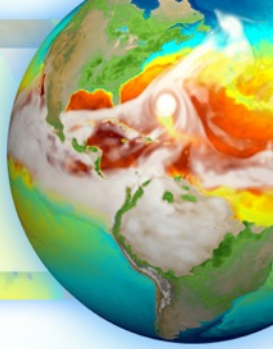


E3SM Science Goals and Progress

L. Ruby Leung

DOE E3SM Review, November 9-10, 2020

Outline

- Science goals ----- implementations
- Implementing science plan through project phases
- Progress towards science goals
- Measure of success - actionable metrics

Science goals define our strategies and implementations

Goals	Science Drivers	Strategies	Implementations
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	Water cycle: water availability, storms, floods and droughts Biogeochemistry: temperatures, heat extremes, wildfires Cryosphere: sea level rise, coastal inundation	• Push the high-resolution frontier of Earth system modeling • Represent natural, managed and manmade systems across scales • Quantify uncertainty using ensemble modeling	• 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)

Implementations through project phases

Phase 1 (2014-2018)

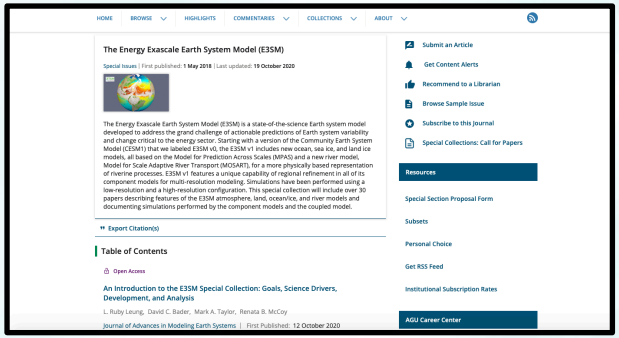
- Development of v1 from v0 based on CESM1
- Science questions focus on **model behaviors**:
  - Water cycle: impacts of resolution (1° vs. 0.25°); contrasting effects of forcing (all vs. GHG)
  - BGC: structural uncertainty in nutrient limitation; implications to carbon-climate feedback
  - Cryosphere: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

Progress towards science goals

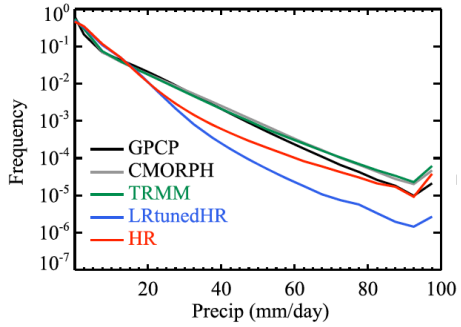
- Development of E3SM v1 and v2, and v1 science simulation campaigns and analysis are documented in the **AGU E3SM special collection** with 50 papers
- Modeling challenges addressed in the special collection
  - Water cycle:
    - Advances and uncertainties in modeling **clouds and precipitation**
    - Representing **impacts of human activities** on terrestrial water cycle
    - **Coupled physical climate simulations** at LR and HR
  - Biogeochemistry:
    - Representing **nutrients** in terrestrial system
    - **Uncertainty** in modeling biogeochemistry
    - **Coupled earth system simulations** at LR
  - Cryosphere:
    - **Resolution sensitivity** of ocean-ice simulations
    - **Asymmetric response** of ice shelf melt rates to variability of ocean forcing
- Analysis of **resolution and uncertainty** will be highlighted next



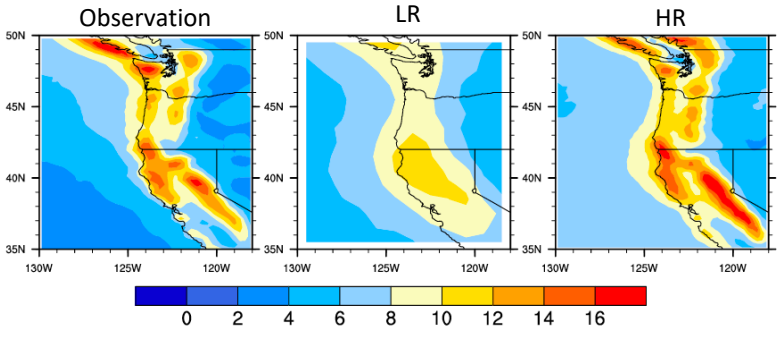
Does higher resolution improve modeling of water cycle?

