifying time-evolving climate change with the level of detail needed for adaptation. Perhaps the most important data archives are those tailored to facilitate access to model data by a wide variety of users outside the community developing and implementing the Earth System models who are concerned with climate processes or adaptation.

Workshop participants addressed advancing observational programs by augmenting the current ARM program to include carbon budget issues. The need for a large multiyear regional field project should be discussed with other federal agencies in the Mississippi River Basin that would build on the GCIP concept of studying a continental-scale river basin but would go beyond GCIP in at least three ways: (1) **Adding the carbon budget**. With a major focus on water and a minor focus on radiative fluxes, GCIP produced very little data on carbon. (2) **Improving modeling**. Using existing model output, GCIP added little to modeling capabilities. The proposed field project would involve a very large modeling effort aimed at providing new modeling capability at scales from clouds to planetary dynamics. (3) **Improving instrumentation and data collection.** GCIP funded very little instrumentation because it had limited funding from the National Oceanic and Atmospheric Administration (NOAA). This regional study would be an ARM-like effort with new instrument sites and a dedicated infrastructure. Such a large field project clearly needs further discussion. Thus it is recommended that DOE sponsor a workshop to further explore the possibilities of such a study.

A workshop on research needed to better understand terrestrial ecosystem carbon-cycle feedbacks and future impacts of climate change was held several weeks after the Grand Challenges workshop described in this report. Its conclusions are being summarized in another report for DOE and can be viewed as a source of additional details regarding ecosystem research needs (Hanson et al. 2008).

**Table 1. Challenges and Research Topics**

- Individual research conducted along disciplinary lines is a requisite component of the challenges, but such research must now connect across disciplinary boundaries in a more integrated approach to address the Grand Challenges involving the entire global Earth System.
- This effort will require tackling many science issues not in isolation but in the context of how each contributes to modeling and understanding of the overall system.

