U.S. DEPARTMENT OF ENERGY | Office of Science

EAGLES: ENABLING AEROSOL-CLOUD INTERACTIONS AT GLOBAL CONVECTION-PERMITTING SCALES

Enabling Aerosol-cloud interactions at GLobal convection-permitting scalES (EAGLES) is a project funded through the Department of Energy's (DOE's) Earth System Model Development program area. EAGLES seeks to increase confidence in—and understanding of—the role of aerosols and aerosol-cloud interactions (ACI) in the evolution of the earth system.

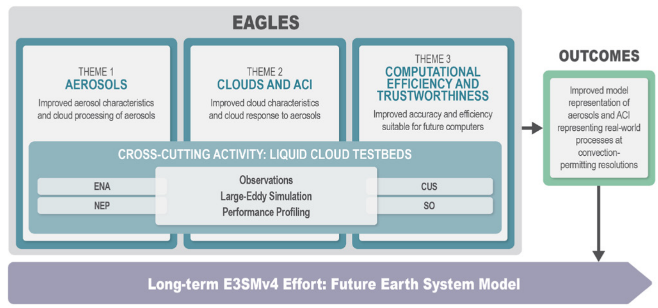
The EAGLES project team develops new modeling techniques to represent aerosols and ACI for the future Energy Exascale Earth System Model (E3SM) capable of running at global convection-permitting resolutions.

RESEARCH CHALLENGES

The EAGLES project team will address the challenge of balancing between the representation of complex aerosol and cloud processes that occur at convection-permitting scales and the associated computational cost.

Taking on this major challenge, the project team combines expertise in atmospheric science, data science, computational science, and software engineering to address three model development themes. Meanwhile, a cross-cutting activity provides an integrated framework to allow parameterization development, evaluation, and assessment. The themes and activity are:

- **Aerosols Theme:** This work focuses on improving aerosol process treatments that influence the size distribution and composition of natural and anthropogenic aerosols, which in turn, are necessary for achieving reasonable estimates of aerosol radiative effects and aerosol-mediated cloud radiative effects.
- **Clouds Theme:** The focus of this work is liquid clouds. Research concentrates on improving cloud processes that are critical for ACI as well as cloud properties, radiative effects, and precipitation.
- **Computation Theme:** This work focuses on advanced computational science techniques needed to improve the numerical accuracy and computational efficiency of aerosol and ACI parameterizations to achieve accurate and affordable global convection-permitting simulations on DOE high-performance computing systems.



Shown here is an illustration of the overall approach, which consists of three model development themes and a cross-cutting activity to guide the science vision.

- **Testbeds Cross-Cutting Activity:** This work will establish four liquid cloud testbeds Eastern North Atlantic (ENA), Northeast Pacific (NEP), Central United States (CUS), and the Southern Ocean (SO) that include a wide range of cloud and aerosol regimes.

