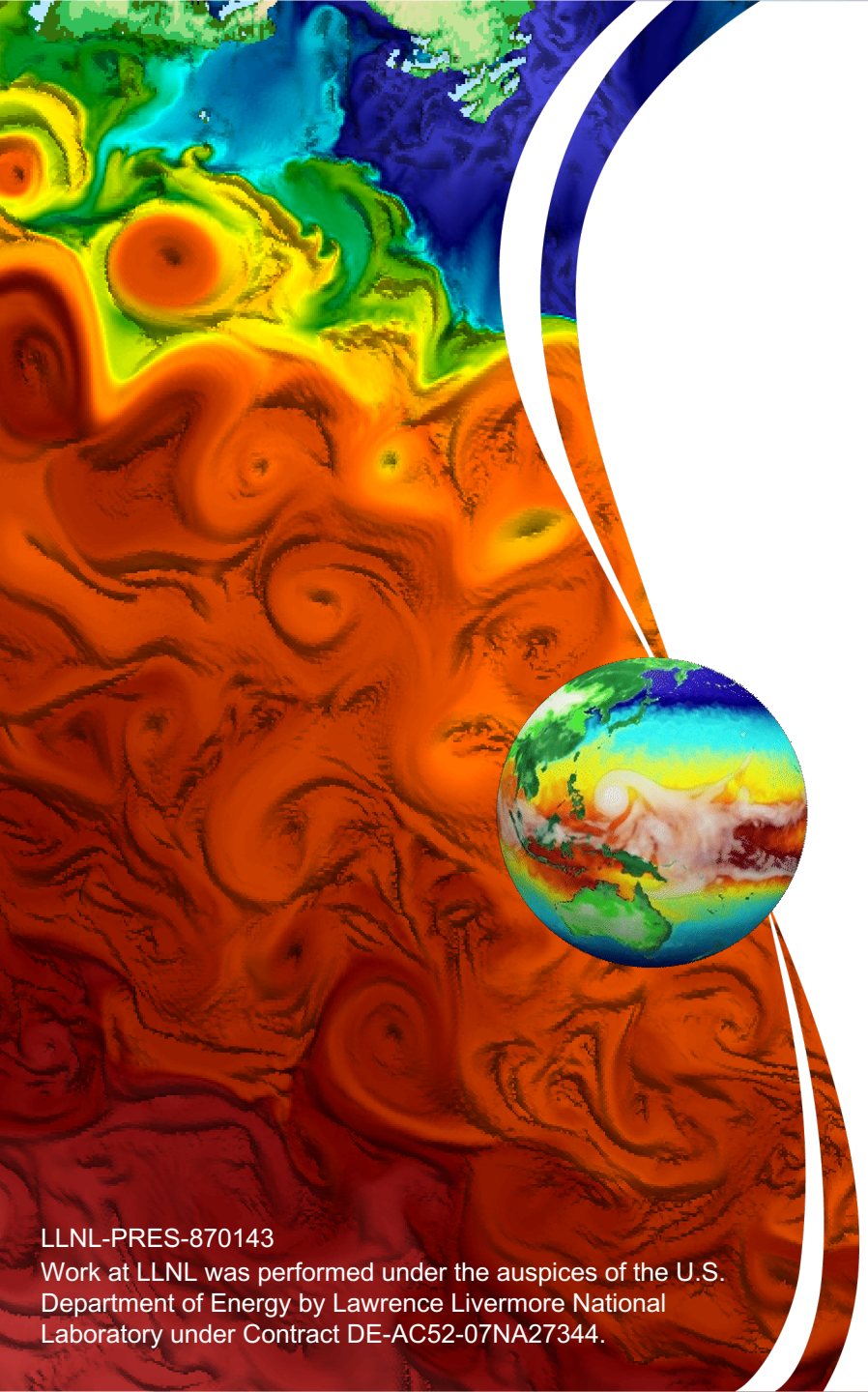


E3SM: Lessons from a stubborn model

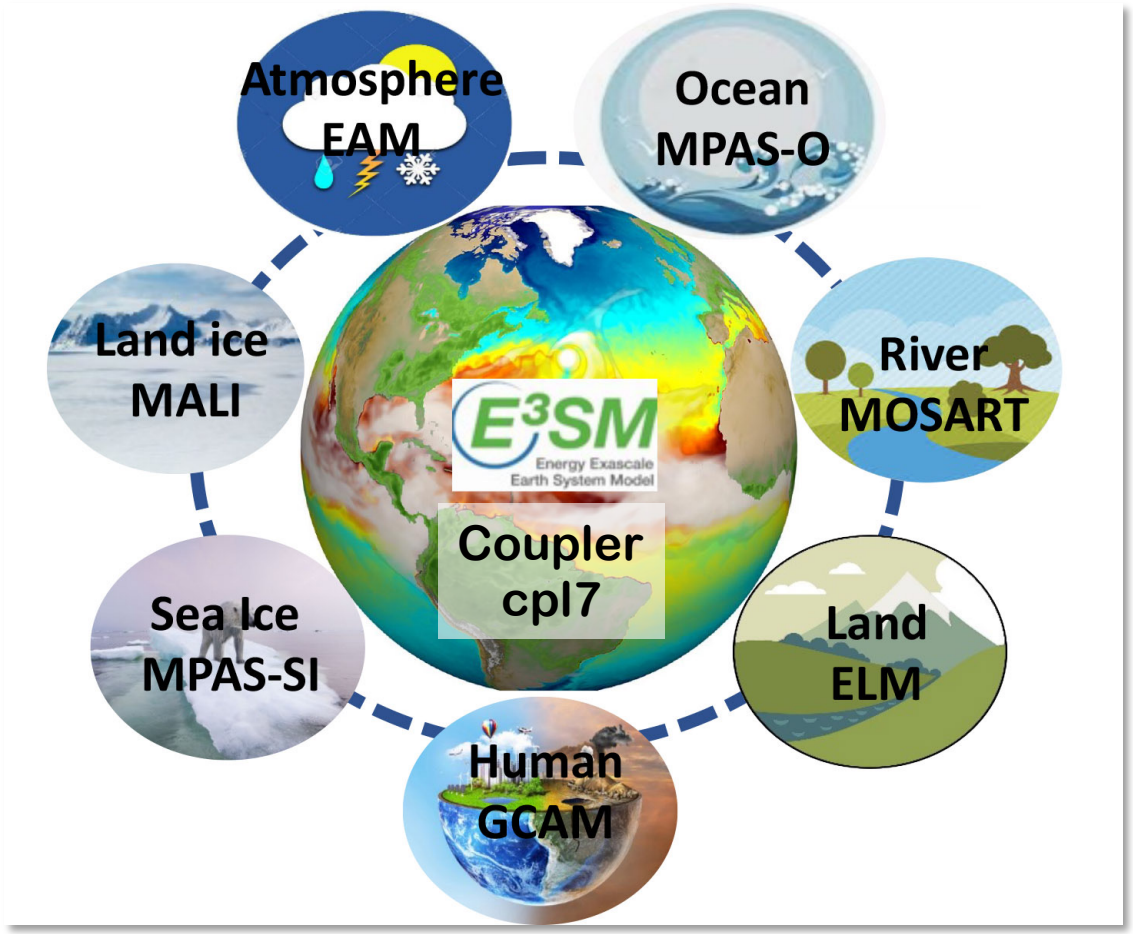
Chris Golaz, LLNL

and the entire E3SM Coupled Model Group

CERES Science Team Meeting
LLNL, Livermore, CA
October 1-3, 2024

LLNL-PRES-870143
Work at LLNL was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

A DOE model for DOE science on DOE computers



Source: e3sm.org

E3SM Components

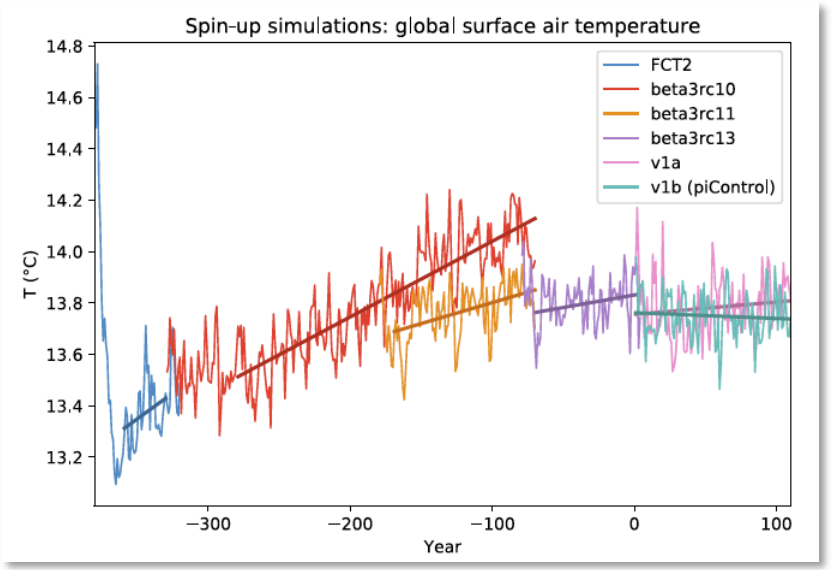
- **cpl7 – Coupler**
- **EAM**: E3SM Atmosphere Model
- **ELM**: E3SM Land Model
- **MOSART** – Model for Scale Adaptive River Transport
- **MPAS-SI**: Model for Prediction Across Scales (MPAS) – Sea Ice
- **MPAS-O**: MPAS – Ocean
- **GCAM**: Global Change Assessment Model – Human Earth System
- **MALI**: MPAS-Albany Land Ice Model.
- **WAVEWATCH III®** – Wave model

Model Tuning

Component-level tuning

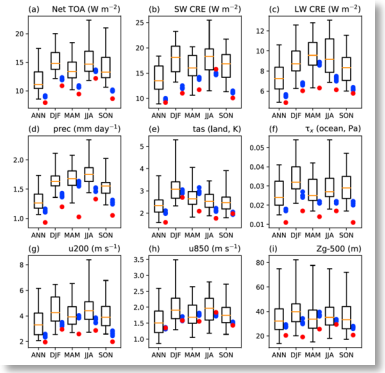
- Ocean, sea-ice (G-cases)
- AMIP simulations (F-cases)
- Land (I-cases)

Coupled model tuning



Objectives

1. Near-zero long-term average net top-of-atmosphere energy flux.
2. Minimum long-term drift in global mean surface air temperature.
3. Reasonable absolute global mean surface air temperature.
4. Climate metrics.