| Climate Grand Challenges | Earth Systems Modeling | Aerosols, clouds, and Atmospheric Chemistry | Interactions between Ecosystems and Climate | Interactions between climate change and management of hydrological systems | Energy Systems and Climate Change |
|---|---|---|---|---|---|
| **Characterize the Earths <u>Present Climate</u>**<br>• **Assimilate long-term data sets for the evolution of Earth System components.**<br>• **Improve and evaluate representations of components in models.** | • Plan and develop next generation ESMs.<br>• Improve parameterizations, use of computing advances.<br>• Improve cloud aerosol links.<br>• Validate parameterizations and process descriptions.<br>o Clouds - ARM and satellite data.<br>o Upper troposphere $H_2O$ and clouds.<br>• Extend reanalysis to long memory components of ESM, e.g., oceans and ice-sheets.<br>• Regional Closure Study. | • Long-term data sets describing the evolution of clouds and aerosols and their application to improvement of models.<br>• Present day radiative forcing from aerosols.<br>• Interactions of clouds and aerosols.<br>• Appropriate dimensions.<br>• Assimilate into models. | • Ecosystems state variables for ESMs.<br>• Understand and quantify interactions between ecosystems and climate.<br>• Changes of vegetation cover, species habitats and populations.<br>• Establish long term data sets –assimilation in Earth System models.<br>• Management of ecosystems for goods and services in context of impacts from climate change. | • Better information on current managed systems and benefits of climate information.<br>• Land use and land cover impacts on climate.<br>• How to incorporate climate impacts into water management strategies.<br>• How to incorporate management strategies into ESM to improve projections?<br>• Quantify supply and demand for developing countries to aid projections. | • Near term strategies for incentive or technology driven emission reductions.<br>• Impacts of bio-fuels on global food supply. |
| **Predict Climate Over The <u>Next Several Decades</u>**<br>• **High resolution models of oceans, land, atmosphere, and ice sheets.**<br>• **Include past and additional forcing, natural variability.**<br>• **Guide adaptation choices.** | • ESMs at finer scales to resolve clouds.<br>• Initialization of state variables.<br>• Couple regional details to IA models – Impacts and vulnerability – health and adaptation.<br>• Address uncertainty and statistics.<br>• Predict abrupt change and incidence of extreme events. | • Regional changes in cloud and aerosol properties.<br>• Impact of clouds and aerosols on regional scale temperature, precipitation, water resources and use.<br>• Sources of and reduction options for black carbon.<br>• Cloud feedbacks. | • Climate and air quality impacts on ecosystems.<br>• Climate and human land use impacts on disturbance regimes. Their effects on climate.<br>• Impacts of land use on carbon and nitrogen fluxes, and energy and water exchange with atmosphere.<br>• Initialization of long term ecosystems state variables. | • Studies to improve regional precipitation predictions.<br>• Better predictions of extremes – intensity and frequency.<br>• Regional details on water resources – timing and magnitude.<br>• Impacts of biofuel and carbon sequestration strategies on climate.<br>• Sensitivity to climate change.<br>• Impacts on energy use. | • Inadvertent consequences of various mitigation options.<br>• How and to what degree will climate impact economies?<br>• Most urgent threats from and adaptive strategies for abrupt change and extremes.<br>• Societal vulnerabilities. |
| **Simulate Earth System <u>Change Over Centuries</u>**<br>• **Interactions between human drivers and natural systems.**<br>• **ESMs project extent of climate change.**<br>• **Economic, technological and environmental aspects of mitigation options.** | • Carbon emissions scenarios with human drivers.<br>• Advanced carbon cycle and dynamic vegetation models.<br>• Models for large ice sheets.<br>• Project centuries long-climate change .<br>• Sector vulnerabilities to change. | • Aerosol, methane, and ozone forcing over centuries.<br>• Human and climate induced changes.<br>• Feedbacks between long term climate change and forcing.<br>• Project changes from human or natural causes. | • Long term response of ecosystems to climate variables.<br>• Ecosystem forcing feedbacks to climate.<br>• Limitations on carbon flows and stocks due to climate driven nutrient cycle changes. | • Impacts of land cover and soil moisture on global temperature change over land.<br>• Response of clouds and precipitation to changing aerosols and climate and water management.<br>• Regional water shortages over the next century. | • Dependence of long term climate impacts on near term mitigation decisions.<br>• Sectors of society most vulnerable to change.<br>• Better predictions of ice sheet and sea level dynamics. |

Table 2. Examples of Decision Support Needs of Federal, State, and Local Governments, Private Industry and Individual Citizens that would be Met through the Climate Change Grand Challenges

| Grand Challenge | Present Climate | Next Several Decades | Change over Centuries |
|---|---|---|---|
| ***Decision Issue*** | | ***Decisions needed to be made*** | |
| Options for mitigation of greenhouse warming | Promote needed technologies; economic incentives; costs. Conservation; patterns of consumption. Social institutions. | Mitigation consequences for food production, water resources, etc. Mid-course correction for mitigation. Technological diffusion. Geo-engineering needed? | Optimum mitigation path to limit damage from global warming. Adaptation options. |
| Coastal/river infrastructures and flooding hazards | Insurance rates and policies | Safety provided over design lifetime. | Risk judgment |
| Water resources | Limit irrigation and lawn watering. Deploy conservation measures. Relate to political stability. | Deploy new dams and reservoirs. National security-prevent regional conflict | Valuation of consequences. |
| Agricultural production | Impact of bio-fuel production on world food supplies. | Optimum strategies for land and new crop development. Increase in occurrence of droughts | |
| Ecosystem management | Impacts realized-habitat loss. Thresholds. | Selection of biological reserves. | |
| Protection of Lives | Sensitivities to severe weather. | Threats of famine. Conflict avoidance. Abrupt change. | |

## APPENDICES

### *A. The context set by IPCC 2007 and more recent workshops*

The DOE workshop "Identifying Outstanding Grand Challenges in Climate Change Research" took place in the context of several other recent activities that have addressed climate change and new directions for climate research. This section briefly reviews these activities.