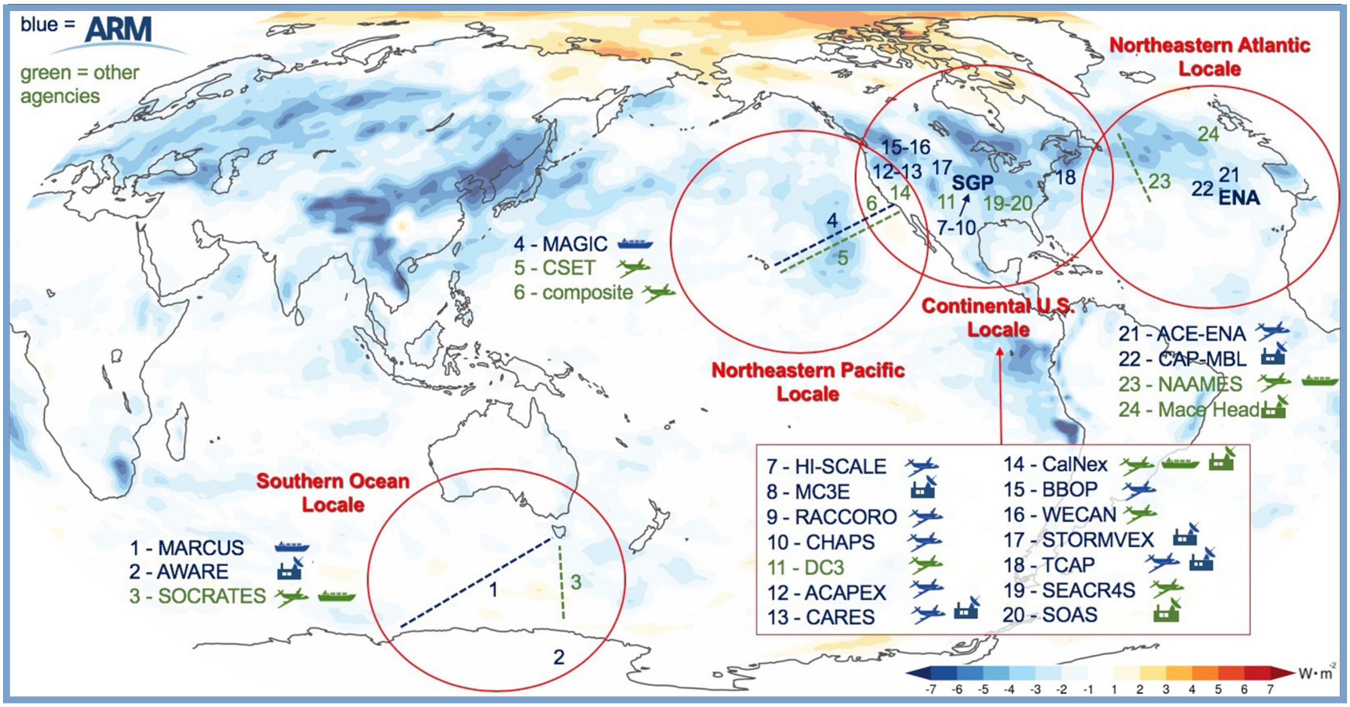
Observations from the Atmospheric Radiation Measurement (ARM) user facility, satellites, and other sources, and benchmark large-eddy simulations will be compiled for these four testbeds to enable routine comparisons with the newly improved model simulations. The scientific evaluation and computational performance profiling will identify hotspots for reducing biases in aerosols and ACI and for reducing the computational cost.

The team also employs novel artificial intelligence (AI) and machine learning (ML) techniques to better integrate data and model to improve understanding and predictability. Combining observational and simulation datasets of aerosols, clouds, precipitation, and meteorology, the team creates new understanding through AI-assisted analytics, develops deep neural network emulators to improve parameterizations, and generates new metrics and diagnostics for model evaluation.

RESEARCH QUESTIONS

The EAGLES project team is focusing on the following science questions:

- What are the key factors and mechanisms affecting aerosol characteristics (including mass and number concentrations,



This figure illustrates field campaigns in the four focus areas, overlaid with anthropogenic aerosol-mediated net top-of-atmosphere radiative effects of liquid clouds in E3SMv1.

lifetime, size distribution, hygroscopicity, radiative properties, and anthropogenic fraction) that determine aerosol radiative effects and ACI in various aerosol and cloud regimes?

- What are the key factors and processes affecting liquid cloud properties in various cloud regimes, and what roles do aerosols play in shaping these cloud properties (including cloud fraction, liquid water path, droplet number and size distribution, lifetime, and geometric depth)?
- What are the modeling choices needed to optimize model fidelity in representing these processes and their interactions (involving parameterization formulation, process splitting and coupling, time integration, numerical methods, modern programming techniques, and approximation methods that reduce computational cost and support high-performance computing usage)?
- What are the impacts of the new parameterizations on E3SM simulations of the past, present, and future?

OUTCOMES AND FUTURE WORK

The integrated approach employed by EAGLES brings together a team with expertise in each of the themes and the cross-cutting activity to ensure that new parameterizations, evaluated against real-world observations and large eddy simulations, are scientifically robust and computationally efficient for global convection-permitting simulations. The new parameterizations assessed in several climatic regimes will provide greater confidence in predictions of aerosols and ACI for the entire globe.

While the focus of the EAGLES project is on the liquid clouds, the interactions between aerosols and mixed-phase and ice clouds require future investigation. A methodology that develops mixed-phase cloud testbeds and ice cloud testbeds similar to the EAGLES liquid cloud testbeds can be adopted for future research.

CONTACTS

Xujing Davis
DOE Program Manager
Earth System Model Development
xujing.davis@science.doe.gov

Po-Lun Ma
Principal Investigator
Pacific Northwest National Laboratory
po-lun.ma@pnnl.gov