Earth System Modeling (ESM) Accelerated Climate Model for Energy (ACME)

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Earth System Modeling

Climate and Environmental Sciences Division

Biological and Environmental Research

July 9, 2014

CLIVAR summit

Climate and Environmental Sciences Division

Atmospheric Science

Atmospheric System Research

Atmospheric Radiation Measurement Facility

Climate and Earth System Modeling

Earth System Modeling

Regional & Global Climate Modeling

Integrated Assessment

Environmental System Science

Terrestrial Ecosystem and Subsurface Research

Data Informatics

Environmental Measurements Laboratory

Earth System Modeling portfolio
Global climate model development

1. **20% University-led projects (FY14-16)**
(SciDAC: Scientific Discovery through Advanced Computing)
New awards: 8 multi-institutional projects on atmosphere/cloud modeling, atmospheric chemistry, terrestrial modeling, paleoclimate-ice-sheets, ocean dynamics (MPAS-O, NCAR/LANL)**, ocean biogeochemistry** (modularize O-BGC and install in MPAS-O, NCAR/LANL)
More awards in FY15

2. **20% SciDAC-Lab (FY11-16)**

3. **60% Lab projects (now ACME)**

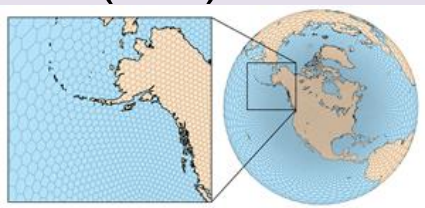
SciDAC3, 3 Lab-led projects, 2011-2016
Co-managed, co-funded with DOE Computing

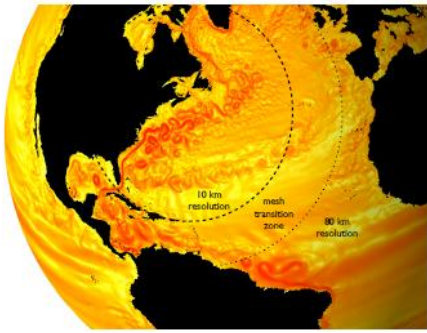
All engage with ASCR (computing) SciDAC Institutes:
"Super" (performance), "FastMath" (math methods), "Quest" (UQ)

1. Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System

LBNL, LANL, PNNL, ORNL, LLNL, SNL, NCAR, UW-M, CSU, UCLA

Scale-aware physics for variable mesh dycores (MPAS-O and CAM-SE): Atmospheric convection (4 approaches); Ocean eddies

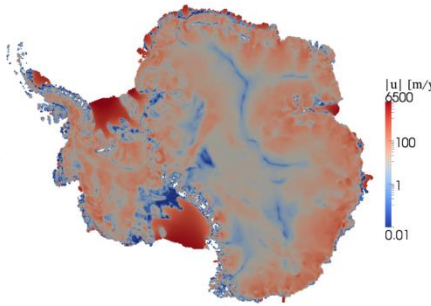




2. Predicting Ice Sheet and Climate Evolution at Extreme Scales (PISCEES)

LBNL, LANL, ORNL, SNL, NCAR, MIT, FSU, U-SC, UT-Austin

Two ice sheet dynamical cores with variable mesh; UQ for boundary, initial conditions V&V Toolkit

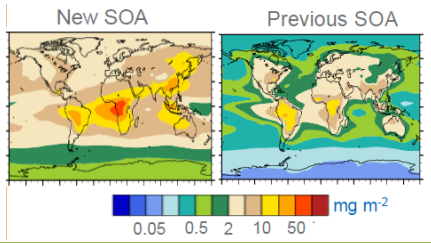


3. Applying Computationally Efficient Schemes for BioGeochemical Cycles (ACES4BGC)

ORNL, SNL, LLNL, PNNL, LANL, ANL, NCAR

Organic species for atmosphere, ocean and land

Tracer transport, variable mesh



ESM Multi-Laboratory projects

1. **COSIM – ocean, sea-ice, land-ice (with RGCM)**
2. **IMPACTS – abrupt changes, e.g. permafrost, clathrates, drought**
3. **"Polar": Arctic ocean, sea-ice, clouds, aerosols**
4. **Ultra-high-resolution: ocean-atmosphere focus**
5. **UV-CDAT: tools for visualization and analysis**
6. **Climate Science for a Sustainable Energy Future (CSSEF): UQ, workflow, variable-mesh dycores**
7. **Integrated Earth System Model (iESM): GCAM-IAM to CESM through carbon cycle (with IAR)**
8. **FASTER: using ARM data to test and improve cloud simulations**

