U.S. DEPARTMENT OF ENERGY | Office of Science

BIOLOGICAL AND ENVIRONMENTAL RESEARCH

Climate and Environmental Sciences Division

STRATEGIC PLAN



DOE/SC-0151

BIOLOGICAL AND ENVIRONMENTAL RESEARCH

Climate and Environmental Sciences Division

STRATEGIC PLAN

Prepared by the
Climate and Environmental Sciences Division

within the

U.S. Department of Energy Office of Science
Office of Biological and Environmental Research

Report released
July 2012

U.S. DEPARTMENT OF ENERGY | Office of Science

Executive Summary

The Climate and Environmental Sciences Division, part of the Department of Energy's Office of Biological and Environmental Research within the Office of Science, is the intellectual home for fundamental research to understand the energy-environment-climate connections and their implications for energy production, use, sustainability, and security. This strategic plan addresses the mission and goals of nine CESD programs/user facilities:

- Atmospheric System Research (ASR) Program
- Subsurface Biogeochemical Research (SBR) Program
- Terrestrial Ecosystem Science (TES) Program
- Earth System Modeling (ESM) Program
- Regional and Global Climate Modeling (RGCM) Program
- Integrated Assessment Research (IAR) Program
- Atmospheric Radiation Measurement (ARM) Climate Research Facility
- Environmental Molecular Sciences Laboratory (EMSL)
- Carbon Dioxide Information Analysis Center (CDIAC)

CESD Mission Statement: To advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solutions to the Nation's energy and environmental challenges.

CESD Goals:

- Synthesize new process knowledge and innovative computational methods advancing next-generation, integrated models of the human-Earth system.
- Develop, test, and simulate process-level understanding of atmospheric systems and terrestrial ecosystems, extending from bedrock to the top of the vegetative canopy.
- Advance fundamental understanding of coupled biogeochemical processes in complex subsurface environments to enable systems-level environmental prediction and decision support.
- Enhance the unique capabilities and impacts of the ARM and EMSL scientific user facilities and other BER community resources to advance the frontiers of climate and environmental science.
- Identify and address science gaps that limit translation of CESD fundamental science into solutions for DOE's most pressing energy and environmental challenges.

Each of the nine programs/user facilities lists priorities for the next five years that are designed to meet these goals. These priorities include:

- Developing Earth system models and strengthening the predictive understanding of climate
- Advancing studies to enhance the understanding of atmospheric and terrestrial system processes
- Understanding and predicting biogeochemical processes in subsurface environments
- Utilizing CESD's user facilities for experimental studies designed to achieve unprecedented understanding of Earth's dynamic processes
- Strengthening engagements with internal and external energy and environmental stakeholder communities.

Contents

1.0 Mission

The mission of the Department of Energy (DOE) is to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions. One of DOE's four goals is to "maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas."

The Office of Science (SC) is the home for DOE's fundamental research programs and scientific user facilities. Within SC the Office of Biological and Environmental Research (BER) supports a broad range of fundamental science and three scientific user facilities in the strategic areas of biological and environmental science. The BER research programs seek to understand energy-relevant complex biological and environmental systems across spatial and temporal scales ranging from sub-micron to global, from individual molecules to ecosystems, and from nanoseconds to millennia.

As one of BER's two research divisions, the Climate and Environmental Sciences Division (CESD) is the intellectual home for fundamental research to understand the energy-environment-climate connections and their implications for energy production, use, sustainability, and security. This strategic plan addresses the mission and goals of nine CESD programs/user facilities:

- Atmospheric System Research (ASR) Program
- Subsurface Biogeochemical Research (SBR) Program
- Terrestrial Ecosystem Science (TES) Program
- Earth System Modeling (ESM) Program
- Regional and Global Climate Modeling (RGCM) Program
- Integrated Assessment Research (IAR) Program
- Atmospheric Radiation Measurement (ARM) Climate Research Facility
- Environmental Molecular Sciences Laboratory (EMSL)
- Carbon Dioxide Information Analysis Center (CDIAC)

CESD invests in basic research that addresses key uncertainties in the understanding of Earth's complex climate and environmental systems. This research is needed to understand and predict the interactions between climate and environmental processes and energy production practices. Particular emphasis is placed on the potential impact of increased anthropogenic emissions on Earth's climate system and DOE's unique concerns regarding contaminant transport in subsurface systems. The scope of the research spans global to molecular scales and includes processes ranging in duration from nanoseconds to millennia.

CESD Mission Statement: To advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solutions to the Nation's energy and environmental challenges.

The scaling challenge confronted by all CESD research activities is to identify and capture the multi-scale structure and function of complex and coupled climate and environmental processes so that they can be quantitatively represented in models of overall system behavior. This scaling challenge is addressed by developing a robust predictive understanding of key system components that is incorporated into models of the overall system behavior. The fidelity of the system models and their components is tested and advanced by comparing model predictions to observations made across a wide range of environmental conditions and spanning many spatial and temporal scales. As the models are subject to rigorous testing against measurements, we gain confidence in their ability to project future conditions and to evaluate the impact of both natural and anthropogenic alteration of these systems. By advancing a predictive understanding of key climatic and environmental systems, CESD provides foundational science that DOE and other decision makers can use to support sound decisions for future energy and environmental challenges.

2.0 CESD Goals

By advancing research towards accomplishing these goals, CESD provides the basic scientific understanding and capabilities to answer the following high-priority questions:

Goal 1: Synthesize new process knowledge and innovative computational methods advancing next-generation, integrated models of the human-Earth system.

Goal 2: Develop, test, and simulate process-level understanding of atmospheric systems and terrestrial ecosystems, extending from bedrock to the top of the vegetative canopy.

Goal 3: Advance fundamental understanding of coupled biogeochemical processes in complex subsurface environments to enable systems-level environmental prediction and decision support.

Goal 4: Enhance the unique capabilities and impacts of the ARM and EMSL scientific user facilities and other BER community resources to advance the frontiers of climate and environmental science.

Goal 5: Identify and address science gaps that limit translation of CESD fundamental science into solutions for DOE's most pressing energy and environmental challenges.

- What are the impacts of our current and future energy systems on Earth's climate and environment?
- What are the likely consequences of climate change on Earth systems, and what are the implications for the U.S. energy sector?
- What processes control the mobility of the by-products of energy production and use (both fossil fuels and nuclear) and other anthropogenic emissions in environmental and climatic systems?
- What are the critical thresholds and tipping points for climate and environmental systems and the implications for future energy production processes?

These are profound questions with global implications, and they represent a significant challenge for climate and environmental science. CESD is at the forefront of providing the foundational scientific knowledge needed to address these questions. CESD research focuses on the five interrelated CESD goals through the integration of observational, experimental, and computational approaches to address climate and environmental challenges of importance to DOE, the U.S., and our planet.

