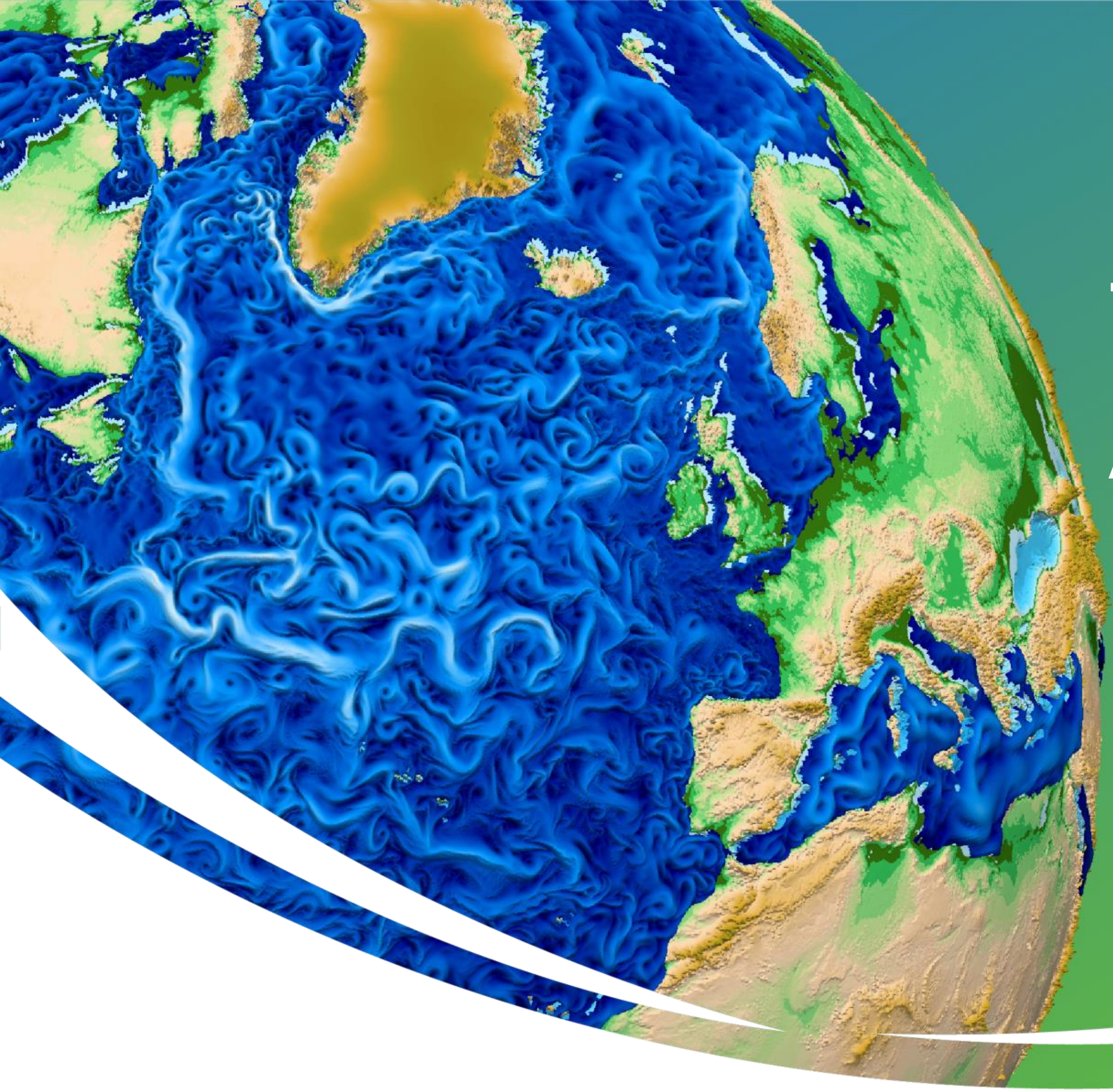

Plans and Progress on the E3SMv4 Atmosphere Model

Chris Terai and E3SM Atmosphere Group

Lawrence Livermore National Laboratory

Atmosphere Model, Chemistry, Earth System Prediction, CVC, and Whole Atmosphere Working Group Meeting 2026

U.S. DEPARTMENT OF ENERGY

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E3SM
Energy Exascale Earth System Model

What is E3SMv4?

Components

- EAMxx atmosphere (C++, new)
- Omega ocean (C++, new)
- MPASSI sea ice (F90)
- ELM land (F90)

Resolution

- Workhorse (Low-res) = 13km atm, ~10km ocean/sea ice, 5km land
- High-resolution = 3km atm, 18 – 2km ocean, sea ice, and land

AI emulation

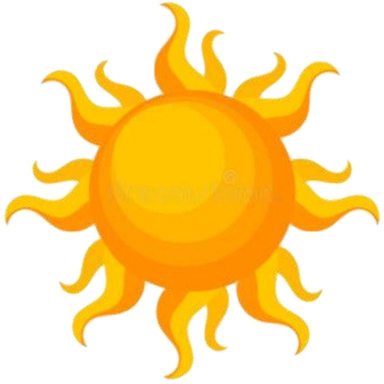
- An AI emulator alongside all physical model releases in E3SM (starting with E3SMv3.LR)

Science focus

- S2S and S2D prediction

What is in EAMxx 13km (ne256)?