ESM-Lab projects in 2014: Model development in 8 Laboratories and 8 projects

	CSSEF	Polar	COSIM	IMPACTS	UV-CDAT	Hi-Res	iESM	FASTER
ANL								
LANL								
LBNL								
LLNL								
ORNL								
PNNL								
SNL								
BNL								

ESM-Labs:

	ACME	iESM
ANL		
LANL		
LBNL		
LLNL		
ORNL		
PNNL		
SNL		
Other	NCAR, UC-Irvine, Scripps, Kitware, NYU-Poly, U-MD, BNL	

Multi-Laboratory development project (8 Labs, 6 non-Labs)
Proposal submitted: January 2014
Project reviewed: March 2014

Accelerated Climate Model for Energy

High resolution (15-25 km) off-shoot of the CESM coded to run efficiently on current and future DOE computers: a climate projection capability (1970-2050) in support of DOE science and mission.

Review March 4-5, 2014
Face-to-face (reverse-site)
18 reviewers
30 Team scientists
DOE program managers

Review panel
50% from model groups; 50% University
2/3 Climate 1/3 Computational
4 non-U.S.

Accelerated Climate Model for Energy

Major Review Findings

- ❖ **Solid plan, solid team**
- ❖ **DOE plan to consolidate, coordinate**
- ❖ **"Top-down" structure, serious project commitment – crucial for this project**

- ➢ **Concise and more focused project description recommended.**

Brief Project Plan has been developed (available soon; see DOE modeling website – next week - http://www.climatemodeling.science.energy.gov/***)***

- ➢ **Project management challenges**

Project engineer, management softwares…

- ➢ **Energy-societal elements require further definition**

Workshop planned

Accelerated Climate Model for Energy

Science Goals

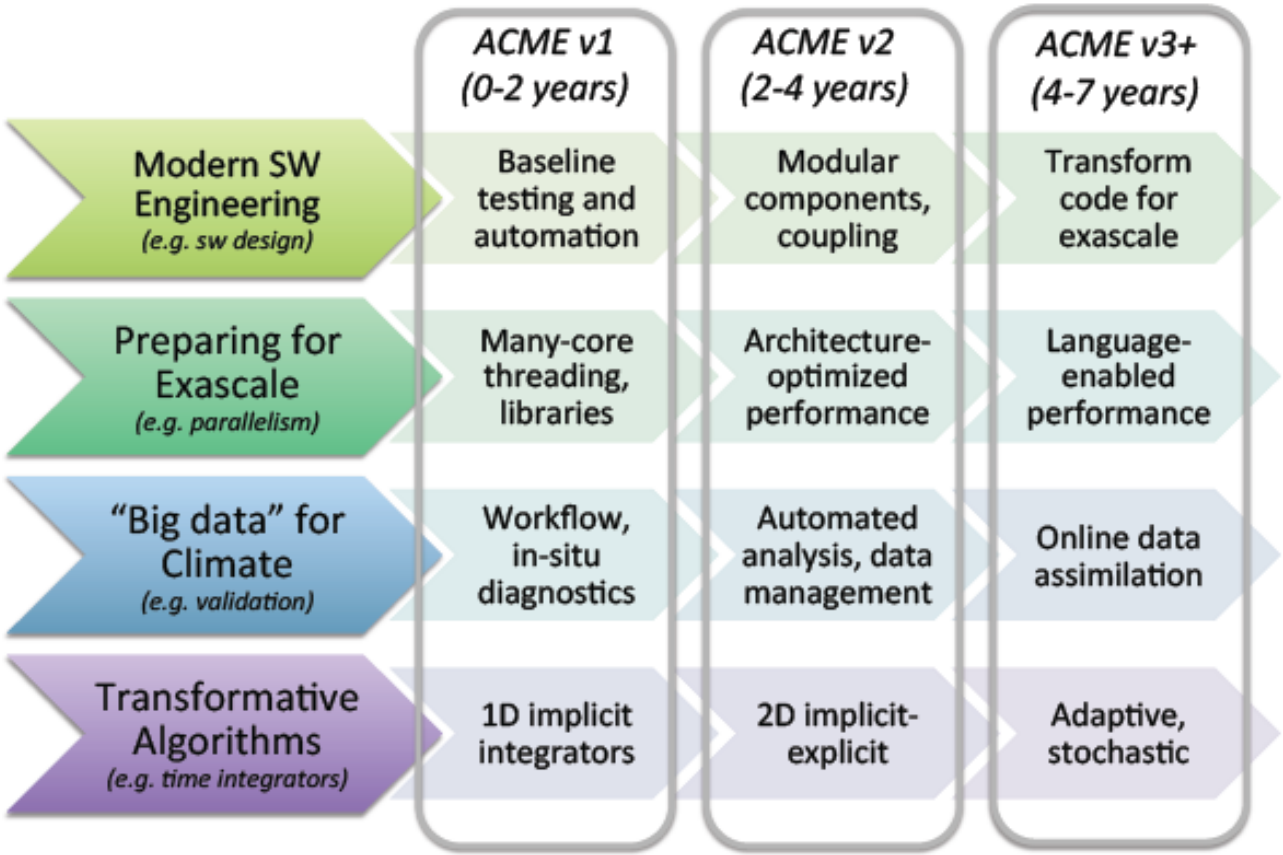
Water cycle: How do the hydrological cycle and water resources interact with the climate system on local to global scales?
Evolution of precipitation and river flow.

