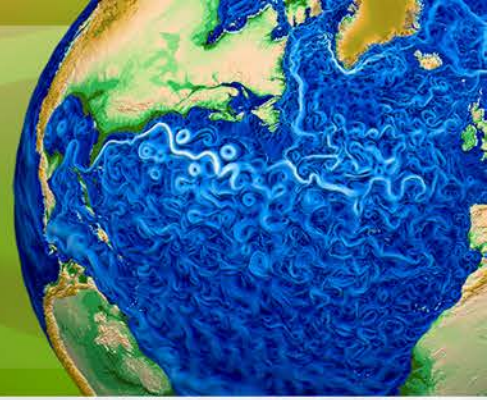


E3SM Version 1 Release

L. Ruby Leung, E3SM chief scientist

Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory

The E3SM team

Dave Bader, PI

Ruby Leung, Chief Scientist

Mark Taylor, Chief Computational Scientist

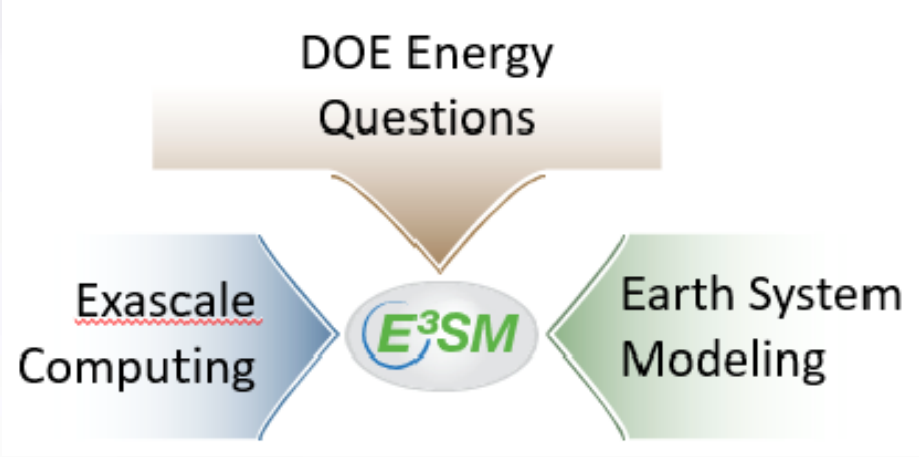
Renata McCoy, Project Engineer

Dorothy Koch, Program manager

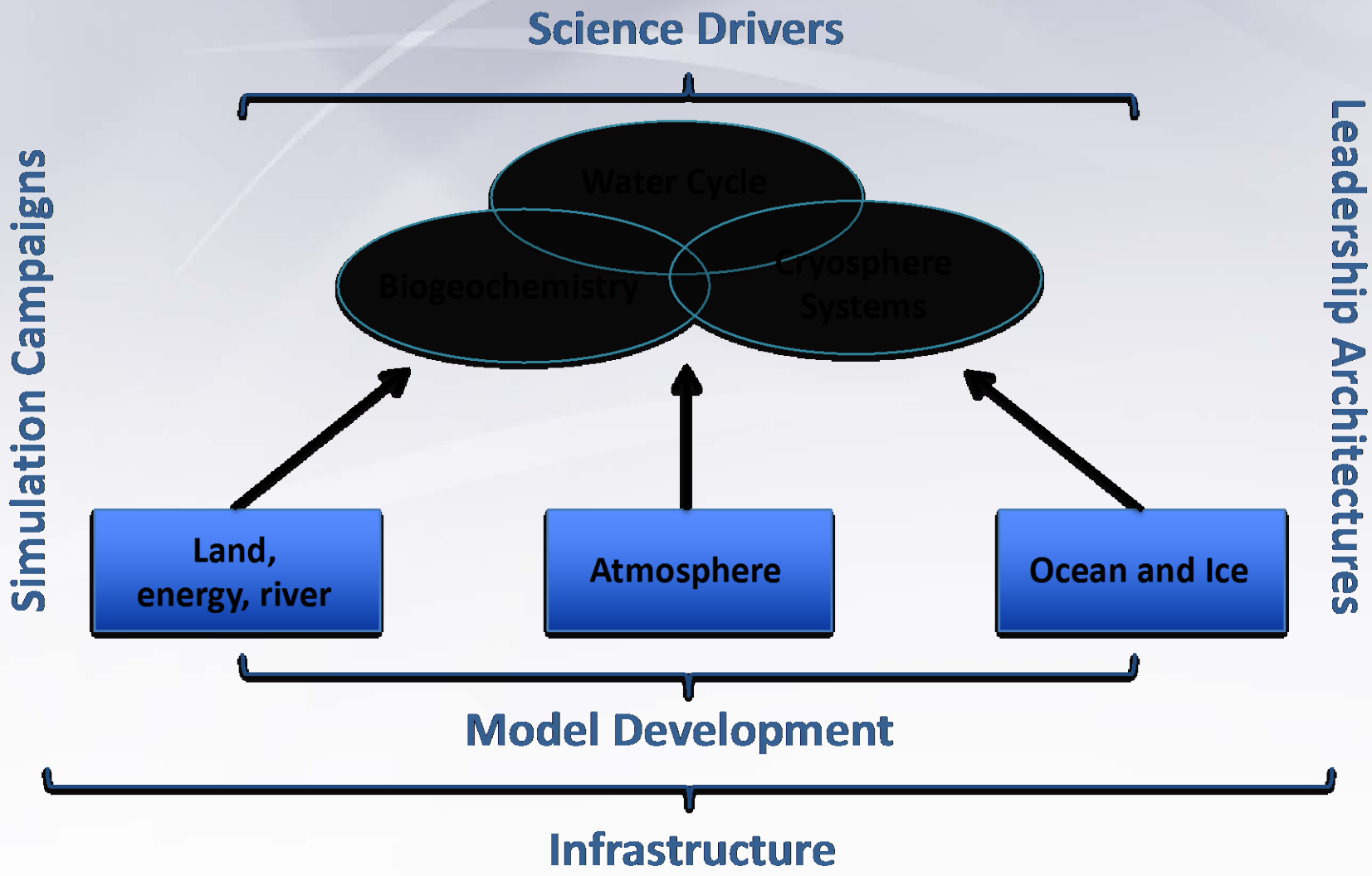
2017 E3SM All-Hands Meeting, Potomac, MD

Long term goal of E3SM

- Address the grand challenge of actionable predictions of Earth system variability and change, with an emphasis on the most critical scientific questions facing the nation and DOE, by:
  - Pushing the high-resolution frontier of Earth system modeling
  - Representing natural, managed and manmade systems across scales
  - Ensemble modeling to quantify uncertainty