SCREAM physics

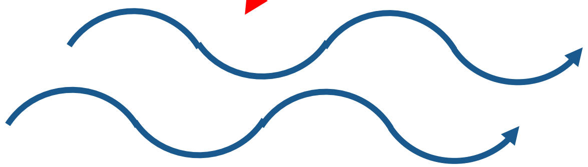


Radiation handled by **RRTMGP** rewritten in C++ for GPUs

Turbulence and **cloud formation** handled by Simplified Higher-Order Closure (**SHOC)**

Microphysical processes handled by a modified Predicted Particle Properties (**P3)** scheme

Resolved-scale **fluid dynamics** treated by a non-hydrostatic Spectral Element (**SE**) approach (homme-xx)



simple prescribed aerosol: CCN and aerosol optical properties are prescribed from E3SMv2 run

Orographic drag handled by turbulent mountain stress **(TMS)** (Richter et al., 2010)

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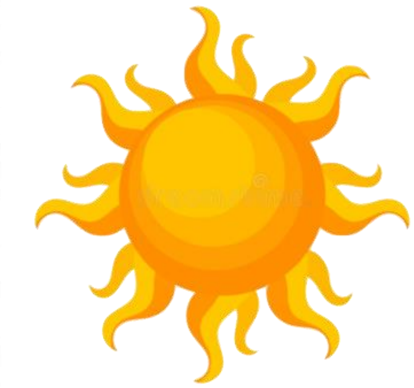

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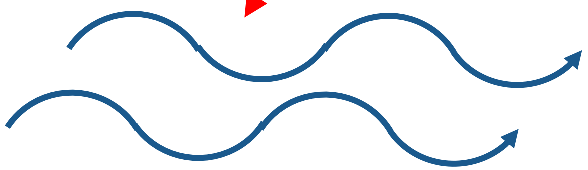

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New* parameterizations

Subgrid-scale deep convection handled by Zhang-MacFarlane

Gravity wave drag for frontal and convective GWD (Richter et al., 2010)

Orographic drag based on Beljaars et al. (2004), Tsiringakis et al. (2017), Xie et al. (2020)

Interactive aerosol scheme **MAM4xx** (to be included in v4.X)

* Porting from F90 schemes

Where are we in our development?

Jan 2025 | Jan 2026 | Jan 2027 | Jan 2028

SCREAM Era

Feature freeze (Jan 2027)

E3SMv4.0 release (Jan 2028)

Test, evaluate, and fix EAMxx 13km in prescribed ocean simulations

Porting new parameterizations

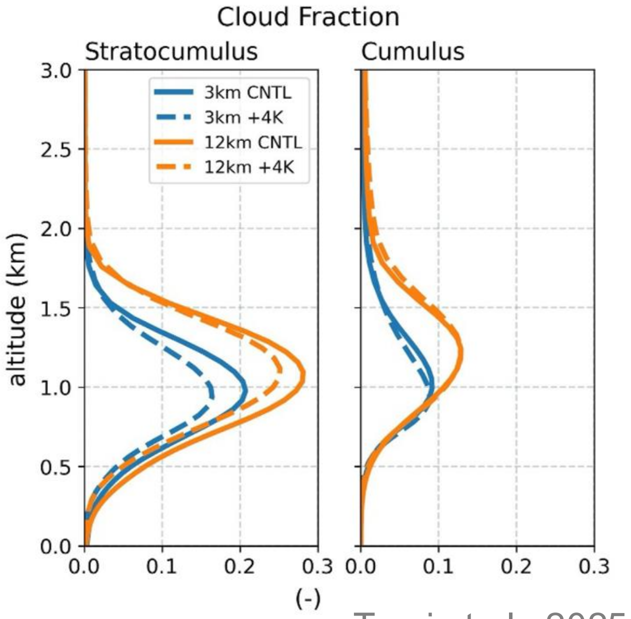
- ZM (deep convection)
- Gravity wave drag schemes
- Orographic drag

Coupled tests

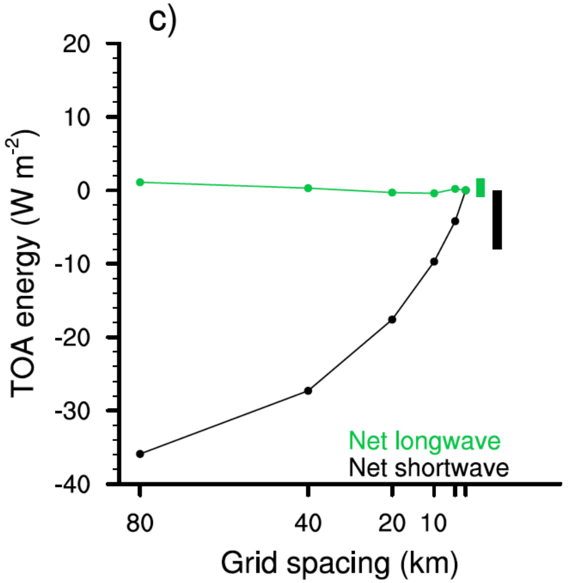
- Test EAMxx 13km in coupled configuration
- EAMxx+Omega