Biogeochemistry: How do biogeochemical cycles interact with global climate change?
Evolution of natural versus managed systems fluxes of greenhouse gases.

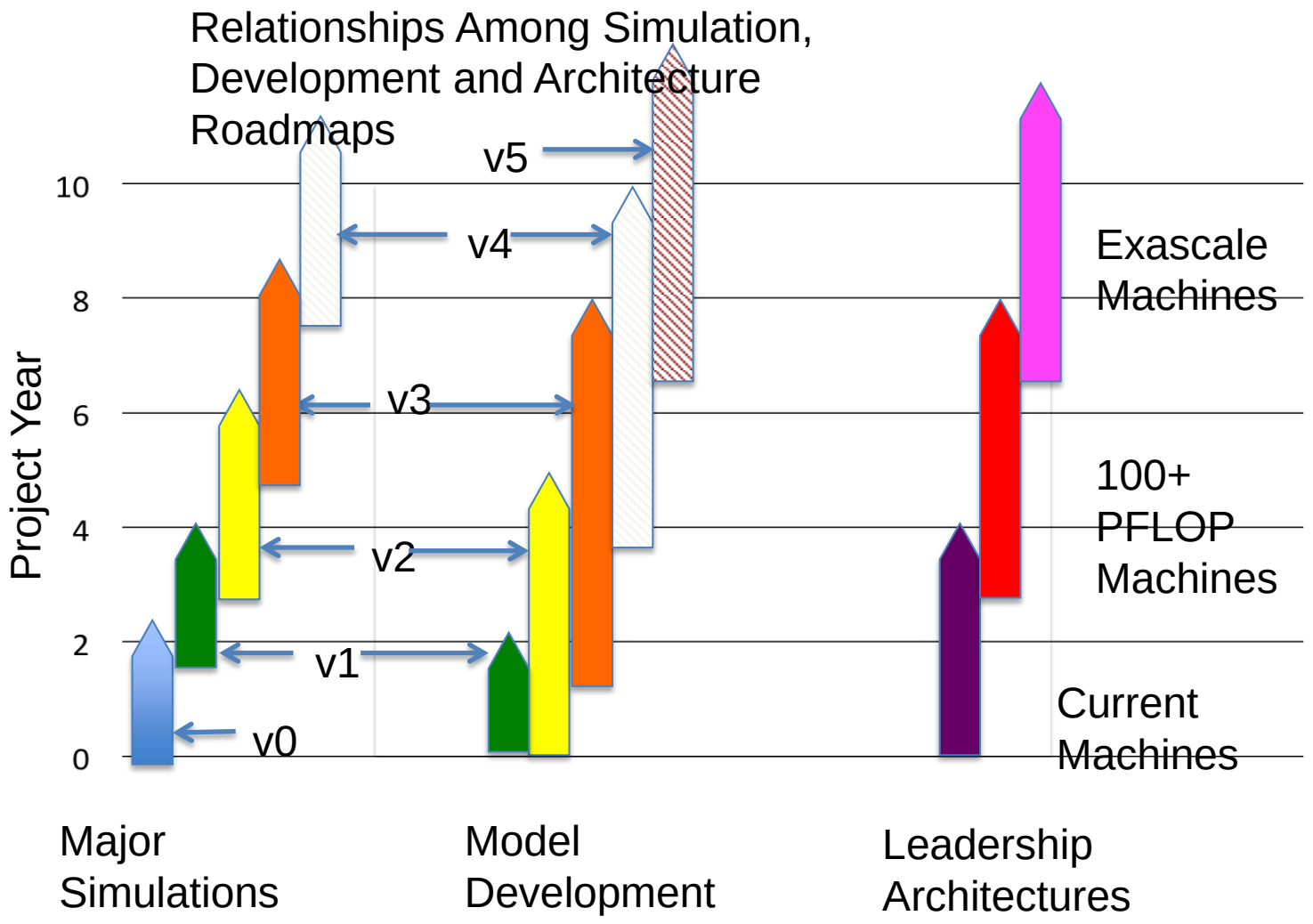
Cryosphere: How do rapid changes in cryospheric systems interact with the climate system?
Long term committed Antarctic ice sheet contribution to SLR from changes in 2010-2050.

