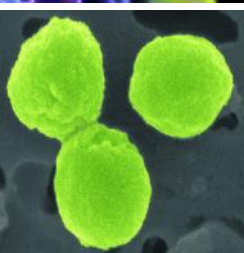
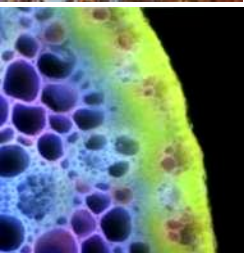


Biological & Environment Research Office (BER)

SciDAC3: Climate modeling

Dorothy Koch

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Climate and Environmental Sciences Division
Biological and Environmental Research



July 22, 2015

SciDAC-3 Principal Investigator Meeting



U.S. DEPARTMENT OF
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Sharlene Weatherwax

Biological Systems Science

Todd Anderson

- Genomic Science
 - Bioenergy Research Centers
- Radiological Sciences
- Facilities & Infrastructure
 - Joint Genome Institute
 - Structural Biology

Climate & Environmental Sciences

Gary Geernaert

- Climate & Earth System Modeling
 - **Earth System Modeling**
 - Regional & Global Climate Modeling
 - Integrated Assessment Research
- Atmospheric System Research
- Environmental System Science
- Facilities & Infrastructure
 - Environmental Molec. Sciences Lab
 - ARM Climate Research Facility
 - Data Informatics

Earth System Modeling computational challenges

Objective: Simulate predictive changes in a weakly-forced system (temperature, hydrologic responses to greenhouse gas changes), where changes depend on cross-system fluxes and feedbacks.

Multi-physics: coupled systems (atmosphere, ocean, land, cryosphere)
E.g. water cycle cuts across all systems (sea level rise, drought)

Multi-scale: cloud microphysical (aerosols and droplet) processes in to global circulation; ice sheet change happens primarily in narrow regions; soil microbial changes can influence greenhouse gas exchange.

Challenges:

Prediction: statistics of weakly forced, uncertain systems

Algorithmic: across coupled, diverse systems (atmosphere, ocean, etc.)


Software: typically lengthy, legacy, yet rapidly evolving codes

Performance: heterogeneous system, not clear how to deploy on heterogeneous architectures

Earth System Modeling (ESM) Program

Goal: Develop an advanced, high-resolution, climate model projection capability, in support of DOE mission and science

ESM portfolio (35M/y)

1. Accelerated Climate Modeling for Energy (ACME) 
Develop a branch of CESM for DOE computers and mission Laboratory “Science Focus Area” (SFA) (2014-2016) 60%

2. SciDAC3 Lab-led projects (2011-2016) 20%



3. SciDAC (& other) University-led projects (2014-2016) 20%

All 3 of these elements align in 2017

“SciDAC” supports exploration and development of “next-generation” approaches for ACME

Accelerated Climate Model For Energy



ACME is a multi-institutional (8 Labs, 6 non-Labs) project to develop a version of the Community Earth System Model to run efficiently on DOE LCF's and NERSC, at high and variable resolution, in support of DOE science and mission.

Started in July 2014, from several existing Laboratory model development projects.

Science and **mission** drivers:

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 vs **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 Sea Level Rise** from changes in 2010-2050.*

Accelerated Climate Model For Energy



ACME Version 1 (release in 2017) capabilities:

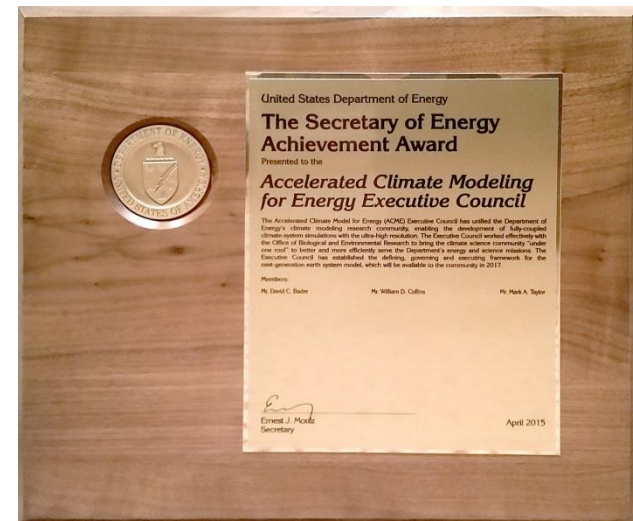
- New MPAS ocean, sea-ice, **land-ice**
- New **convection scheme**, TBD
- Coupled **regional refinement** system (ocean-ice-atmosphere),
- Land biogeochemistry-CNP,
- Land watershed hydrology, sub-grid orography

