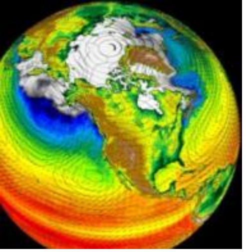
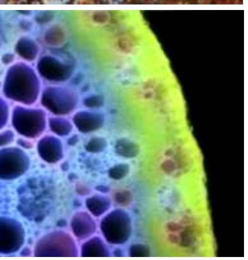
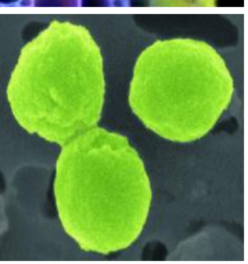


Biological & Environment Research Office (BER)

SciDAC3: Climate modeling

Dorothy Koch

Earth System Modeling
Climate and Environmental Sciences Division
Biological and Environmental Research

July 22, 2015

SciDAC-3 Principal Investigator Meeting

Office of Biological & Environmental Research

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.

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

<u>Multi-scale</u>: 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.

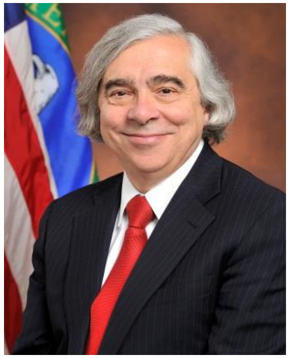
Biogeochemistry: How do biogeochemical cycles interact with global climate change?
Evolution of natural vs managed systems fluxes of greenhouse gases.

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:

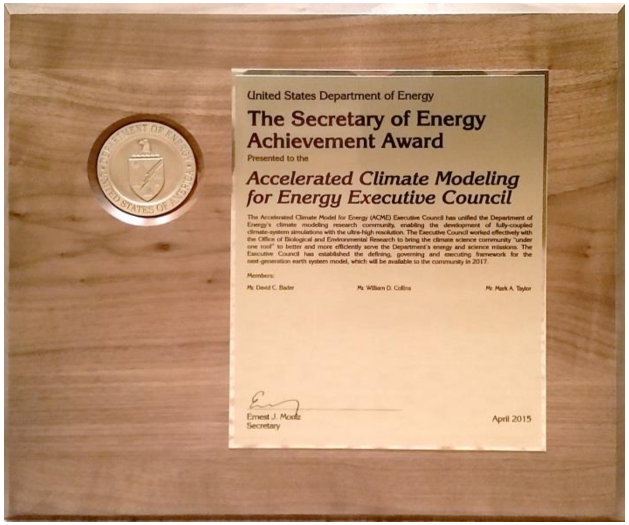
- New MPAS ocean, sea-ice, land-ice
- New convection scheme, TBD
- Coupled regional refinement system (ocean-ice-atmosphere),
- Land biogeochemistry-CNP,
- Land watershed hydrology, sub-grid orography



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 Council
Dave Bader, Chair
Executive Committee: W. Collins, M. Taylor
R. Jacob, P. Jones, P. Rasch, P. Thornton, D. Williams, T. Ringler
Ex Officio: J. Edmonds, J. Hack, W. Large, E. Ng

Executive Committee
Chair: D. Bader
Chief Scientist: William Collins
Chief Computational Scientist: Mark Taylor

