U.S. DEPARTMENT OF ENERGY | Office of Science

EARTH AND ENVIRONMENTAL SYSTEM MODELING (EESM)

Earth and Environmental System Modeling (EESM) seeks to advance understanding and improve U.S. Department of Energy- (DOE) relevant predictability of the earth system, including natural- and human-driven processes, and their interactions over multiple temporal and spatial scales.

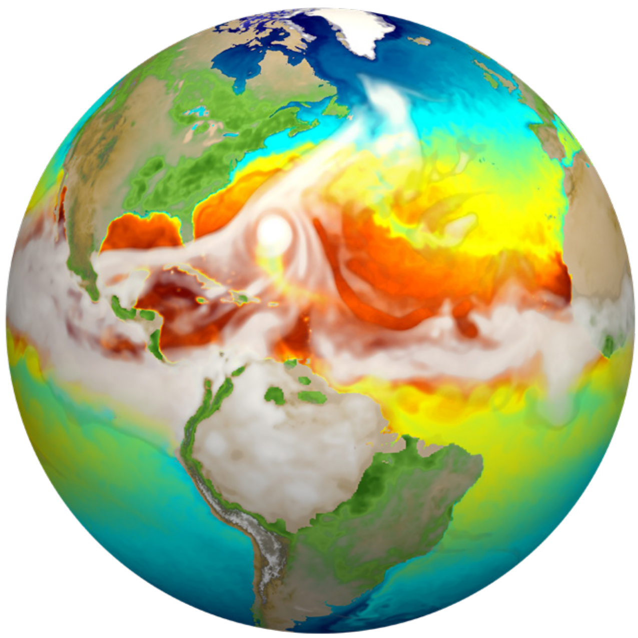
The vision for EESM is to provide DOE with the best possible information about the evolving earth system so that energy assets and infrastructures remain robust throughout their lifetimes. Key examples include projections of water availability, drought incidence and persistence, temperature extremes such as prolonged heat stress, probability of storms, opening of the Arctic Ocean, sea-level and storm-surge interactions with coastal regions, land-use and land-cover change, and transitions in development-driven demands for natural resources and availability.

EESM investments focus on model development, model analysis, and understanding of the role of multisector interactions with the coupled, physical-human earth system.

MODEL DEVELOPMENT

The Model Development sub-area supports innovative and computationally advanced earth system modeling capabilities, with the ultimate goal of providing accurate representations of the fully coupled and integrated earth system, as needed for energy and related sectoral infrastructure planning.

Central to the Model Development activities is the Energy Exascale Earth System Model



E3SM is a state-of-the-science earth system modeling, simulation, and prediction project that optimizes the use of DOE laboratory resources to meet the science needs of the nation and the mission needs of DOE.

(E3SM) project, which is developing a high-resolution earth system model that efficiently runs at high-resolution on DOE high-performance computers, simulating the near-term past (for model validation) and future (3-4 decades) in support of the DOE science and mission.

The E3SM project designs and performs high-resolution earth system simulations, targeting the research community's more challenging science questions, such as those involving water cycle science, cloud-aerosol interactions, ice sheet physics and dynamics, biogeochemical cycles, ocean eddy dynamics, and the interdependence of low-frequency variability and extreme weather. Complementary Model

Development projects explore higher-risk E3SM system approaches and support community engagement with E3SM.

The Model Development strategic goals for the coming decade include:

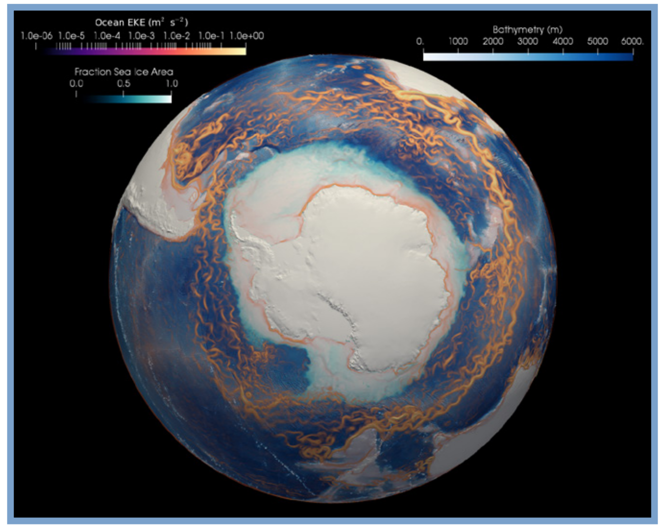
- An ultra-high cloud-resolving E3SM with advanced software and workflows to run efficiently on advanced computational architectures
- Advanced and efficient methods for characterizing how earth system uncertainty affects uncertainty in the projected coupled system changes
- New methods to initialize and calibrate high-resolution earth system models
- Regionally-refined versions of E3SM over regions of particular interest to DOE science and mission, including polar regions, coastal regions, and the United States