3.0 CESD Core Capabilities

CESD's research priorities are based on advancing a predictive understanding of climate and environmental systems and their key components within the context of DOE's energy and environmental missions. The observational and experimental components of CESD-supported research target understanding critical aspects of the atmosphere and the carbon and water cycles. The scientific approach combines interdisciplinary and model-driven research in an iterative format to understand and predict the coupled physical, chemical, biological, and human systems that control the complex behavior of the climate and environment, from local to regional and global scales. The state of that understanding is then captured in models at a variety of scales. These models help to inform future research and observations and provide the scientific basis for DOE's applied offices to develop decision-making tools.

Energy-relevant research that advances the cycle of observing, understanding, modeling and testing distinguishes CESD from other U.S. Federal research programs, as do DOE's strengths and unique assets.

DOE Strengths and Assets

- Development of community-based models, databases, and analytical and diagnostic tools
- Long-term, large-scale, highly complex field experiments and observational networks
- Unique and sustained interdisciplinary research capabilities provided by DOE National Laboratories
- Complementary portfolio of university mission-driven basic research
- Scientific user facilities and research infrastructure enabling a broad range of mission-relevant climate and environmental sciences
- Leadership-class computation capabilities and advanced mathematical methods.

CESD's core capabilities include the following:

1. **DOE-focused Earth system modeling and integrated modeling of the human-natural system:**
   - Internationally recognized capabilities for representing global atmosphere, land, ocean, and cryosphere systems, primarily within the Community Earth System Model (CESM). Model development is facilitated by DOE computational expertise to implement innovative numerical schemes and by construction of sophisticated frameworks to test and calibrate codes using process/observational data sets.
   - Pioneering work in high-resolution climate modeling methodologies to produce robust regional climate projections, including information on extremes, feedbacks, variability and change, and thresholds and tipping points. Regional focus is on areas of vital interest to climate assessments, including the tropics and the Arctic. Development of metrics for multi-model diagnostics includes support for the Program for Climate Model Diagnostics and Intercomparison (PCMDI).
   - Leading federal steward for IAR with the goal of understanding global change, climate, and the associated complex interactions of evolving human and natural systems. Focus is on the role of energy systems, technology, natural resources, infrastructure, human activity, and economics, delivering insights on anthropogenic forcings and impacts on energy and interconnected human-Earth systems.

2. **Focused research on key Earth system processes that represent significant uncertainties and currently limit predictive understanding:**
   - Comprehensive portfolio of research on cloud-aerosol-precipitation interactions using lab-based experiments, major ARM Climate Research Facility long-term and field campaign observations, and innovative model testbeds. A combination of process modeling and dedicated experimental measurements is used to provide insight into understanding and describing cloud and aerosol influences on Earth's radiative balance and climate. These insights are in turn used to address the major uncertainties in modeling climate-relevant atmospheric processes.
   - Long-term, multi-scale field-based research activities and valuable long-term data sets to understand climate and environmental processes and to parameterize process and system models. Innovative, long-term experiments focusing on understanding terrestrial ecosystem interactions with both the atmosphere and subsurface are critical to improving prediction of future climates and addressing the role of the carbon cycle in governing the rates of climate change.
   - Multiscale approaches to understanding subsurface environmental systems and biogeochemical cycles with particular relevance to DOE's energy and environmental missions. Research approaches that couple laboratory results with field-relevant research on carbon, nutrient, and radionuclide transport in a variety of subsurface biogeochemical settings are studied in an iterative format, with computer modeling to advance a predictive understanding of these systems.
3. **DOE scientific user facilities and research infrastructure:**
   - The ARM Climate Research Facility provides unmatched measurement capabilities enabling the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol, and precipitation characteristics at climate-sensitive sites around the world. ARM's fixed and mobile facilities support U.S. and international users in the conduct of experiments and development and testing of climate models. The ARM facilities are valuable resources for NASA, NOAA, and foreign space satellite programs for testing or validating instruments and retrieval algorithms.
   - EMSL offers leading-edge research instruments, supercomputing capabilities, and open-source software to investigate and simulate molecular- and atomic-level biological, chemical, and physical interactions. EMSL supports users from academia, national laboratories, other federal agencies, and industry.
   - CESD data infrastructure provides internationally recognized data sets and tools to support community research. CDIAC provides quality-assured data on the carbon cycle and terrestrial ecosystems. The ARM Data Archive provides community access to long-term cloud, aerosol, and precipitation characteristics for numerous climatic regimes. Climate model output and selected ARM and CDIAC observational data are provided to the community through the Earth System Grid Federation.
4. **Leveraging other DOE research capabilities:**
   - The partnership between CESD and the SC Office of Advanced Scientific Computing Research (ASCR) enables the development of computationally advanced climate and subsurface biogeochemical modeling by providing expertise to develop codes that run efficiently on leadership-class computers; new approaches to increase spatial resolution;

methods for quantification of uncertainty and for model validation; and advanced data analysis, transfer, and visualization capabilities.

- CESD leverages BER's Biological Systems Science Division's diverse portfolio of fundamental research and technology development that targets a systems-level understanding of complex biological systems to advance DOE missions in energy, climate, and environment. These include the following:
  - The Joint Genome Institute, a scientific user facility, provides genome sequencing, genome data acquisition, and genome analyses in support of DOE mission needs in bioenergy, carbon cycling and biosequestration, and environmental characterization and cleanup.
  - Genomic Science Research supports fundamental research on plant and microbial systems biology to advance DOE missions in energy, climate, and environment.
- CESD also exploits synchrotron radiation light sources and neutron-scattering facilities provided by the SC Office of Basic Energy Sciences. These facilities provide CESD with unmatched capabilities to analyze basic biological structures of critical importance to subsurface environments.

4.0 Vision and Supporting Objectives for CESD Goals

By bringing to bear and combining these DOE strengths and assets, CESD provided a five-year vision for the CESD research goals:

1

Goal 1: Synthesize new process knowledge and innovative computational methods advancing next-generation, integrated models of the human-Earth system.

To accomplish this goal, CESD will provide key insights into multi-scale, complex dynamics and system behavior using newly developed knowledge including climate variability and change, carbon and water cycles, clouds and aerosols, oceans, terrestrial, cryosphere, and human systems impacts and feedbacks.

Vision: To develop community-based, integrated human-Earth system models, exploring systems dynamics with improved process representations, while strengthening our predictive understanding of climate, its natural and anthropogenic influences, and its effects.

Integrated Earth System models couple the physical, biogeochemical, and human systems to provide a comprehensive understanding of the current climate and are crucial in providing a predictive understanding of the future climate and elucidating the relative roles of the various Earth system components that influence climate variability and change. These models must be intimately engaged with observations and process research, continually challenged to faithfully represent observed processes at various scales, and used to guide and prioritize observational programs by indicating the gaps in our scientific understanding of the complex Earth system.