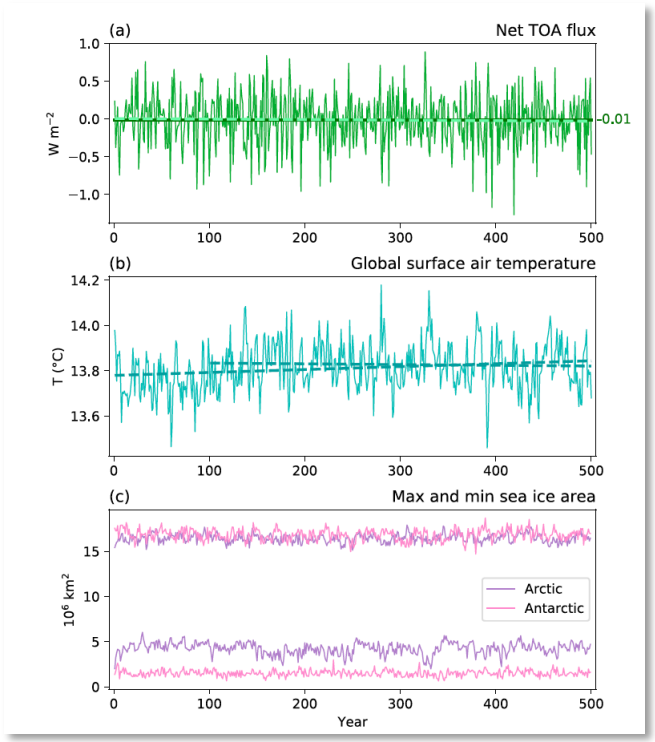
Additional tests

- Climate sensitivity (abrupt-4xCO2)
- Effective radiative forcing (aerosol, ...)
- Historical simulations

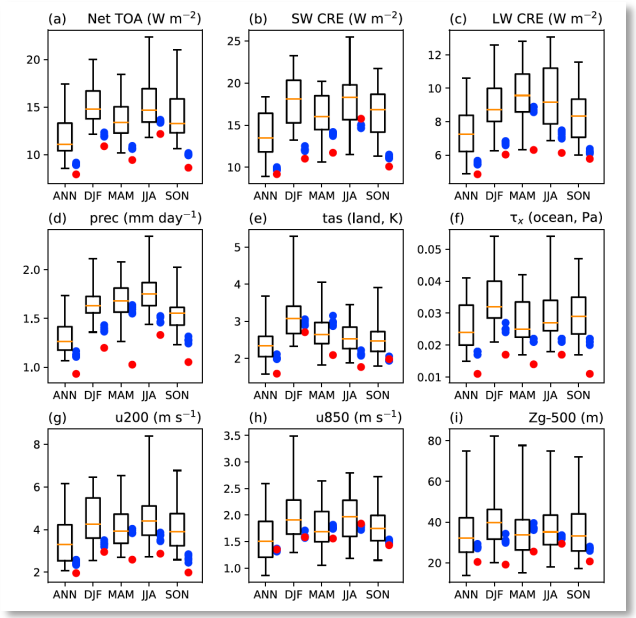
Brief retrospective...

E3SMv1: “we made it!”

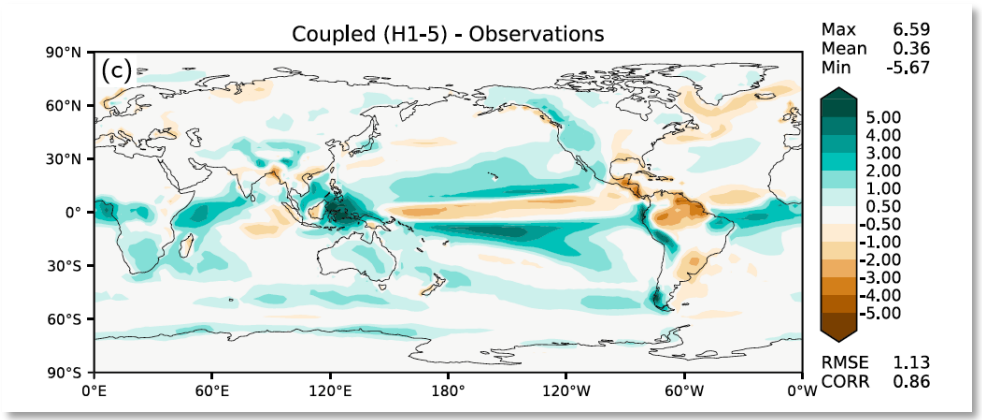
v1.LR



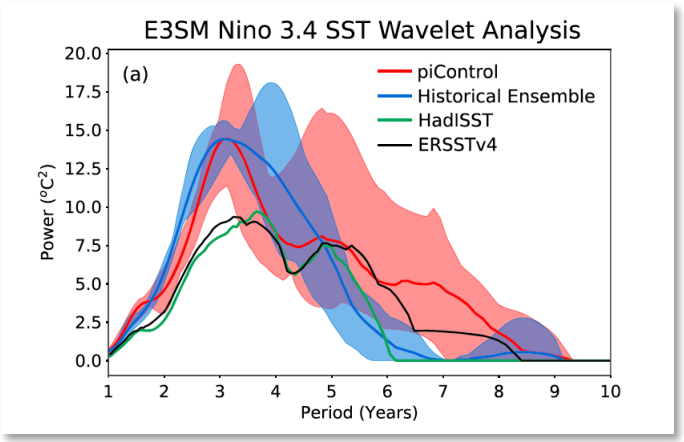
Stable climate, when boring is good



Competitive climatology



Decent precipitation



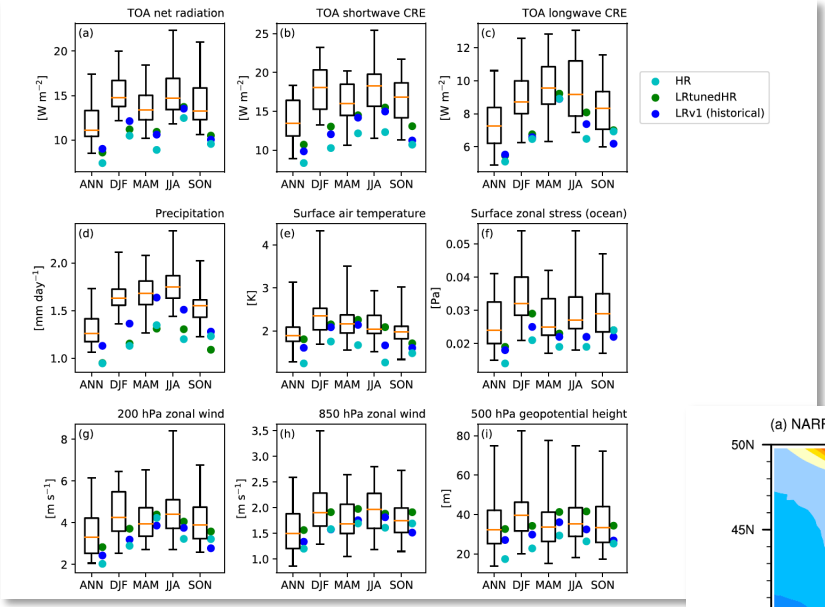
We have an ENSO!!!

Golaz et al. (2019)

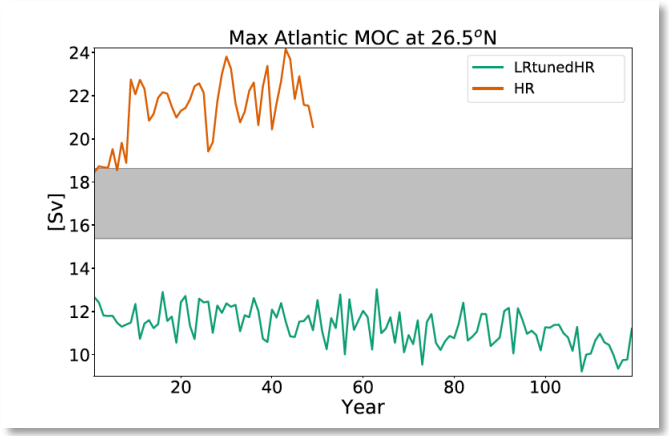
Brief retrospective...