E3SM Long Term Roadmap



Science drivers of E3SM

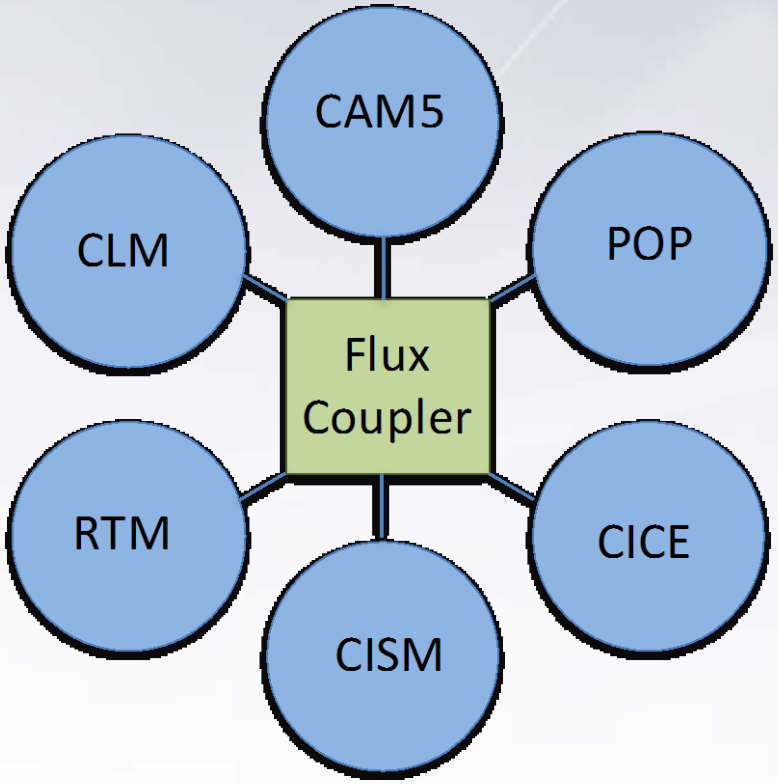
- **Water Cycle:** How does the hydrological cycle interact with the rest of the human-Earth system on local to global scales to determine water availability and water cycle extremes?

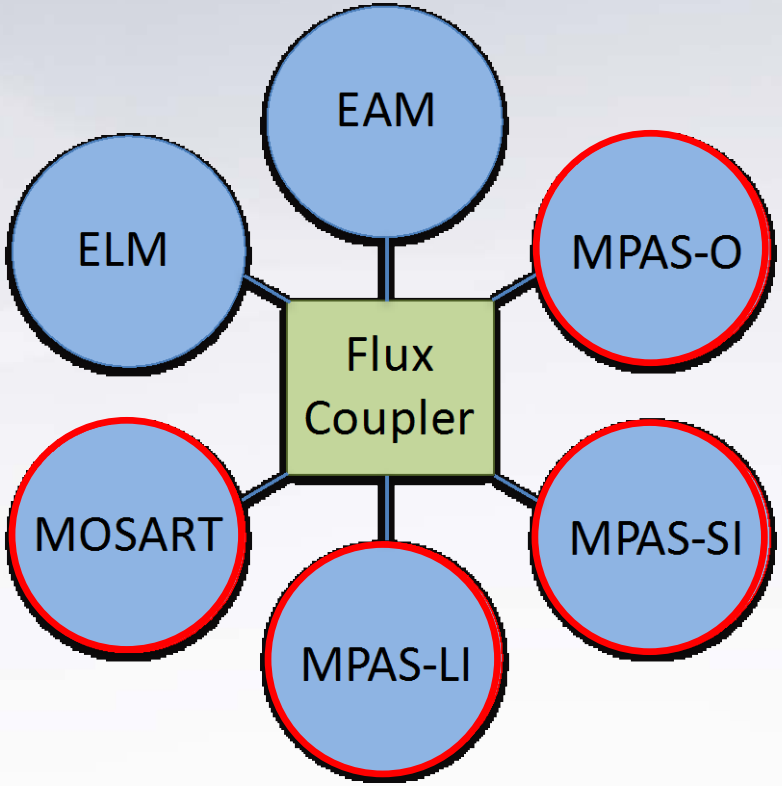
- **Biogeochemistry:** How do the biogeochemical cycles interact with other Earth system components to influence energy-sector decisions?

- **Cryosphere Systems:** How do rapid changes in cryospheric systems evolve with the Earth system and contribute to sea level rise and increased coastal vulnerability?

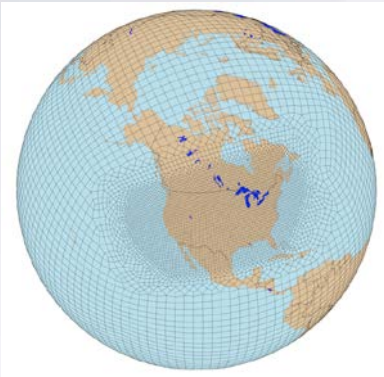
E3SM model components

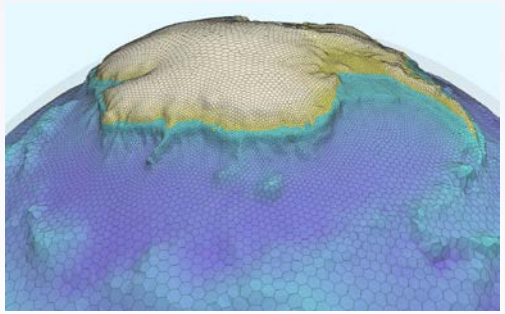
CESMv1 → E3SMv0 → E3SMv1





Unstructured grids allowing regional refinement in all model components



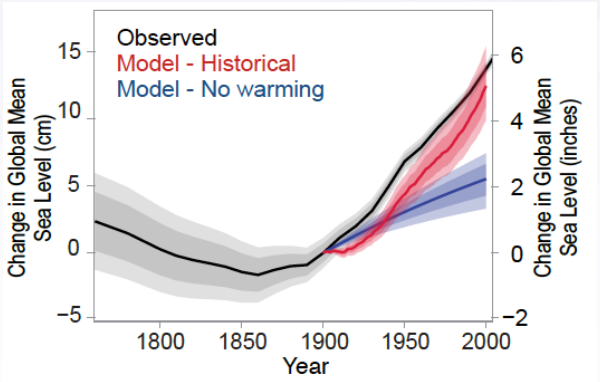


Coupled model challenges

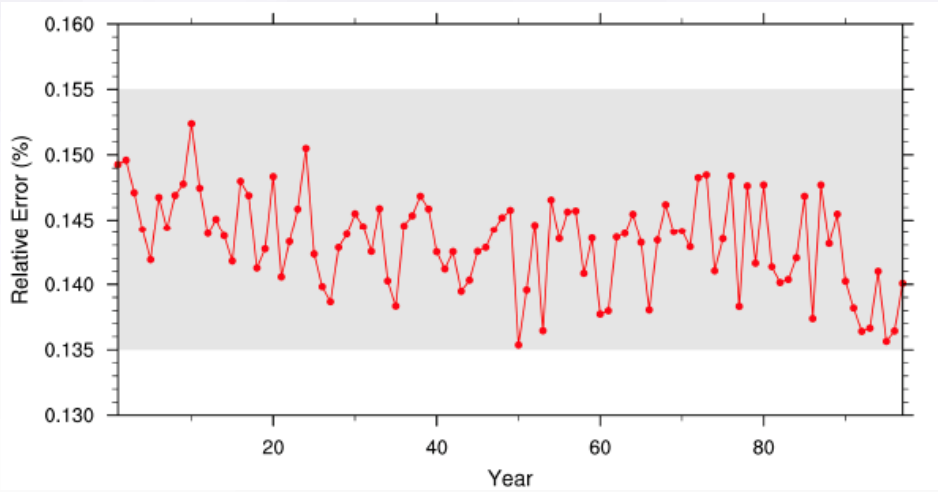
- E3SM has four new component models that have never been coupled in an Earth system model before
- The biggest challenges for E3SM were related to coupled system behaviors - water conservation

First problems fixed: grid inconsistency, coupler remapping; runoff fluxes to rivers

