E3SM Water Cycle Group Update

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on behalf of the entire group

E3SM Spring All-Hands Meeting
2021-06-03

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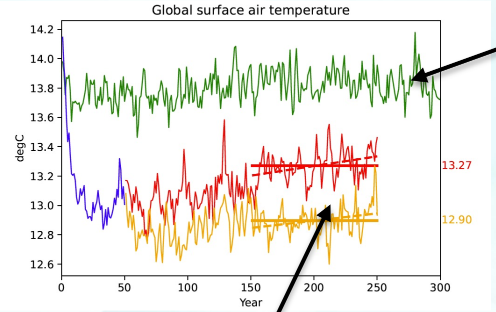
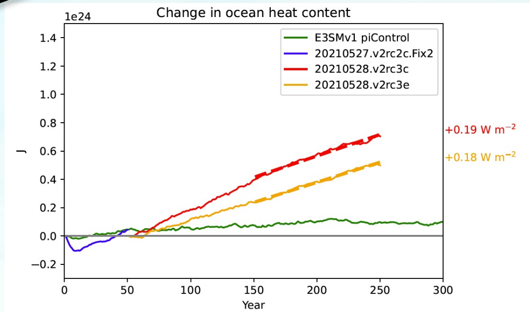
The road to v2...

- Much **longer** and more **tortuous** than expected.
- Unexpected challenges discovered late in the development phase caused delays.
- Everything is in place now.
- Currently running third iteration of release candidate as part of long pre-industrial control spin-up **simulation**.

https://www.dixence-resort.ch

v1 fully spun-up





v2 spin-up

Fruits of the labor:
“**faster and better**”
than v1.

Lessons learned

Developers are very optimistic

We love the enthusiasm and optimism!

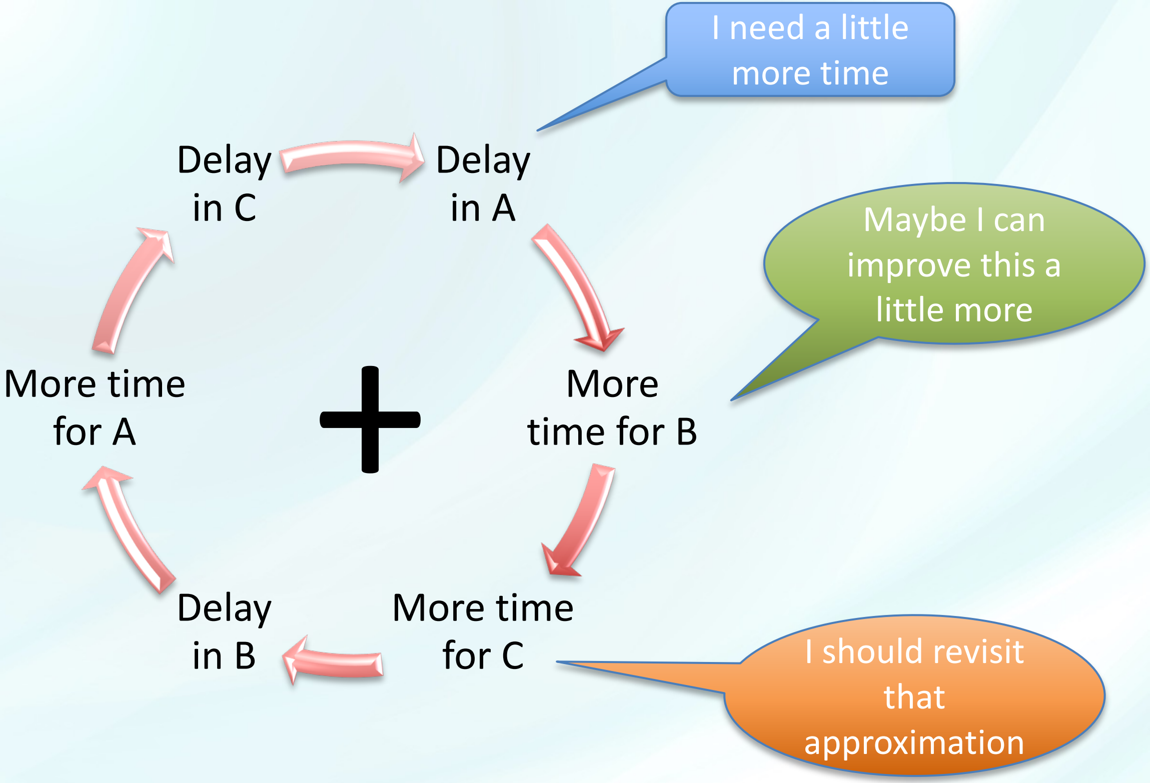
"I have this great new feature that is all ready to go and you guys should really consider it for v2!"

Sometimes... but sometimes it also does take a little bit more effort... or a lot...