What we found shifting from 3km → 13km: Resolution sensitivity of low clouds

- Strong resolution sensitivity in the TOA SW flux
- Low-cloud regions dominate sensitivity
- Reasons for the resolution sensitivity depend on cloud regime (see below)



Terai et al., 2025



Hohenegger et al., 2020

Stratus (S12)

Time step sensitivity is the dominant source. Surface coupling frequency is the main culprit.

Transitional stratocumulus (S11)

Time step and parameterization errors contribute equally.

Cumulus (S6)

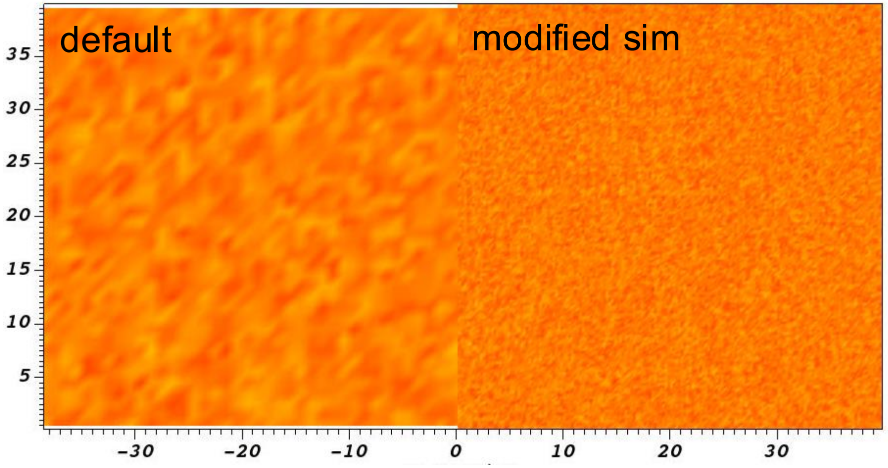
Turbulence parameterization is the dominant source. Dynamics tries to resolve clouds that should remain subgrid.

Summary schematic courtesy of Peter Bogenschutz

Physics fixes and tuning the TOA radiation in EAMxx 13km

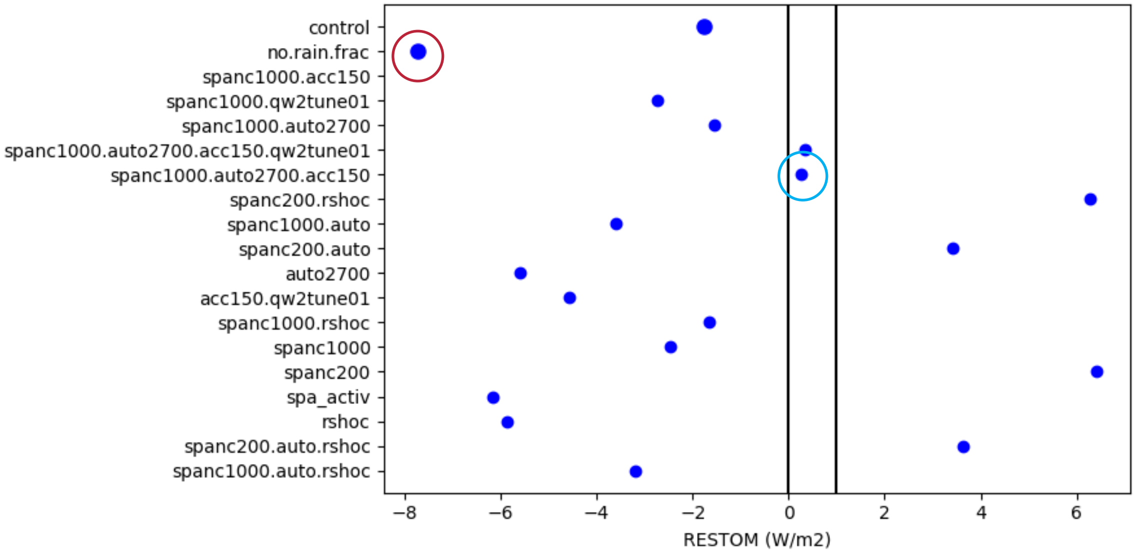
- First attempt to tune EAMxx 13km (target TOA radiation)
- Tuned parameters in SHOC, SPA, and P3
- 'Final' tuning changed autoconversion & accretion prefactors, and SPA scaling parameters
- Slowing cloud to rain process improved cloud organization but produced too much cloud reflection