Design of the E3SM model system targets specific scientific research challenges, including:

- Improved model simulation of water cycling, including uncertainty characterization of extreme conditions such as storminess and drought
- Integration of land and water use with natural systems
- Simulation and uncertainty estimation for ice sheets, sea-level, and coastal impacts
- Cloud and aerosol-cloud-interaction effects and feedbacks
- Biogeochemical fluxes across interfaces and their dependencies on natural and disturbance conditions

MODEL ANALYSIS

The goal of the Model Analysis sub-area is to enhance predictive and process- and system-level understanding of the modes of variability and change within the earth system by advancing



E3SM science includes resolution of the Antarctic Ice sheet and flow of ocean around and beneath the ice shelves. Shown here is kinetic energy (gold) and sea-ice (white-dark blue).

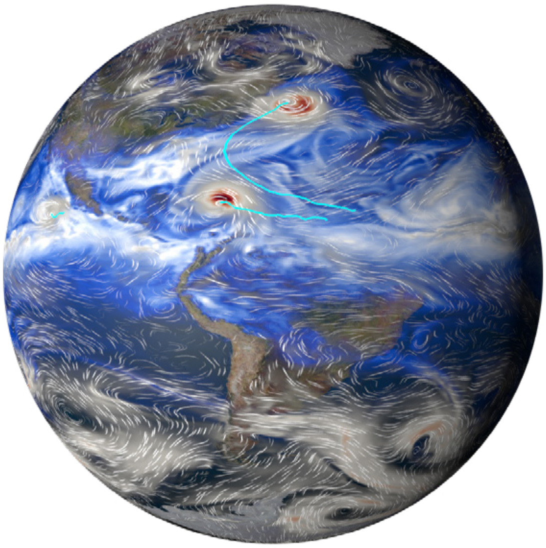
capabilities to design, evaluate, diagnose, and analyze global and regional earth system model simulations informed by observations.

Model Analysis activities employ multifaceted, multi-systems approach to probe and understand the physical, chemical, and biological feedbacks within and between individual components, including the atmosphere, ocean, terrestrial, and cryospheric systems. Analysis focuses on regions critical to understanding the dynamics of climate variability and change across a wide range of spatial and temporal scales.

The Model Analysis sub-area supports the use of hierarchical models, ranging from the most complex high-resolution climate models (such as E3SM) to reduced complexity models for hypothesis testing. Configuring, diagnosing, and evaluating the complex behavior of models provides pathways for advancing understanding of the earth system, improving models, and reducing uncertainties in current earth system models.

The Model Analysis sub-area has six major themes:

- **Cloud Processes and Feedbacks:** Focuses on improving simulation accuracy through better cloud representations in models and



The Model Analysis portfolio within EESM supports the development of community tools for analyzing tropical cyclones and other impactful weather systems.

determining the cloud feedbacks that influence variability and change

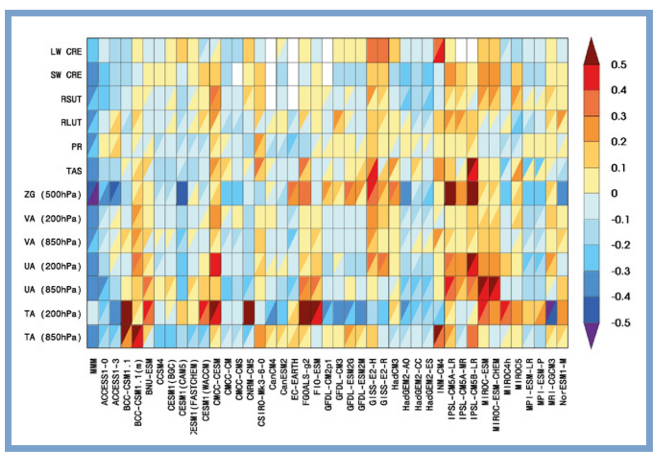
- **Biogeochemical Processes and Feedbacks:** Focuses on identifying and quantifying feedbacks between biogeochemical cycles and quantifying and reducing the uncertainties in earth system models
- **High-Latitude Processes and Feedbacks:** Aims at understanding the processes driving rapid system change at high latitudes and the subsequent effects on the globe
- **Modes of Variability and Change:** Provides insight on the interplay between internally generated variability and externally forced response for improved understanding
- **Extreme Event Statistics and Uncertainties:** Develops predictive understanding of extreme weather events, with a focus on understanding the physical mechanisms that drive variability and long-term changes
- **Water Cycle:** Focuses on advancing understanding of multiscale water cycle processes and hydrologic extremes and their response to perturbations in the context of the whole earth