Revisit code review procedure

Lessons learned: everyone wants to be last

Delay positive feedback loop

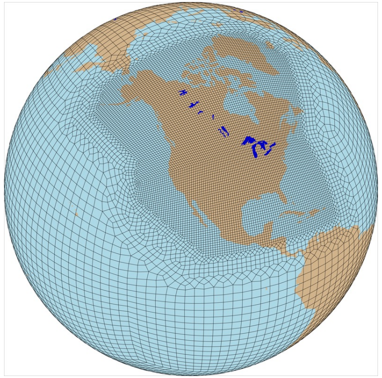


Fruits of the labor

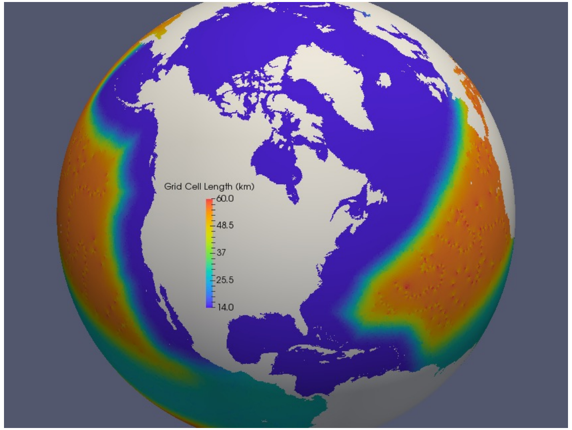
Not one, but two v2 Water Cycle configurations

- Low-resolution
  - 100 km atmosphere, 30 to 60 km ocean.
  - Approximately **twice as fast as v1** (similar number of nodes).
  - As fast at **40 SYPD** on Chrysalis.
- N America regionally refined mesh (RRM)
  - 100 to 25 km atmosphere.
  - Ocean down to 14 km.
  - Ideal for DOE applications.
  - Around **10 SYPD** on Chrysalis.
- RRM climate outside of refined mesh is very similar to its low-resolution counter-part.