E3SMv1: also in high-resolution

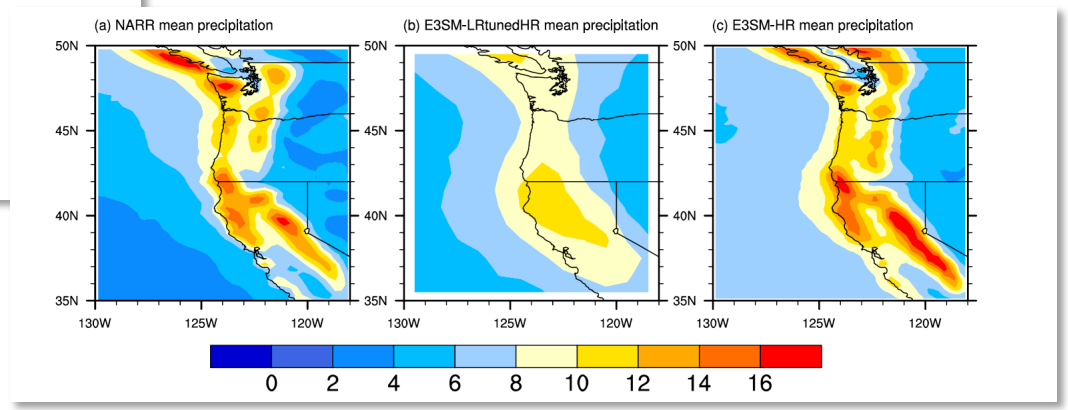
v1.HR



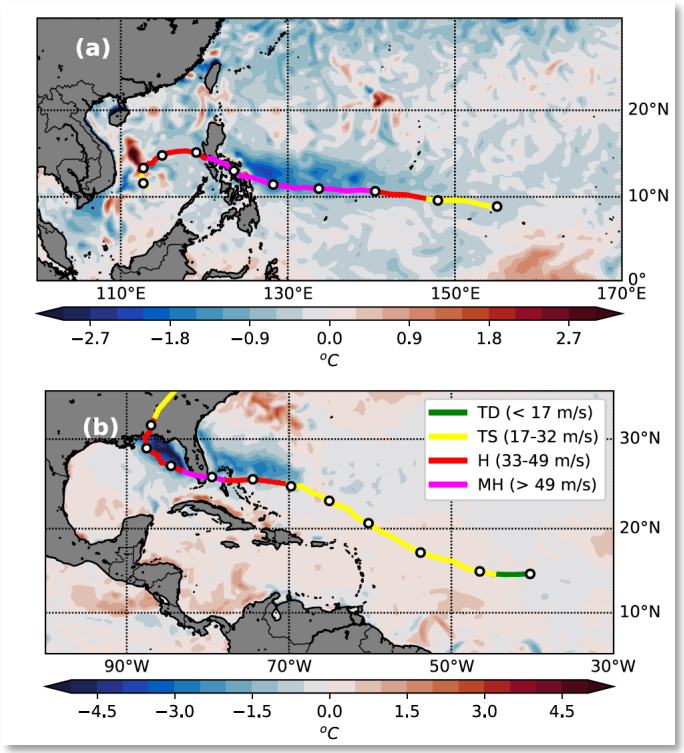
Improved climatology



Strong AMOC!



Improved regional precipitation

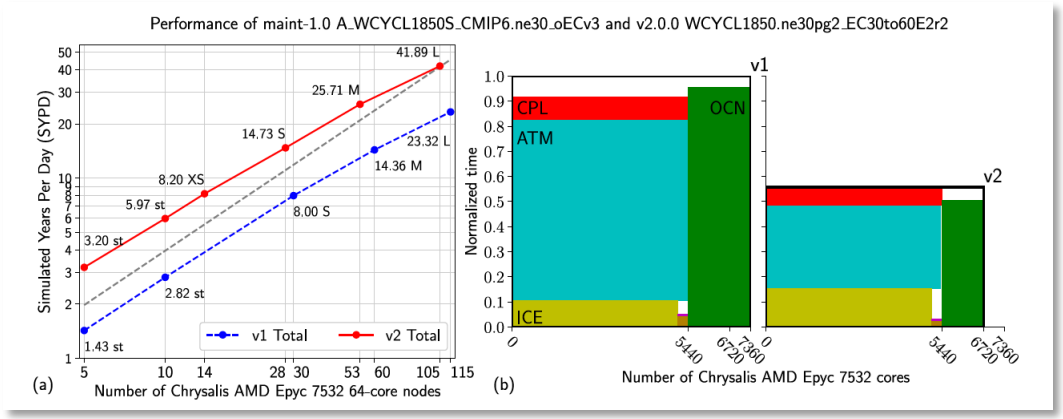


Strong TCs

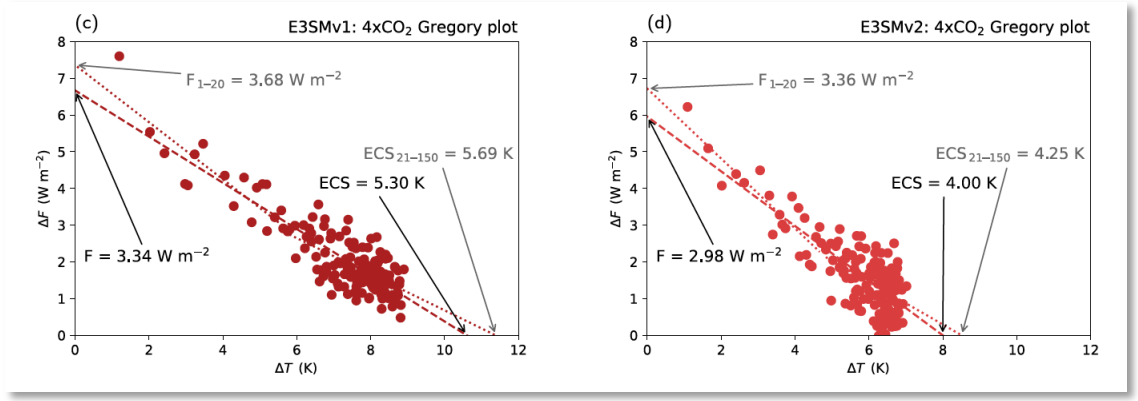
Caldwell et al. (2019)

Brief retrospective...

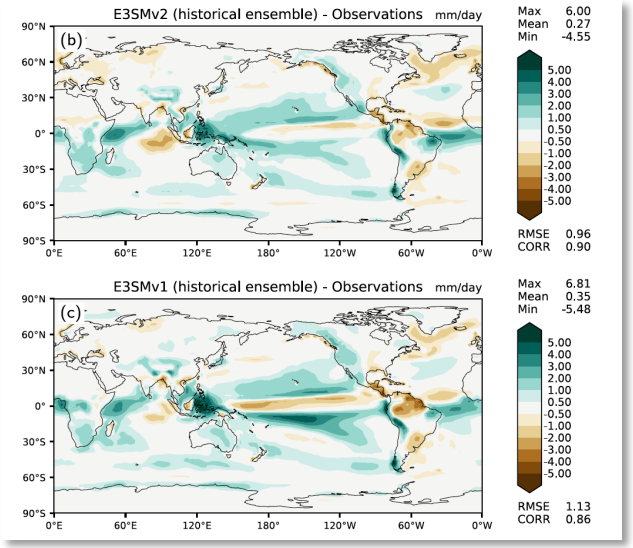
E3SMv2: nice improvements



Computational performance

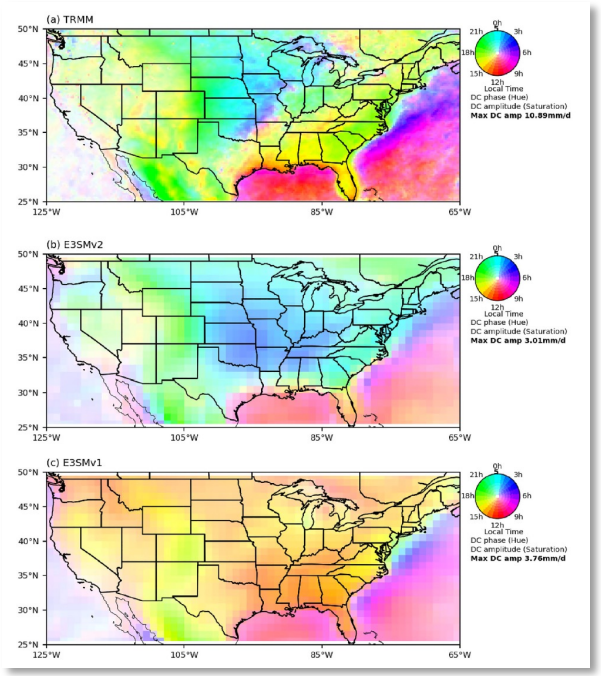


Reduced climate sensitivity



Improved precipitation climatology and diurnal cycle

v2.LR

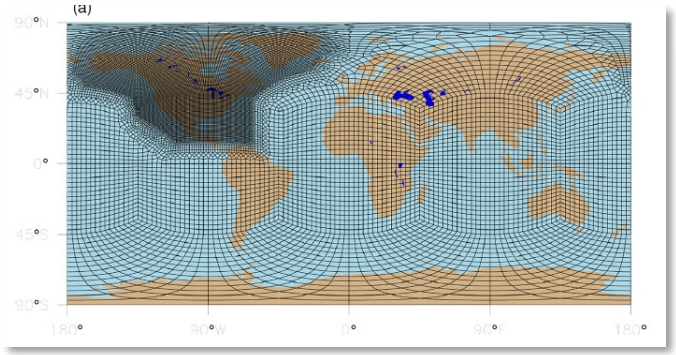


Golaz et al. (2022)

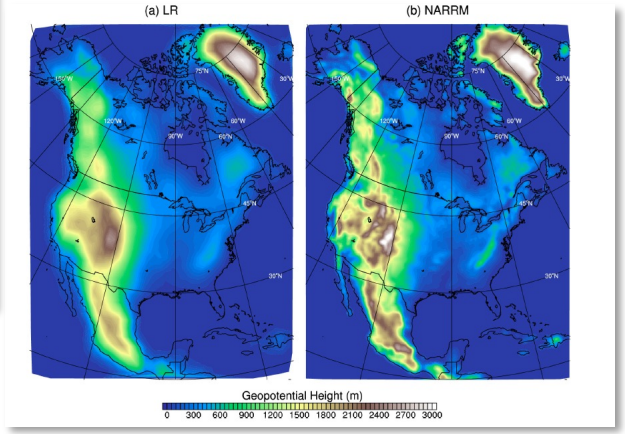
Brief retrospective...