Supporting objectives:

1. Develop, test, and evaluate a fully integrated community Earth system model (iESM) built around the CESM and best-in-class integrated assessment models, offering the potential to explore climate change impacts, responses, and climate-human system feedbacks with highly detailed interoperable representations of the Earth system.
2. Develop a new generation high- and variable-resolution Earth system model built on the foundations of DOE's numerical, computational, climate, and environmental science expertise, and based on advancing and testing scale-aware schemes for oceanic, cryospheric, terrestrial, and atmospheric systems.
3. Strengthen model representations of energy and other human systems and their interactions with natural Earth systems, including dynamic emissions, land-use changes, and influences of both natural processes and human activity on water and biogeochemical cycles.
4. Develop, test, and analyze simulations of the integrated water cycle, including feedbacks and interactions among components and systems, the relative roles of global and local human and natural processes, and projections of shifts in means and extremes.
5. Develop and improve global and regional models by focusing on regions vital to climate assessments and regions with known biases and climate sensitivities, such as the Arctic and the tropics. This includes continuing to advance our understanding and process representations of Arctic sea ice, tropical ocean-atmosphere interactions, terrestrial-atmosphere interactions, and the role of frequent extreme phenomena on terrestrial systems.
6. Improve understanding and predictability of dynamical processes governing sea-level rise. Enhance and improve dynamic ice sheet processes and predictive modeling, test against measurements, and couple with the ocean to project spatial patterns of sea-level change.
7. Establish advanced model metrics, observation-based diagnostics, and uncertainty quantification methods to guide model development, gauge model improvement, and establish confidence in model projections.
8. Refine analytical methods to distinguish climate feedbacks, discern evolving patterns of extremes within a changing climate, identify potential abrupt system changes, and detect and attribute sources of climate change.

2

Goal 2: Develop, test, and simulate process-level understanding of atmospheric systems and terrestrial ecosystems, extending from bedrock to the top of the vegetative canopy.

To accomplish this goal, CESD will capture predictive relationships to drive coupled regional and global models that inform future research and energy decisions.

Vision: Targeting natural processes that dominate climate impacts and uncertainties, CESD advances experimental and observational studies to enhance understanding of atmospheric and terrestrial system processes and their part in climate forcing and response.

By iterating observations, experiments, and models at relevant spatial and temporal scales, CESD seeks to scale process results to model grid scales. We use models to evaluate our understanding of these coupled processes, to improve models, and to inform next-generation research that advances DOE's broad science and energy missions.

Supporting objectives:

1. Determine robust scale-aware relationships for key atmospheric processes, including dynamics and microphysics of stratiform and convective cloud systems, cloud-aerosol interactions, and aerosol indirect effects.
2. Develop a predictive understanding of the mechanisms and processes controlling the climate forcing role of terrestrial ecosystems through observations, manipulations, and experiments across relevant temporal and spatial scales.
3. Improve understanding and representation of Arctic and tropical atmospheres and ecosystems, both of which represent significant model uncertainties and potential climate tipping points/thresholds.
4. Use laboratory studies, targeted ARM field campaigns, and ARM long-term observations to quantify local atmospheric aerosol and precipitation processes, including aerosol formation, chemical evolution, and optical properties; initiation of cloud droplets, ice crystals, and precipitation; and feedbacks involving the terrestrial-aerosol-cloud system.
5. Advance a predictive understanding of the significant, dynamic carbon pool in below-ground ecosystems.
6. Advance understanding and process representation of the couplings involving energy, carbon, and water cycles, and improve dynamical representations of these cycles to better represent climate forcings at the interfaces of terrestrial, aquatic, and urban systems.
7. Develop, test, and analyze simulations of the Earth's full carbon cycle, including terrestrial, atmosphere, and ocean. Constraint is provided by DOE measurements and process research on terrestrial ecosystems.

3

Goal 3: Advance fundamental understanding of coupled biogeochemical processes in complex subsurface environments to enable systems-level environmental prediction and decision support.

To accomplish this goal, CESD will provide key insights relevant to DOE's energy security mission.

Vision: Use an integrated multi-disciplinary, multi-scale approach to understand and predict biogeochemical processes in subsurface environments and provide innovative insight to a broad range of biogeochemical transport and cycling processes of relevance to DOE missions.

Supporting objectives:

1. Develop fully coupled models of subsurface environmental processes that incorporate metabolic modeling of microbial processes; molecular-scale understanding of geochemical stability, speciation, and biogeochemical reaction kinetics; and diagnostic signatures of the system response at varying spatial and temporal scales.
2. Develop integrated approaches to test model predictions and to identify and reduce sources of prediction uncertainty (e.g., model formulation and parameterization).
3. Develop strategies to test, predict, manipulate, and control subsurface biogeochemical processes in key subsurface environments as a means to more efficiently advance the science in support of DOE's energy and environmental challenges.
4. Use EMSL facility resources to characterize fundamental physical, chemical, and biological interactions in subsurface environments relating to carbon cycle and radionuclides.

4

Goal 4: Enhance the unique capabilities and impacts of the ARM and EMSL scientific user facilities and other BER community resources to advance the frontiers of climate and environmental science.

To accomplish this goal, CESD will deliver the leading scientific user facilities and other mission-critical community resources, including unique field research sites; environmental observational networks; dedicated high-performance computational systems; a world-renowned climate model diagnostics center; visualization, analysis, and data dissemination capabilities; and public data archives.

Vision: To use premier, best-in-class instrumentation; tailored computational hardware and software; robust, accurate, and timely data sets; and defined field sites for experimental studies to achieve unprecedented understanding of Earth's dynamic processes at the full range of scales.

Understanding Earth's dynamic processes, including the human-Earth system, atmospheric systems, terrestrial ecosystems, and the subsurface environment, requires a wide range of specialized tools for observation, characterization, testing, and simulation. Many of these specialized tools are available to the scientific community through CESD's support of the ARM and EMSL scientific user facilities, but CESD also provides a broad spectrum of additional resources to the research community.

Supporting objectives:

1. Advance capabilities and aggressively exploit the unique DOE facilities that provide critical detailed observations necessary to understand cloud, aerosol, and radiative properties over land, sea, and ice.
2. Exploit existing and new ARM facilities and recently procured American Recovery and Reinvestment Act of 2009 (Recovery Act) instrumentation to provide high-resolution, three-dimensional documentation of evolving cloud, aerosol, and precipitation

characteristics in climatically sensitive regions. A new site in the Azores and an extended-duration deployment of a new mobile facility at Oliktok, Alaska, will add new observations for marine and Arctic regimes.

3. Develop and implement a next-generation integrated CESD data management plan for atmospheric, terrestrial ecosystem, and model data sets, maximizing synergy among common needs, existing tools, and capabilities. Maintain linkages and compatibility with other national and international data management efforts.
4. Promote the use of multiple EMSL instruments coupled to high-performance computing to enable research teams to characterize and understand the experimental and theoretical basis of molecular-level reactions that occur in atmospheric, terrestrial, and subsurface systems.
5. Apply EMSL instrumentation and computing resources to enable fundamental studies of aerosol particle reactions, biogeochemical cycles in terrestrial ecosystems, and the interactions of microorganisms, minerals, fluids, and contaminants in near-surface and subsurface environments.
6. Develop more sophisticated frameworks and software for model and measurement analysis, comparison, and visualization for the community through mechanisms such as the Earth System Grid Federation (ESGF).
7. Support the continued accessibility and efficient and effective use of high-performance computing for dedicated, leadership-class research collaborations exploring human-Earth system interactions.
8. Maintain long-term interdisciplinary field research sites for climate and environmental science researchers to conduct in situ field studies, hypothesis testing, and model development and evaluation using dedicated data testbeds.