Computing awards:

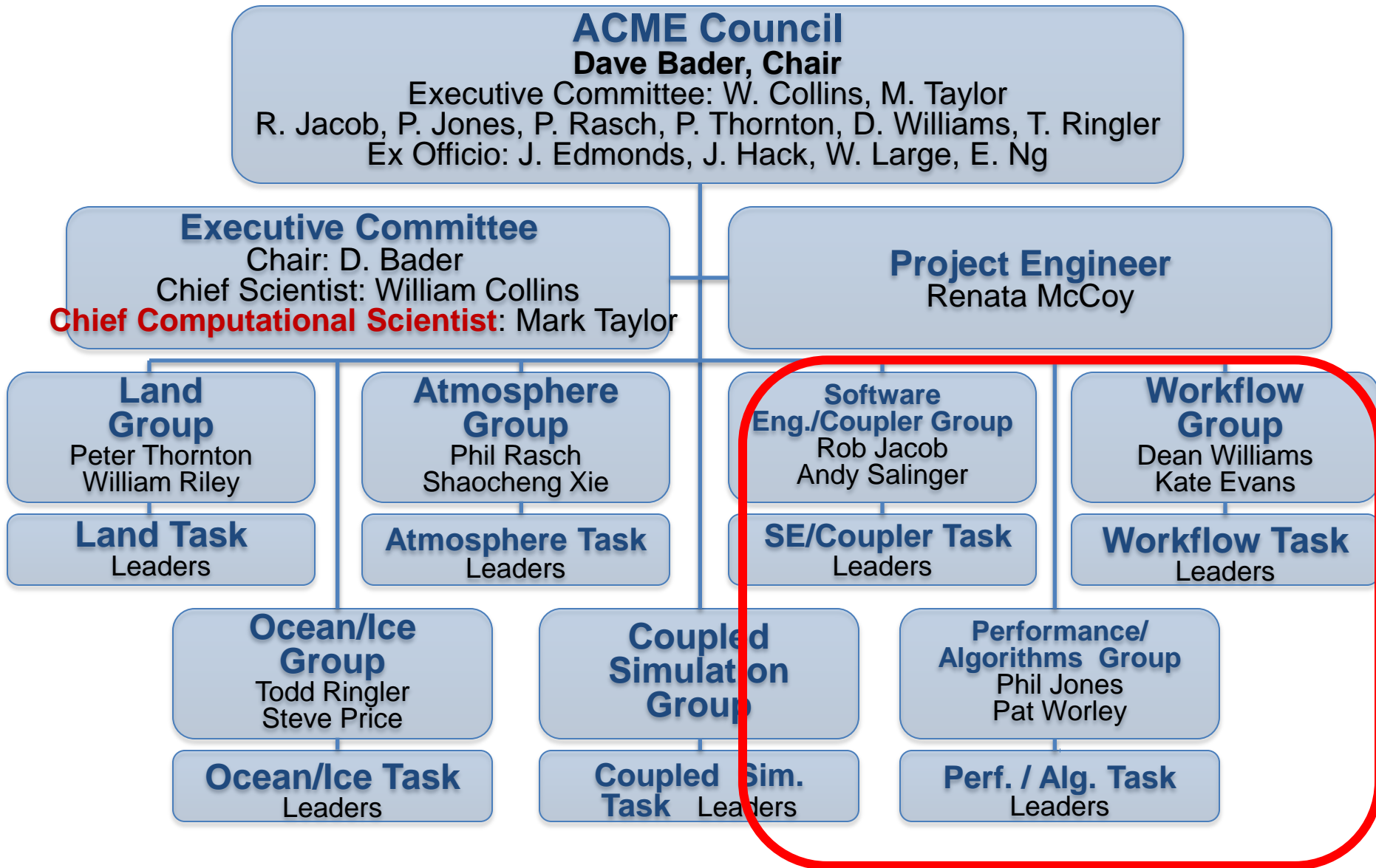
- INCITE (2015) 190M hours
- ALCC (2015) 165M hours
- NESAP – Cory – NERSC early access
- CAAR – Summit – OLCF early access