Project Engineer
Renata McCoy

Land Group
Peter Thornton
William Riley

Land Task Leaders

Atmosphere Group
Phil Rasch
Shaocheng Xie

Atmosphere Task Leaders

Software Eng./Coupler Group
Rob Jacob
Andy Salinger

SE/Coupler Task Leaders

Workflow Group
Dean Williams
Kate Evans

Workflow Task Leaders

Ocean/Ice Group
Todd Ringler
Steve Price

Ocean/Ice Task Leaders

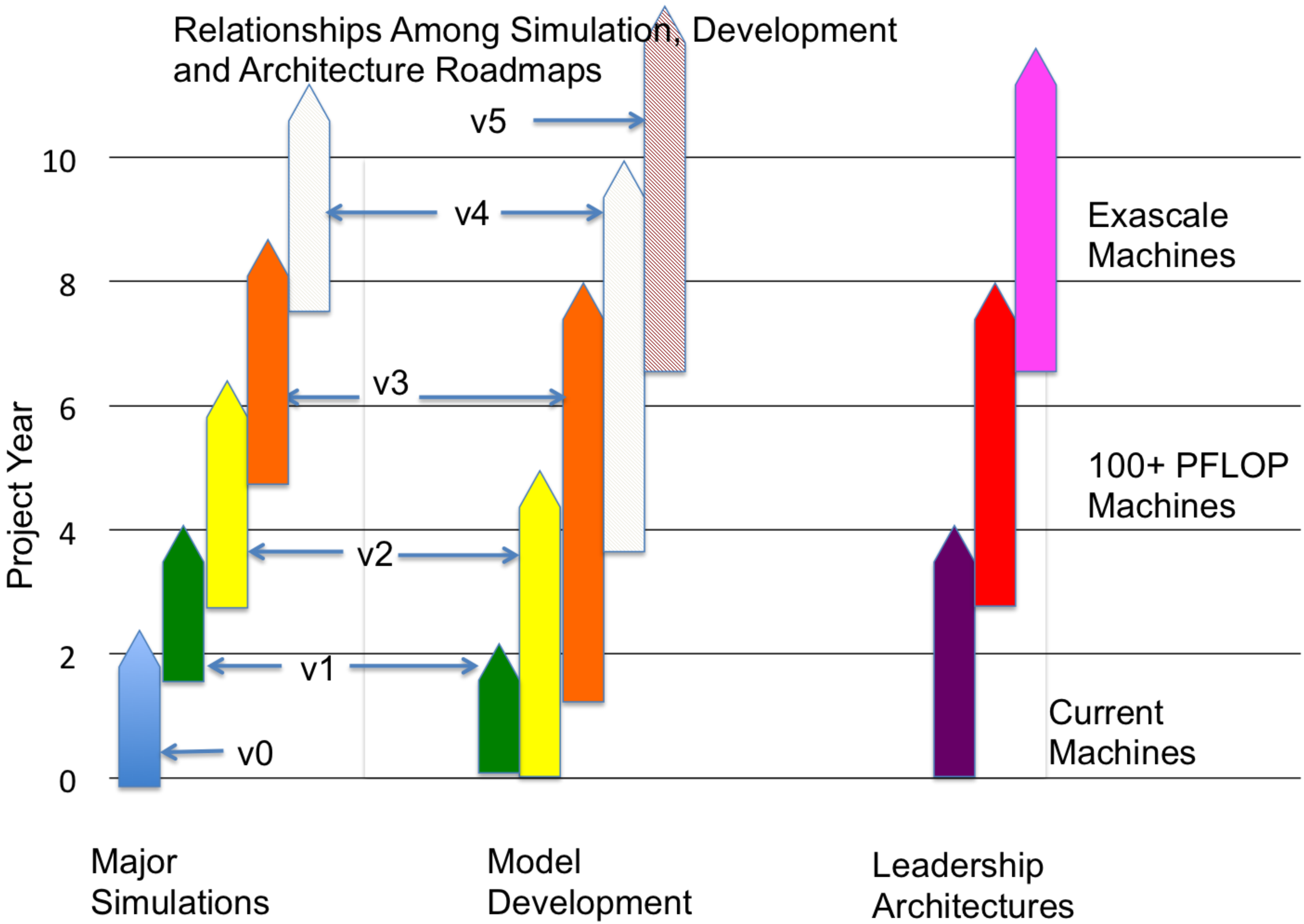
Coupled Simulation Group

Coupled Sim. Task Leaders

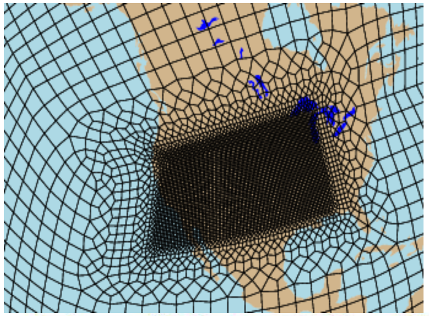
Performance/ Algorithms Group
Phil Jones
Pat Worley