**i. The IPCC 2007 Assessment Report**

In 2007, the Intergovernmental Panel on Climate Change (IPCC), released the Fourth Assessment Report (AR4) as part of a series of major assessments of scientific understanding of climate change. IPCC AR4 consists of individual reports from three working groups and a synthesis summary. The latter begins with the statement:

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."

IPCC Working Group I, examining the physical science basis of climate change, summarized the current level of understanding as follows:

"Since IPCC's first report in 1990, assessed projections have suggested global average temperature increases between about 0.15°C and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. Model experiments show that even if all radiative forcing agents were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans. About twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the SRES scenarios. Best-estimate projections from models indicate that decadal average warming over each inhabited continent by 2030 is insensitive to the choice among SRES scenarios and is *very likely* to be at least twice as large as the corresponding model-estimated natural variability during the 20th century."

IPCC Working Group I also concluded that past scientific research with climate observations and modeling has unequivocally established that climate already has changed well outside the bounds expected from natural variability consistent with the hypothesis that it has been forced by a combination of warming by greenhouse gases and net cooling from aerosols. Furthermore, much larger changes are very likely in the future, with the magnitude of these changes highly uncertain because of various uncertainties in the forcing, which depends on future use of fossil fuels, and on the feedbacks on the global radiation balance from clouds, aerosols, and net greenhouse gas exchange from terrestrial and oceanic systems.

Working Group II of IPCC characterized the impacts of climate change, possible adaptation measures, and the vulnerability of human systems. Working Group III addressed what mitigation measures are possible. They report that mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels.

**ii. Sydney Workshop on Future Climate Change Research and Observations, 2007**.

In October 2007, the international organizations most responsible for coordinating climate research, the Global Climate Observing System (GCOS), the World Climate Research Programme (WCRP), and the International Geosphere-Biosphere Programme (IGBP), held a workshop in Sydney, Australia, "Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Assessment Report." The purpose of the workshop was to help guide future strategies for climate change observations and research and to address the gaps and uncertainties in climate change science identified in the IPCC assessment report. As part of participants' conclusions, the workshop report stated:

> "Now that the IPCC has been so successful in convincing society about the reality of anthropogenic climate change, there is an urgent demand at the highest political level for better information to underpin mitigation and adaption decisions in order to do something about it."
> http://www.wmo.int/pages/prog/gcos/Publications/gcos-117.pdf

This theme was underscored in the plenary presentations and breakout discussions of the Grand Challenges workshop.

Urgent needs identified in the Sydney workshop included "an authoritative set of information at the scales relevant for adaptation policy" and "better regional information on past and future climate." The climate impacts community has been requesting such information for at least the last quarter of a century. What is new is that such requests are being echoed by a wider range of decision makers and environmental managers.  Science and modeling capabilities are only now advancing to the point that providing such information appears feasible.

As a major contributor to the U.S. Climate Change Science Program and supporter of climate change research in the U.S., the Department of Energy is well positioned to contribute to the science and modeling advances called for at the Sydney workshop.  However, achieving such advances will require DOE's dedicated support of new generations of climate models and computational resources and research into the processes that must be accurately represented in these models.

Urgent needs identified by the Sydney workshop included:

- Identification of regions where society is most vulnerable to climate change.
- Identification of thresholds beyond which potentially "dangerous" changes (to society) will occur.
- An authoritative set of information at the scales relevant for adaption policy.
- Better information on past and future climate change.
- Quantification of radiative forcing due to aerosols and clouds by comprehensive model-model and model-observation comparisons.
- Better understanding of the hydrological cycle, especially convection and precipitation processes.
- Ensuring analysis, reanalysis, and reprocessing of all climate data.

**iii. Aspen Global Change Institute Study on Earth System Models, 2006**

Some features of the Grand Challenges have also been anticipated in a "white paper" released by a 2006 Aspen Global Change Institute summer study on Earth System Models that was cosponsored by the Working Group on Coupled Models (WGCM) of the WCRP and Analysis, Integration and Modeling of the Earth System (AIMES) of the IGBP.  The study emphasized the need for a near-term focus on prediction of decadal scale climate change to better quantify regional aspects of climate change for adaptation planning, and longer-term integrations of Earth System models with new mitigation scenarios to quantify the feedbacks that would affect climate change.

