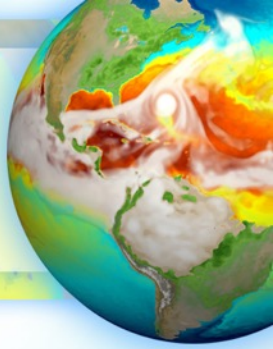


E3SM Science Goals and Priorities

L. Ruby Leung, E3SM chief scientist

DOE ESMD/E3SM meeting, October 26 – 29, 2020

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 1 (2014-2018)

- Development of v1 from v0 based on CESM1
- Science questions focus on **model behaviors**:
  - Water cycle: impacts of resolution (1^o vs. 0.25^o); contrasting effects of forcing (all vs. GHG)
  - BGC: structural uncertainty in nutrient limitation; implications to carbon-climate feedback
  - Cryosphere: resolution sensitivity of modeling ocean-ice shelf interactions

Phase 2 (2018-2022)

- Development of v2 (incremental improvement in model capability and computational performance)
- Parallel next generation development (NGD) of v3/v4
- Science questions are more **use-inspired addressed using RRM**:
  - Water cycle: contrast local vs. large-scale impacts of human activities on floods and droughts
  - BGC: evaluate impacts of different energy futures on extremes
  - Cryosphere: impact of atmosphere, ocean, and sea-ice on Antarctic ice sheet melt rate

Implementations through project phases

- Water cycle
- Biogeochemistry
- Cryosphere

V2 development and integration, v1 and v2 simulation campaigns, analysis to address science questions of the coupled system

- Infrastructure
- Performance

Code and data management, automated testing, timing and profiling, diagnostics, computational performance

- Software and algorithm
- Nonhydrostatic atmosphere model
- Atmosphere physics
- Energy and land
- Ocean modeling
- Dynamic ice sheet
- Large ensemble modeling

Development towards v3 and v4, focusing on component models

Implementations through project phases

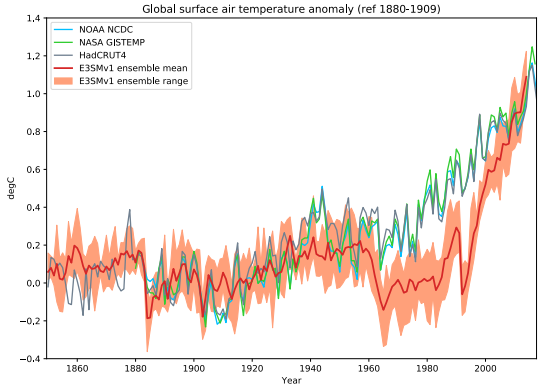
Phase 3 (2022-2025/26)

- 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**

Water cycle: insights from v1

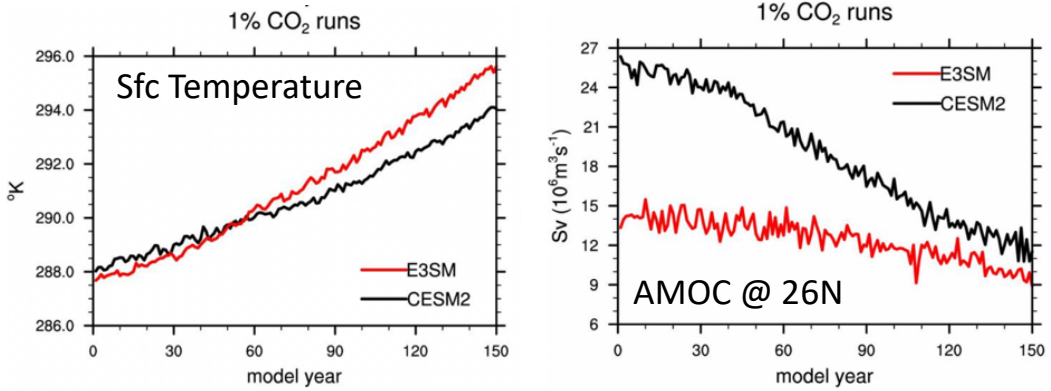
- E3SM v1 has high ECS partly due to large positive cloud feedback, with strong aerosol forcing
- E3SM v1 has high TCR, due partly to a weak AMOC
- These characteristics have important implications for projecting future water cycle changes
- Significant NGD development offers an opportunity to better constrain future projections of water cycle changes

E3SM v1 simulated historical temperature (ECS = 5.3 K)



(Golaz et al. 2019 JAMES)

E3SM v1 has a weak AMOC



(Hu et al 2020 J. Climate)

Water cycle: v3 science

Clouds, aerosols, ocean, sea ice, coupled processes, …

ECS and TCR

Energy flow in the earth system

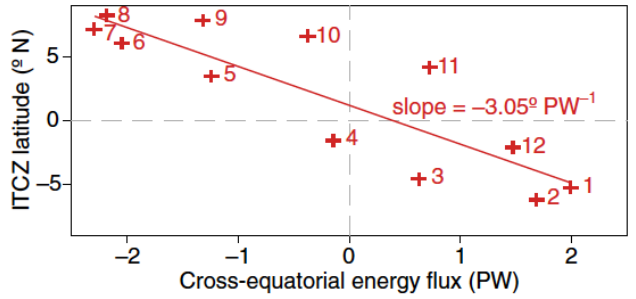
Precipitation and other water cycle processes

Historical climate

TCR — constrain? ↓

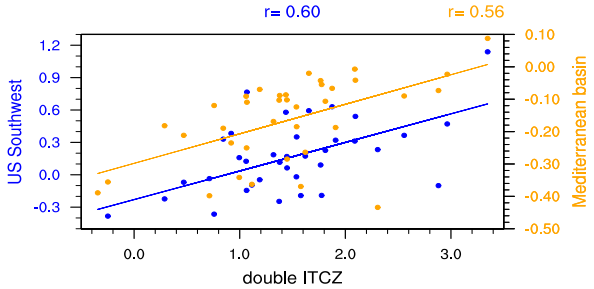
Future projection

Energetic constraint on tropical precipitation



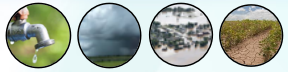
(Biasutti et al. 2018 NGEO)

Double ITCZ constraint on future precipitation changes



(Dong et al. in review)

Water cycle: v4 science



GPU-enabled

Storm-resolving to standard resolution

Resolution frontier

- Impacts of model resolution on water cycle processes (through impacts on cloud feedback, …)
- Impacts of air-sea interactions in cloud-resolving atmosphere and eddy-resolving ocean simulations on hydrological cycle

Quantify uncertainty through large ensemble simulations

- Relative contributions of uncertainties from internal variability, model physics, grid resolution to uncertainties in water cycle
- Relationships between uncertainties in present-day and future water cycle

Biogeochemistry: v3 science

Land focused

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

- Natural processes
- Diagnostic CO_2

Human and land focused

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

- Human-earth interactions
- Prognostic CO_2

Coupled system

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

- Natural/anthropogenic sources (e.g., energy, LU) and sinks (e.g., CO_2 removal)
- Anoxia through land-river-coastal processes

Cryosphere: v3/v4 science

Ocean-ice shelf

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

Atmosphere, ocean, and sea ice forcing

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

Biases in processes driving ice shelf melting, tipping points, and implications for global climate and coastal vulnerability

V3: Key uncertainties in projecting regional sea level rise

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

Dynamic ice sheet (GIS and AIS)

Offline RSL modeling

Online RSL modeling

Coastal modeling

Questions?

More discussion of v3/v4 after the overview presentations