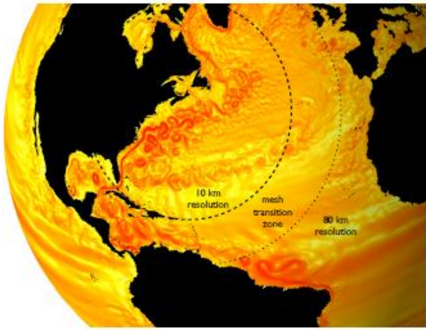
Perf. / Alg. Task Leaders

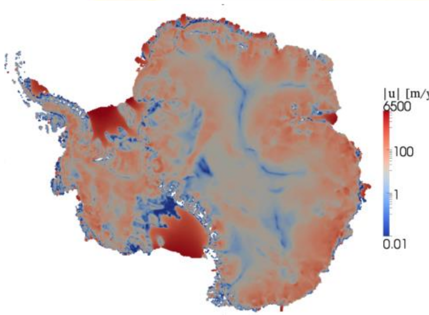
ACME development Roadmap

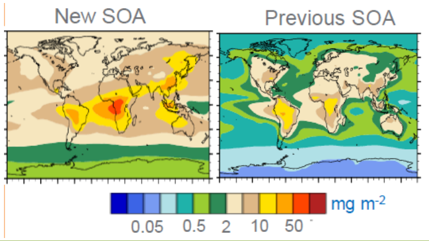


SciDAC3, 3 Lab-led projects, 2011-2016
Next-generation component capabilities









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

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

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

LBNL, 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**

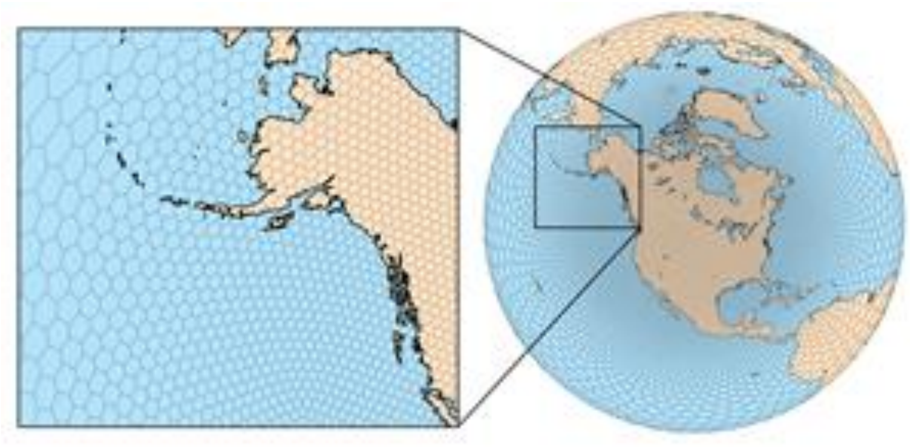
Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System LBNL, LANL, PNNL, ORNL, LLNL, SNL, NCAR, UW-M, CSU, UCLA

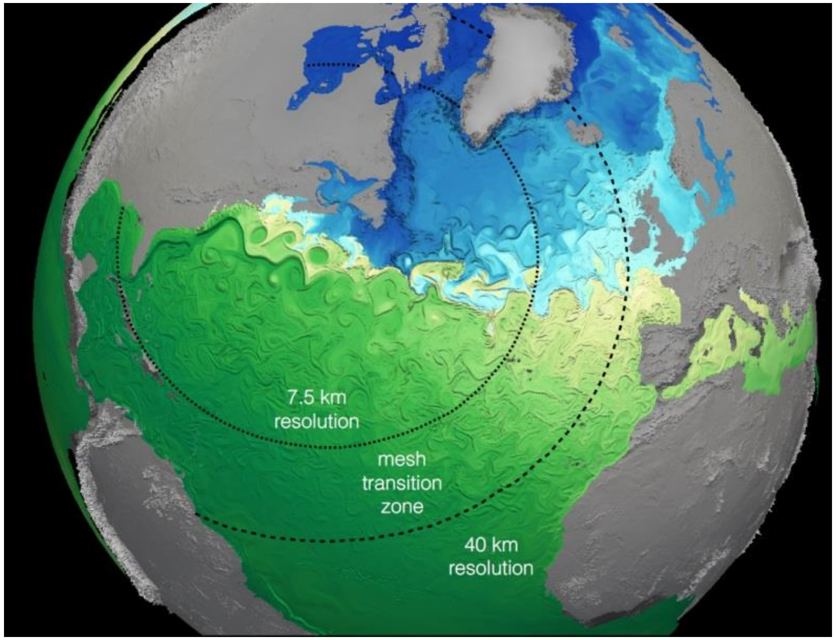
Atmosphere

- **"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)