The Aspen Global Change Institute 2006 summer session represented a new linkage between the physical climate science community and the integrated assessment modeling community (whose research is assessed, respectively, by IPCC Working Groups I and III).  It also acknowledged the need for a group to represent the climate impacts community (sometimes referred to as the Impacts, Adaptation, Vulnerability, or IAV, community, whose research is assessed by IPCC Working Group II) for better interaction and coordination with scientists in the other two working groups.

### iv. ASCAC-BERAC Report on Computational and Informational Technology Rate Limiters to the Advancement of Climate Change Science, 2008

A 2008 report of an ASCAC-BERAC (ASCAC: Advanced Scientific Computing Advisory Committee, DOE; BERAC: Biological and Environmental Research Advisory Committee, DOE) subcommittee reviewed the state of climate change science with the goal of identifying computational and information technology obstacles pacing progress. The subcommittee identified the need for "a balanced investment portfolio in computational infrastructure, climate science, computer science, and applied mathematics. The subcommittee noted that in the short term, computational capability, albeit growing at a relatively healthy rate due to investment from DOE's Office of Advanced Scientific Computing Research (ASCR), remains a bottleneck and should continue to be a high priority. The subcommittee acknowledged that as the science and complexity of climate simulation grows, so will new technical and scientific challenges. The subcommittee strongly recommended immediate investments in software, algorithms, data management, computational infrastructure, and other pacing items so that needed advances can keep pace with the evolving science, noting that effective management of these investments is also critical to success. The subcommittee recommended that: "ASCR and BER undertake joint ventures to:

- Continue to invest in leadership-class computational facilities, data storage facilities, analysis environments, and collaborative tools and technologies. A significant fraction of these resources should be dedicated, configured, and managed to support integrated and multifaceted climate research and prediction across DOE and broader national and international efforts.
- Invest in strategic collaborations to develop computational algorithms and scalable software to accelerate computational climate change science.
- Develop computational and theoretical foundations for new modes of climate simulation, including ensemble short-range forecasts with regional fidelity and Earth System assimilation.
- Focus the scientific effort to pursue robust, predictive capability of lower-probability/higher-risk impacts, including climate extremes and abrupt climate change.
- Develop a strong scientific understanding of leading-order uncertainties in the carbon cycle, in particular how the efficiency of natural carbon sinks will change with our changing climate. A more tightly coordinated effort in climate change science via well-defined partnerships with ASCR and BER is highly desirable and will provide the best path forward for accelerating progress in this important scientific area."

The Grand Challenges workshop did not explicitly focus on the requirements for computational capabilities and infrastructure necessary to address climate change but underscored the needs identified by the ASCAC- BERAC report.

*B. Implications for DOE's Research Program*

The workshop charge was to define Grand Challenges that DOE could use to refocus its climate program. The required research described in this report already has been somewhat tailored by workshop participants to benefit from the strengths of DOE's current climate research. However, success in making research progress will require some enhancement and realignment of current programs and active partnerships with other agencies in the Climate Change Science Program and participation in internationally coordinated research activities. It will also require attracting and training new scientific talent into the areas addressed by the Grand Challenges. The identified Grand Challenges require integration of modeling capability with process understanding and large-scale observations. DOE is a national leader in developing the requisite modeling capability and understanding of some of the processes most important for climate. Much more can be gained from these capabilities by integrating them with contributions from other partners into the complete system representation needed to address the Grand Challenges.

DOE already has a strong focus on Earth System modeling over the century time scale and development of requisite computational capabilities. However, many of the physical processes on this time scale are not, at present, adequately characterized. Thus their inclusion in Earth System models is still preliminary and exploratory. DOE's ecology and carbon programs are positioned to rapidly advance the information needed to model terrestrial processes in Earth System models. However, a stronger interface between process and experimental research and Earth System modeling is needed. DOE scientists currently address the modeling of sea ice, large ice sheets, and oceanic circulation, but the requisite observational research in these areas must be secured through partnerships with other U.S. agencies, especially NOAA.