MULTISECTOR DYNAMICS

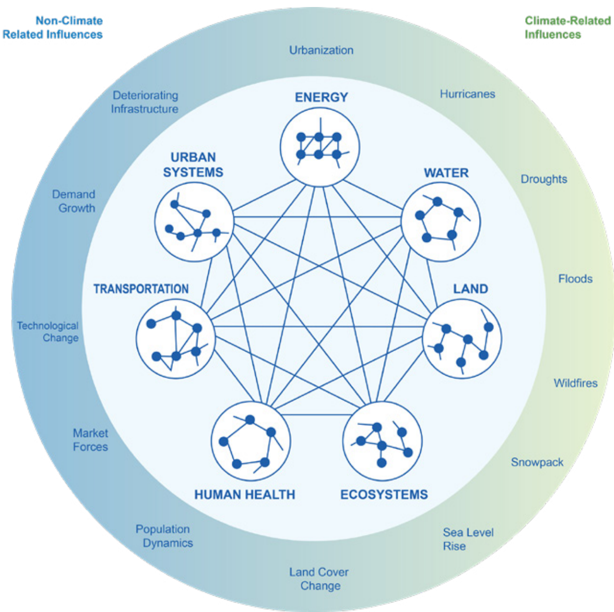
The goal of the Multisector Dynamics sub-area is to advance scientific understanding of the complex interactions, interdependencies, and co-evolutionary pathways within the human-earth system, including non-linear system behaviors, potential for cascading failures among sectors and infrastructures, and feedbacks within the coupled system.

The human-earth system—including settlements, infrastructure, natural resources, socio-economics, and interdependent sectors and natural systems—is highly complex and continuously changing, with stressors, constraints, and other factors that affect change taking many forms and influencing the system at varying spatial and temporal scales, often in unanticipated ways.

Multisector Dynamics seeks to advance relevant socio-economic, risk analysis, and complex decision theory methods for advancing insights into earth system science, emphasizing the development of interoperable data, modeling, and analysis tools for integration within flexible modeling frameworks. Scientific insights and tools emerging from Multisector Dynamics hold



Portrait plots, invented at the Program for Climate Model Diagnosis and Intercomparison (PCMDI), are now commonly used to summarize model skill. This summary of the large-scale mean climate as simulated by CMIP5 models appeared in the model evaluation chapter of IPCC's Fifth Assessment Report (2013).



Sectors are interacting and interdependent through physical, social, institutional, environmental, and economic linkages. These sectors and the interactions among them are affected by a range of natural and human-systems influences and stressors. (Source: Pacific Northwest National Laboratory, Arizona State University, and Cornell University)

significant potential to inform next-generation U.S. infrastructure and new development pathways for improved energy and economic security, including implications of and for technological and systems innovations.

Topical areas of focus in Multisector Dynamics include:

- Multi-model, multi-scale frameworks, software couplers, and component emulators
- Interdependencies among energy, water, and land systems and the natural environment
- Infrastructure, sectoral interactions, and resilience under rapid change
- Urban morphologies, population dynamics, and landscape evolution
- Simulation complexity in energy-intensive, multisector regions under stress, (e.g., coasts)

EESM-supported research investigates the interdependencies of energy, water, and land systems, such as the drought-induced low waters at Lake Mead and Hoover Dam in Nevada.

- Influences of extreme events and compounding stressors on system shocks and responses
- Scenarios, sensitivity studies, uncertainty characterization, and interpretation of results
- Data science, analytics, fusion methods, and machine learning

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