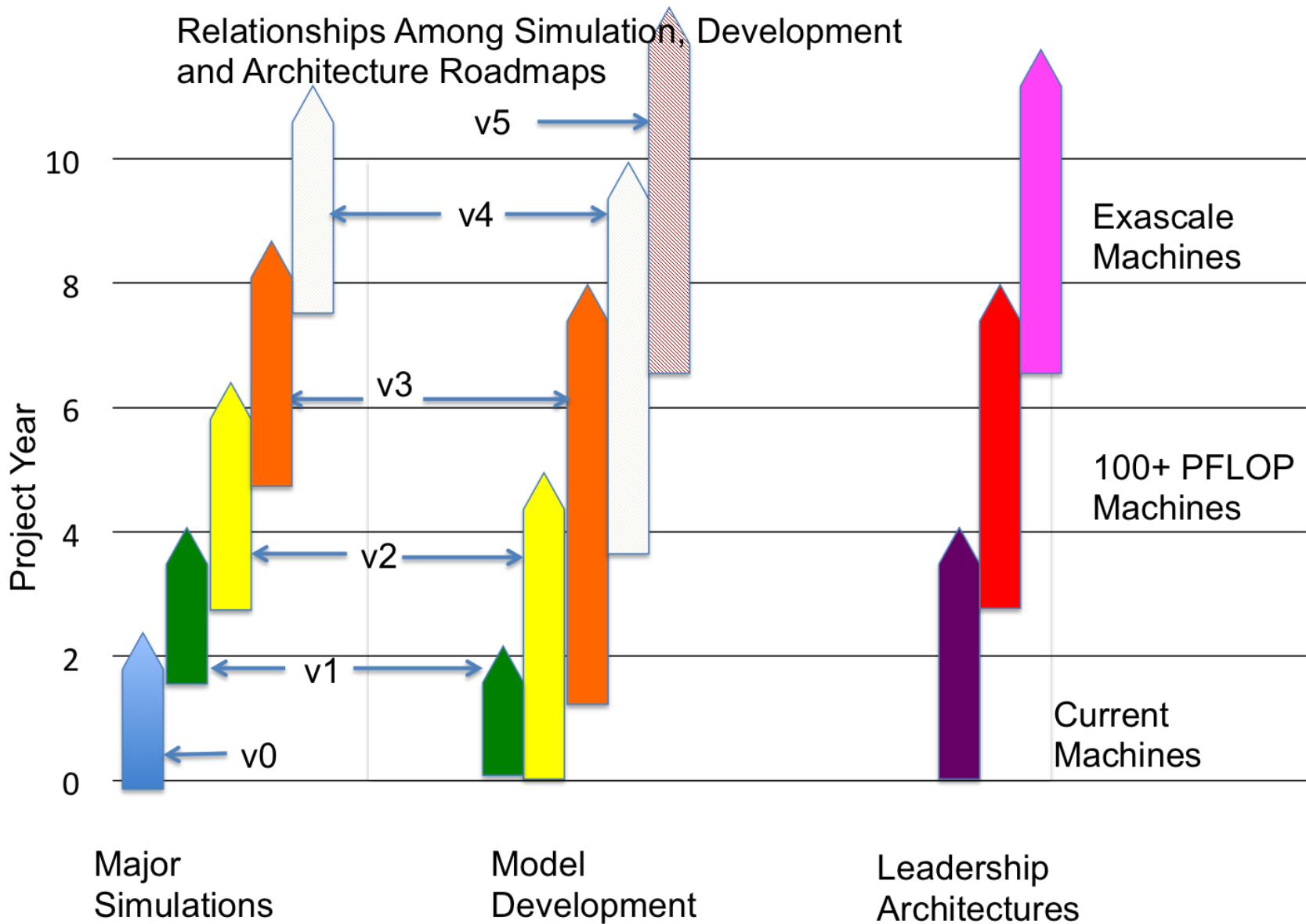
Secretary of Energy Achievement Award 2014