Recommendations from this report call for the DOE CCSP and SciDAC programs to further emphasize: (i) reducing systematic biases in coupled models that are essential for decadal-scale climate predictions, (ii) developing efficient computational methodologies and models that can afford high-resolution climate change simulations directly relevant to policy makers. The report calls for the DOE Ecology and Carbon Program to emphasize more the incorporation and validation of carbon and ecological processes in the Earth System Models for century-scale climate change projections.

DOE through its Atmospheric Sciences Program is leading national efforts to understand the basic science processes underlying the formation of aerosols, their fate in the atmosphere, and their interactions with clouds. Through its ARM Program, DOE has become a world leader in development of process data for cloud functioning and its controls on atmospheric radiation. More emphasis is needed on the use of DOE-derived information on aerosols, clouds, and radiation for testing and improvement of climate model simulations and for using this process understanding to assimilate global satellite observations into models.

Recommendations from this report call for the ASP and ARM program to put more emphasis on:
(i) improvement and development of more accurate parameterizations of cloud and aerosol processes,
(ii) integration of measurements to characterize current climate and their use in atmospheric models,
and (iii) consideration of augmenting the ARM program to include carbon cycles.

DOE has not previously had much programmatic focus on the current climate state and its anticipated changes over the next few decades. Consequently, it is unlikely DOE on its own would make adequate progress on the first two challenges. However, these Grand Challenges have not been programmatic foci of any other agency, either. NOAA has had the most experience with assimilating weather data and its reanalysis into climate data. National Center for Atmospheric Research (NCAR) scientists worked extensively with NOAA in the past on this topic and more recently have been addressing climate models extensions. A crucial aspect of any data analysis is the data itself. NOAA maintains archives of weather data. However, other data needed is provided largely by NASA and NOAA remote sensing satellites. NOAA and NASA have developed efforts to initialize and assimilate ocean data. NASA has begun efforts to assimilate terrestrial land temperatures and soil moisture. It also provides products characterizing ice sheets and terrestrial vegetation but has not addressed how such information can be assimilated into Earth System models.

NASA satellite products are also the primary observational basis for describing the global distribution of aerosols. However, such satellite data are incomplete in their characterization of the variables needed to include aerosols in climate models.

Characterization of the present climate and predicting climate change on decadal and century scales require assimilation of observational data and initialization of Earth System Models. While DOE currently does not have programs in these areas, its leadership in Earth System modeling and high-performance computing can make significant contributions to these efforts. This report implies that

DOE should partner with NASA, NOAA, and NCAR to integrate its understanding of ecology, carbon, aerosols, cloud processes sea-ice and large ice sheets into global models, leading to improved decadal predictions of climate change on regional scales, a capability to provide an early warning for any incipient abrupt climate change, and better information on the evolution of the Earth System over the next century to provide guidance as to the appropriate mix and timing needed for mitigation measures.