5

Goal 5: Identify and address science gaps that limit translation of CESD fundamental science into solutions for DOE's most pressing energy and environmental challenges.

To accomplish this goal, CESD will deliver targeted predictive models, observations, tools, and insights through specific initiatives that address mission-critical scientific issues, including high-resolution climate projections, water cycle shifts, climate extremes, and coupled energy system impacts and responses.

Vision: Strengthen engagements with the energy and environmental stakeholder communities, both internal and external to DOE, facilitating more deliberate discussions on basic research needs.

Outcomes will provide improved, regular inputs into CESD's basic research agenda, enhance connections among basic research and applied research programs, and accelerate the scientific insights and capabilities for "transformative science and technology solutions" that are the core of DOE's mission.

Supporting objectives:

1. Develop improved high-resolution climate models and companion data sets that are capable of projecting, with increased level of skill and certainty, seasonal to decadal estimates of precipitation and water availability, wind speeds, cloud cover, and likelihood of extreme events such as droughts, floods, and storm surges, on scales relevant to DOE stakeholders.
2. Engage in an ongoing dialog with end users of CESD's climate science in order to establish realistic and high-value sets of Earth system modeling performance goals and model development metrics that in turn can be used to assist CESD in guiding a use-inspired basic research agenda.
3. Provide data and process studies that investigate the impact of Earth system constituents on renewable energy systems (e.g., the impact of aerosols on solar energy capacity).
4. Provide data for investigations of the impact of local to regional climate change and extreme events on renewable energy potentials.
5. Provide data and process models that describe subsurface mobility and transport of energy-derived contaminants, with a view towards advancing the capabilities of community environmental prediction systems that describe flow and transport as well as identifying efficient remediation strategies.
6. Develop new software tools that facilitate use of CESD model and data by user communities.

5.0 CESD Research

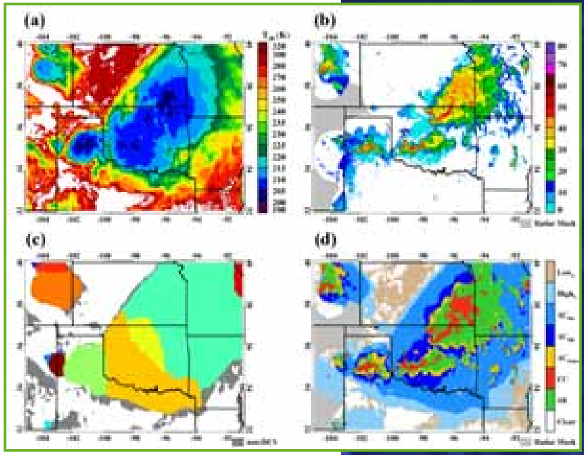
The CESD programs and facilities, working together and individually, support research that contributes to the CESD mission and goals. The following are brief goals, descriptions, and plans for the next five years.

5.1 Atmospheric System Research Program

ASR is the primary U.S. activity addressing the two major areas of uncertainty in climate change model projections: the role of clouds and the effects of aerosols on precipitation and the atmospheric radiation balance. This program coordinates strongly with the ARM Climate Research Facility, utilizing the ARM Facility's continuous long-term data sets that provide measurements of radiation, aerosols, clouds, precipitation, dynamics, and thermodynamics over a range of environmental conditions at climatically diverse locations. These long-term observational data sets are supplemented with laboratory studies and shorter-duration ground-based and airborne field campaigns to target specific atmospheric processes under a diversity of locations and atmospheric conditions.

ASR program goals include physical understanding and accurate representation of the important aerosol-cloud-precipitation processes that drive precipitation and the atmospheric radiation balance and the successful incorporation of this understanding into regional and global climate models. To successfully understand and model the aerosol-cloud-precipitation continuum, ASR considers cross-cutting variables and processes, including atmospheric thermodynamic profiles, surface turbulent heat fluxes, radiative transfer, and surface albedo, as well as how these variables and processes respond to diurnal, synoptic, and seasonal variability.

ASR programmatic research results are incorporated into Earth system models developed within the Climate and Earth System Modeling Program both to understand the processes that govern atmospheric components and to advance the Earth system model capabilities with greater certainty of predictions. Finally, ASR seeks to develop integrated, scalable testbeds that incorporate process-level understanding of the life cycles of aerosols, clouds, and precipitation into dynamic models. Using these model testbeds, the predictions of candidate model formulations can be compared to benchmarked ARM Facility data to validate or diagnose the skill or usefulness of the candidate formulations.



Priorities for the Next Five Years:

- Utilize and extend the capabilities of the new Recovery Act instruments and ARM Facility sites. To enhance characterization of cloud, aerosol, and precipitation properties ASR will prioritize and solicit targeted research to develop new analyses and data techniques suitable for the new instrumental capabilities (e.g., retrieval development, uncertainty analysis, data product collocation).
- Support integrated studies of key processes driving aerosol-cloud-precipitation-radiation interactions.
- Continue investigations into dominant atmospheric processes in tropical, marine, and Arctic environments. These include analyses and modeling projects leveraging targeted experiments in these regions, e.g., the ARM Madden-Julian Oscillation Experiment (AMIE) and GreenOcean Amazon2014 (GOAMAZON) tropical campaigns, the Marine ARM GPCI Investigation of Clouds (MAGIC) marine campaign and the previous and upcoming ARM measurements in the Azores, and upcoming measurements from the Arctic Oliktok site as well as existing and anticipated arctic campaign data.
- Investigate processes responsible for the observed tropical biases in regional and global models (in collaboration with RGM).

5.2 Subsurface Biogeochemical Research Program

The subsurface environment, which encompasses the vadose and saturated zones, is a heterogeneous, geologically complex domain. Believed to contain a large percentage of Earth's biomass in the form of microorganisms, the subsurface is a dynamic zone where important biogeochemical cycles work to sustain life. Actively linked to the atmosphere and biosphere through the hydrologic and carbon cycles, the subsurface serves as a storage

location for much of Earth's fresh water. Coupled hydrological, microbiological, and geochemical processes occurring within the subsurface environment are now well recognized as responsible for the local and regional natural chemical fluxes that govern water quality. These processes play a vital role in the formation of soil, economically important fossil fuels, mineral deposits, and other natural resources.

Priorities for the Next Five Years:

SBR's overarching goal is to develop robust predictive models of subsurface biogeochemical processes to understand the structure and function of complex subsurface systems. It is a programmatic objective that modeling efforts transition to community resources, i.e., models openly accessible and used by the research community. SBR supports a wide range of research activities to advance the development of fully coupled models of subsurface environmental processes that incorporate the following:

- metabolic modeling of microbial processes
- molecular-scale understanding of geochemical stability, speciation, and biogeochemical reaction kinetics
- diagnostic signatures of the system response at varying spatial and temporal scales.