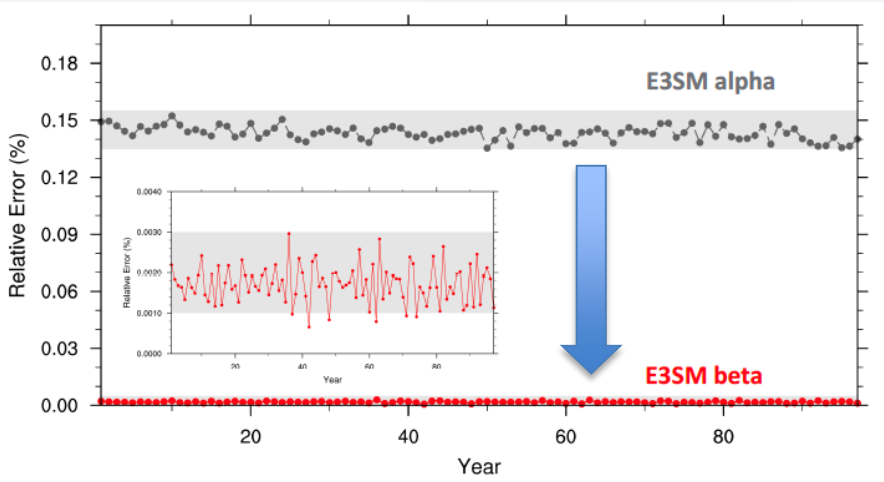
Observed Sea Level Rise ~ 15 cm from 1900 to 2000



Implied sea level rise due to water conservation error in the atmosphere model in 100 years: 14.5 cm



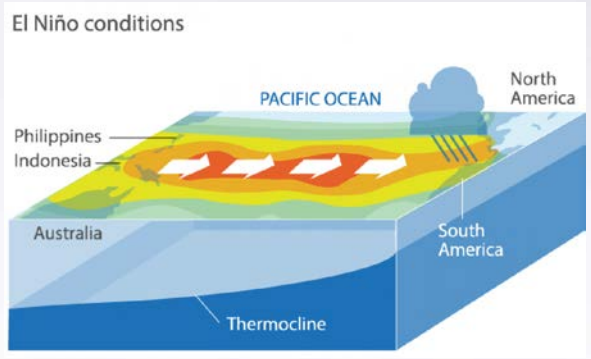
Error reduced to 2 mm, a factor of 80



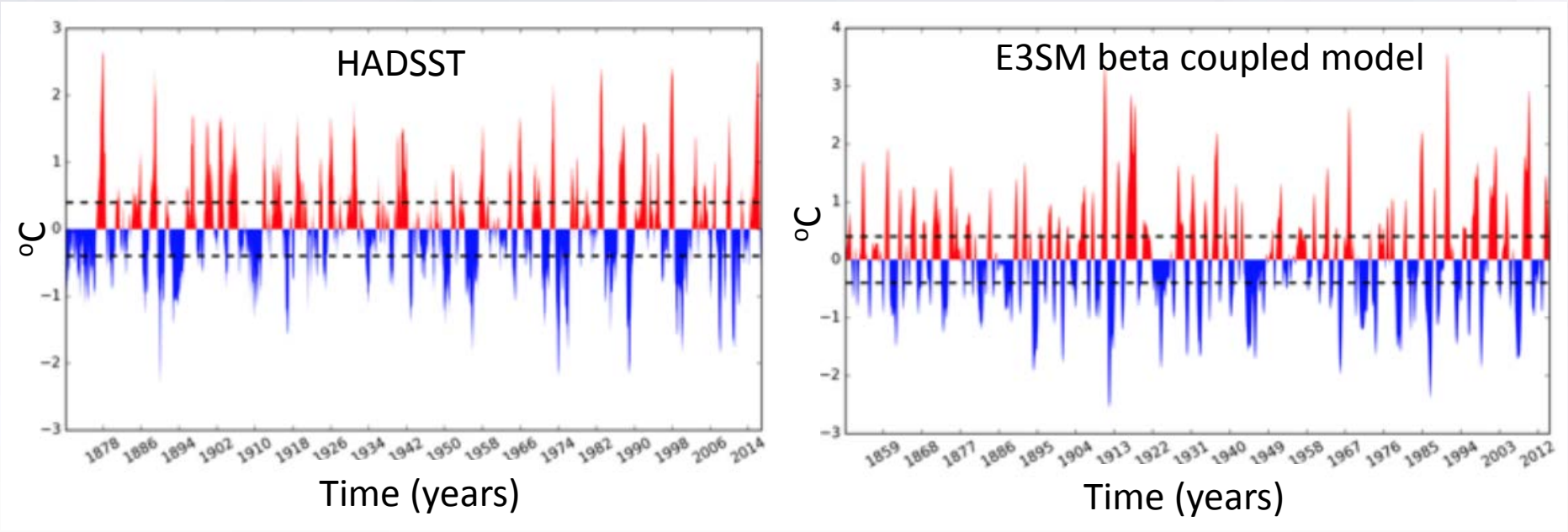
Coupled model challenges

- The biggest challenges for E3SM were related to coupled system behaviors - ENSO variability