E3SMv2: fully coupled RRM

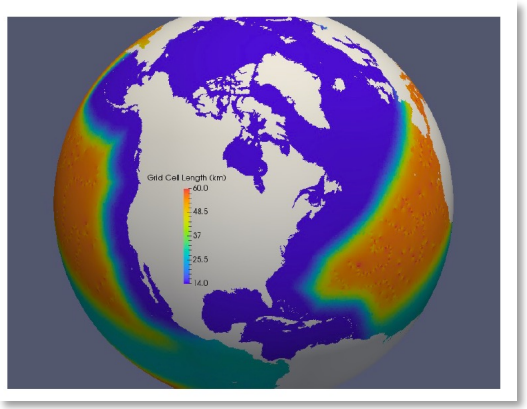
v2.NARRM



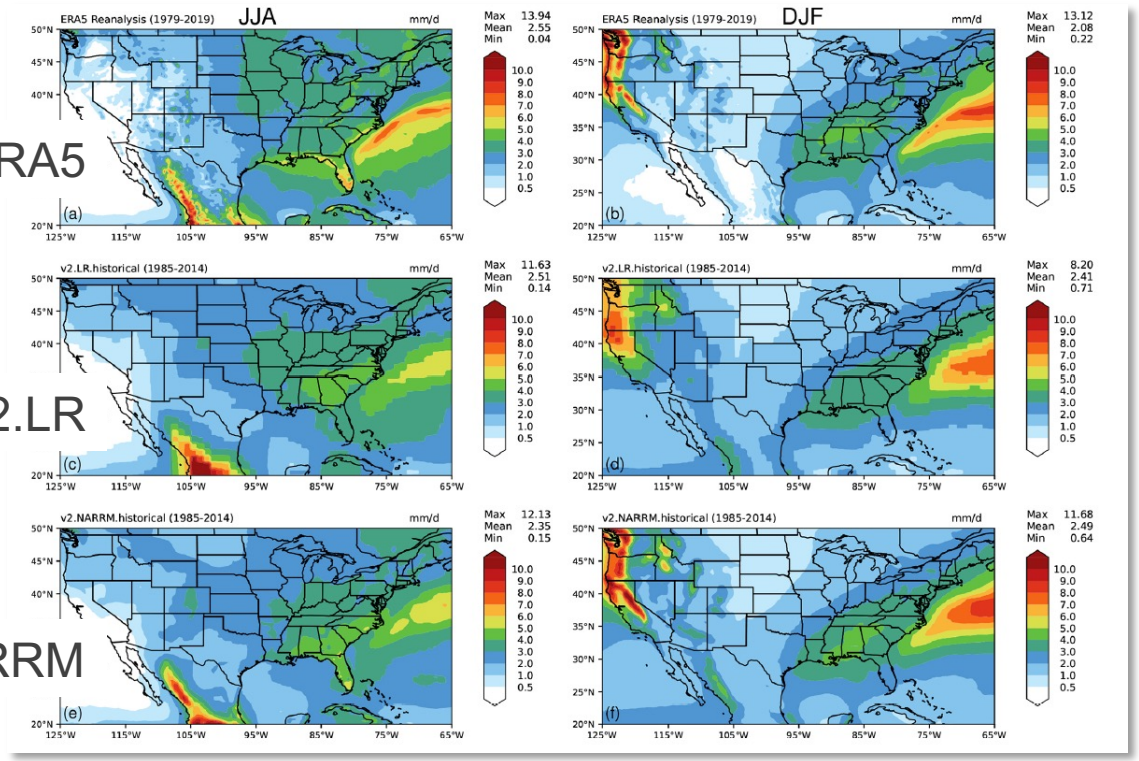
Atmosphere North America regionally refined model (NARRM)



Terrain



Ocean and sea-ice mesh



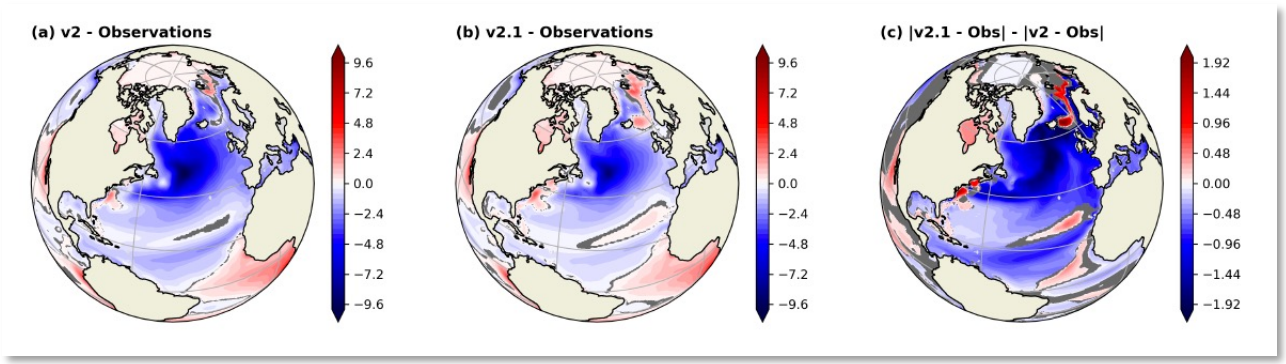
Precipitation (JJA, DJF)

Tang et al. (2023)

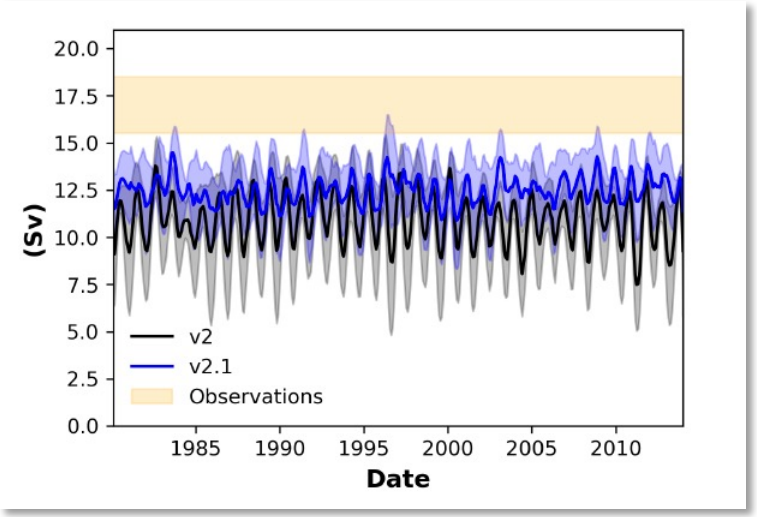
Brief retrospective...