2-m temperature in DPxx test simulations



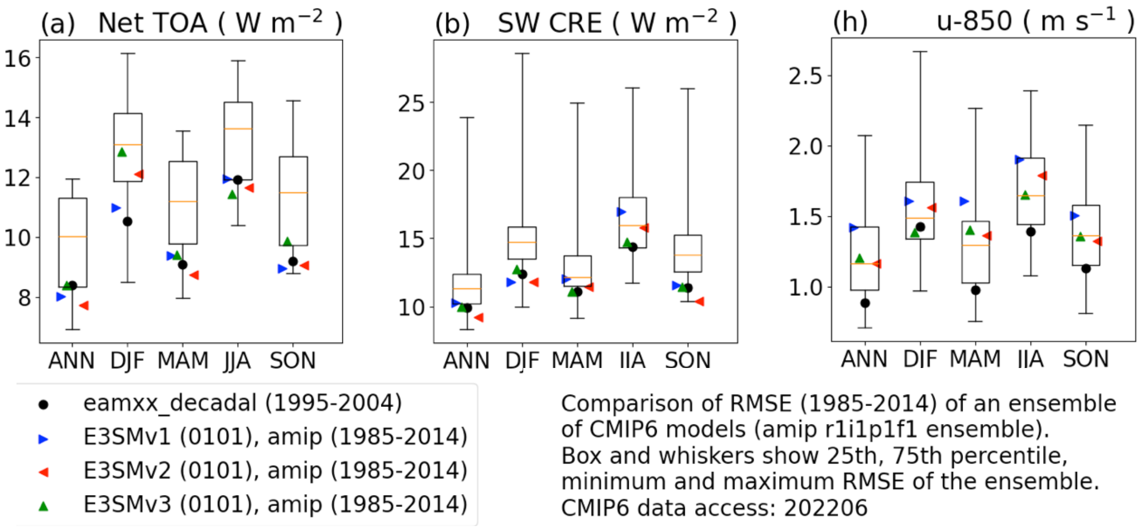
2-m T from default (left) and modified rain evaporation (right) GATE DPxx simulations.
Blue = 295 K and red= 298 K.
Modifications to rain evaporation help improve free troposphere dry bias.
Animation by Hassan Beydoun

TOA imbalance in subset of 20 tuning experiments



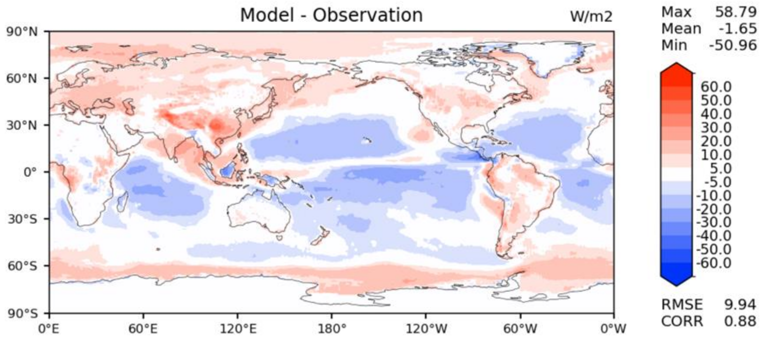
Skill in representing the present-day climate

- Reasonable skill in radiation despite 20 years used for tuning
- Improvements in circulation