ACME management



ACME development Roadmap

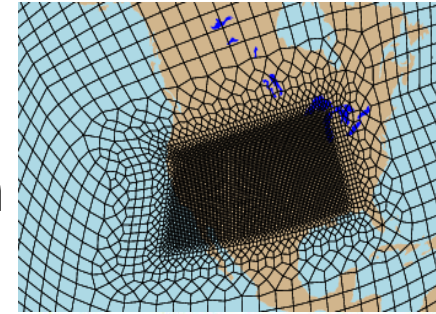


SciDAC3, 3 Lab-led projects, 2011-2016

Next-generation component capabilities

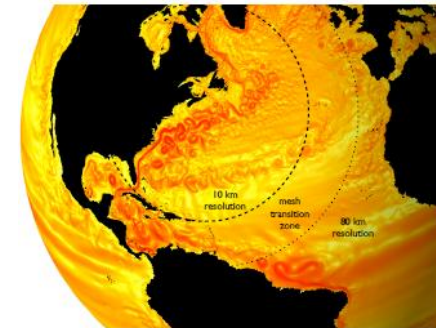
1. Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System

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



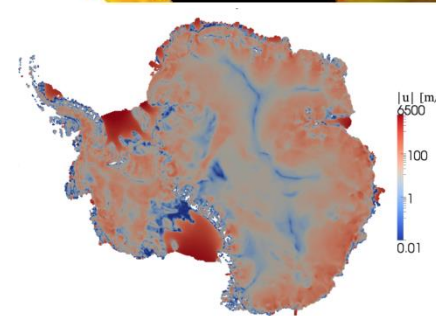
2. Predicting Ice Sheet and Climate Evolution at Extreme Scales (PISCEES)

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



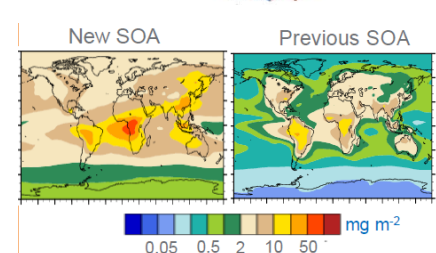
3. Applying Computationally Efficient Schemes for BioGeochemical Cycles (ACES4BGC)

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



Mid-term review: Termination of ACES4BGC

- ** Two “replacement” proposals under review
- ** ACME performance and portability
- ** ACME high-resolution atmosphere



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

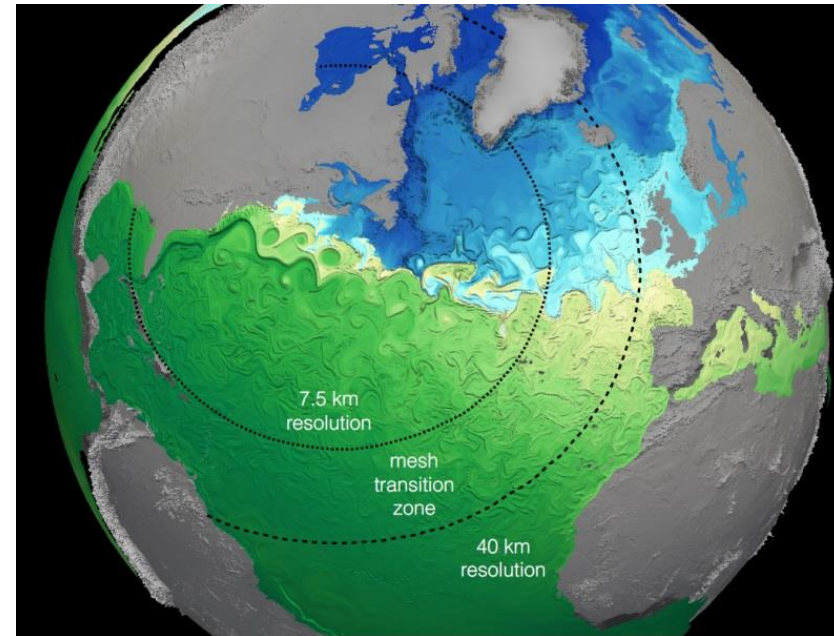
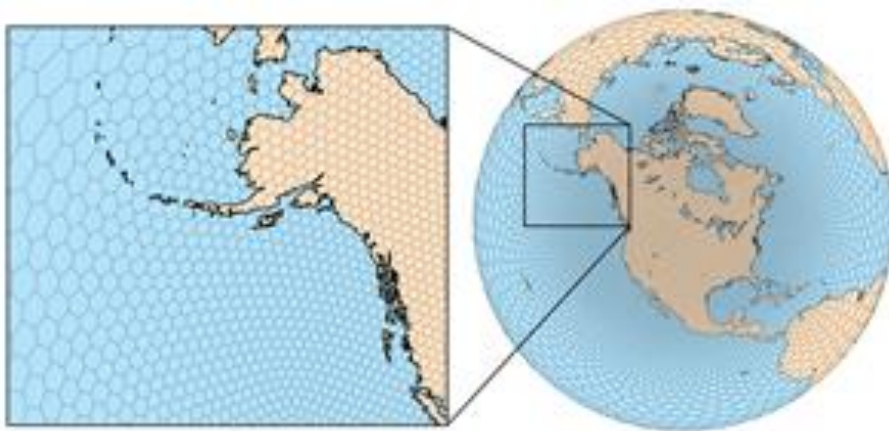
LBNL, LANL, PNNL, ORNL, LLNL, SNL, NCAR, UW-M, CSU, UCLA