v2_1.LR

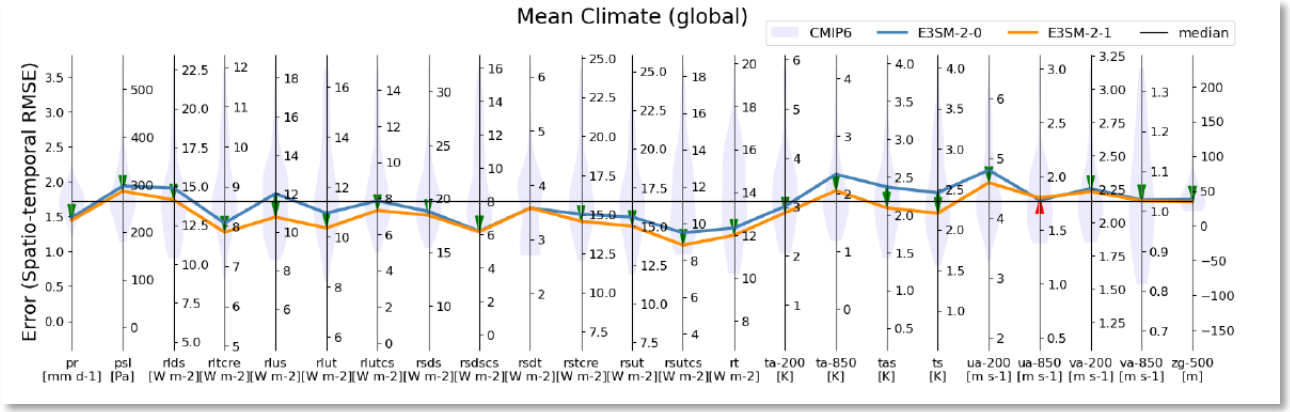
E3SMv2.1: improving the ocean



SST biases – large reduction in regional biases



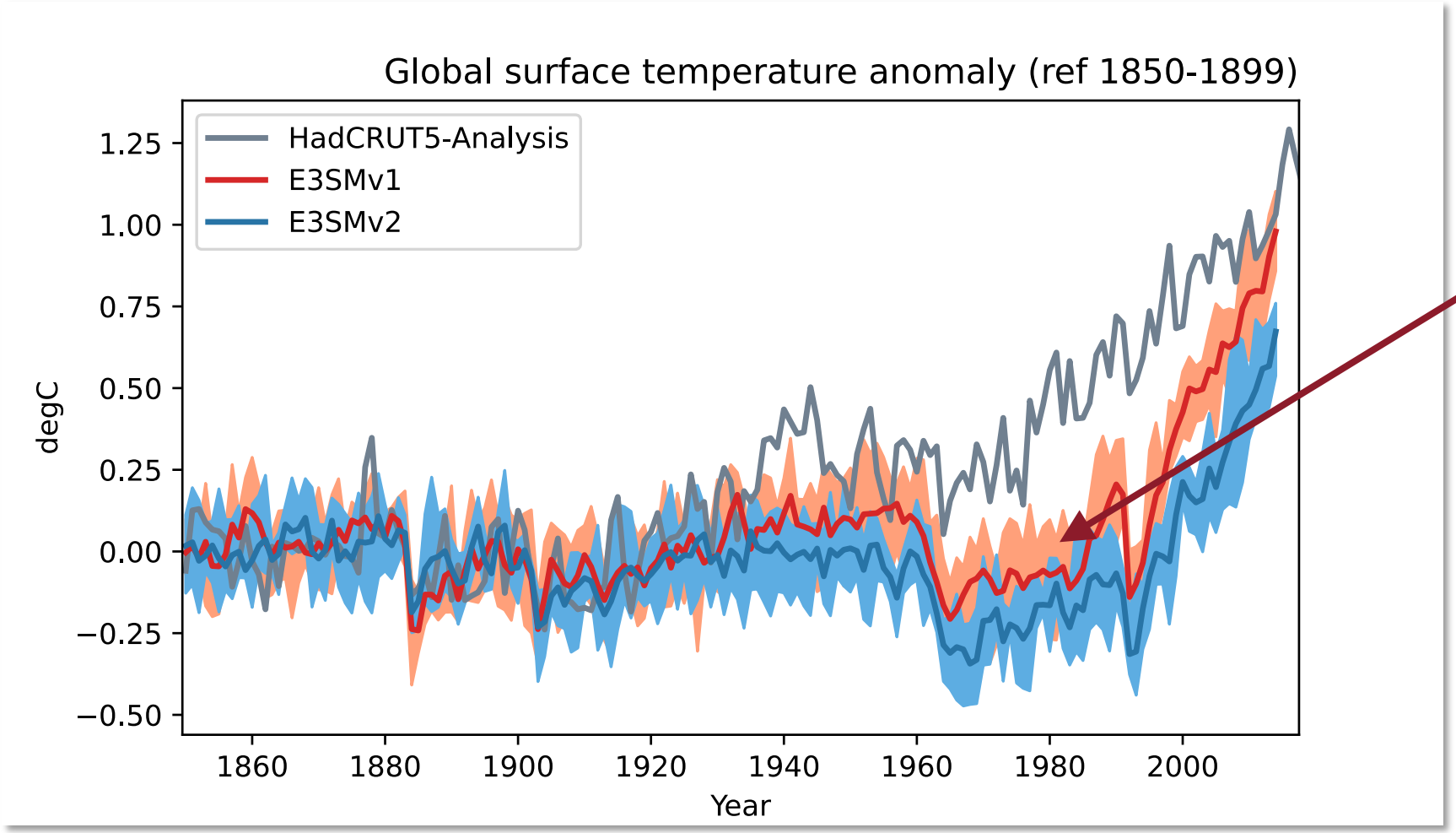
Strengthening in AMOC



Climate improves or remains comparable

Smith et al. (2024, in prep)

Historical temperature (E3SMv1/v2)



The “pothole” problem.
[Not unique to E3SM]

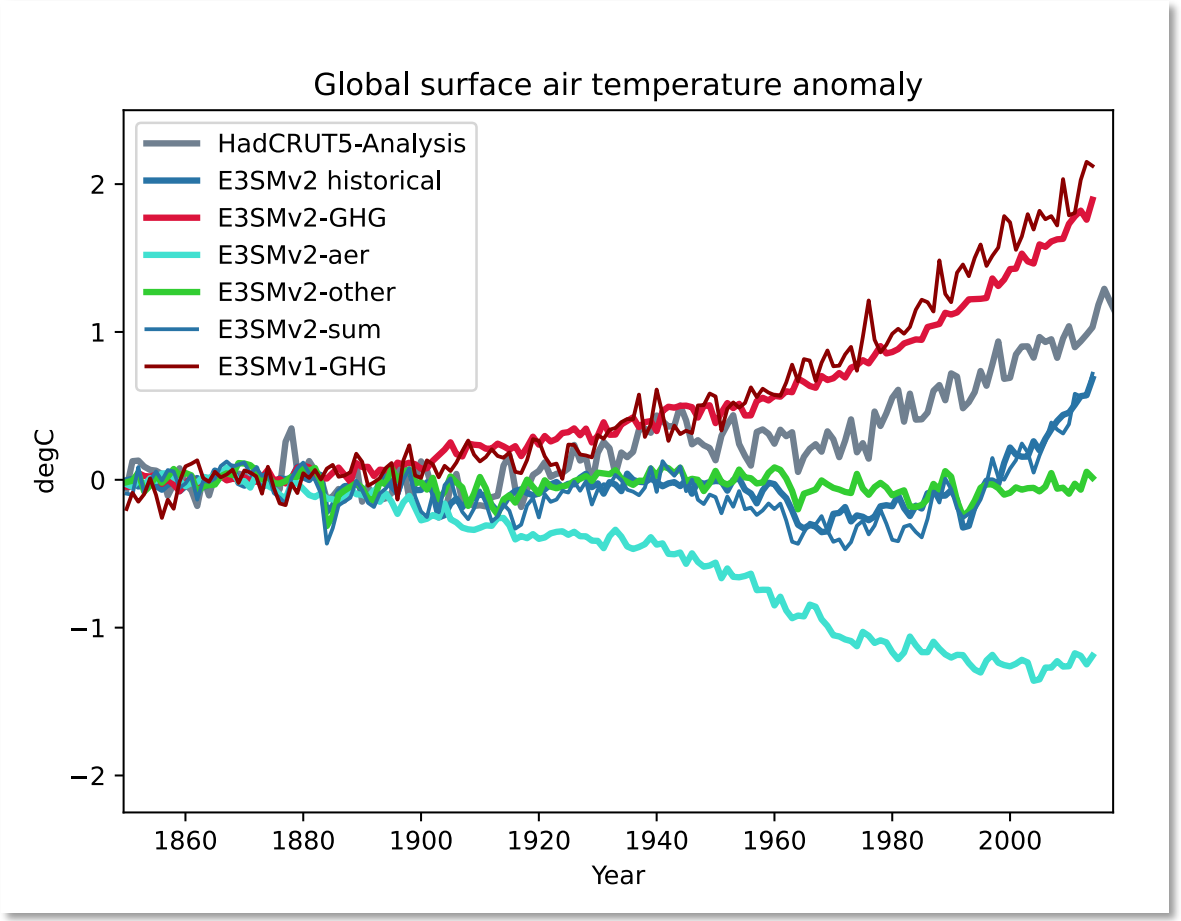
Golaz et al. (2022)

Single forcing ensemble

Single-forcing decomposition

- GHG
- Aerosol related
- Everything else (other)

Fully coupled simulations (1850-2014), 5 members for each forcing.