## *C. Acronyms*

**AR4** – IPCC’s Fourth Assessment Report

**ASCAC** – Advanced Scientific Computing Advisory Committee

**BERAC** – The Biological and Environmental Advisory Committee

**CCSP** – The U.S. Climate Change Science Program

**CRC** – The National Research Council’s Climate Research Committee

**DOE** – The U.S. Department of Energy

**IPCC -** Intergovernmental Panel on Climate Change

**NASA** – National Aeronautics and Space Administration

**NOAA –** National Oceanic and Atmospheric Administration

**NRC** – National Research Council

## *D) Participant List*

| | |
|---|---|
| Ackerman, Thomas<br>University of Washington, Seattle | Ganguly, Auroop<br>Oak Ridge National Laboratory |
| Bader, David<br>Lawrence Livermore National Laboratory | Gent, Peter<br>The National Center for Atmospheric Research |
| Bierly, Eugene<br>American Geophysical Union | Ghan, Stephen<br>Pacific Northwest National Laboratory |
| Buja, Lawrence<br>The National Center for Atmospheric Research | Gutowski, William<br>Iowa State University |
| Cameron-Smith, Philip<br>Lawrence Livermore National Laboratory | Hack, James<br>Oak Ridge National Laboratory |
| Collins, William<br>Lawrence Berkeley National Laboratory | Hanson, Paul<br>Oak Ridge National Laboratory |
| DelSole, Timothy<br>George Mason University | Hartmann, Dennis<br>University of Washington, Seattle |
| Deluca, Cecilia<br>The National Center for Atmospheric Research | Houser, Paul<br>George Mason University |
| Dickinson, Robert<br>Georgia Institute of Technology | Jackson, Robert<br>Duke University |
| Donner, Leo<br>National Oceanic and Atmospheric Administration | Jacob, Robert<br>Argonne National Laboratory |
| Drake, Bert<br>Smithsonian Institution | Janetos, Anthony<br>Pacific Northwest National Laboratory |
| Easterling, Dave<br>National Oceanic and Atmospheric Administration | Jones, Philip<br>Los Alamos National Laboratory |
| Edmonds, James<br>Pacific Northwest National Laboratory | Klein, Stephen<br>Lawrence Livermore National Laboratory |
| Ellingson, Robert<br>Florida State University | Koster, Randy<br>National Aeronautics and Space Administration |
| Erickson, David<br>Oak Ridge National Laboratory | Kraucunas, Ian<br>The National Academies |
| Feddema, Johannes<br>The University of Kansas | Leinen, Margaret<br>Climos |
| Fung, Inez<br>University of California, Berkeley | Leung, Lai-Yung<br>Pacific Northwest National Laboratory |
| | Linn, Anne |

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|---|
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| Liu, Zheng-Yu<br>University of Wisconsin |
| McCalla, Margaret<br>National Oceanic and Atmospheric Administration |
| McClean, Julie<br>University of California, San Diego |
| Meehl, Jerry<br>The National Center for Atmospheric Research |
| Nenes, Athanasios<br>Georgia Institute of Technology |
| O'Neill, Brian<br>The National Center for Atmospheric Research |
| Penner, Joyce<br>University of Michigan |
| Prather, Michael<br>University of California, Irvine |
| Randall, David<br>Colorado State |
| Reilly, John<br>Massachusetts Institute of Technology |
| Schneider, Edwin<br>George Mason University |
| Schwartz, Stephen<br>Brookhaven National Laboratory |
| Shevliakova, Elena<br>Princeton University |
| Taylor, Karl<br>Lawrence Livermore National Laboratory |
| Thompson, Anne<br>Pennsylvania State University |
| Waliser, Duane<br>National Aeronautics and Space Administration |
| Washington, Warren<br>The National Center for Atmospheric Research |
| Webster, Mort<br>Massachusetts Institute of Technology |
| Wilbanks, Thomas<br>Oak Ridge National Laboratory |
| Wiscombe, Warrren<br>Brookhaven National Laboratory |
| Zhang, Minghua<br>Stony Brook University |

**Department of Energy - Observers**

| |
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| Alapaty, Kiran |
| Amthor, Jeff |
| Bamzai, Anjuli |
| Dahlman, Roger |
| Dehmer, Pat |
| Elwood, Jerry |
| Ferrell, Wanda |
| Marley, Robert |
| Palmisano, Anna |
| Petty, Rickey |
| Thomassen, David |
| Vallario, Bob |
| Williamson, Ashley |