Atmosphere

- “Scale-independent” convection representations: several schemes under development and testing, with focus on tropical testbed
- Development of pdf-based scheme to represent cloud physics, microphysics
- Time-stepping and process coupling methods (FASTMath), Implicit atmosphere dynamics
- Dynamic adaptive mesh (CHOMBO) for the atmosphere (FASTMath)
- Parameter calibration for e.g. cloud microphysics (QUEST)

Ocean

- “Scale-independent” ocean-eddies
- Performance (SUPER)



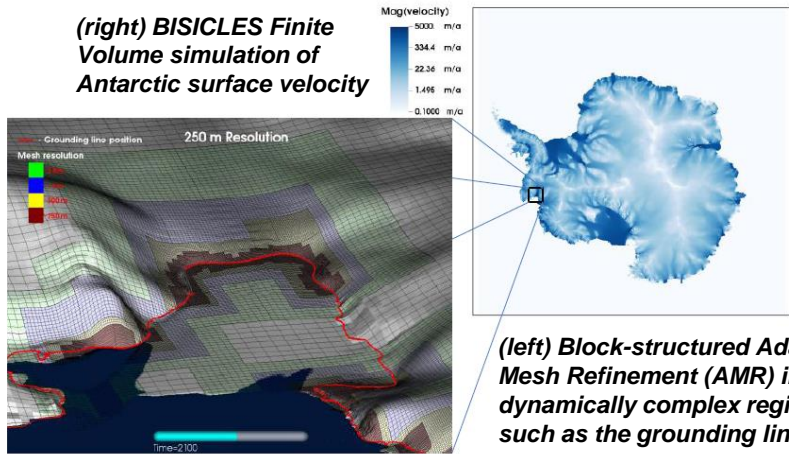
Predicting Ice Sheet and Climate Evolution at Extreme Scales (PISCEES)

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

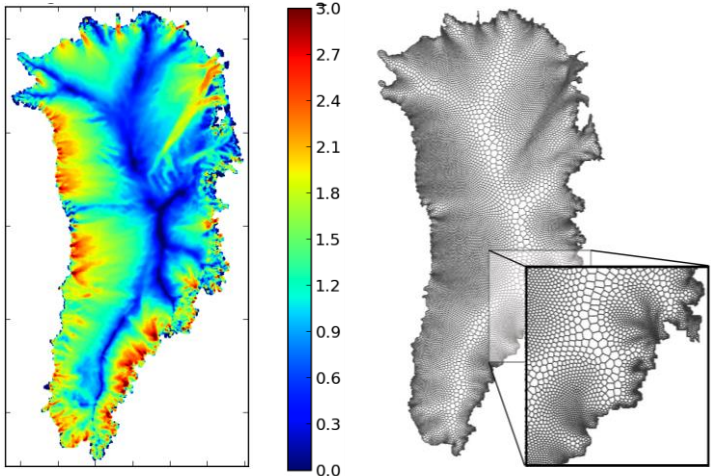
Objectives

- Develop ice sheet model dynamical cores on unstructured and adaptively refined meshes
- Methods for verifying and validating these models
- Methods for uncertainty quantification of model projections of future sea-level rise
- Couple new ice sheet models with ACME