Accelerated Climate Model for Energy

Computation roadmap



Strategy: simulations-development-architectures



Management

Council
David Bader - Chair; William Collins - Chief Scientist, Mark Taylor – Chief Computational Scientist
Robert Jacob, Philip Jones, Philip Rasch, Peter Thornton, Dean Williams
Ex Officio – James Edmonds, James Hack, William Large, Esmond Ng,

Executive Subcommittee
Council Chair, Chief Scientist, Chief Computational Scientist

Project Engineer
Renata McCoy

Ice/Ocean Task Team
Philip Jones and Mathew Hecht, Leaders

Atmosphere Task Team
Philip Rasch and Peter Caldwell, Leaders

Land Task Team
Peter Thornton and William Riley, Leaders

Coupled Simulation Task Team
Peter Caldwell, Matthew Hecht and William Riley Leaders

Performance and Algorithms Team
Hans Johansen and Patrick Worley, Leaders

Coupler and Software Engineering Team
Robert Jacob and Andrew Salinger, Leaders

Workflow Team
Dean Williams and Katherine Evans, Leaders

Ocean/Ice Task Leaders

Atmospheric Task Leaders

Land Task Leaders

Coupled Simulation Task Leaders

Performance Task Leaders

Coupler Task Leaders

Workflow Task Leaders

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CLIMATE SCIENCE FOR A SUSTAINABLE ENERGY FUTURE (CSSEF)

In 2010, the U.S. Department of Energy Office of Science asked its national laboratory system to collectively develop the Climate Science for a Sustainable Energy Future (CSSEF) project to bring

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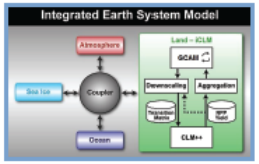
IMPROVING THE REPRESENTATIONS OF HUMAN-EARTH SYSTEM INTERACTIONS: iESM PROJECT

Sponsored by the U.S. Department of Energy Office of Science, the Integrated Earth System Model (IESM) Project has produced a first generation, complex earth system model that integrates detailed representations of human systems. By merging major components from two of DOE's core modeling programs, Earth System Modeling and Integrated Assessment Science and Modeling, a new breed of sophisticated, detail-rich simulation capabilities has emerged to advance the science of human and Earth system interactions, including studies of land use, future bioenergy systems, hydrology, climate adaptation and mitigation. IESM is built around four underlying models: human systems components from the Global Change Assessment Model (GCAM); the Community Earth System Model (CESM) and a major CESM component model, the Community Land Model (CLM), as well as a land coupling model, the Global Land Model (GLM).

Initiated in 2009 and running through 2013, this 5-year project is a collaboration between five institutions. Pacific Northwest National Laboratory's Joint Global Change Research Institute develops and maintains GCAM while providing regional testbed development capabilities for hydrology modeling. Oak Ridge National Laboratory is working with the Community Land Model, a component of the CESM. Lawrence Berkeley National Laboratory is developing the code structure for full integration within the CESM framework. University of Maryland applies and develops the GLM model to integrate land representations between GCAM and CLM. All five institutions work together on experimental applications for overall model development and analysis.



OPPORTUNITY

Create a first-generation iESM with both the human components of an integrated assessment model and the physical characteristics of an earth system model.

Further develop components and applications within the iESM and test the model against policy scenarios to improve the understanding of the coupled physical, ecological, and human systems.

Add realistic hydrology, including freshwater availability from surface water, ground water, and desalination.