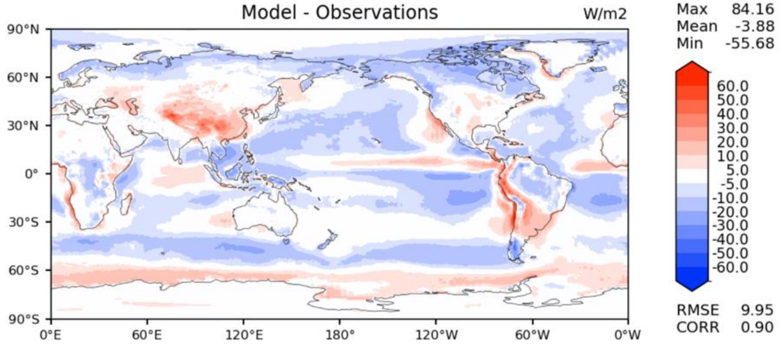


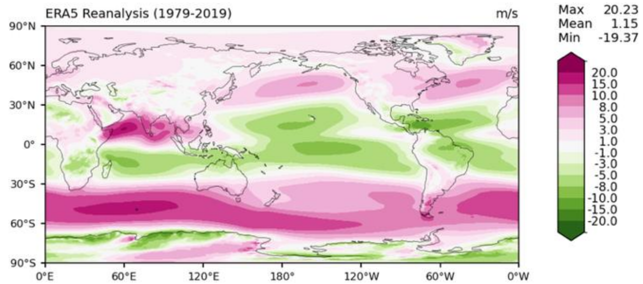
Shortwave cloud forcing biases

EAMxx 13km



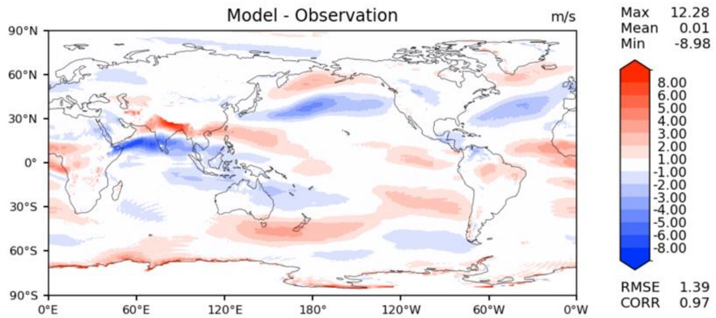
EAMv3.LR



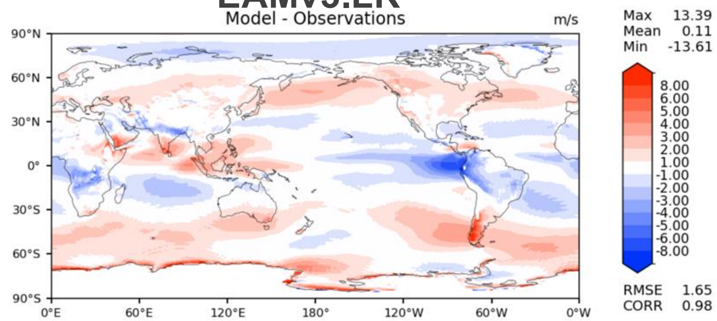


850hPa zonal winds

EAMxx 13km



EAMv3.LR

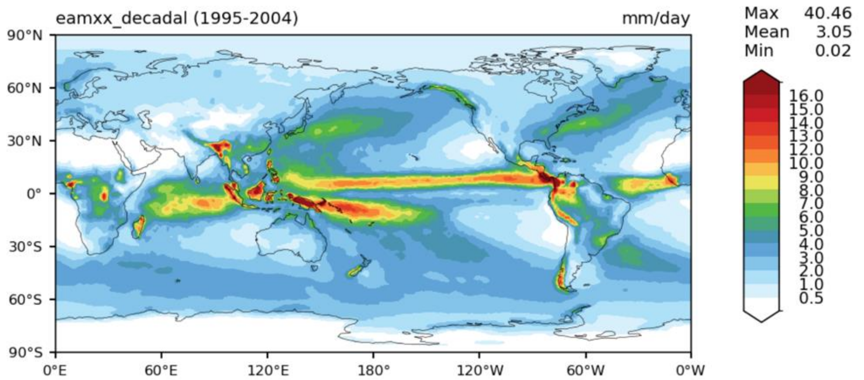


Issues (areas for improvement) in early version

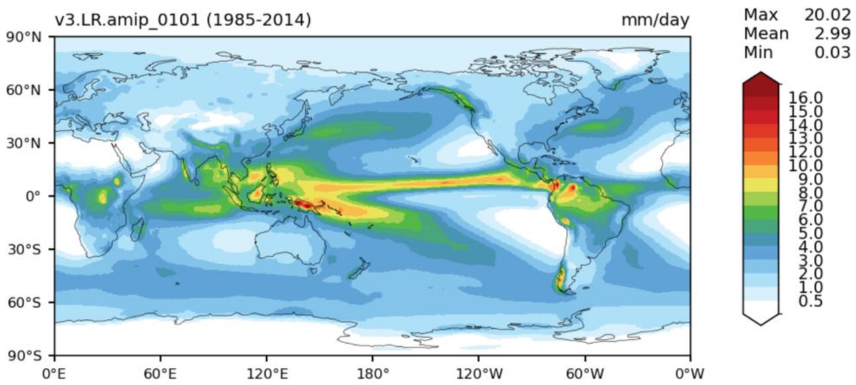
- Precipitation biases
- Weak tropical variability
- Warm land surface temperature biases