Special thanks to Dave Bader, Golaz et al. (2022)

Composite configurations

- Treating single-forcing simulations as linear perturbations from the piControl, we can recompose them with alternate strengths:

$$\psi_{\text{all}} = \psi_{\text{piControl}} + \alpha_{\text{GHG}} \left(\psi_{\text{GHG}} - \psi_{\text{piControl}}\right) + \alpha_{\text{aer}} \left(\psi_{\text{aer}} - \psi_{\text{piControl}}\right) + \left(\psi_{\text{other}} - \psi_{\text{piControl}}\right)$$

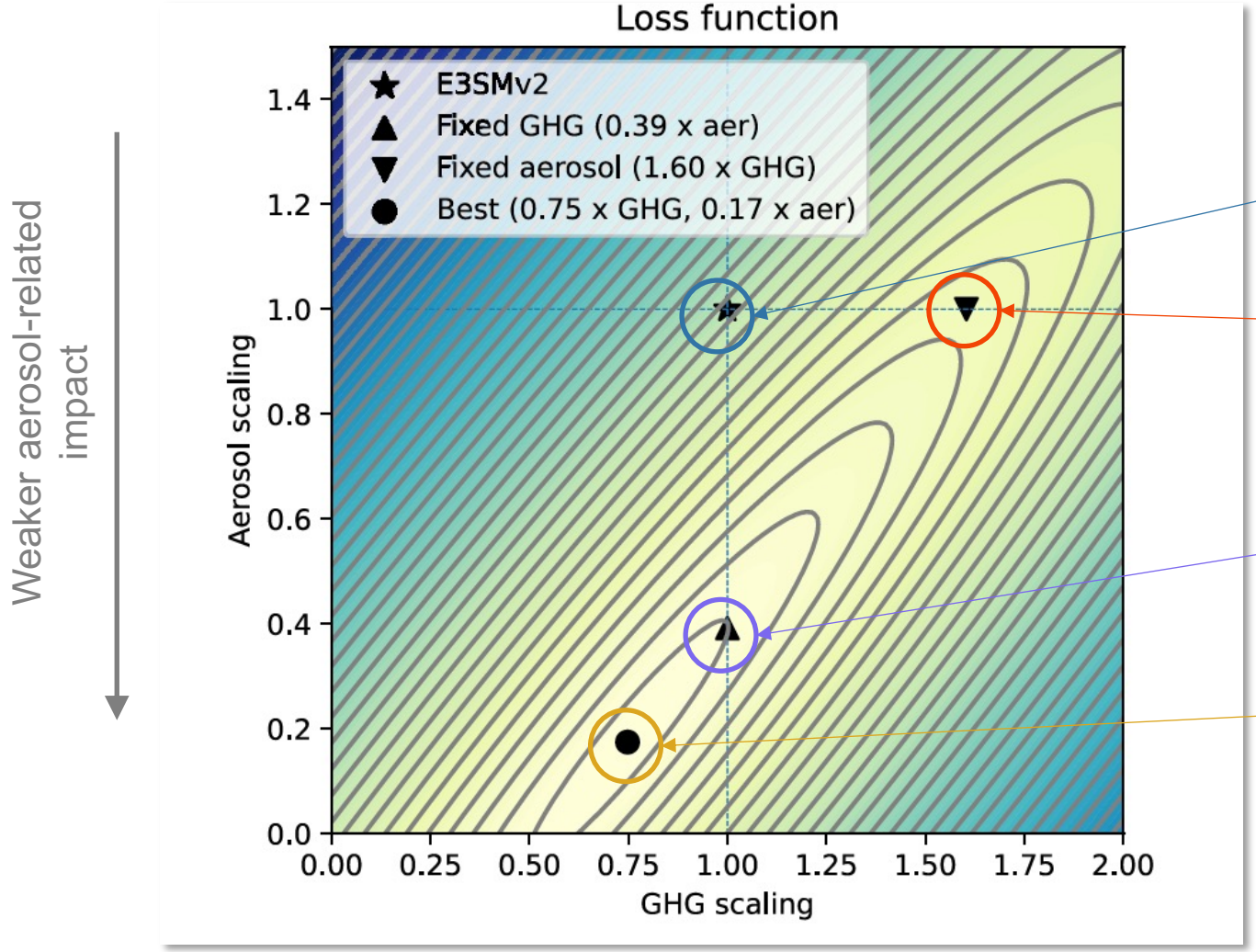
Baseline | Modulate GHG response | Modulate aerosol response | Keep the rest unchanged

- Modulate strength of GHG response (proxy for TCR/ECS) and aerosol related to create alternate **composite configurations**.
- Applicable to any field; linear approximation holds well.

Inspired from Neelin et al. (2010), Gillett et al. (2012) and Winton et al. (2020)

https://portal.nersc.gov/project/e3sm/E3SMv2_Golaz_et_al_2022/

Looking for an optimum



Weaker aerosol-related impact

Weaker GHG impact (proxy for TCR/ECS)

E3SMv2

holding aerosol

holding GHG

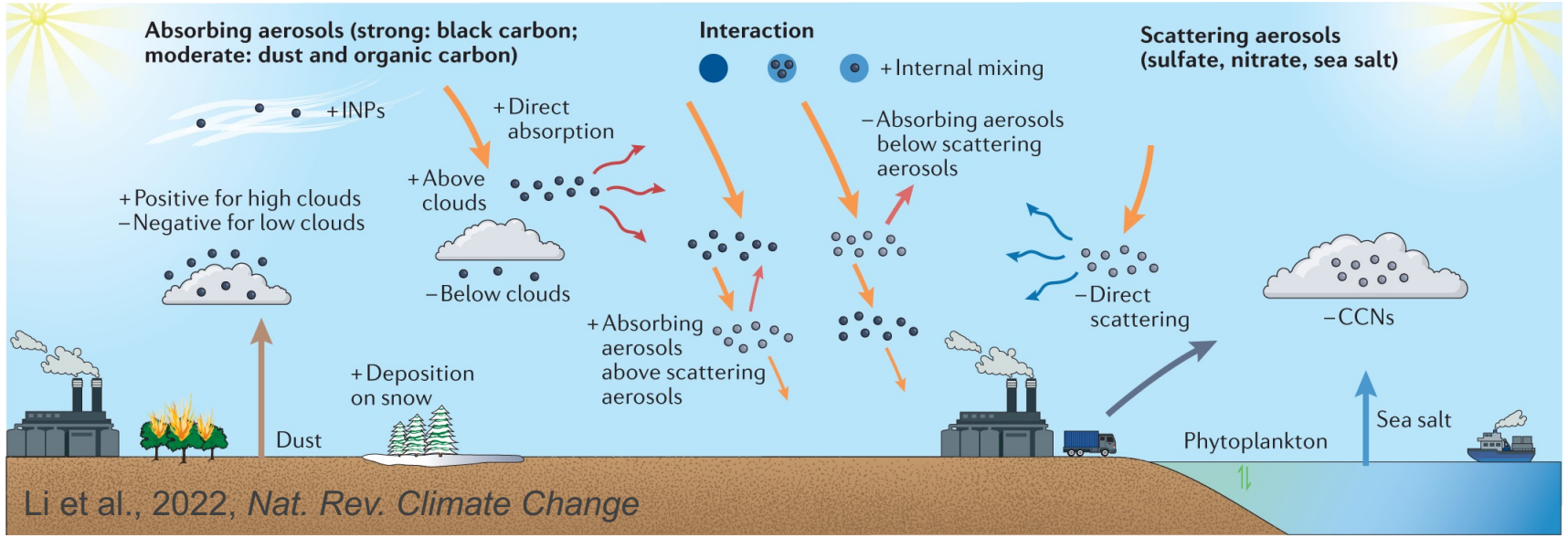
best

Golaz et al. (2022)

E3SMv3: balancing bottom-up and top-down constraints

Aerosol–cloud changes in E3SMv3

- New cloud microphysics
- Increased lower bound on droplet number
- Reduced droplet autoconversion exponent
- Improved wet removal
- Improved aerosol–chemistry interactions
- Increased natural dimethyl sulfide (DMS) emissions
- Faster black carbon (BC) aging
- Increased particulate organic matter (POM) hygroscopicity
- ...



More realistic

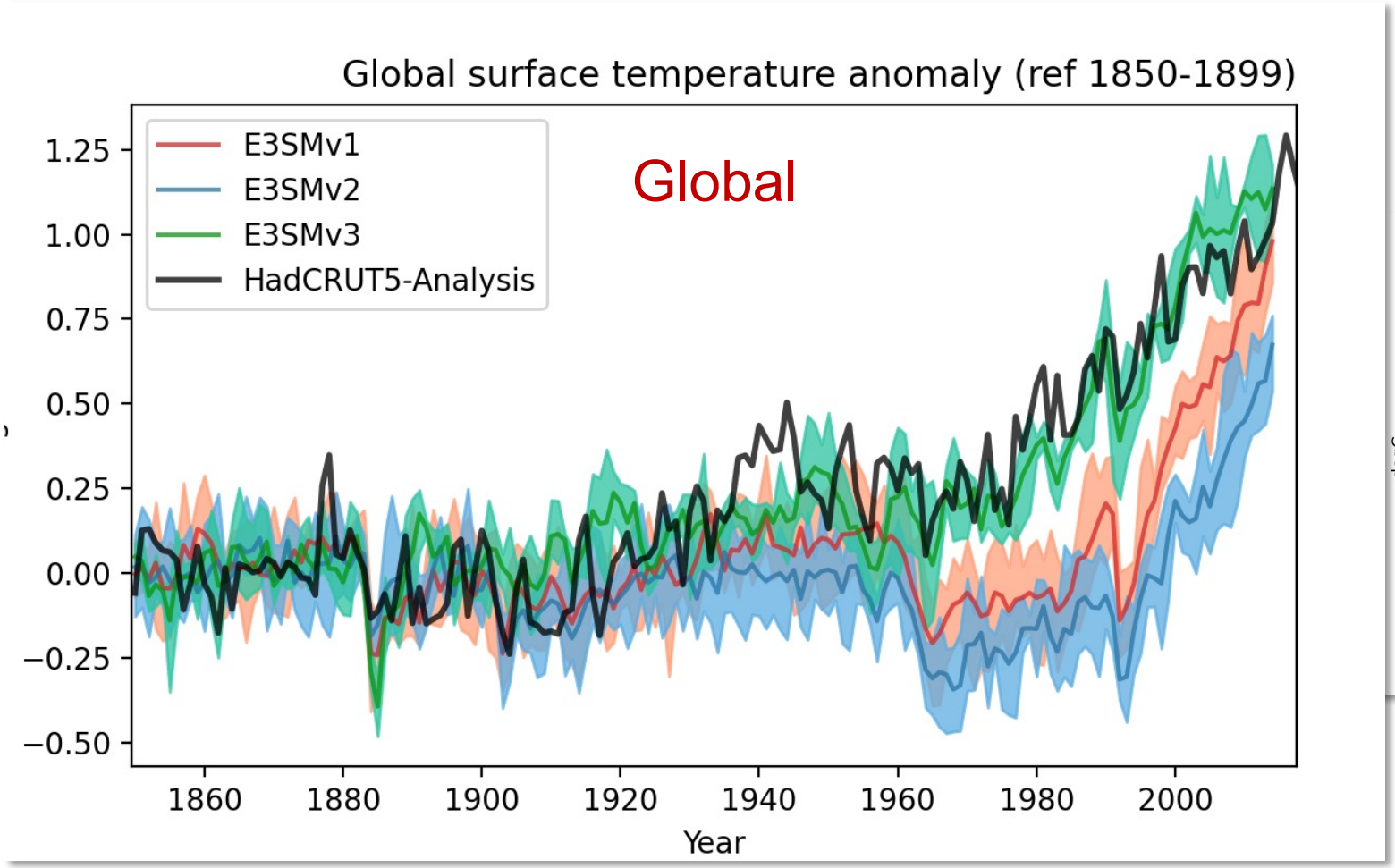
- Total aerosol radiative forcing
- Direct effect
- Indirect effect