Impact: New Capability in DOE Climate Models



FELIX Finite Element dynamical core simulation of Greenland surface velocity (log10 m/yr) on MPAS unstructured mesh



Recent Accomplishments

- Good scaling on DOE LCF architectures
- Collaborations with FASTMath, SUPER, QUEST
- Formal methods for deriving optimal model initial conditions with smooth coupling to climate models
- Coupling of FELIX Finite Element dynamical cores to Model for Prediction Across Scales (MPAS) unstructured mesh framework
- Antarctic, whole-ice-sheet forward model integrations of BISICLES with AMR and coupling to POP2x ocean circulation model

University FOA (2014-2016)

6 SciDAC, 6 non-SciDAC projects



“Expanding the computational frontier of multi-scale atmospheric simulation to advance understanding of low cloud / climate feedbacks”

Pritchard et al.: UC-Irvine, U-Washington, SUNY-Stony Brook, PNNL

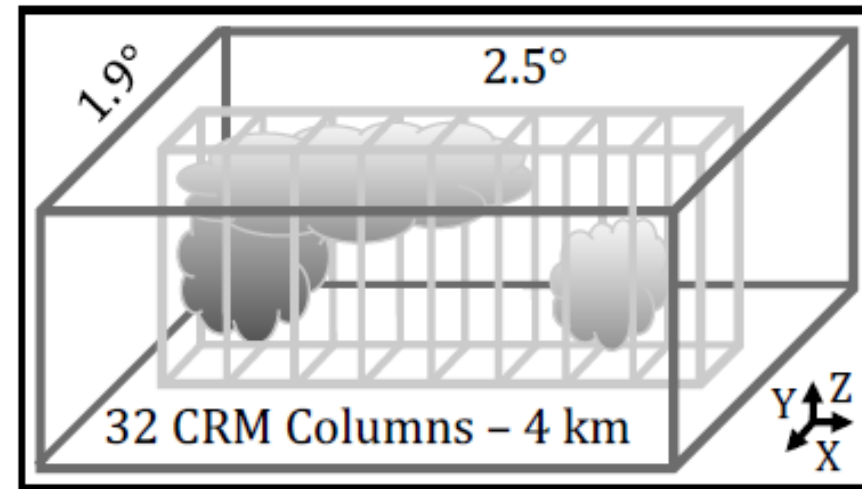
High resolution Cloud Resolving Model (CRM) embedded in a Global Climate Model (GCM) gridbox:

High resolution will resolve (instead of parameterize) many cloud processes

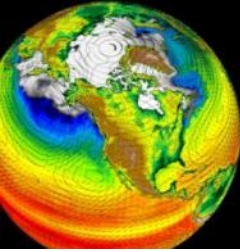
Very slow computationally!

Efficiency:

- **Algorithmic:**
 - Coupling, timestepping requirements for processes
 - Partial representation of CRM
- **Computational:**
 - CRM physics onto GPUs
 - Global dynamics on CPUs



Strategy for Climate modeling on Summit/Titan; ACME CAAR application



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

MULTISCALE is a SoDAC 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.

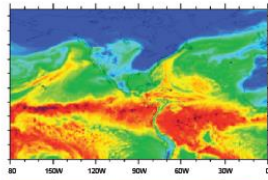
MULTISCALE is an integrated team of climate and computational scientists working to accelerate the development and integration of multiscale atmospheric and oceanic parameterizations into the Community Earth System Model (CESM).

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.



Snapshots of precipitable water from CAM-SE climate simulations at global 1/8° resolution (top) and a variable resolution (bottom). These snapshots are not expected to agree, but instead demonstrate CAM's variable resolution capability. On the top, the detailed structure of water content is visible over the entire globe, while on the right, the 8x lower resolution over the tropics is clearly visible, but high resolution is maintained over the central U.S.

