# 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.

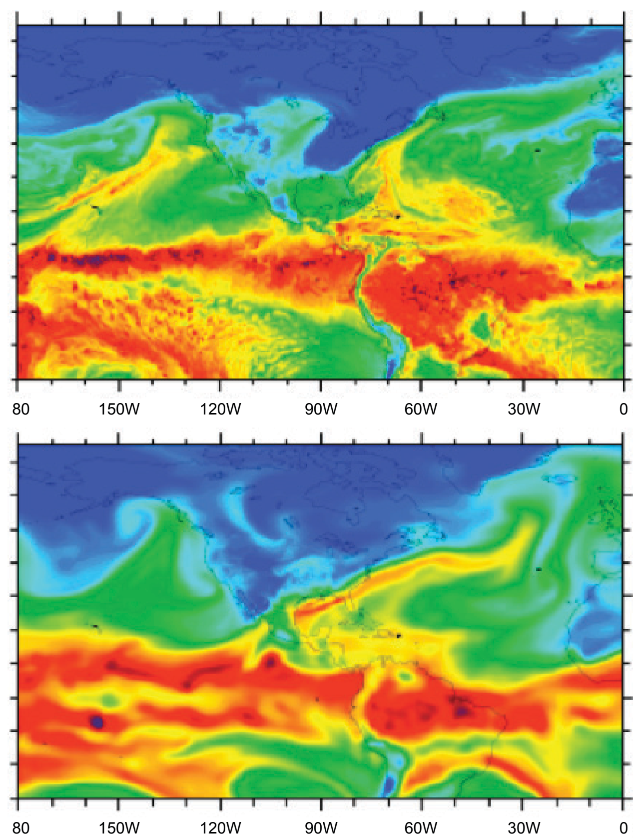
MULTISCALE is an integrated team of climate and computational scientists working to accelerate the development and integration of multiscale atmospheric and oceanic parameterizations into the Community Earth System Model (CESM).

## *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*

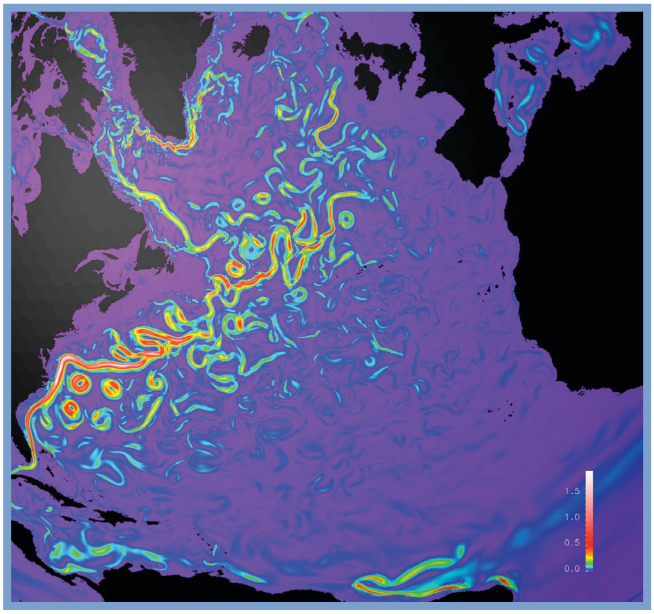
We are developing, validating, and applying multiscale models of the climate system based upon atmospheric and oceanic components with variable resolution. This effort is centered on new variable resolution unstructured grids based on finite element and finite volume formulations already developed by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




*Snapshot of near-surface ocean kinetic energy. In this simulation, the ocean is modeled with a 10 km mesh. As a result, mesoscale ocean eddies, which have a characteristic length scale of approximately 100 km, are permitted in the North Atlantic but are not resolved elsewhere in the ocean domain.*

include clouds, convection, and microphysical processes in the atmosphere and turbulent eddies in the ocean. We are enhancing the fidelity of the prototype components through careful process integration and through formal verification, validation, and uncertainty quantification using proven techniques vetted across DOE's physical and mathematical science portfolio. The team is addressing the physical and computational aspects of air-sea interactions required to build a working version of a coupled multiscale climate model. We will then apply this system to several key unresolved questions in climate change projections, including the future frequencies and magnitudes of hurricanes and hydrometeorological climate extremes.

## PROGRAMMATIC RELEVANCE

The team's objectives are aligned with the mission of DOE's Advanced Scientific Computing Research (ASCR) office to “discover, develop, and deploy the computational and networking tools that enable researchers in the scientific disciplines to analyze, model, simulate, and predict complex phenomena important to the Department of Energy."

To address this mission, the team is developing close partnerships with the SciDAC Institutes in order to:

- Work with **FASTMath** investigators to exploit advanced methods for variable-resolution grid generation and for implicit time integration required for accurate yet economical time evolution of our new multiscale model physics.
- Collaborate with members of **SUPER** to optimize the computational performance of core algorithms of variable-resolution dycores using auto-tuning techniques, and to accelerate the numerical quadrature over multivariate distributions of small-scale atmospheric fluctuations using forthcoming advances in computer architectures.
- Partner with members of **QUEST** for validation, verification, and uncertainty quantification of our prototypes for multiscale earth system components. This activity will be essential both to test the premise that multiscale models are a more accurate representation of the climate system and to characterize the effects of the multiscale physics and dynamics on the structural and parametric uncertainty of the resulting models.

Our work is also directly relevant to the goal of DOE's Office of Biological and Environmental Research (BER) to produce “improved scientific data and models about the potential response of the Earth's climate and terrestrial biosphere to increased greenhouse gas levels for policy makers to determine safe levels of greenhouse gases in the atmosphere." This project will deliver a new generation of climate models capable of producing climate projections from local to global scales, in support of energy and other sectoral planning requirements.

## PARTICIPATING INSTITUTIONS

Los Alamos National Laboratory (LANL)
Lawrence Berkeley National Laboratory (LBNL)
Lawrence Livermore National Laboratory (LLNL)
Oak Ridge National Laboratory (ORNL)
Pacific Northwest National Laboratory (PNNL)
Sandia National Laboratories (SNL)
Colorado State University (CSU)
National Center for Atmospheric Research (NCAR)
University of California, Los Angeles (UCLA)
University of Wisconsin, Milwaukee (UWM)
SciDAC Institutes: FASTMath, QUEST, SUPER

## PRINCIPAL INVESTIGATOR

**William Drew Collins, Ph.D.**
Lawrence Berkeley National Laboratory
*wdcollins@lbl.gov*

## DOE PROGRAM MANAGERS

**Dorothy Koch, Ph.D.**
BER Climate and Environmental Sciences, Earth System Modeling
*dorothy.koch@science.doe.gov*

**Randall Laviolette, Ph.D.**
Advanced Scientific Computing Research
*randall.laviolette@science.doe.gov*

**Project Website**
https://outreach.scidac.gov/multiscale