JJA precipitation

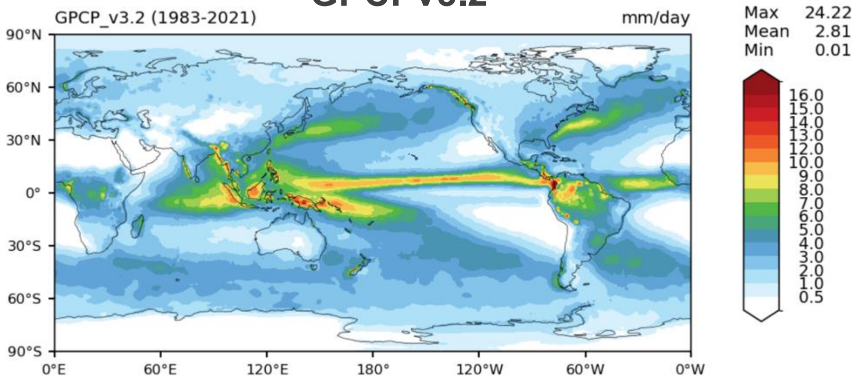
EAMxx 13km



EAMv3.LR

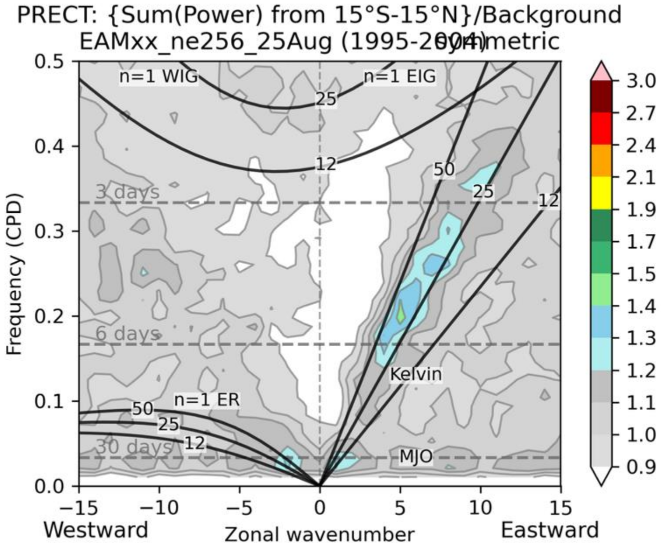


GPCPv3.2

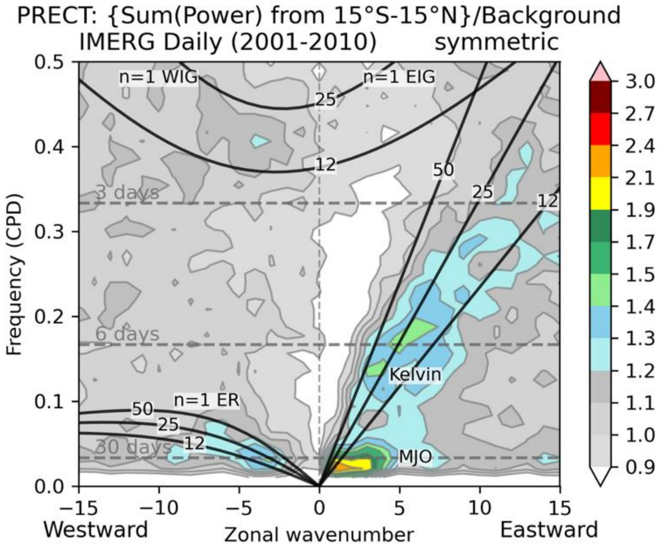


Wheeler Kiladis Diagram

EAMxx 13km



GPM-IMERG



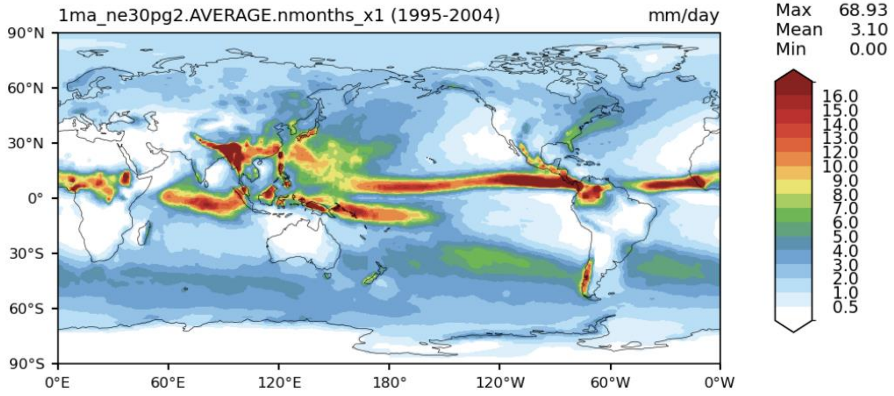
Potential improvements with inclusion of ZM

- Improvement of precipitation biases
- Improvements to variability (not shown)

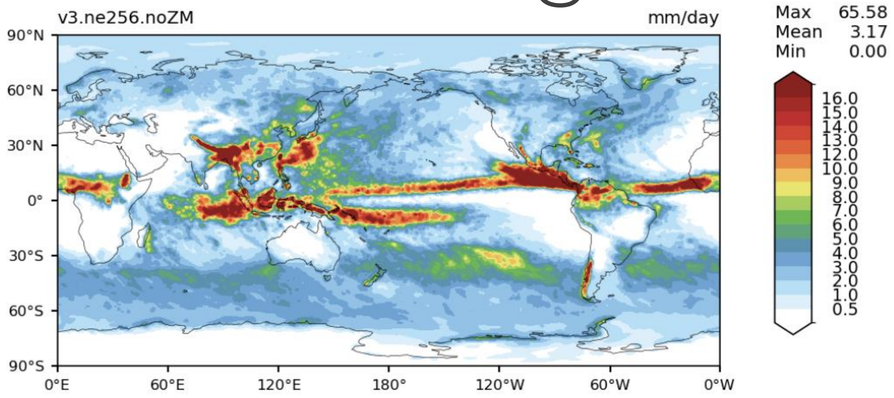
- Degrades (weakens) extreme precipitation