HR better simulates extreme precipitation

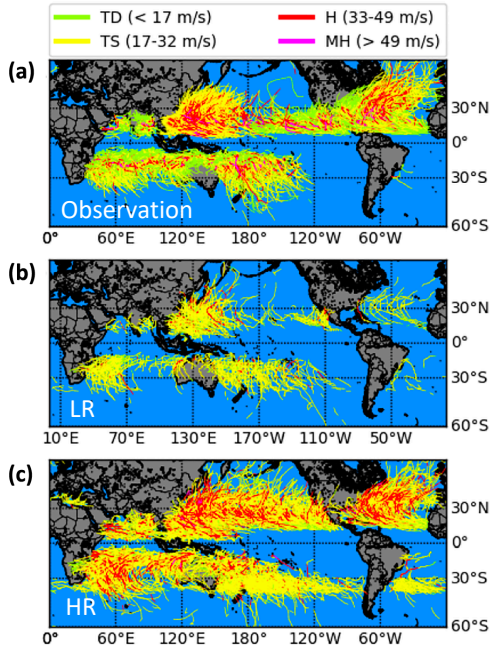
PDF of rain rate (25S-25N land)



HR improves precipitation over complex terrain



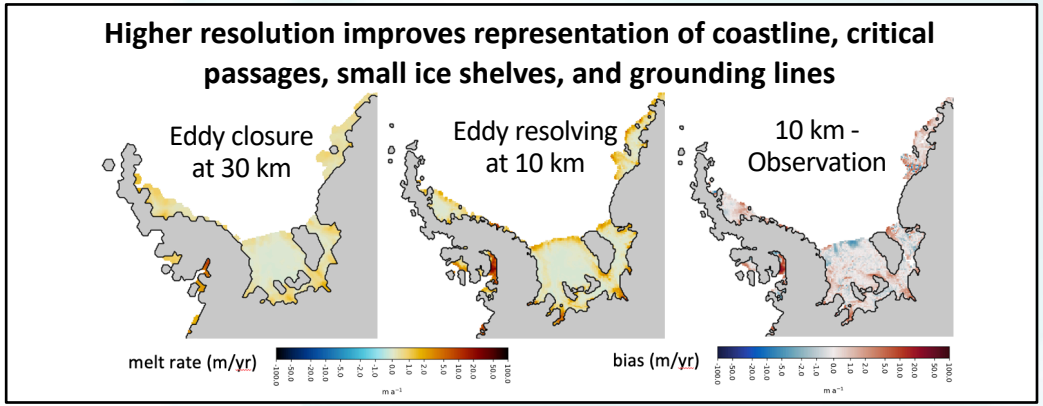
Tropical cyclone frequency and intensity much better simulated at HR

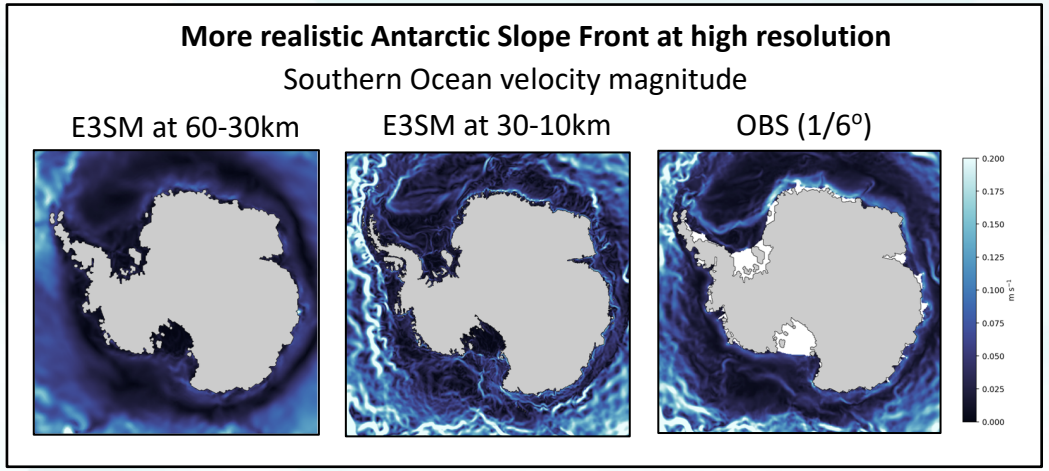


(Caldwell et al. 2019 JAMES)