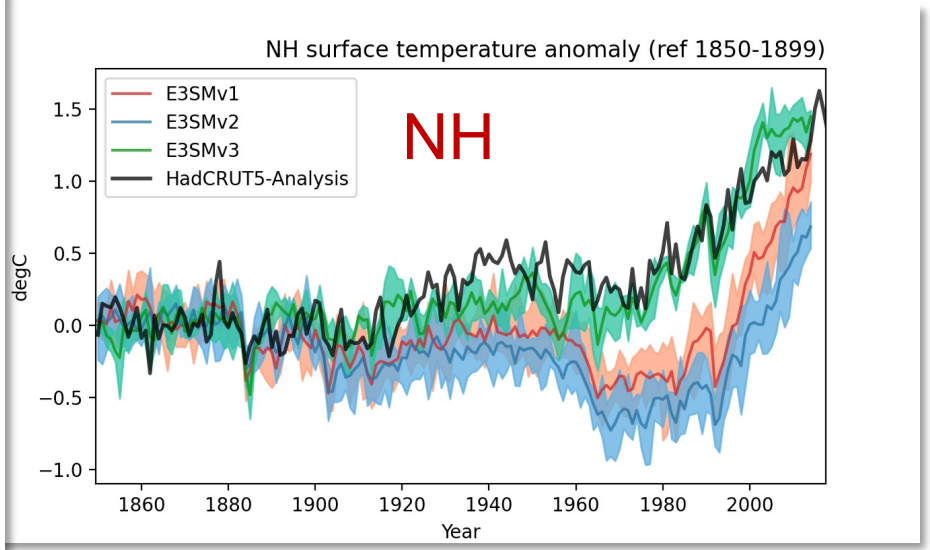
Credit:
Shaocheng Xie (LLNL)
Susannah Burrows (PNNL)

Aerosols are complicated.

E3SMv3: fixing the pothole

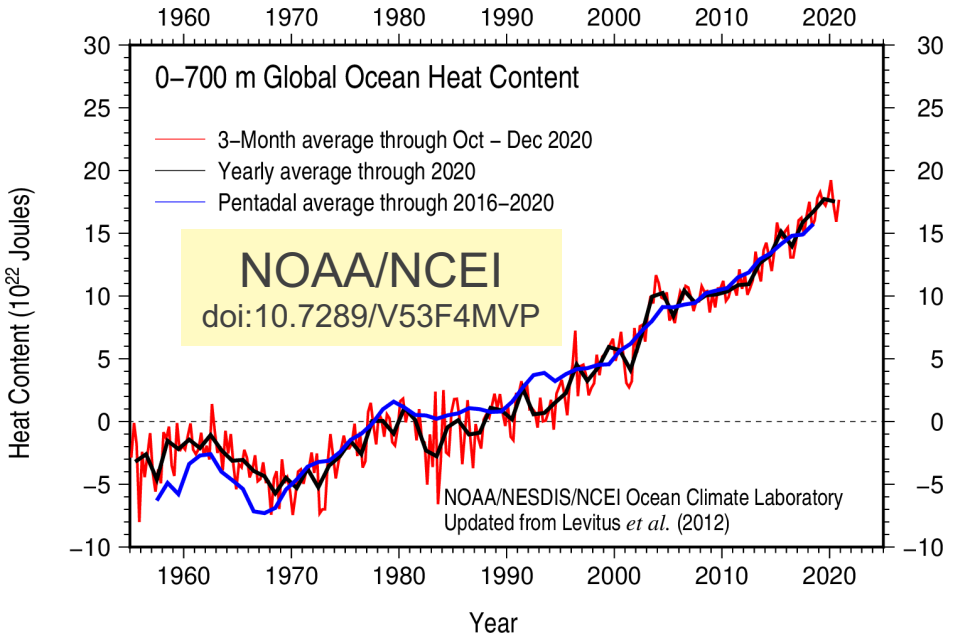
Historical temperature ("Third time's a charm")



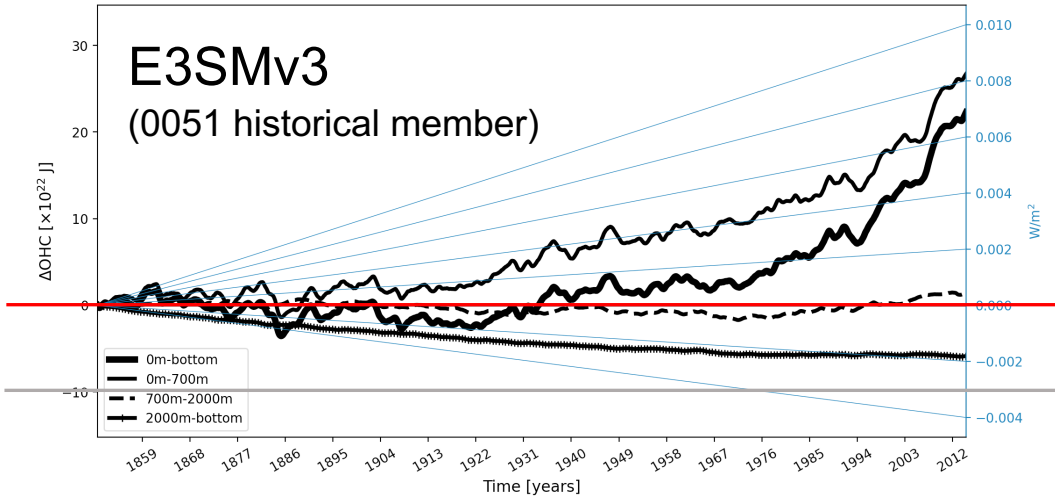


E3SMv3: large impact on ocean heat content

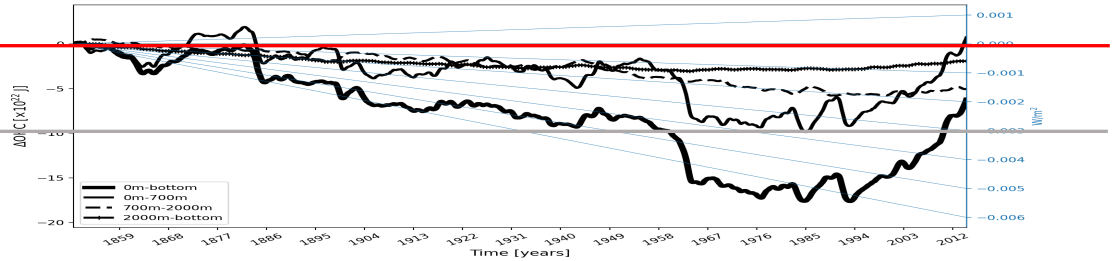
It's not just in the atmosphere!
Global ocean heat content



Global OHC anomaly



Global OHC anomaly



Day and night!