JJA precipitation

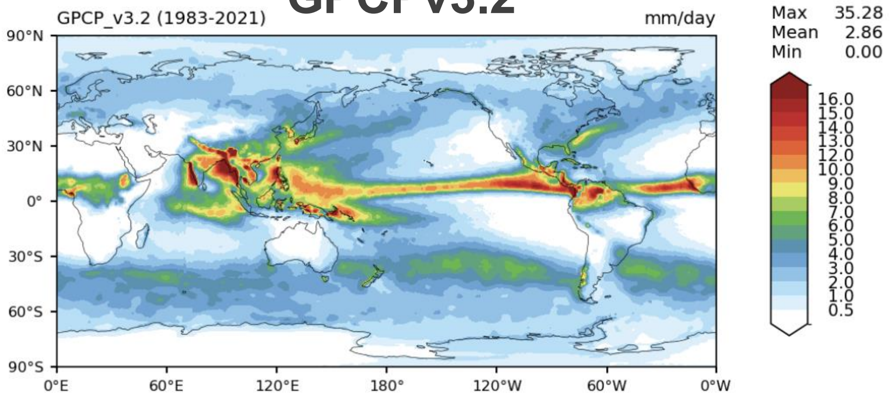
EAMxx 13km



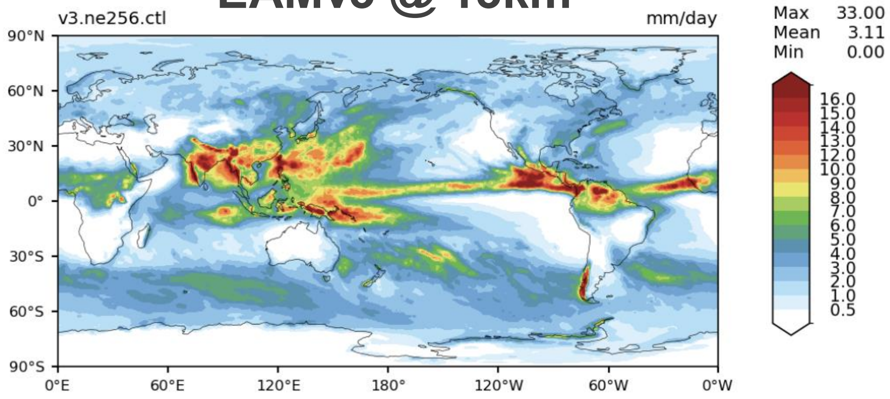
EAMv3 w/o ZM @ 13km



GPCPv3.2



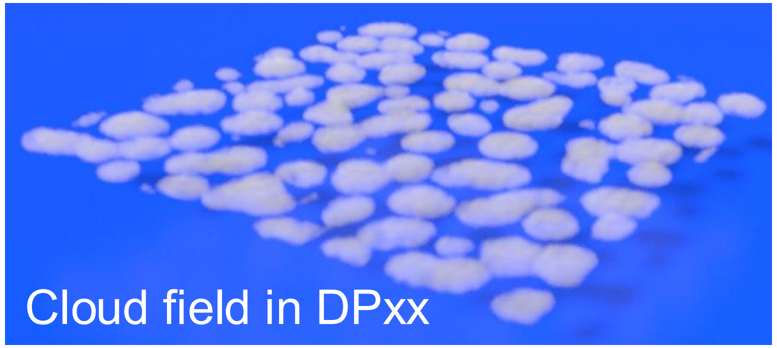
EAMv3 @ 13km



Figures courtesy of Xiaoliang Song (effort led by Shaocheng Xie)

What is our plan to tune such an expensive model?

- Currently performing a 128+ member one-year ne256 PPE
- Exploring ne128 and lower resolution for tuning (Geoffroy and Saint Martin, 2025) and PPEs
- Testing process fidelity of globally tuned configurations in DPxx