## *E) Workshop Agenda*

**<u>Day 1: Tuesday, March 25</u>** **<u>Venue</u>**

| | | |
|---|---|---|
| 9:00 a.m. | **Introduction to Workshop** – Chairs | **James/Potomac** |
| 9:15 a.m. | Dr. Pat Dehmer, Deputy Director for Science Programs, DOE Office of Science - *Workshop context and charge* | |
| 9:30a.m. | Dr. Robert Marlay, Deputy Director of the Office of Climate Change Policy and Technology in DOE's Office of Policy and International Affairs - Grand Challenges in Science for Guiding Climate Change Mitigation and Adaptation | |
| 9:50 a.m. | Dr. Robert Dickinson, Georgia Institute of Technology - *NRC CCSP Committee Priority Setting* | |
| 10:05 a.m. | *Plenary: Jerry Meehl, National Center for Atmospheric Research - New Challenges for Predicting Near-Term and Long-Term Climate Change with a New Generation of Climate Models* | |
| 10:35 a.m. | ***Break*** | |
| 10:50 a.m. | *Plenary: Tim DelSole, Center for Ocean-Land-Atmosphere Studies Design of/Requirements for Climate Model Simulations to Ascertain Shifts in the Distribution of Extreme Weather Events* | |
| 11:15 a.m. | Plenary: Jae Edmonds, Joint Global Change Research Institute, Pacific Northwest National Laboratory, University of Maryland – *Synthesis of Integrated Assessment with Comprehensive Climate Models* | |
| 11: 40 a.m. | *Plenary: Inez Fung, University of California, Berkeley - Carbon Modeling* | |
| 12:10 p.m. | ***Lunch*** | |
| *1:00 p.m.* | ***Introduction to First Breakout** - Chairs* | |
| *1:10 p.m.* | *First Breakout: 4 Groups* | |

*Identify key grand challenges in four areas:*

1. *Variability and Forcing (John Reilly, Duane Waliser)* **Mount Vernon**
   *Understanding Earth's past and present climate variability and forcing*

2. *Projections (Tom Wilbanks, Zhengyu Liu)* **Monticello**

   *Reducing uncertainty and improving confidence in projecting how the Earth's climate at regional to global scales may change in the future in response to natural and/or human-induced forcing*

3. *Ecosystems (Rob Jackson, David Erickson)* **Williamsburg**
   *Understanding and predicting the sensitivity and adaptability of managed and natural ecosystems to climate change*

4. Observations to improve models (Paul Houser, Joyce Penner) **Jamestown**
   Integrating data and knowledge from research and observations on climate and Earth system processes into climate and Earth system *models and modeling.*

*3:15 p.m.* ***Break***

*3:30 p.m.* *Plenary: Steve Schwartz, Brookhaven National Laboratory - Aerosols*

4:00 p.m. Plenary: Karl Taylor, Lawrence Livermore National Laboratory - Reducing Uncertainty/Increasing Confidence in Climate Models

*4:30 p.m.* *Plenary: Steve Klein, Lawrence Livermore National Laboratory - Application of*

*Knowledge from Research and Observations to Improvement of Climate/Earth System Models*

*5:00 p.m.* ***Adjourn***

**Day 2: Wednesday, March 26** **Venue**

9:00 a.m. Breakout Chairs and Rapporteurs Report **James/Potomac**

9:45 a.m. Plenary: Mike Prather, University of California, Irvine - *Radiative Forcing*

10:15 a.m. **Break**

10: 30 a.m. Plenary: Jim Hack, Oak Ridge National Laboratory – *Computational Capabilities*

11: 00 a.m. *Plenary: Johan Feddema, University of Kansas - Land Use/Land Cover*

*Change Scenarios*

11:30 a.m. *Plenary: Paul Hanson, Oak Ridge National Laboratory - Natural and Managed Ecosystems*

12:00 p.m. ***Lunch***

1:00 p.m. Plenary: Bill Collins, Lawrence Berkeley National Laboratory - *Clouds and Radiation*

1:30 p.m. Plenary: Tony Janetos, Joint Global Change Research Institute, Pacific Northwest National Laboratory, University of Maryland - *What is Needed and the Challenge of Finding Out What Information is Needed About the Future from Climate Modeling*

2:00 p.m. *Introduction to Second Breakout: Chairs*

2:10 p.m. Second Breakout: 4 Groups
Identify the key research, observational and computational capabilities that are necessary to address the grand challenges in each of these four areas:

1. Variability and Forcing (Thanos Nenes, Dennis Hartman) **Mount Vernon**
   Understanding Earth's past and present climate variability and forcing