ENSO arises from atmosphere-ocean coupled processes



Nino 3.4 index

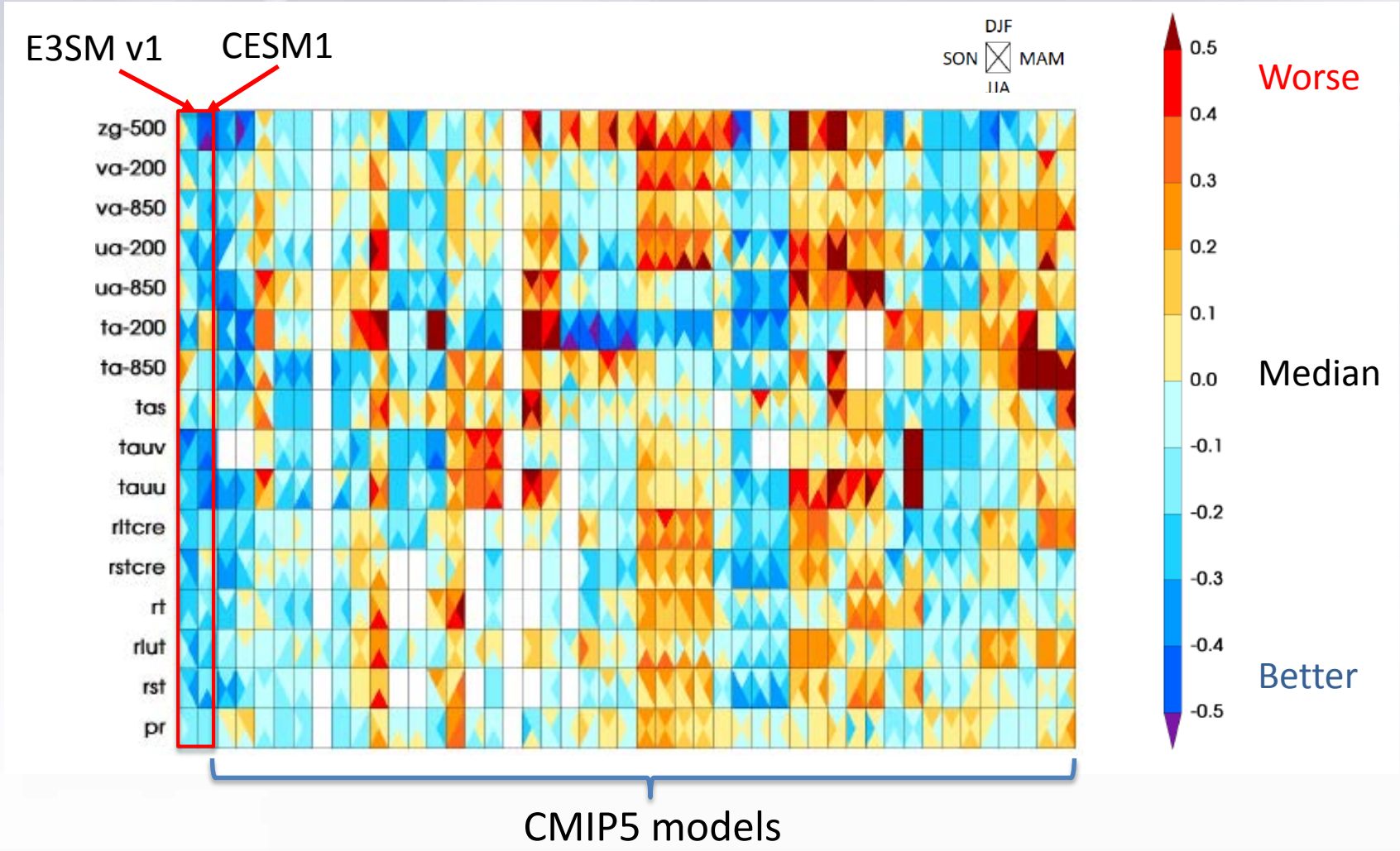


E3SM low resolution coupled model performance

Historical simulation: 1981-2005

Atmosphere/land: 100 km

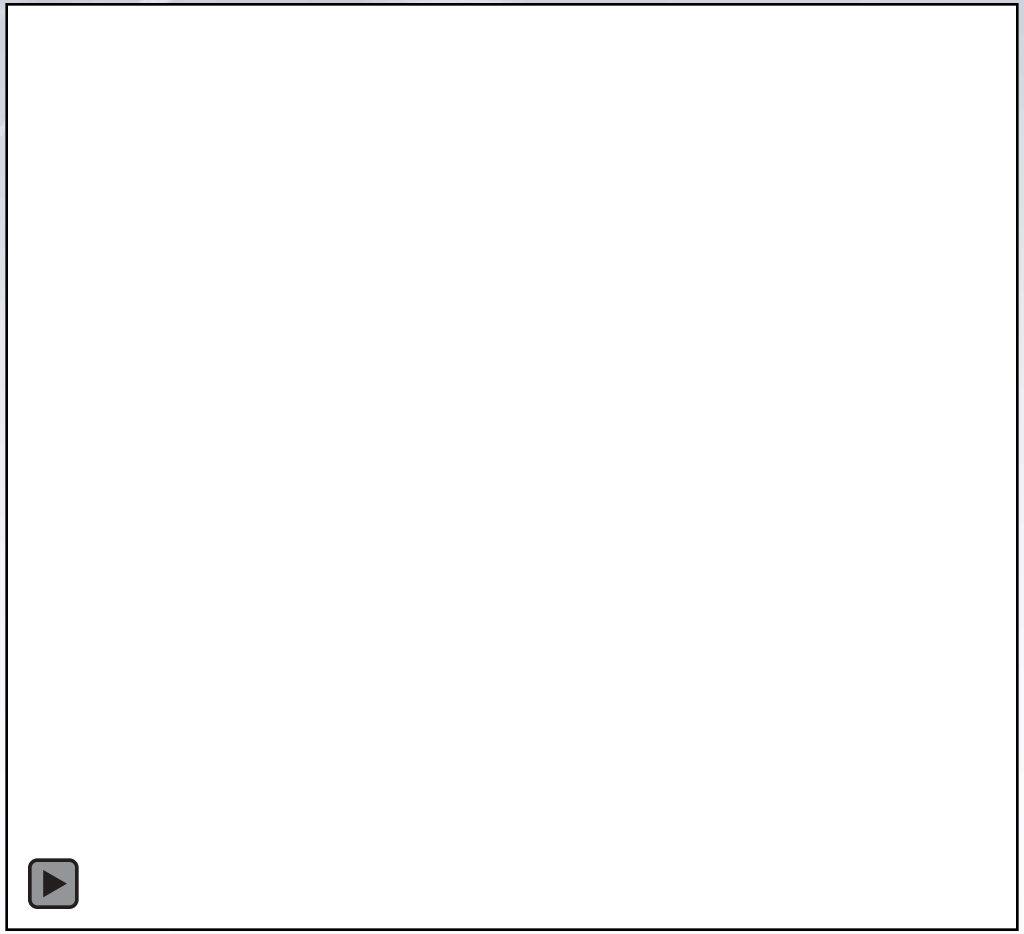
Ocean/ice: 30-60 km



E3SM high resolution coupled simulations

Atmosphere/land: 25 km

Ocean/ice: 6-18 km



V1 water cycle experiments

- **Question:** How will more realistic portrayals of earth system features affect the simulation of Earth's water cycle, including river flow and freshwater supplies at the watershed scale?
- **Hypothesis:**

- **Model configurations:**

Low resolution (LR)

Atmosphere and land: 100 km
Ocean and sea ice: 30-60 km

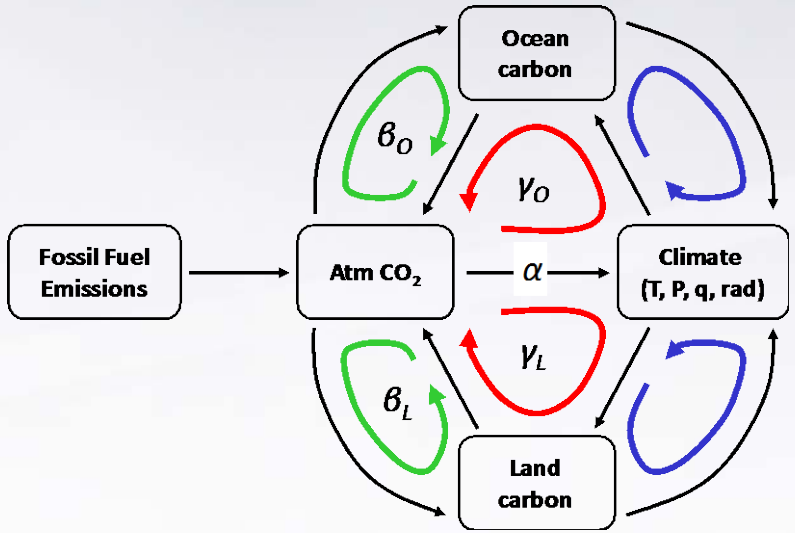
High resolution (HR)

Atmosphere and land: 25 km
Ocean and sea ice: 6-18 km

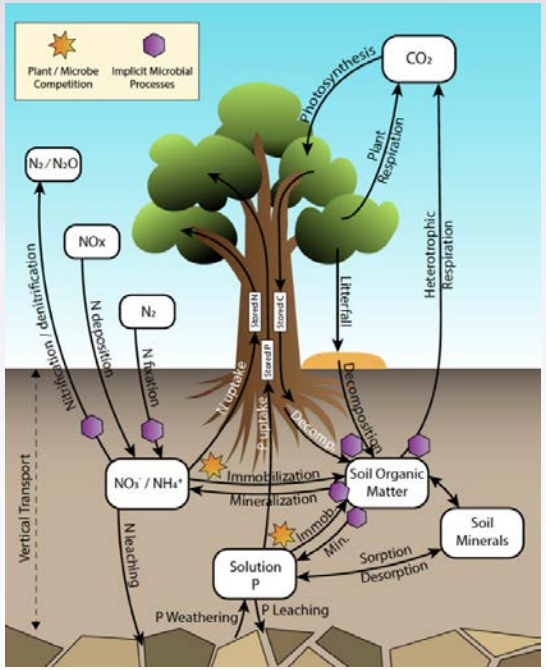
V1 biogeochemistry experiments

- **Question:** What are the nitrogen (N) and phosphorus (P) effects on climate-biogeochemistry feedbacks? How sensitive are the feedbacks to model structural uncertainty?