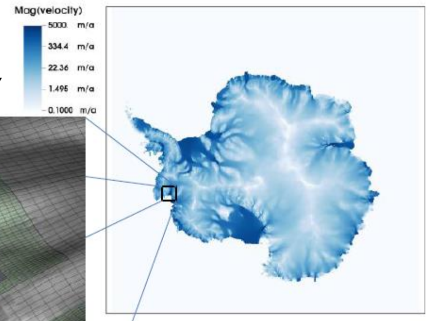
LBNL, LANL, ORNL, SNL, NCAR, MIT, FSU, U-SC, UT-Austin

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

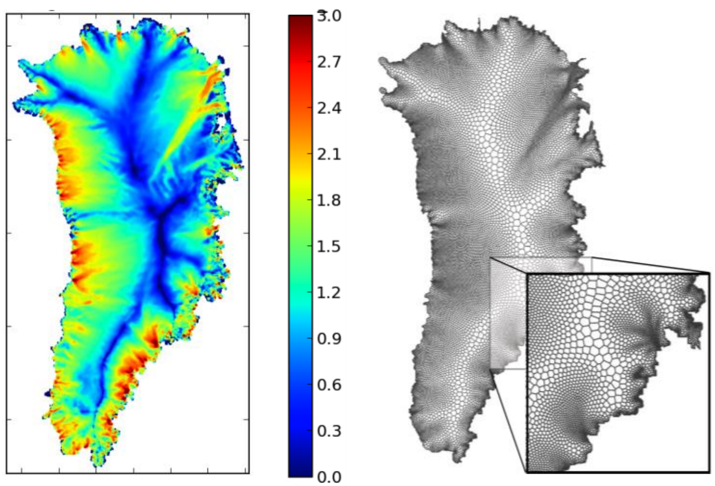
Impact: *New Capability in DOE Climate Models*

(right) BISICLES Finite Volume simulation of Antarctic surface velocity



(left) Block-structured Adaptive Mesh Refinement (AMR) in dynamically complex regions, such as the grounding line

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

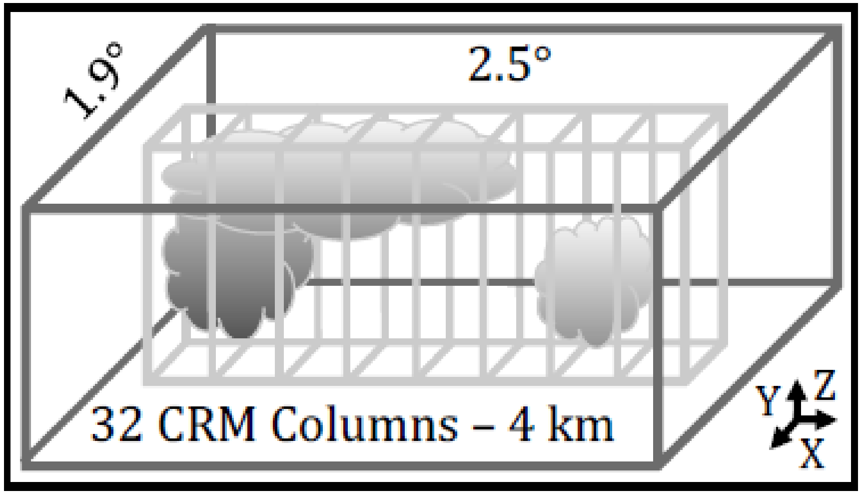
University FOA (2014-2016)
6 SciDAC, 6 non-SciDAC projects

"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

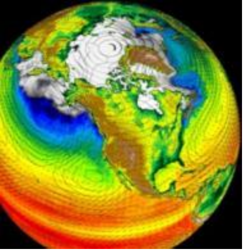
High resolution Cloud Resolving Model (CRM) embedded in a Global Climate Model (GCM) gridbox:
High resolution will resolve (instead of parameterize) many cloud processes

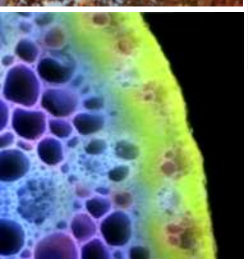
Very slow computationally!
Efficiency:

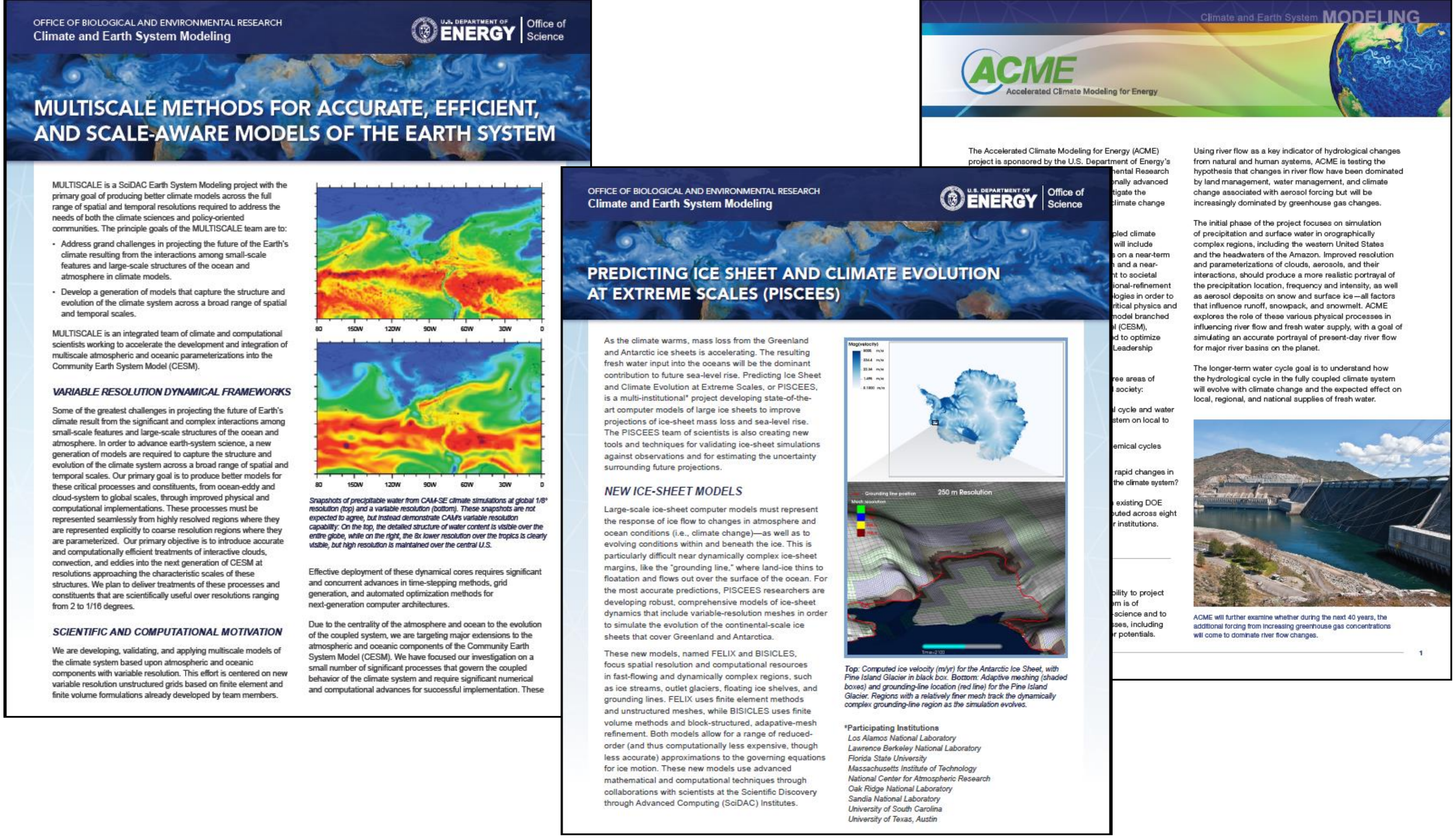
- **Algorithmic:**
  - **Coupling, timestepping requirements for processes**
  - **Partial representation of CRM**
- **Computational:**
  - **CRM physics onto GPUs**
  - **Global dynamics on CPUs**



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







Thank you!

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