CHALLENGE

Development of an IESM makes it possible to integrate human dimensions of energy and land use scenarios directly into full global climate models to improve prediction of potential future climate change, the implications of emissions mitigation options, and climate change impacts and adaptation options. Changes in behavior of the coupled climate-energy-land modeling system based on full ESMs, such as CESM, are yielding different results than coupled models based on Earth System Models of Intermediate Complexity (EMICs) and significantly different results than uncoupled models. One trade-off, however, is computational intensity for the near limitless options in human systems and decision-making. Accordingly, IESM is expected to advance a new class of human-earth systems understanding and analytic capabilities while working in tandem with other established modeling capabilities. The convergence of these leadership class models will greatly advance our understanding of the physical climate system.

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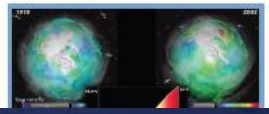
THE ULTRA-SCALE VISUALIZATION CLIMATE DATA ANALYSIS TOOLS

As the need to understand and project climate change becomes increasingly critical, climate model complexity, model resolution and the number of simulations required increases. To keep pace with the growing size and complexity of climate simulations, new software tools are required to enhance and speed manipulation and analysis of the climate data and model output. This creates a challenge for global computational teams to visually and analytically assist scientists in their mission to understand and estimate climate change.



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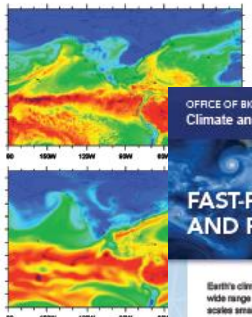
MULTISCALE METHODS FOR ACCURATE, EFFICIENT, AND SCALE-AWARE MODELS OF THE EARTH SYSTEM

MULTISCALE is a SciDAC Earth System Modeling project with the primary goal of producing better climate models across the full range of spatial and temporal resolutions required to address the needs of both the climate sciences and policy-oriented communities. The principle goals of the MULTISCALE team are to:

- Address grand challenges in projecting the future of the Earth's climate resulting from the interactions among small-scale features and large-scale structures of the ocean and atmosphere in climate models.
- Develop a generation of models that capture the structure and evolution of the climate system across a broad range of spatial and temporal scales.

MULTISCALE is an integrated team of climate and computational scientists working to accelerate the development and integration of multiscale atmospheric and oceanic parameterizations into the Community Earth System Model (CESM).



Snapshots of precipitable water from CAM-SE climate resolution (top) and a variable resolution (bottom). The expected to agree, but instead demonstrate CAM's va capability: On the top, the detailed structure of water v extra globe, while on the right, the 6x lower resolution visible, but high resolution is maintained over the cent

VARIABLE RESOLUTION DYNAMICAL FRAMEWORKS

Some of the greatest challenges in projecting the future of Earth's climate result from the significant and complex interactions among small-scale features and large-scale structures of the ocean and atmosphere. In order to advance earth-system science, a new generation of models are required to capture the structure and evolution of the climate system across a broad range of spatial and temporal scales. Our primary goal is to produce better models for these critical processes and constituents, from ocean-eddy and cloud-system to global scales, through improved physical and computational implementations. These processes must be represented seamlessly from highly resolved regions where they are represented explicitly to coarse resolution regions where they are parameterized. Our primary objective is to introduce accurate and computationally efficient treatments of interactive clouds, convection, and eddies into the next generation of CESM at resolutions approaching the characteristic scales of these structures. We plan to deliver treatments of these processes and constituents that are scientifically useful over resolutions ranging from 2 to 1/16 degrees.

SCIENTIFIC AND COMPUTATIONAL MOTIVATION

We are developing, validating, and applying multiscale models of the climate system based upon atmospheric and oceanic components with variable resolution. This effort is centered on new variable resolution unstructured grids based on finite element and finite volume formulations already developed by team members.

Effective deployment of these dynamical core and concurrent advances in time-stepping me generation, and automated optimization metho next-generation computer architectures.

Due to the centrality of the atmosphere and o of the coupled system, we are targeting major atmospheric and oceanic components of the C System Model (CESM). We have focused our small number of significant processes that gov behavior of the climate system and require sig and computational advances for successful in

climatemode

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PREDICTING ICE SHEET AND CLIMATE EVOLUTION AT EXTREME SCALES (PISCEES)

As the climate warms, mass loss from the Greenland and Antarctic ice sheets is accelerating. The resulting fresh water input into the oceans will be the dominant contribution to future sea-level rise. Predicting Ice Sheet and Climate Evolution at Extreme Scales, or PISCEES, is a multi-institutional* project developing state-of-the-art computer models of large ice sheets to improve projections of ice-sheet mass loss and sea-level rise.