Climate-BGC feedbacks



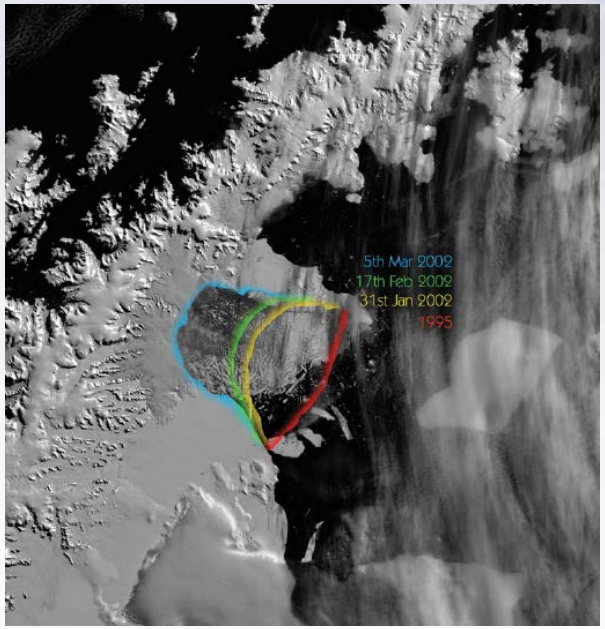
BGC processes

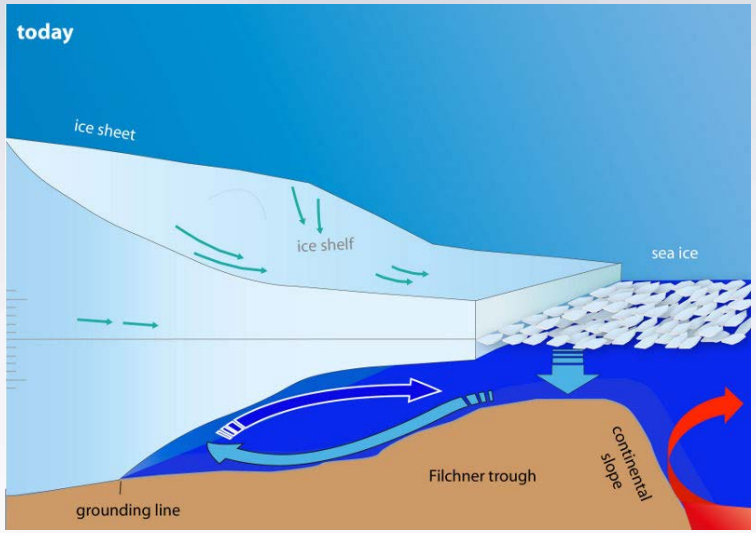


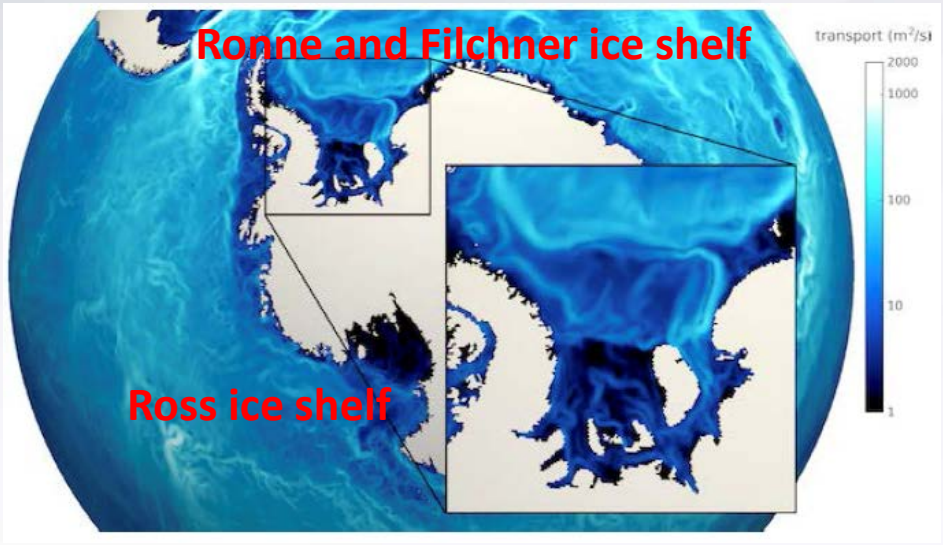
Evaluate structural uncertainty in subsurface biogeochemistry, nutrient competition, plant allocation, and stoichiometric constraints using two BGC representations

V1 cryosphere experiments

- **Question:** What are the impacts of ocean-ice shelf interactions on melting of the Antarctic Ice Sheet and implications to sea level rise?



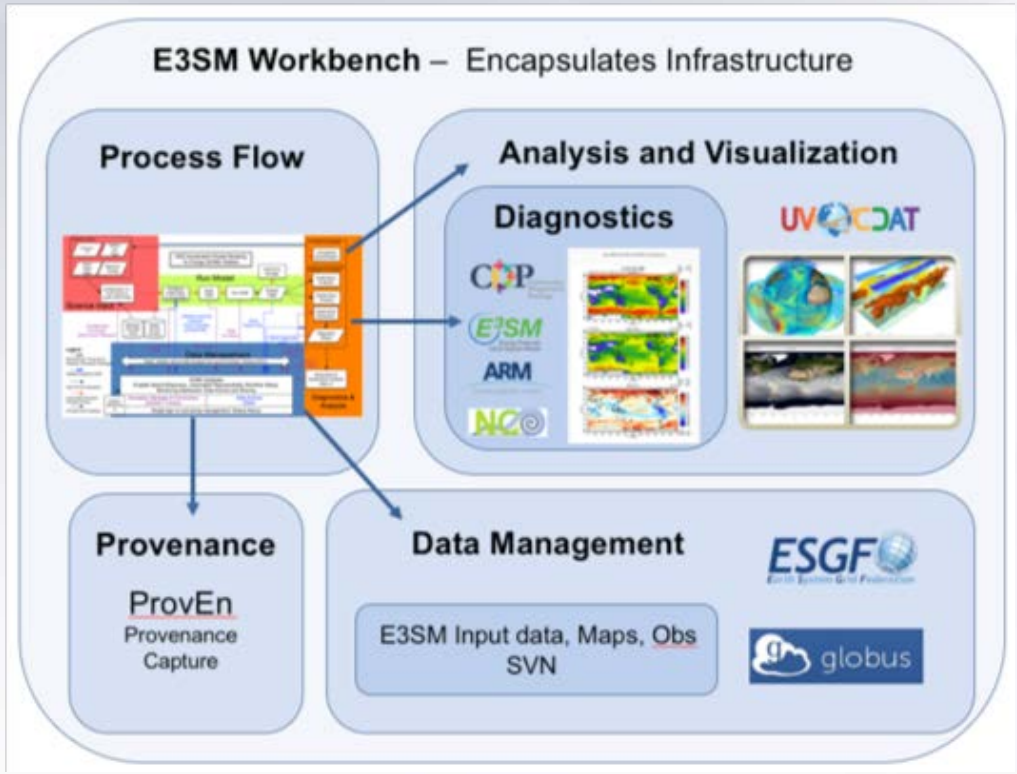




Explore likelihood of abrupt Antarctic change and rapid sea-level rise due to ocean-land ice interactions, targeting simulations that include ocean-ice interactions in ice shelf cavity