State-of-science understanding codified in models provides the basis for testing hypotheses, guiding experimental design, integrating scientific knowledge on multiple environmental systems into a common framework, and translating this information to support informed decision making and policies. Critical to SBR's goal is a better understanding of how the behavior and interactions of contaminants, carbon, and nutrients affect their mobility, reactivity, and stability in complex subsurface environments that encompass the vadose and saturated zones and key interfaces between ground and surface waters. SBR programmatic activities span:

- Molecular-scale processes
- Geochemistry and biogeochemistry
- Environmental microbiology and applied genomics
- Geophysics and geohydrology
- Measurement and monitoring
- Field-scale research
- Modeling using high-performance computing at each scale and across scales.

5.3 Terrestrial Ecosystem Science Program

The goal of TES is to improve the representation of terrestrial ecosystem processes in Earth system models, thereby improving the quality of climate model projections and providing the scientific foundation needed to inform DOE's energy decisions. TES seeks to focus its research on ecosystems that are globally important, climatically sensitive, and comparatively understudied or underrepresented in Earth system models.

TES uses a systems approach to understand ecosystems over multiple scales that can be represented in models (e.g., single process models, system models, and CESM). This emphasis on the capture of advanced understanding in models has two goals. It seeks to improve the representation of these processes in coupled models, thereby increasing the sophistication of the projections from those models. It also exercises those models and compares the results against observations or other data sets to inform future research directions.

Priorities for the Next Five Years:

- Understand the role of disturbances in altering ecosystem functions and climate forcing.
- Gain a mechanistic understanding of the role of subsurface processes (e.g., microbiology, geochemistry, root/rhizosphere, soil processes) in the terrestrial carbon cycle.
- Support large-scale coupled modeling and process research projects as well as large-scale, long-term ecosystem manipulations.
- Expand emphasis on Arctic and tropical ecosystems and the role of their carbon stocks in a changing climate.
- Analyze long-term ecosystem observational records to inform and evaluate models.
- Encourage exploratory projects to address previously unrecognized or innovative questions.

TES plans to expand investments in biogeochemical cycles (e.g., carbon, nutrients) associated with subsurface ecology; address interfacial systems that have previously been excluded from TES portfolios (e.g., water/land interface; natural/urban interfaces); initiate a new thrust in tropical system ecology; and support novel research that couples regional and global carbon cycle dynamics.

TES seeks to connect its projects closely to other research activities within the Division, within BER, and among the other Federal agencies. Specifically, TES interacts with the CESD modeling programs by tying each TES-funded project to a model-justified hypothesis and by requiring that each large project have an explicit modeling component. TES will increase its coordination with the CESD modeling activities by coordinating research solicitations and jointly funding projects: for example, developing an Arctic regional model to support the growing emphasis in Federal Arctic research. In addition, TES management will forge strong programmatic coordination with other CESD research areas such as ASR and EMSL. TES management will furthermore establish a collaboration arrangement with the Genomics Sciences Program (within the BER Biological Systems Sciences Division) to engage the molecular biology community.

5.4 Earth System Modeling Program

ESM supports development of the CESM and community model evaluation tools. The program's general goals are to improve the detailed physical and biogeochemical processes in the CESM; to implement and test variable and high-resolution model components, both individually and in the coupled system; and to optimize model performance with respect to model resolution, model complexity, and scalability on DOE Leadership Class computer architectures. Model development strategies are formulated to enhance climate projection capabilities, improving competencies in simulating climate feedbacks, tipping points, and responses to past and possible future energy pathways. These enhancements are then analyzed more extensively within RGCM, which provides feedback to ESM with respect to analysis-driven model development requirements.

Specifically, ESM and its collaborations with other CESD research activities will advance a capability for improved climate system predictability through advances within the CESM model components (CAM, CLM, CICE, ocean model, CISM, etc.).

Priorities for the Next Five Years:

- Community Atmosphere Model (CAM) development, in collaboration with ASR, guided by measurements from the ARM Facility. Priorities include improvement of cloud distributions and feedbacks at various model resolutions and within variable-resolution grids; development and testing of aerosol microphysical schemes to accurately simulate aerosol interactions with clouds; and improved simulations of aerosol-chemistry-climate interactions, including ozone and methane.
- Community Land Model (CLM) development, in collaboration with TES. Priorities include improving model soil moisture, tropical ecosystem dynamics, and evolution of boreal and Arctic land and ecosystems; and improving land-atmosphere interactions, including terrestrial sources of radiatively active gases and aerosols, soil moisture impacts on atmospheric processes, and precipitation influence on the terrestrial systems. Global land models will be evaluated and used to guide TES process research by discerning those geographic regions and system representations that are characterized by significant parametric uncertainty.
- Modeling of the full terrestrial-ocean-atmospheric carbon cycle to enable comprehensive understanding of the fluxes and reservoirs of carbon and the relative importance of natural and combustion sources. CESM isotopic capabilities will be enhanced and developed and compared to measurements to further enable this distinction.
- Effective coupling of the human and natural systems within ESMs building upon partnerships with IAR. This modeling collaboration develops and couples CESM components in order to explore critical human-climate interactions, such as the impacts of water and land use on the climate system and the implications of water availability on human adaptation and energy choices, as well as an improved understanding of the impacts that energy by-products have on the climate system.

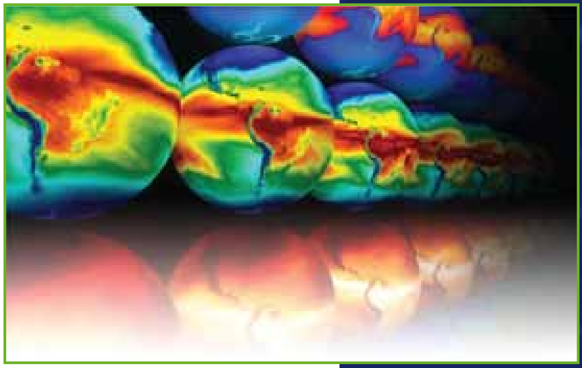
- Development of CESM ocean, sea-ice, and land-ice systems. The Community Ice Sheet Model (CISM) will develop and improve processes needed to simulate ice sheet evolution and destabilization and performance of adaptive and variable mesh grids; CISM-ocean coupling will enable sea-level change simulations. Sea-ice (CICE) process development supports projections and analysis of sea-ice change. The variable-mesh Model Prediction Across Scales (MPAS) Ocean represents a high priority strategic investment, and MPAS-O development and testing activities will greatly improve the CESM climate simulations, including ocean heat uptake, changes in circulation, and Arctic ocean research.
- Development of advanced computational and software analysis tools to optimize CESM performance on DOE leadership class computers. The ESM-ASCR SciDAC partnership supports development of efficient and scale-aware system physics at increased or variable resolution for CAM, MPAS, and ice sheets, including code development for optimal performance on DOE Leadership Class computers. New computational methods will permit the CESM to efficiently carry more interactive biogeochemical species. Uncertainty Quantification (UQ) methods will be used to guide model development, calibrate parameters and parameterizations, and facilitate interpretation of climate model projections. Sophisticated statistical model-measurement testbeds will be built to efficiently determine the model parameters with the greatest effects on the system and to use measurements to test and calibrate the model components. Finally, ESM will pursue a comprehensive assessment of required complexity for the coupled climate system, including evaluation of climate model sensitivity, feedbacks and performance, as a function of model complexity and resolution.

