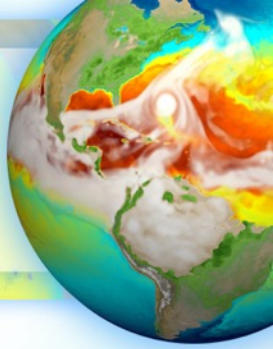


E3SM V3/V4 Model Capabilities: An Outlook

L. Ruby Leung, E3SM chief scientist

(contributions from Chris Golaz, Luke van Roekel, Kate Calvin, Susannah, Steve Price, Wuyin Lin, Mark Petersen)

Overarching plan

Goals

Understand Earth system variability and change

Simulations, predictions, and projections to support DOE's energy mission

Prepare for and overcome the disruptive transition to next era of computing

Science Drivers

Water cycle: water availability, storms, floods and droughts

Biogeochemistry: temperatures, heat extremes, wildfires

Cryosphere: sea level rise, coastal inundation

Strategies

- Push the high-resolution frontier of Earth system modeling
- Represent natural, managed and manmade systems across scales
- Quantify uncertainty using ensemble modeling

Implementations

- Regional refinement using unstructured grids (v2)
- Global cloud resolving modeling (v4 - exascale)
- Coupled human-earth system modeling (v2)
- Coastal modeling (v3/v4)
- Large-ensemble modeling (v4 - exascale)
- Use of ML/AI (v4)

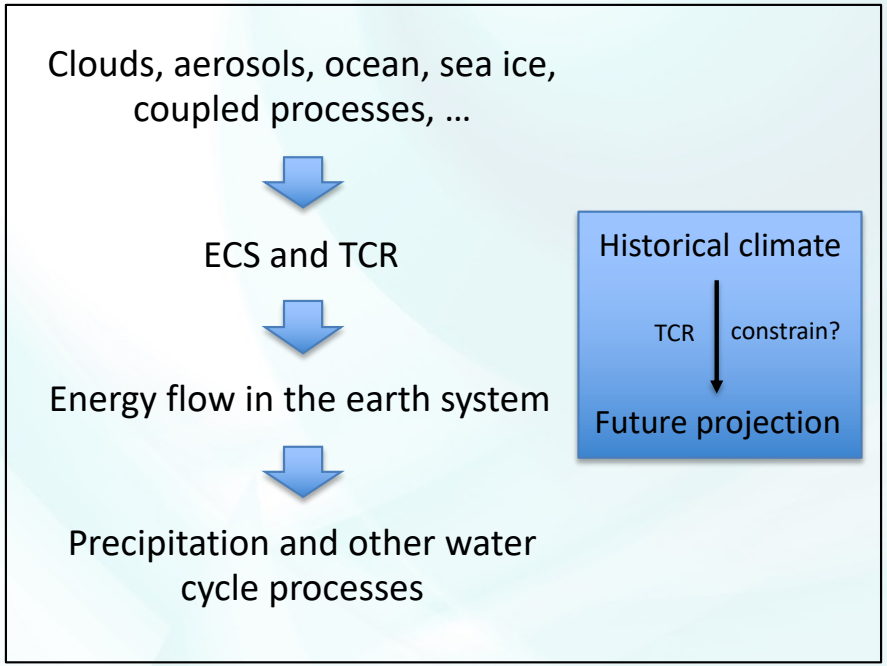
Science questions → **Model development** → **Simulation and analysis**

Implementations through project phases

Phase 3 (2022-2025/26)

- Development of v3: integrating new capabilities from phase 2 NGD efforts
- Parallel development of v4: extension of phase 2 NGD and new NGD efforts
- Science questions include aspects to **address model biases and understand model behaviors** and **advance use-inspired science**

V3 science and model capabilities: water cycle



- Integration of NGD development into a single v3 code base for CPU machines
- Applications across a range of resolutions including RRM for atmosphere and ocean
- Atmosphere: more scale-aware physics and improved aerosols representations
- Ocean/ice: waves; improved eddies and vertical mixing
- Land/river: processes important for land-atmosphere interactions; unified land, river, ocean grid for coastal modeling

V3 science and model capabilities: biogeochemistry

V1: Impact of terrestrial CNP and nutrient competition on carbon-climate feedback

V2: Implications of different energy futures for BGC through LULC, water availability, and extreme events

V3: Impacts of changes in carbon, methane, and other nutrients on climate and the coupled earth system

- Atmosphere: gas-phase atmospheric chemistry; nitrate aerosols; stratospheric sulfate aerosol
- Ocean/ice: seafloor BGC
- Land: dynamic vegetation; crops; natural CH_4; improved fire; managed disturbances
- River: nutrient flow from land to ocean; lakes
- GCAM*: energy, water, food storage; separation of investment and operation

* GCAM developments are funded by the GCIMS project for FY21-FY23.

V3 science and model capabilities: cryosphere

V1: Impact of ocean-ice shelf interactions on melting of Antarctic Ice Sheet (AIS)

V2: Mediation of atmosphere, ocean, and sea-ice to sea level rise from AIS

V3: Key uncertainties in projecting regional sea level rise

V4: Impacts of sea level rise and extreme storms on coastal inundation

- Integration of capabilities from SciDAC, E3SM, Ocean NGD, CICE Consortium, and coastal (InterFACE, ICoM), and early-career projects
- Ocean: wetting-and-drying at ice sheet grounding line; non-Boussinesq ocean; tidal impacts on sub-ice shelf melting
- Sea ice: eulerian icebergs; Icepack integration; landfast sea ice physics, sea ice and tidal interactions; variational ridging
- Land ice: dynamic Greenland ice sheet; dynamic Antarctic ice sheet; new ice sheet model physics
- Other: offline regional SLR modeling capability

V4 science and model capabilities: water cycle

GPU-enabled

Storm-resolving to standard resolution

Resolution frontier: flagship

- Atmosphere: 3 km
- Ocean/ice: 30 to 3 km to resolve mesoscale from equator to poles

Quantify uncertainty through large ensemble simulations: workhorse

- O(2000) years of simulation
- Standard resolution, possibly with RRM

- Integration of NGD storm-resolving model development and v3/v4 development into a single v4 code base for GPU-CPU hybrid machines
- Applications across a range of resolutions
- Atmosphere: NH dynamical core (C++/Kokkos); physics and aerosol chemistry in C++/Kokkos or Fortran OpenACC (including EAGLES contribution)
- Ocean: MPAS infrastructure and dynamical core improvements; upgraded physics for flagship (mesoscale/submesoscale eddy parameterizations); scale-aware capabilities for workhorse (Bolus and Redi mixing); waves and wave-sea ice interactions
- Sea ice: MPAS-seaice embed in MPAS-ocean
- Land/river: hyper-resolution modeling

V4 science and model capabilities: crysosphere

V1: Impact of ocean-ice shelf interactions on melting of Antarctic Ice Sheet (AIS)

V2: Mediation of atmosphere, ocean, and sea-ice to sea level rise from AIS

V3: Key uncertainties in projecting regional sea level rise

V4: Impacts of sea level rise and extreme storms on coastal inundation

- Ocean: sea surface responding to spatiotemporally varying gravity field
- Sea ice: Lagrangian icebergs; integration and testing of DEMSI; full embedding of sea ice mechanics in ocean barotropic mode
- Land ice: dynamic Antarctic ice sheet; new ice sheet model physics (e.g., tabular iceberg calving; subglacial hydrology; ice shelf hydrofracture); coupling between variable sea level and land ice dynamics; coupling between solid earth and land ice dynamics (GIA); prognostic glaciers and icecaps
- Other: regional SLR from steric and eustatic sources

Questions?