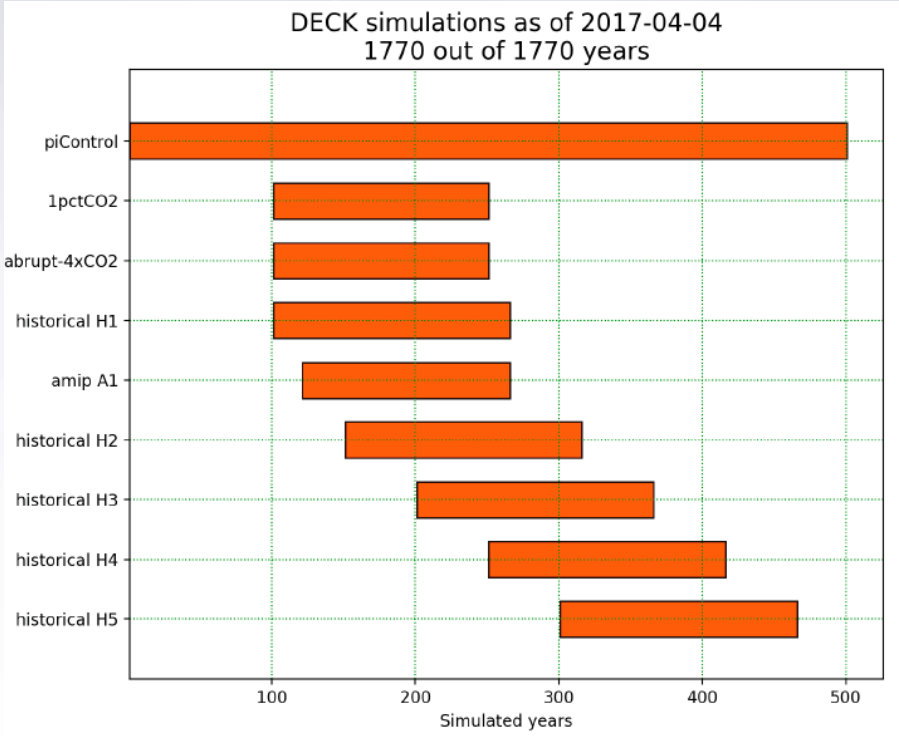
E3SM infrastructure and performance

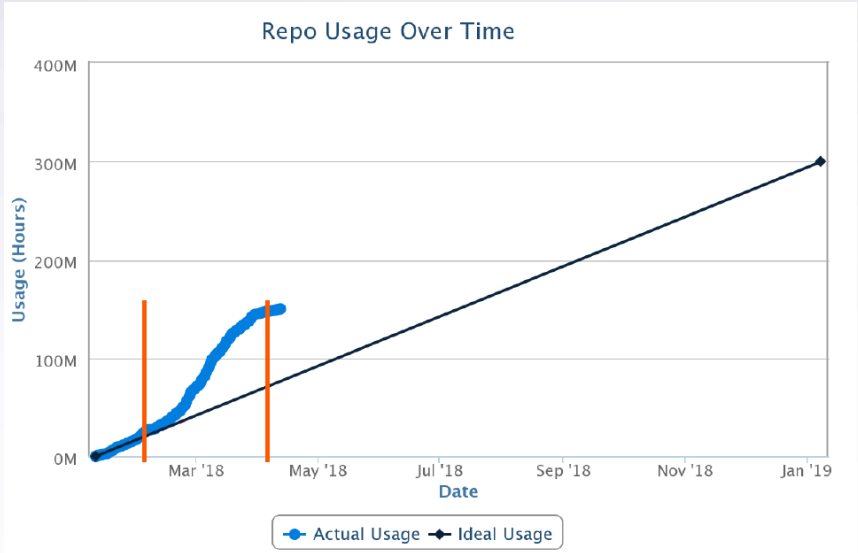
- Computational performance: 2x improvement
  - LR: 5.8 SYPD on Cori; 4.54 SYPD on Titan
  - HR: 0.97 SYPD on Cori; 1.41 SYPD on Titan
- Python and CDAT based diagnostic packages:
  - E3SM Diagnostics, AMWG, ARM Diagnostics, A-Prime Package, MPAS-Analysis, PCMDI Metrics Package (PMP), ILAMB Package
- Infrastructure:
  - An automated process flow job scheduling and orchestrating tool
  - A provenance management system based on ProvEn
  - A data management system for archiving and publishing data



Simulations completed

- Averaged aggregate throughput: 28 SYPD
- Completed in 64 days without a single model crash
- Used 158 Mh – data available for analysis





E3SM release (April 23, 2018)

- E3SM v0 and v1 source code, compsets for LR and HR configurations
- Open source software tools for model diagnosis, evaluation, and intercomparison
- Model output for a 1850 control simulation as part of CMIP6 DECK and documentation and provenance of the run
- Website to document supported compsets, versions, machines and tools, publications, and project activities (E3SM meetings, webinars and tutorials)
- User support managed through (1) a public website forum for Q&A, (2) github tracking system that tracks issues and bug reports, and (3) newsletters and notifications via self-subscribed email lists

Preview of Phase II (2018-2021)

Model development and simulation campaign with v2:

- A stronger regional focus on North America
- Routine use of regional refinement at 25 km over North America and surrounding oceans and regional refinement at 6 km over Antarctica
- Representing human systems at global and regional scale
- A new vegetation dynamics model (FATES) [collaboration with NGEE tropics]
- A new subgrid topography over land
- A new ocean biogeochemistry model (MARBL)
- Increase ensemble size of simulations

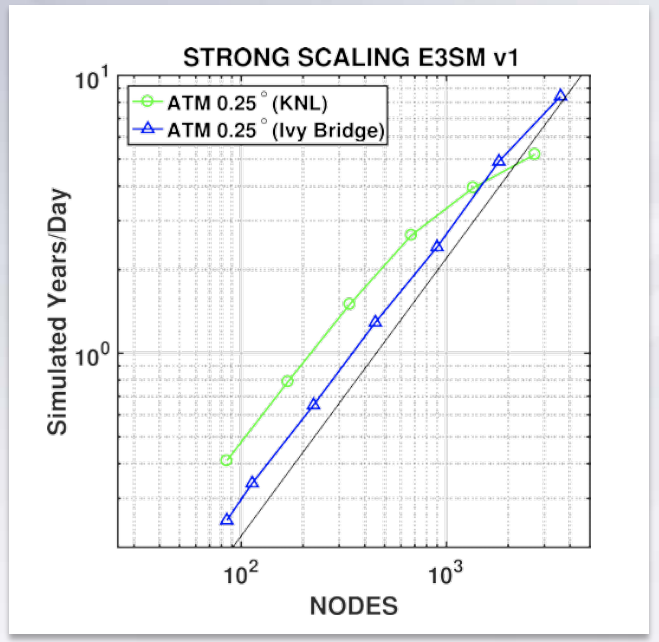
Preview of Phase II (2018-2021)

Next generation development for v3/v4:

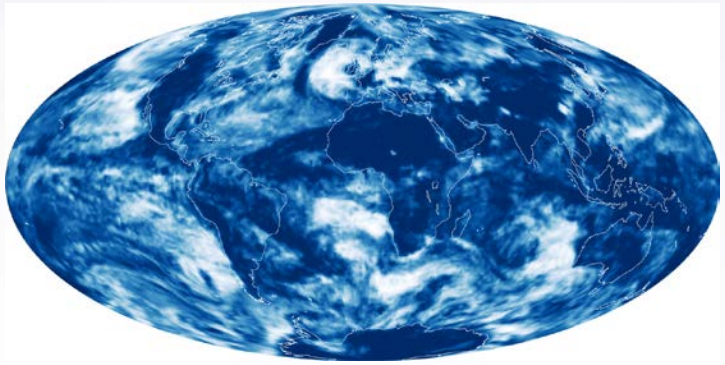
- **Software and Algorithms for Exascale**: major algorithmic changes and a sustainable software system for Exascale
- **Nonhydrostatic Atmosphere Model**: computational and scientific advances to extend the atmosphere model for convection-permitting and convection-resolving simulations
- **Atmospheric Physics**: correct identified biases in the simulated climate for LR and HR applications
- **Energy and Land**: further account for natural, managed and man-made systems and their interactions, with an emphasis on the relationships between the energy system and the water cycle
- **Coastal Modeling:** couple an unstructured grid wave model to MPAS-O
- **Dynamic Ice Sheet Modeling:** couple the BISICLES Chombo framework into E3SM