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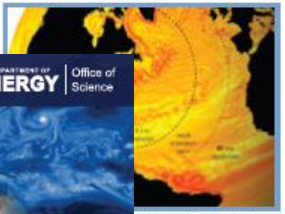
CLIMATE, OCEAN AND SEA ICE MODELING

The Climate, Ocean and Sea Ice Modeling (COSIM) project at Los Alamos National Laboratory is responsible for developing advanced computer models of the ocean, sea ice, and ice



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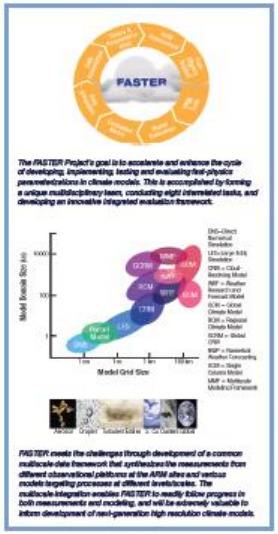
FAST-PHYSICS SYSTEM TESTBED AND RESEARCH (FASTER) PROJECT

Earth's climate system involves multiple physical processes over a wide range of space-time scales. Many key processes occur on scales smaller than climate model grid sizes and representation (parameterization) of the so-called fast physics—primarily cloud-related processes—a main source of uncertainty in climate models. Parameterizations pose daunting challenges in a variety of areas, ranging from observations to modeling, from understanding the processes to formulating effective parameterizations, from testing parameterizations to ultimately using them in climate models. The Earth System Modeling (ESM) Program of the U.S. Department of Energy's Office of Science initiated the Fast-Physics System Testbed and Research (FASTER) project in 2009 to meet the challenges by forming a multi-institutional*, interdisciplinary team of complementary areas of expertise to develop an effective, integrated multiscale model evaluation framework that best capitalizes on the detailed, continuous, long-term measurements from the different climate regimes of the Atmospheric Radiation Measurement (ARM) climate research facility sites.



The FASTER Project's goal is to accelerate and enhance the cycle of developing, implementing, testing and evaluating fast-physics parameterizations in climate models. This is accomplished by forming a unique multidisciplinary team, conducting eight interrelated tasks, and developing an innovative integrated evaluation framework.

THEMES AND OBJECTIVES

- Focus on the ARM sites with detailed, continuous, long-term measurements in different climatic regimes.
- Construction of a fast physics testbed, a multiscale data assimilation system, and eventually a multiscale visualization and evaluation system (MVES) that permits rapid, efficient evaluation and diagnosis of various fast processes at multiple scales.
- Integrative evaluation by combining models of different types and scales (from cloud to global scales), in addition to multiple models of each type, to better address the multiscale nature of processes and process interactions.
- Interactive utilization of targeted, idealized case studies as well as investigation of continuous, realistic, long-term observations.
- Strong integration of observations and models at multiple scales through use of multiscale data platform.
- Direct participation of main U.S. climate modeling centers to facilitate/accelerate implementation and testing of new/improved fast physics parameterizations in climate models.

ACCOMPLISHMENTS

- A fast-physics testbed has been constructed and the beta-version released for the registered users. The current testbed consists of two major complementary components that capitalize on the continually evolving cloud measurements at the ARM sites: a single-column model (SCM) testbed and a numerical weather prediction model (NWP) testbed. The SCM-NWP integration allows use of not only rich ARM measurements, but also a vast pool of NWP results.

FASTER meets the challenges through development of a common multiscale data framework that synthesizes the measurements from different observational platforms at the ARM sites and various models targeting processes at different levels/scales. The multiscale integration enables FASTER to readily follow progress in both measurements and modeling, and will be extremely valuable to inform development of next-generation high resolution climate models.

* BNL, LBNL, Stony Brook University, Columbia University/GISS, GFDL, UCLA/GFL, University of Reading, Royal Netherlands Meteorological Institute, Texas A&M

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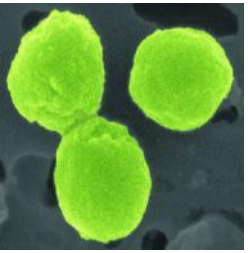

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