5.5 Regional and Global Climate Modeling Program

RCGM's goal is to advance the predictive understanding of Earth's climate, its variability, and change by focusing on analysis of regions critical to climate; evaluating robust methods to obtain higher spatial resolution; and diagnosing and analyzing state-of-the-science for coupled climate and Earth system models to understand climate variability and change at regional and global scales. RGCM investments are designed to develop metrics for model validation, to conduct climate analysis research in order to inform the model development strategies of ESM, and to inform the process research priorities within TES and ASR. RGCM also coordinates with IAR on understanding individual and select coupled systems, such as water resources, critical for the energy mission.

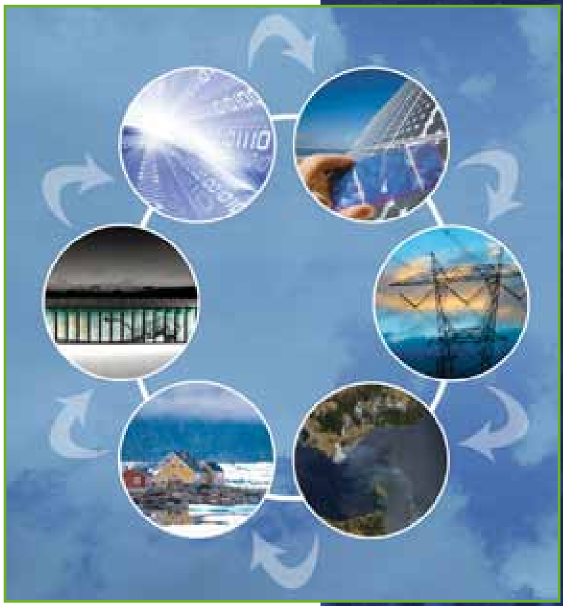
Priorities for the Next Five Years:

1. Development of robust analytic frameworks and model hierarchies to advance Earth system projections, predictions, and hindcasts, and to understand climate evolution at multiple scales. The focus also includes decadal predictions for specific regions, using high-resolution and variable scale climate modeling, and applying a combination of dynamical and statistical downscaling methodologies. Metrics will be developed and assessed depending on measurement availability and quality, and depending on temporal and spatial scales.



2. Focused investigation of regions that are climatically sensitive or vital to climate assessments.
   - **Arctic focus:** Analyze the complex interactions between sea ice, ice sheets, cold oceans, regional climate, and permafrost stability in the context of both high-resolution regional and global models. This links closely with the vegetation and biogeochemical focus of the Next Generation Ecosystem Experiment (NGEE) Arctic and informs ESM model development.
   - **Tropical focus:** Includes an emphasis on understanding and identifying tropical biases, such as cloud-precipitation biases, in collaboration with ASR, and in the carbon cycle, in collaboration with TES and NGEE tropics.
   - **Regional focus:** Analysis of the integrated water cycle as climate changes will be done in collaboration with IAR.
3. The assessment and delineation of natural and forced climate variability. Estimating the anthropogenic climate change and natural variability will need a combination of modeling and observational expertise. This also includes a thorough understanding of the different long- and short-term modes of climate variability (e.g., El Niño Southern Oscillation, Madden-Julian Oscillation) and how these change in a changing climate.
4. The analysis and understanding of climate extreme events, including floods and droughts, potential abrupt system changes, and tipping points, and how these are affected in a changing climate. Further emphasis will be placed on multivariate extremes, such as simultaneous combinations of hot, dry, and windy conditions and hot, moist, and stagnant conditions, and characterizing the number and amount of exceedances above given thresholds and quantifying the uncertainties. Climate system resilience, reversibility, and tipping points will be investigated.
5. The characterization of climate feedbacks and their uncertainties to quantify the cloud-climate, carbon-cycle climate, high-latitude feedback processes and address the fidelity of the models that capture these processes at regional and global scales. The result of understanding these uncertainties will be to inform model development.
6. Model evaluation, analysis, uncertainty characterization, diagnostics, and frameworks to improve and facilitate comparison among models and between models and measurements in order to challenge and inform model development. Metrics to evaluate the new components of the Earth system like the carbon cycle, ocean eddies, and cloud-aerosol interactions will feed back to the need for observational and process research.
7. Dissemination of data through the ESGF. The ESGF is an interagency and international effort led by DOE and co-funded by national and international agencies for the management and dissemination of CMIP5 model output and observational data. Efforts will soon be placed on developing a roadmap to upgrade the ESGF to handle data emerging post-CMIP5.
8. Development of visualization and analysis tools to enable effective model analysis. Climate model analysis tools that focus on metrics that evaluate and intercompare models will make the climate model output more accessible to science and scientists.

5.6 Integrated Assessment Research Program



IAR supports the development of models and tools to explore the interactions of human and natural systems in a context of climate change and a changing world. IAR examines the dynamics of energy systems, future energy technologies and options, land and water use, and combined interactions with other sectors and natural systems giving rise to complex behaviors and unanticipated system responses. Applied research programs within DOE benefit directly from such long-term predictive research and science-based models and tools. Additionally, Integrated Assessment Models (IAMs) support advances in understanding and modeling efforts of the broader climate research enterprise. They provide deep insights into potential sources of greenhouse gas emissions, biogeochemical cycles, human-influenced natural resource demands, and impacts and potential adaptations, all built around economic and risk based modeling frameworks.

Priorities for the Next Five Years:

- Expand IAM representations of impacts, adaptations, and vulnerabilities, with a particularly strong focus on representations of energy system vulnerabilities and potential responses. Corresponding improvements will strengthen DOE's capacity to project energy system challenges in a multi-sector context and to collectively model system behaviors and issues at the intersection of mitigation and adaptation.
- Improve linkages among open-source, community-based models spanning the various climate modeling communities. Work will focus on IAMs of intermediate and high complexity. Efforts will focus on creating more interoperable modeling structures that enable couplings of IAMs with detailed regional climate models and/or the CLM of the CESM. Collaborations between IAR and the recently formed CESM Societal Dimensions Working Group will be explored. Improved interoperability and model couplings will enable new frontiers of "deep dive" modeling experiments on issues such as land use and land cover change, biogeochemical cycles, and feedbacks to the climate system, eventually paving the way for next-generation, fully integrated Earth system models working in partnership with ESM. Interoperability enhancements will also facilitate connections with discrete impact, adaptation, and vulnerability component models.
- Improve model resolution and representations across temporal and spatial scales. Impacts and adaptation are inherently local; therefore, advancing model resolution to finer scales will be necessary. Multi-scale issues will be explored through a large, dedicated project to examine the potential for a regional IAM framework.
- Strengthen representations of complex systems and emergent behaviors within IAMs. Emphasis will be placed on modeling multiple, interactive stressors (sectors and broader dimensions of global change), systems interdependencies, and feedbacks; the role of evolving science and technology and associated uncertainties; and the nexus of mitigation and adaptation; as well as key systems not currently represented or represented well in the models. Understanding energy-water-land systems dynamics is a critical priority.