- Support use of RRM for advancing use-inspired science goals
- Some features are insensitive to resolution – need for physics improvement and/or even higher resolution (NGD physics development and SCREAM)

Does higher resolution improve modeling of cryosphere?

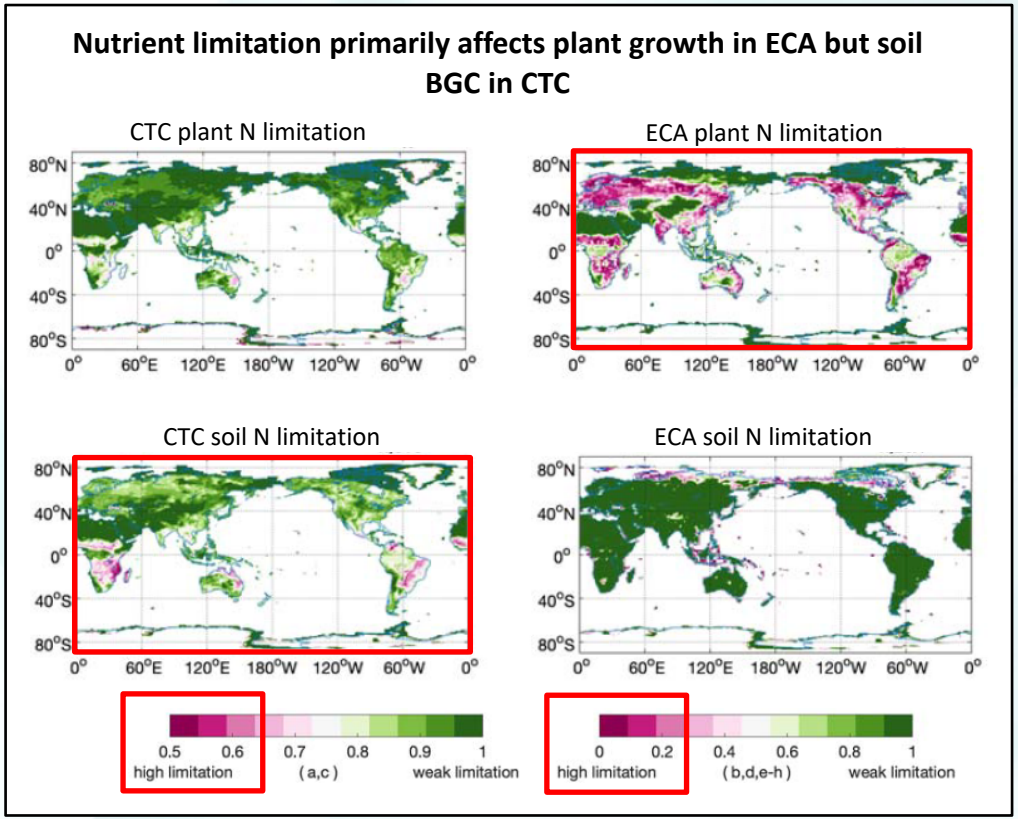




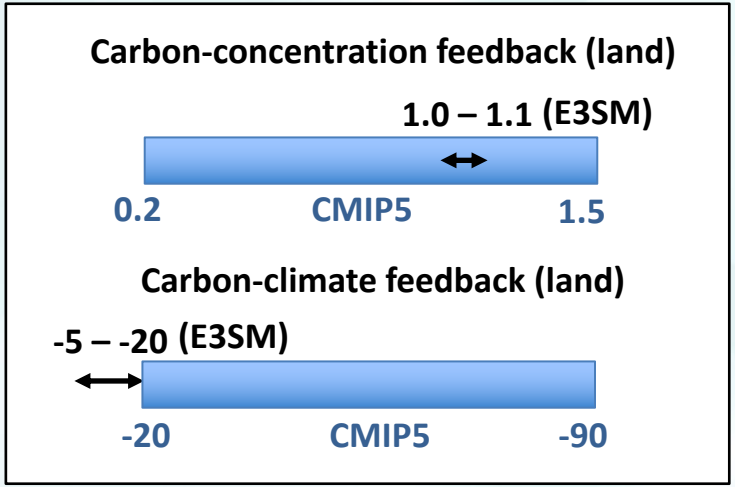
- Melt rate and many ocean and sea ice features are much better simulated at high resolution: support use of RRM
- Wind biases increase at higher resolution – a coupled model challenge