Effective deployment of these dynamical cores requires significant and concurrent advances in time-stepping methods, grid generation, and automated optimization methods for next-generation computer architectures.

Due to the centrality of the atmosphere and ocean to the evolution of the coupled system, we are targeting major extensions to the atmospheric and oceanic components of the Community Earth System Model (CESM). We have focused our investigation on a small number of significant processes that govern the coupled behavior of the climate system and require significant numerical and computational advances for successful implementation. These

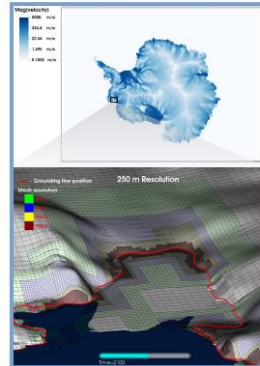
PREDICTING ICE SHEET AND CLIMATE EVOLUTION AT EXTREME SCALES (PISCEES)

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. The PISCEES team of scientists is also creating new tools and techniques for validating ice-sheet simulations against observations and for estimating the uncertainty surrounding future projections.

NEW ICE-SHEET MODELS

Large-scale ice-sheet computer models must represent the response of ice flow to changes in atmosphere and ocean conditions (i.e., climate change)—as well as to evolving conditions within and beneath the ice. This is particularly difficult near dynamically complex ice-sheet margins, like the "grounding line," where land-ice thins to floation and flows out over the surface of the ocean. For the most accurate predictions, PISCEES researchers are developing robust, comprehensive models of ice-sheet dynamics that include variable-resolution meshes in order to simulate the evolution of the continental-scale ice sheets that cover Greenland and Antarctica.

These new models, named FELIX and BISICLES, focus spatial resolution and computational resources in fast-flowing and dynamically complex regions, such as ice streams, outlet glaciers, floating ice shelves, and ice shelves, and grounding lines. FELIX uses finite element methods and unstructured meshes, while BISICLES uses finite volume methods and block-structured, adaptive-mesh refinement. Both models allow for a range of reduced-order (and thus computationally less expensive, though less accurate) approximations to the governing equations for ice motion. These new models use advanced mathematical and computational techniques through collaborations with scientists at the Scientific Discovery through Advanced Computing (SoDAC) Institutes.



Top: Computed ice velocity (m/yr) for the Antarctic ice Sheet, with Pine Island Glacier in black box. Bottom: Adaptive meshing (shaded boxes) and grounding-line location (red line) for the Pine Island Glacier. Regions with a relatively finer mesh track the dynamically complex grounding-line region as the simulation evolves.

*Participating Institutions
Los Alamos National Laboratory
Lawrence Berkeley National Laboratory
Florida State University
Massachusetts Institute of Technology
National Center for Atmospheric Research
Oak Ridge National Laboratory
Sandia National Laboratory
University of South Carolina
University of Texas, Austin



The Accelerated Climate Modeling for Energy (ACME) project is sponsored by the U.S. Department of Energy's

Office of Biological and Environmental Research

Using river flow as a key indicator of hydrological changes from natural and human systems, ACME is testing the hypothesis that changes in river flow have been dominated by land management, water management, and climate change associated with aerosol forcing but will be increasingly dominated by greenhouse gas changes.

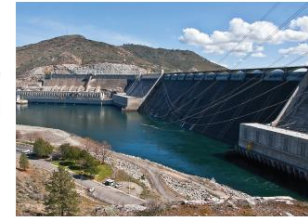
ACME will include a near-term and a near-to societal-scale-refinement physics and model branches in order to explore the role of these various physical processes in influencing river flow and fresh water supply, with a goal of simulating an accurate portrayal of present-day river flow for major river basins on the planet.

The longer-term water cycle goal is to understand how the hydrological cycle in the fully coupled climate system will evolve with climate change and the expected effect on local, regional, and national supplies of fresh water.

ACME will further examine whether during the next 40 years, the additional forcing from increasing greenhouse gas concentrations will come to dominate river flow changes.

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<http://www.climate modeling.science.energy.gov/>

Thank you!