Understanding connected infrastructure impacts and inter-dependencies is another high priority. IAR will join forces with RGCM and ESM, as well as components of TES, to develop improved capacity for modeling regional integrated water cycles and carbon cycles.

- Improve uncertainty characterization and quantification spanning the integration of human and natural systems.
- Enhance rigor, consistency, and innovation in IAM testing and diagnostics.
- Emphasize community-based models and accessible platforms, dedicated data management capabilities, and supporting computational capabilities (e.g., Evergreen HPC system). DOE is a leader and steward in the field of Integrated Assessment research, and such foundational capabilities will continue to produce high leverage and capacity for the nation's research enterprise.

5.7 Atmospheric Radiation Measurement Climate Research Facility

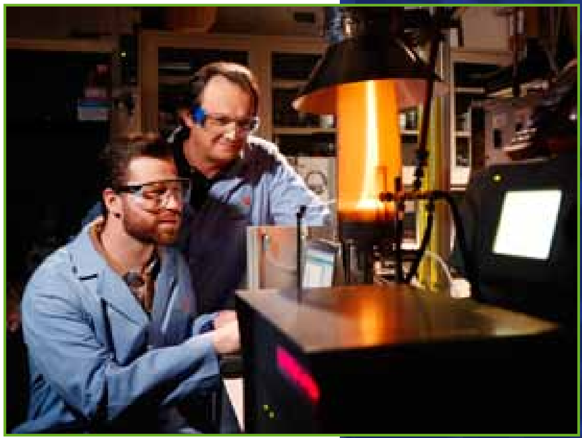
DOE seeks to inform energy decisions by providing scientific knowledge and tools to understand the role of energy production and use in a changing climate and to project the impacts of climate change on future energy systems. Areas of critical scientific uncertainty in this area include the role of clouds and aerosols in controlling the spatial distribution of radiative balance, precipitation, and temperature as the climate evolves. DOE's ARM Climate Research Facility seeks to resolve these uncertainties with extensive long-term ground-based in situ and remote sensing observations supplemented with airborne measurements. ARM's resources are designed to improve the understanding and representation of clouds and aerosols in climate and Earth system models, as well as their interactions and coupling with the Earth's surface.

The four fixed ARM sites are situated in climatically distinct locations to sample continental and marine conditions in tropical, midlatitude, and Arctic environments (U.S. Southern Great Plains, Tropical Western Pacific, North Slope of Alaska, and the Azores). ARM also has an aerial measurement capability and three mobile facilities that can be used in experiments across the globe. While two of the mobile facilities deploy for 6- to 12-month durations, the third mobile facility will be installed at Oliktok, Alaska, for an extended multi-year deployment. The recently added complement of scanning radars to all of the ARM fixed and mobile sites provides a unique capability for high-resolution delineation of cloud dynamical evolution, morphology, and radiative properties, in support of both the atmospheric sciences and climate modeling. The simultaneous and parallel operation of multiple radar and lidar systems, capturing continuous datastreams, provides an unparalleled capability for "interrogating" the three-dimensional growth and decay of individual clouds and their interactions with the larger associated weather systems. To exploit ARM capabilities more efficiently for the climate modeling community, surface observations of geomorphology, turbulent momentum and heat fluxes, aerosol flux, carbon flux, methane, soil moisture, and/or sea surface temperature are often collocated with ARM instrumentation.

Priorities for the Next Five Years:

- Seek to bridge the atmospheric and modeling communities to optimize the collection and reporting of observations in ways that best address the collective needs of these communities.
- Fully exploit new Recovery Act instrumentation and capabilities of all ARM facilities.
- Deploy the third mobile facility at Oliktok, Alaska, coupled with regular deployments of small unmanned aerial vehicles (UAVs) for in situ measurements, in order to launch a multi-year effort to provide critical cloud and aerosol properties over land, oceans, and sea ice.
- Couple data from the Barrow and Oliktok sites to develop grid-scale products for improving model representation of Arctic atmospheric dynamics, cloud, aerosol, and precipitation processes.
- Develop long-term collaborations with European partners to ensure the availability and common format of critical field data needed to improve climate models.
- Utilize shipboard deployments of the second mobile facility and the fixed site in the Azores to investigate physical processes associated with turbulence, convection, and radiation in a variety of marine cloud types.
- Further expand the capabilities of the sites, specifically the Southern Great Plains site, to develop testbeds for better understanding of the coupling of land, ecosystem, and atmospheric interactions.
- Facilitate access to ARM data for scientific and decision-making communities.

5.8 Environmental Molecular Sciences Laboratory



EMSL, a DOE Scientific User Facility located in Pacific Northwest National Laboratory in Richland, Washington, is dedicated to enabling multi-disciplinary research on the complex physical, chemical, and biological interfaces, interactions, and mechanisms that contribute to DOE's science missions. The facility has three science themes: biological interactions and dynamics, geochemistry and biogeochemistry of subsurface environments, and science of interfacial phenomena.

EMSL houses more than 75 premier instruments for experimental studies; a high-performance computing capability optimized for molecular-level modeling and simulation, the open-source NWChem computational chemistry code, and associated data storage systems; collaborative software tools; and in-house scientific expertise. EMSL's capabilities enable users to undertake experimental and theoretical research leading to insights into the fundamental mechanisms of the molecular reactions that influence climate and environmental systems science, including mechanisms of carbon and nutrient cycling in soils and ecosystems; aerosol particle formation and evolution; geochemical and hydrologic processes influencing carbon sequestration; biogeochemical cycling and contaminant transport in subsurface systems; microbial systems and biodesign for bioenergy applications; and other energy recovery, storage, processing, and analysis challenges.

EMSL not only makes premier experimental and computational capabilities available to users in one location, but also ensures that allocations of time on individual resources are coordinated to enable users to fully address their project objectives using as many of the resources as possible. All of these resources can be accessed with a single user proposal.

EMSL's resources are organized into eight capabilities:

1. Cell Isolation and Systems Analysis
2. Deposition and Microfabrication
3. Mass Spectrometry
4. Microscopy
5. Molecular Science Computing
6. Nuclear Magnetic Resonance (NMR) and Electron Paramagnetic Resonance (EPR)
7. Spectroscopy and Diffraction
8. Subsurface Flow and Transport.

While users can submit proposals to use one resource within a single capability, most EMSL users submit proposals that make use of multiple resources that cut across multiple capability groups. By collocating multiple types of capabilities and scientific expertise in a single facility, EMSL serves as an ideal place for research teams to use multiple capabilities to investigate complex scientific challenges, or for individuals from senior researchers through early career scientists and graduate students to use premier capabilities to conduct a wide range of single-investigator studies.