Computational strategy for exascale

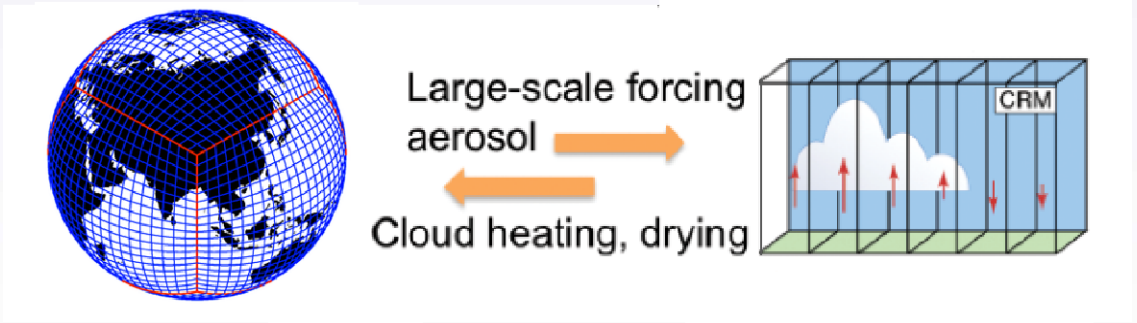
- Maximum throughput is obtained at the limit of strong scaling, but in this limit, there is insufficient work for E3SM v1 to benefit from the KNL architecture
- Good performance on exascale machines requires very high arithmetic intensity, or large amounts of work per node



Global convection resolving modeling



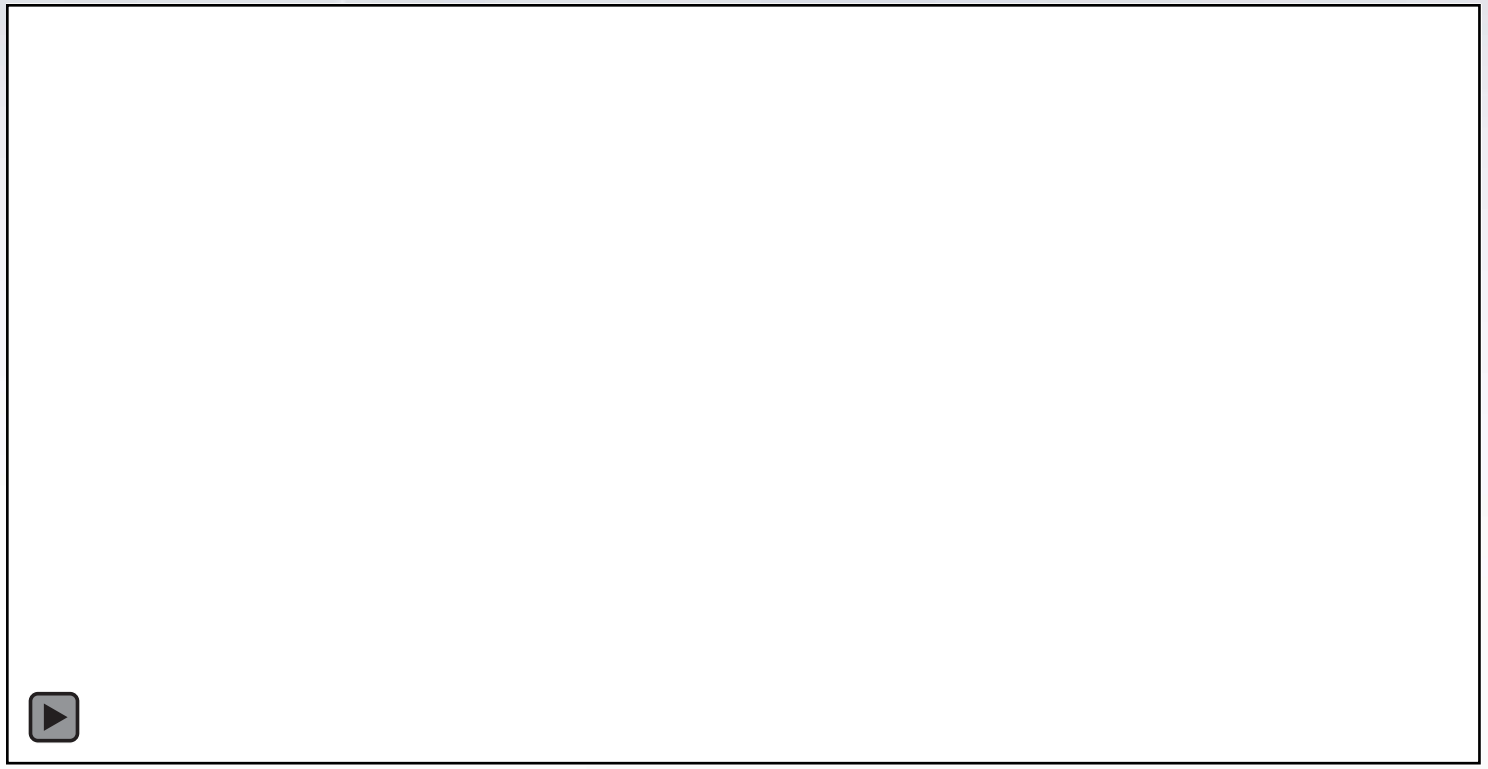
Multiscale Modeling Framework (MMF)

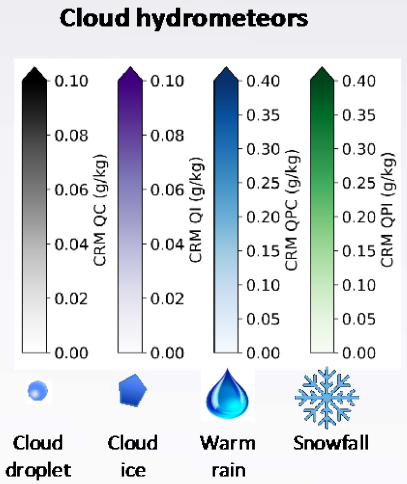


Using hindcast to evaluate E3SM-MMF

- DOE Exascale Computing Project (ECP) (PI: Mark Taylor) is developing E3SM-MMF for improving modeling of the Earth's water cycle