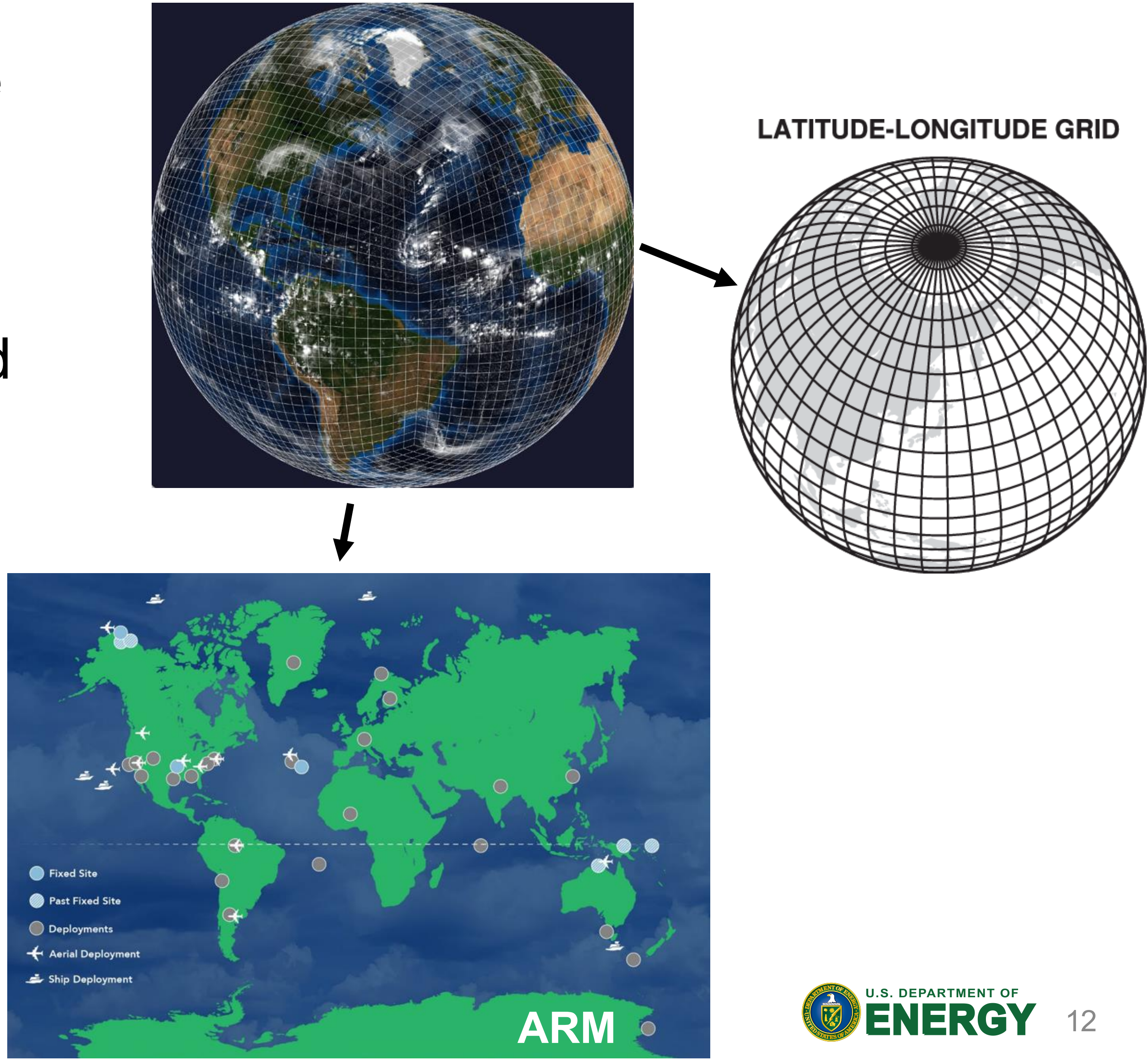
Cloud field in DPxx

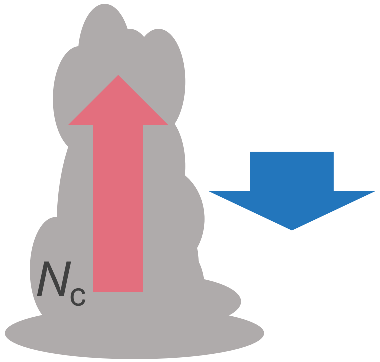
Computational performance of EAMxx 13km on Perlmutter

PM-GPU node count	SYPD
32	0.65
64	1.16
128	2.14
256	3.78

What other capabilities will EAMxx have?

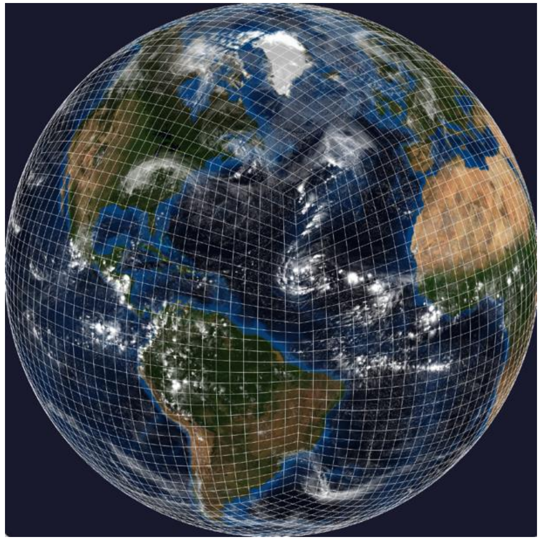
- Online remapping of outputs (to sparse or coarser grids)
- Conditional outputs and inline calculation of diagnostics (e.g., in-cloud variables, convective mass flux, convective transport)

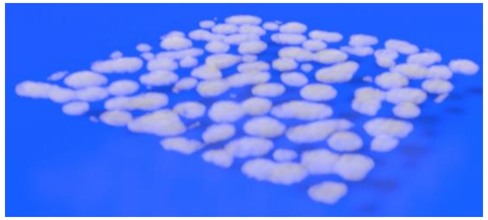




Summary

- E3SMv4 Atmosphere Model will be EAMxx 13km configuration with focus on S2S and S2D prediction
- Convection at these scales continues to be an area to better understand and improve
- DPxx will play a key role in development and tuning
- New model capabilities include online remapping of output and new conditional diagnostics





Questions? Please reach out to terai1@llnl.gov e3sm.org