2. Projections (Dave Bader, Ed Schneider) **Monticello**
   *Reducing uncertainty and improving confidence in projecting how the Earth's climate at regional to global scales may change in the future in response to natural and/or human-induced forcing*

3. *Ecosystems (Johan Feddema, Elena Shevliakova)* ***Williamsburg***
   *Understanding and predicting the sensitivity and adaptability of managed and natural ecosystems to climate change*

4. *Observations to improve models (Dave Easterling, Warren Wiscombe)* ***Jamestown***
   *Integrating data and knowledge from research and observations on climate and Earth system processes into climate and Earth system models and modeling*

*3:00 p.m.* ***Break***

3*:15 p.m.* *Resume Second Breakout Group*

*5:00 p.m.* ***Adjourn***

**<u>Day 3: Thursday, March 27</u>** **<u>Venue</u>**

*9:00 a.m.* *Reports from Second Breakout Group* **James/Potomac**

*Remainder of morning focused on discussion and report writing*

*12:00 p.m.* ***Adjourn***

Charge Letter --

**Under Secretary for Science**
Washington, DC 20585
October 1, 2007

Dr. Michelle Broido
Associate Vice Chancellor for Basic Biomedical Research
and Director, Office of Research, Health Sciences
University of Pittsburgh
Scaife Hall, Suite 401
3550 Terrace Street
Pittsburgh, PA 15261

Dear Dr. Broido:

I would like BERAC to take on a new challenge relating to BER's Climate Change Research Program. For over two decades, DOE has been among the leading agencies supporting climate change research. The Department has invested more than $1.8 billion in climate change research from 1990 to date through the U.S. Global Change Research Program (GCRP) and its successor, the U.S. Climate Change Science Program (CCSP). While much has been learned about climate forcing, climate response and climate change consequences since the inception of the GCRP and the CCSP, significant gaps remain in our understanding and significant questions have not been resolved.

I request that BERAC organize and conduct a workshop to bring together some of the leading experts (regardless of affiliation) to help identify the outstanding scientific grand challenges in climate change research related to each of the questions listed below. The workshop should also identify research priorities and a path forward, including the kinds of research capabilities that are needed to address the challenges. I would like the workshop to provide a report that will be of use in guiding DOE's strategic planning of and future investments in climate change research.

- What are the grand challenges in understanding Earth's past and present climate variability and forcing? What key research, observational and computational capabilities are necessary to understand the past and present climate and the forcing responsible for past and present changes in climate?
- What are the grand challenges in reducing uncertainty and improving confidence in projecting how the Earth's climate at regional to global scales may change in the future in response to natural and/or human-induced forcing? What key basic research, observational and computational capabilities are necessary to reduce uncertainty and improve confidence in projecting future climate response to such forcing?
- What are the grand challenges in understanding and predicting the sensitivity and adaptability of managed and natural ecosystems to climate change? What key basic research and research capabilities, including observational, experimental,

and computational facilities are necessary to understand and predict the sensitivity and adaptability of such systems to changes in climate?

- What are the grand challenges in integrating data and knowledge from research and observations on climate and Earth system processes into climate and Earth system models and modeling? What is needed to ensure that data on climate and Earth system processes are effectively used to assess model performance and help define data and knowledge gaps that require new or additional process research, observations, or capabilities for collecting the needed data?

The current state of knowledge about climate change, impacts, vulnerabilities, and adaptation has been laid out in the recent IPCC Fourth Assessment Reports of Working Groups I and II. Workshop participants should consider these reports as a relatively recent authoritative source of information on the current state of climate change science.

I request that BERAC designate a Chair to identify and organize an executive group to plan and implement the workshop. The group should work collectively to refine and frame the fundamental questions to be the focus of the workshop panels and to identify experts who should be invited to attend. Participation in the workshop should be by invitation only. Lastly, I request that the workshop be organized and implemented as soon as practical so that a report can be submitted for review and approval by the full committee at its spring 2008 meeting if possible.

Sincerely,

Raymond L. Orbach

Raymond L. Orbach