(Comeau et al. and Hoffman et al. in prep)

How does structural uncertainty affect estimates of carbon feedback?



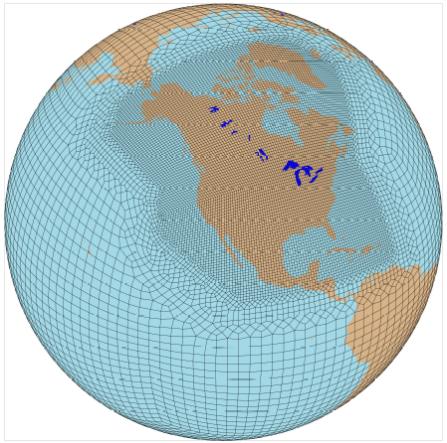
(Burrows et al. 2020 JAMES)

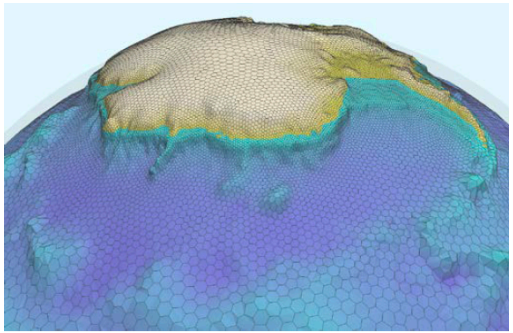


- Including nutrients (N, P) reduces estimates of carbon feedback
- Despite the large structural difference between CTC and ECA, the impact on carbon feedback appears small

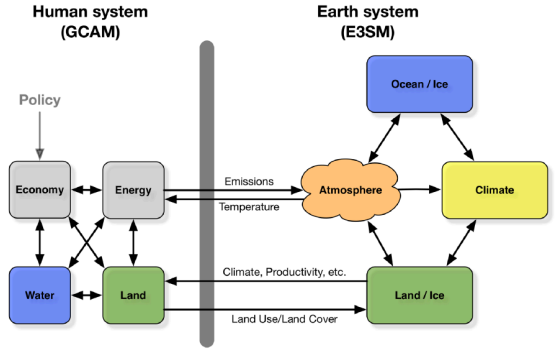
E3SM v2 new features advancing use-inspired science

Regional refinement meshes:
(1) focus on regions of interest: North America and Antarctica; (2) 5x – 7x computational saving enabling a larger ensemble of simulations