Analysis of mesoscale convective systems in initialized hindcast simulations



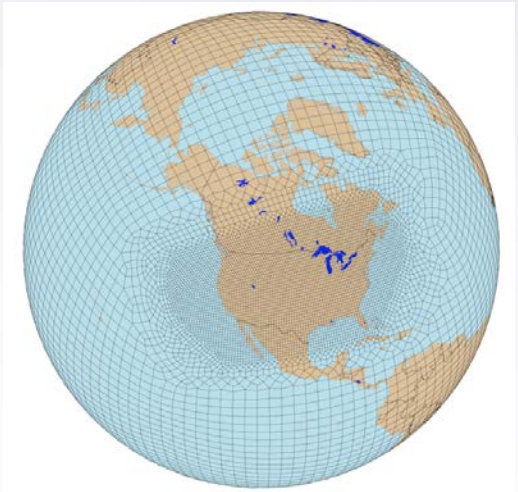


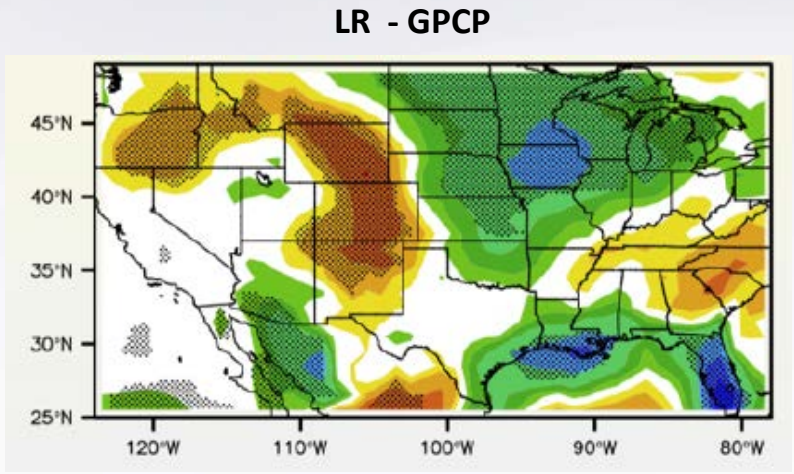
Summary

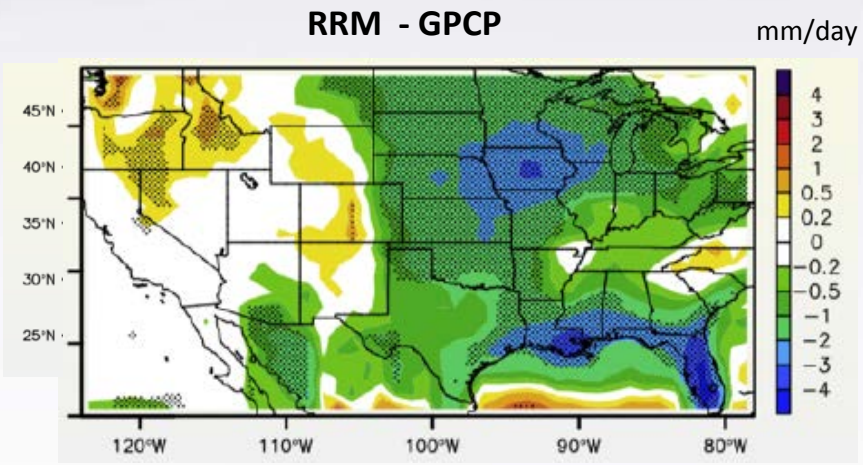
- E3SM v1 LR and HR configurations have been delivered
- HR features a 25 km atmosphere coupled to a 6-18 km eddy resolving ocean
- E3SM v0 and v1 have been released on April 23, 2018
- Phase I (2014-2018) provided a strong foundation for future work in Phase II (2018-2021) to develop v2 and v3/v4 in parallel
- Paths to exascale: convection permitting/resolving modeling in a global model through regional refinement and MMF

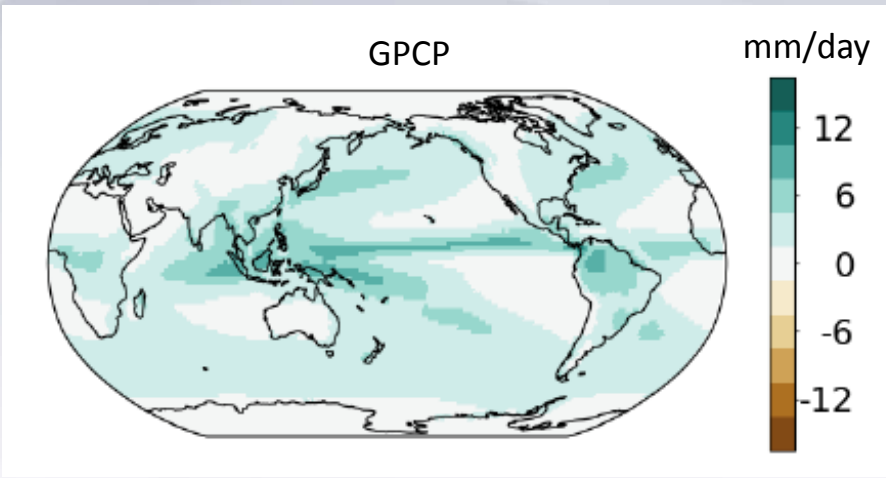
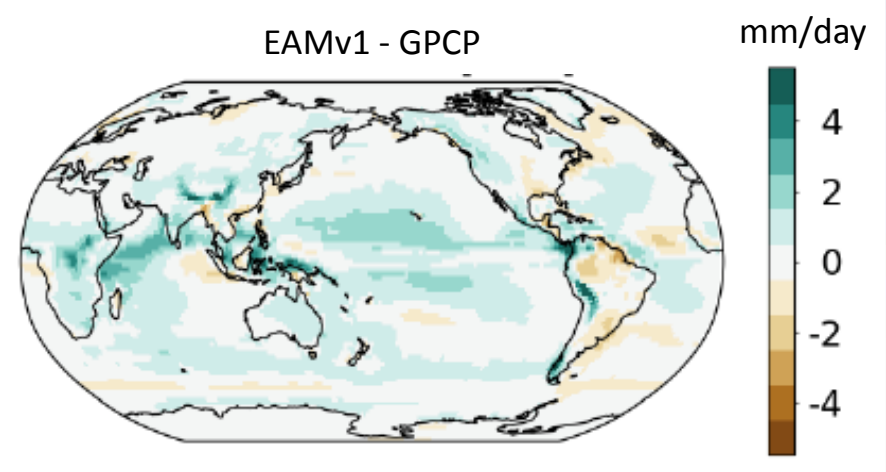
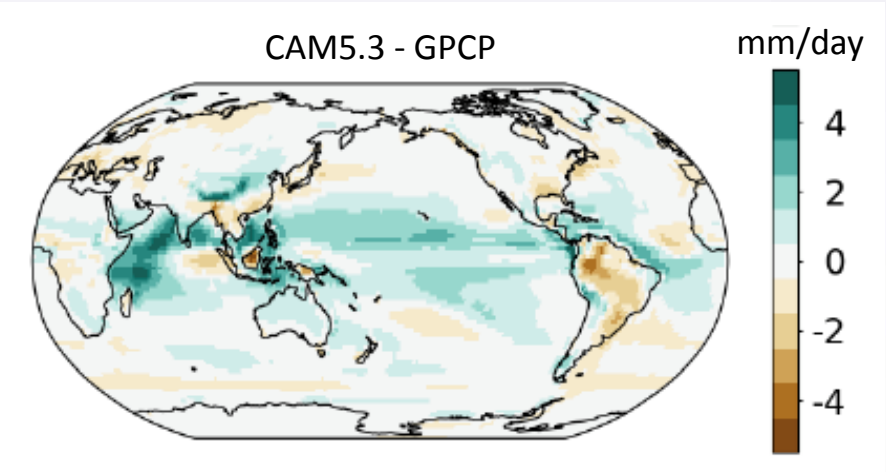
E3SM configurations

- Phase I focuses on a low resolution (LR ~ 100 km) and a high resolution (HR ~ 25 km) configuration
- A “proof-of-concept” regional refinement model (RRM) with 25 km over North America and 100 km outside has been tested
- Model testing and evaluation: single column, RRM, PPE, CAPT, diagnostics such as COSP (satellite and ground based radar), offline aerosol lidar simulator







EAM simulations

Annual mean precipitation