E3SM v2.1
(0101 historical member)

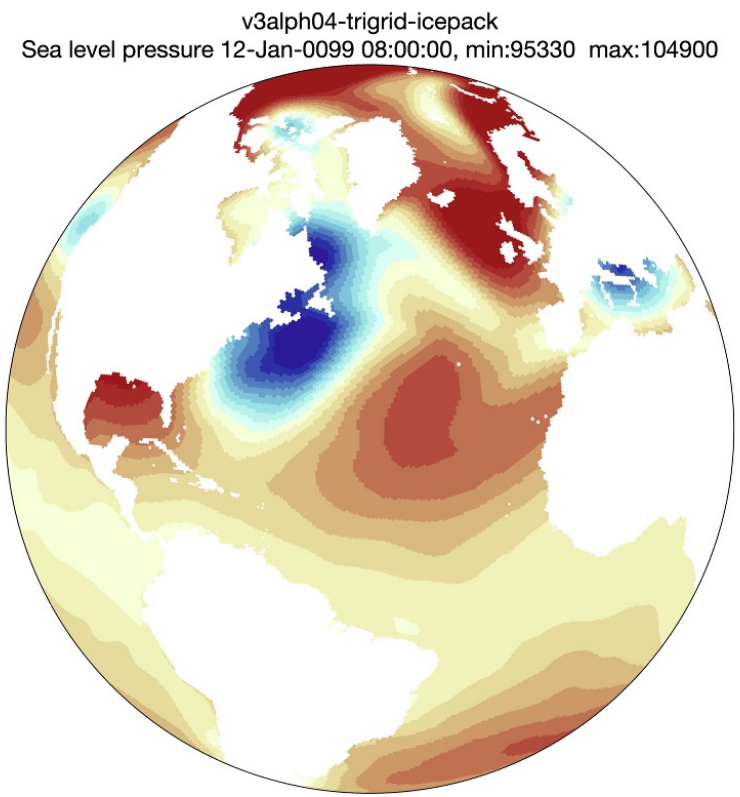
E3SMv3: what's new?

v3 in a nutshell

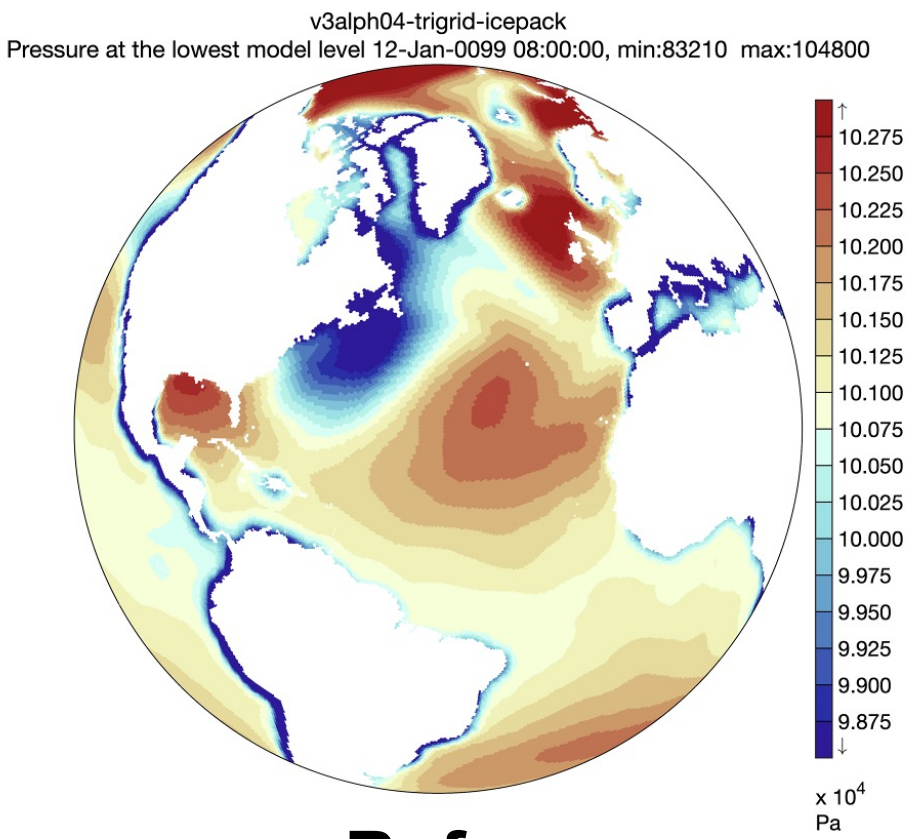
- **Tri-grid**, with **higher-order** non-linear **remapping**. Having the land and river runoff of the same grids opens up new possibilities (water management).
- **Land**: **BGC mode** (instead of SP), **TOP** parameterization (subgrid topographic radiative effects).
- **Atmosphere**: vastly improved, in particular with respect to **tropical atmosphere variability, aerosols, chemistry**.
- **Ocean**: higher resolution ocean mesh (30 km), more efficient numerical time stepping (AB2), new and improved parameterizations.
- **Sea-ice**: Icepack, and too many other improvements to name (including serious bug fixes).

E3SMv3: bug fixed

Sea-ice: the bugs that Andrew Roberts has been chasing for years
Land topography over ocean (1/2)



After



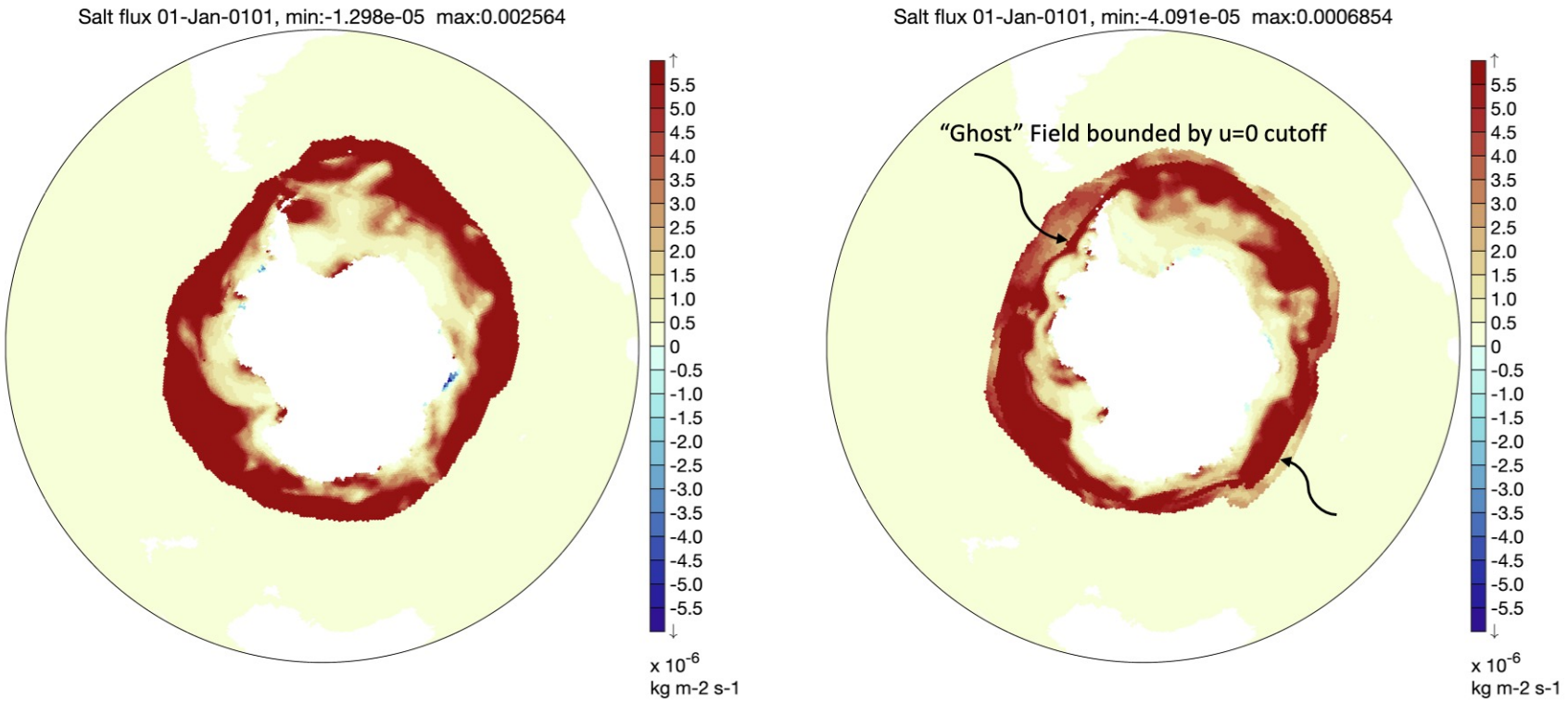
Before

Figure courtesy Andrew R

E3SMv3: bug fixed

Sea-ice: the bugs that Andrew Roberts has been chasing for years
Ghosting (2/2)

Coupler Flux Instant Snapshots, January 01-0101



After This simulation (vslim)

Before Control (pslv)

Figure courtesy Andrew R

E3SMv3 LR: simulation campaign

Completed so far

- Pre-industrial spin-up (2000 years)
- piControl (500 years)
- Idealized CO2 simulations (1pctCO2, abrupt-4xCO2)
- Historical simulations including extension with SSP245 (1850-2024; 7 members).
- AMIP simulation (1850-2024; 3 members)

On-going and planned

- RFMIP-like simulation to calculate forcings
- DAMIP-like single forcing simulations
- ...

Evolution of sensitivity: v1 → v2 → v3

- TCR: 2.93 → 2.41 → **2.28 K**
- ECS: 5.30 → 4.00 → **3.93 K**

IPCC AR6

TCR: best estimate 1.65 K, likely 1.0 - 2.3 K
ECS: best estimate 3.0 K, likely 2.5 - 4 K, very likely 2 - 5 K

E3SMv3: additional configurations

On-going work

E3SMv3.NARRM

- Same atmosphere grid as v2.NARRM (110 km -> 25 km)
- Ocean and sea-ice mesh as in v3.LR (~ 30km)
- Land and river on ¼ deg lat-lon grid

E3SMv3.HR

- 25 km atmosphere (ne120)
- 18-to-6 km ocean and sea-ice
- Land and river on ¼ deg lat-lon grid

e3sm.org