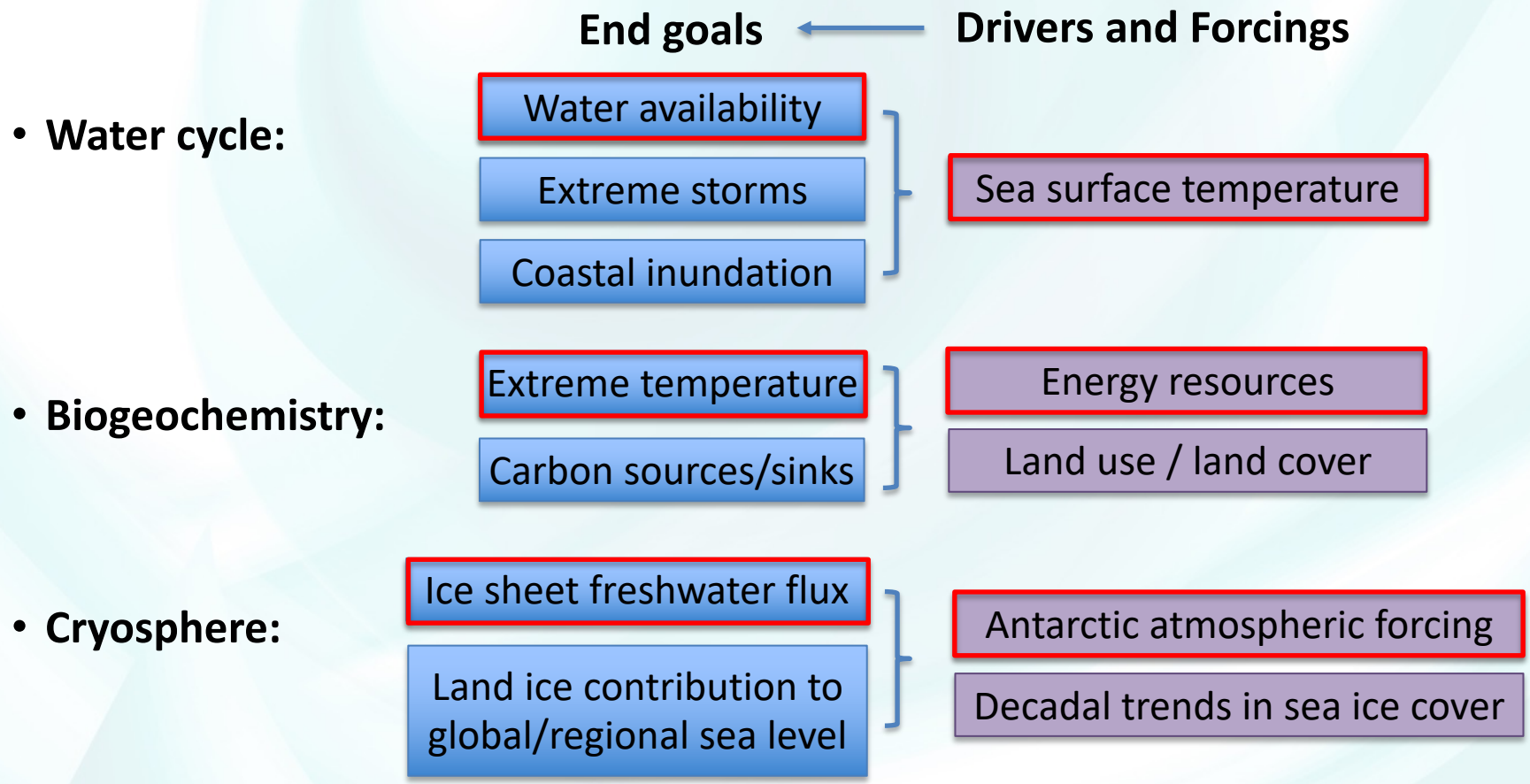


Coupling E3SM-GCAM



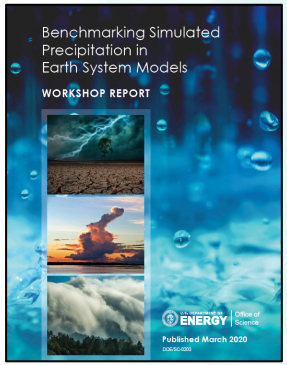
Coupling irrigation-river-water management

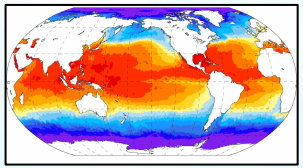
Measure of success: actionable metrics



Measure of success: actionable metrics

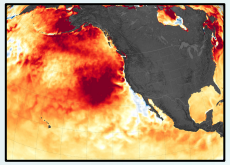
Water cycle





- Water availability
- Sea surface temperature

Biogeochemistry



- Extreme temperature
- Energy resources

Cryosphere

- Ice sheet freshwater flux
- Antarctic atmospheric forcing

Summary

- E3SM has well-defined fundamental and use-inspired science goals and a multi-pronged strategy implementable through project phases
- E3SM takes an iterative approach to defining specific science questions and experimental designs (model behaviors ⇄ use-inspired science)
- Significant progress has been made to advance fundamental and use-inspired science (AGU E3SM special collection and other publications)
- Success measurable using actionable metrics: use-inspired end goals (energy mission) supported by physical relationships (with drivers and forcings)