Priorities for the Next Five Years:

- Promote and demonstrate the use of EMSL's full range of experimental and computing capabilities (in particular the newly inaugurated Quiet Wing, the nanoSIMS system, pore scale micromodels and microfluidics systems, high-resolution spectroscopy, etc.) by more research teams to facilitate the types of multidisciplinary research that are needed to understand the physical, chemical, and biological interfaces and interactions that occur in dynamic climate and environmental systems.

- Emphasize a continuum of research efforts that connects a range of scales from the atomic and molecular through pore- and meso-scales in terrestrial and subsurface systems, and through particle nucleation, aggregation, and transformation in atmospheric systems.
- Advance and provide instrumentation to enable users to better examine and study the in situ dynamics of reactions and processes that occur at solid-gas, solid-liquid, and liquid-gas interfaces, in cellular systems, on surfaces, in materials, and in other environments.
- Build partnerships with globally connected researchers across disciplines through digital libraries, unique informatics, visualization capabilities, and other collaborative resources.

5.9 Carbon Dioxide Information Analysis Center

Although many CESD activities include significant, self-contained, data management components (such as PCMDI, ARM, and NGEE), CDIAC is the only designated data management activity.

CDIAC provides stewardship and access to critically needed and world-renowned data sets that are unique in the federal landscape. Currently, CDIAC provides quality-assured and fully documented numerical data on the carbon cycle and terrestrial ecosystems. The objective is to support the exchange and high-quality analyses of complex data in order to synthesize information used in evaluating environmental issues. CDIAC's data holdings include records of the atmospheric concentrations of carbon dioxide and other radiatively active gases; the role of the terrestrial biosphere and the oceans in the biogeochemical cycles of greenhouse gases; emissions of carbon dioxide from fossil-fuel consumption and land-use changes; long-term climate trends; the effects of elevated carbon dioxide on vegetation; and the vulnerability of coastal areas to rising sea level. The center also supports data stemming from the interagency activities of AmeriFlux and ocean CO_2 observations. The user community includes scientists, educators, students, and policy makers worldwide.

Priorities for the Next Five Years:

- Coordinate and make available results from new terrestrial ecosystem experiments, including SPRUCE (Spruce and Peatland Responses Under Climatic and Environmental Change) and NGEE.
- Expand the AmeriFlux data interface with additional data products resulting from new CDIAC capabilities (gap-filling algorithms, flux re-analysis products, and flux uncertainty estimates). Add new flux measurements (e.g., CH_4, NO_x) to the AmeriFlux data collection.
- Maintain, enhance, and update existing databases, interfaces, and products and create new products in support of BER programs and international climate change research. Data products will cover the major disciplines of climate change research including the atmospheric, oceanic, and terrestrial sciences, as well as climatology and anthropogenic emissions.
- Develop several synthesis products that will serve as benchmark data sets for future climate change modeling and synthesis efforts.
- Release several noteworthy ocean synthesis products. Measurements from additional observational platforms including moorings and additional coastal measurements from the Global Coastal Project will serve to further enhance the world's largest collection of ocean carbonate chemistry measurements.
- Develop and distribute unique regional climate databases and products focusing on U.S., China, and Russia.
- Contribute reviews and analyses of heat waves and cold waves to the United States Global Change Research Program National Climate Assessment.

- Produce core time series of fossil-fuel related emissions at multiple spatial scales annually at global, regional, national, and subnational (1 x 1 degree) scales. A major new thrust will be to quantify and publish uncertainty of national fossil-fuel CO_2 emission estimates.
- Improve existing cyber infrastructure and metadata tools to facilitate finding, using, and citing CDIAC data; facilitate use by other data gateways (e.g., DOE's Earth System Grid); and increase usage of CDIAC data and products worldwide.

While CDIAC is the only currently designated data management activity, many programs in the Division recognize that an urgent need will emerge within the next 2–4 years for an integrated data management architecture that can accommodate the expanding requirements for CDIAC, NGEE, the Earth System Grid, and ARM Facility databases. Beginning in FY2012 and becoming more intensive in FY2013, the Division will launch several town halls and workshops to help define the requirements, partnerships, and best approaches to build this capability that serves the climate research community.

Acronyms

AMIE	ARM Madden-Julian Oscillation Experiment
ARM	Atmospheric Radiation Measurement
ASCR	Advanced Scientific Computing Research
ASR	Atmospheric System Research
BER	Office of Biological and Environmental Research
CAM	Community Atmosphere Model
CDIAC	Carbon Dioxide Information Analysis Center
CESD	Climate and Environmental Sciences Division
CESM	Community Earth System Model
CICE	sea ice
CISM	Community Ice Sheet Model
CLM	Community Land Model
DOE	Department of Energy
EMSL	Environmental Molecular Sciences Laboratory
EPR	electron paramagnetic resonance
ESGF	Earth System Grid Federation
ESM	Earth System Modeling
GoAMAZON	Green Ocean Amazon
IAM	Integrated Assessment Model
IAR	Integrated Assessment Research
iESM	integrated community Earth system model
MAGIC	Marine ARM GPCI Investigation of Clouds
MPAS-O	Model Prediction Across Scales-Ocean
NGEE	Next-Generation Ecosystem Experiment
NMR	nuclear magnetic resonance
PCMDI	Program for Climate Model Diagnostics and Intercomparison
RGCM	Regional and Global Climate Modeling
SBR	Subsurface Biogeochemical Research
SC	Office of Science
SPRUCE	Spruce and Peatland Responses Under Climatic and Environmental Change
TES	Terrestrial Ecosystem Science
UAV	Unmanned Aerial Vehicle
UQ	Uncertainty Quantification

For More Information

Climate and Environmental Sciences Division • http://science.energy.gov/ber/research/cesd/
Gary Geernaert, gerald.geernaert@science.doe.gov

ARM Climate Research Facility • http://www.arm.gov
Wanda Ferrell, wanda.ferrell@science.doe.gov
Rick Petty, rick.petty@science.doe.gov

Atmospheric System Research • http://asr.science.energy.gov/
Ashley Williamson, ashley.williamson@science.doe.gov

Carbon Dioxide Information Analysis Center • http://cdiac.esd.ornl.gov/cdiac/
Wanda Ferrell, wanda.ferrell@science.doe.gov

Earth System Modeling • http://climatemodeling.science.energy.gov/
Dorothy Koch, dorothy.koch@science.doe.gov

Environmental Molecular Sciences Laboratory • http://www.emsl.pnl.gov/
Paul Bayer, paul.bayer@science.doe.gov

Integrated Assessment Research • http://climatemodeling.science.energy.gov/
Bob Vallario, bob.vallario@science.doe.gov

Regional and Global Climate Modeling • http://climatemodeling.science.energy.gov/
Renu Joseph, renu.joseph@science.doe.gov

Subsurface Biogeochemical Research • http://doesbr.org/
David Lesmes, david.lesmes@science.doe.gov
Paul Bayer, paul.bayer@science.doe.gov

Terrestrial Ecosystem Science • http://tes.science.energy.gov/
J. Michael Kuperberg, michael.kuperberg@science.doe.gov
Daniel Stover, daniel.stover@science.doe.gov