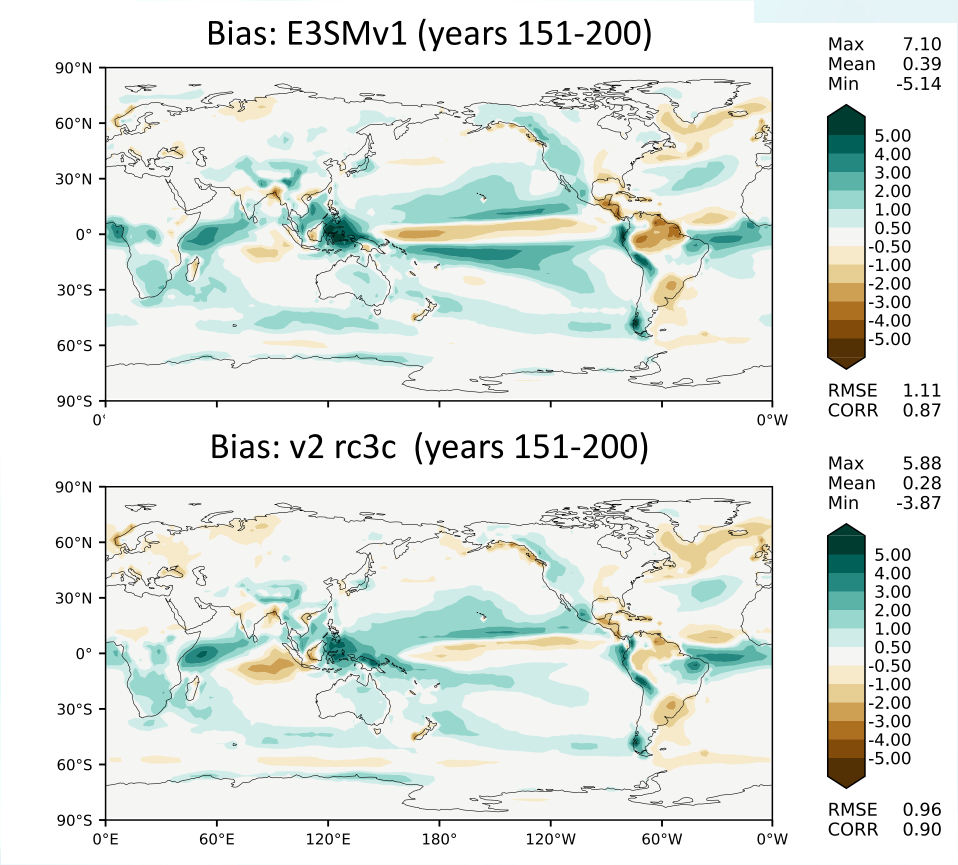
Atmosphere, land



Ocean, sea-ice



Coupled (piControl) simulations: reduced precipitation bias

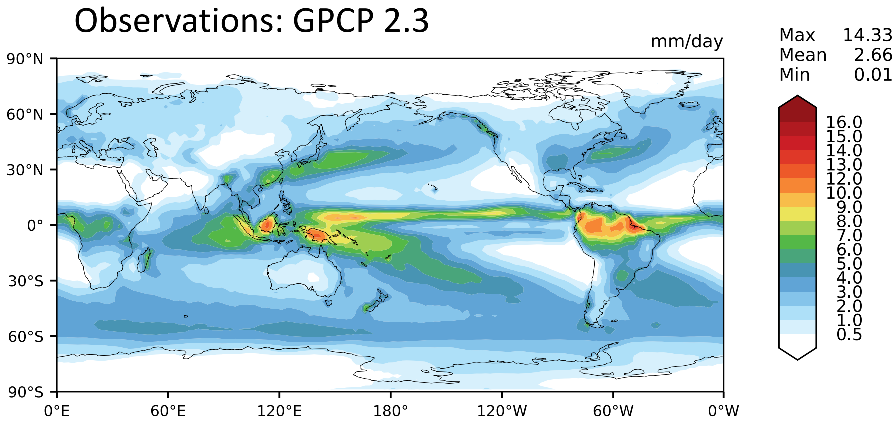


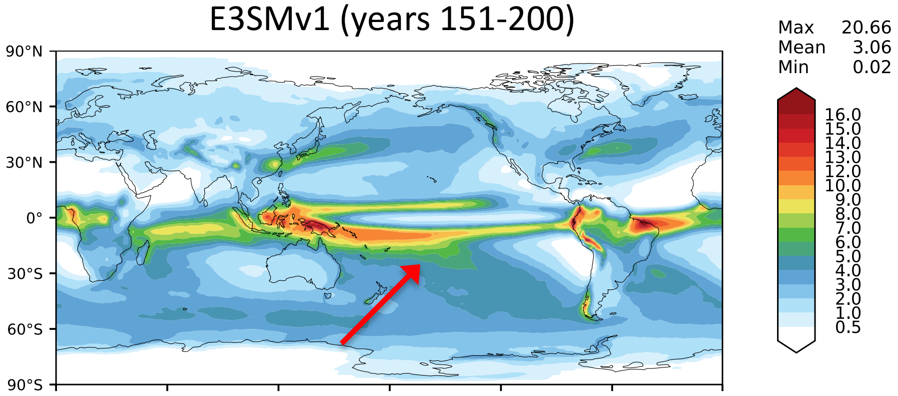
Annual mean precipitation error compared to GPCP v2.3.

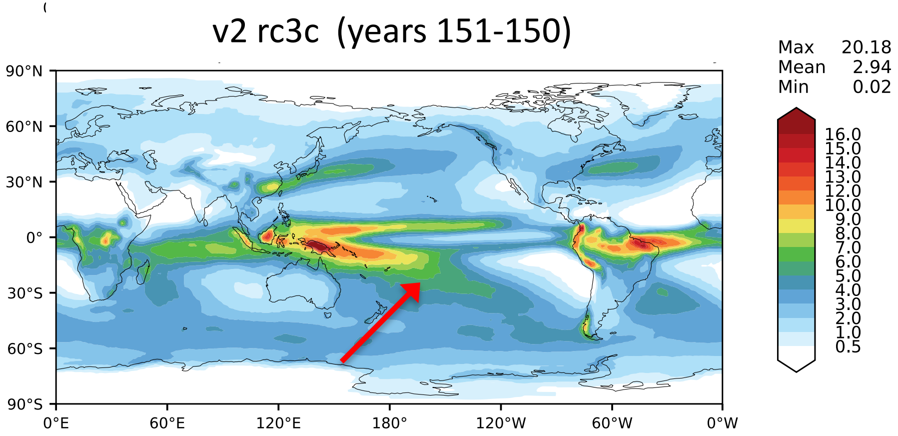
Improvements compared to v1:

- Double-ITCZ.
- Maritime continent
- Amazon dry bias.
- Continental US summertime warm and dry bias.
- Excessive precipitation over high elevation.
- Overall RMS error.

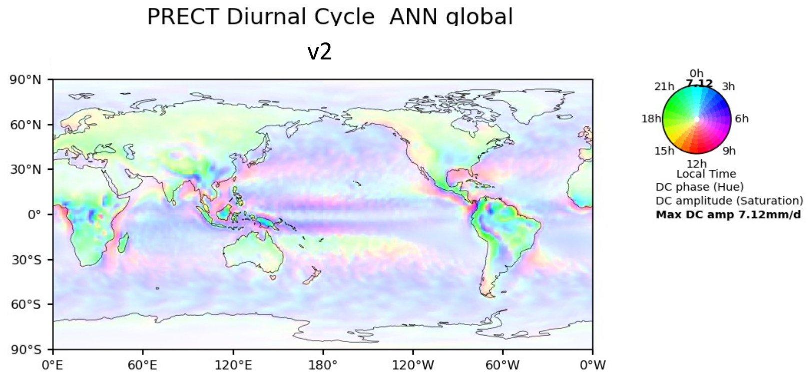
Coupled (piControl) simulations: reduced double-ITCZ
March April May

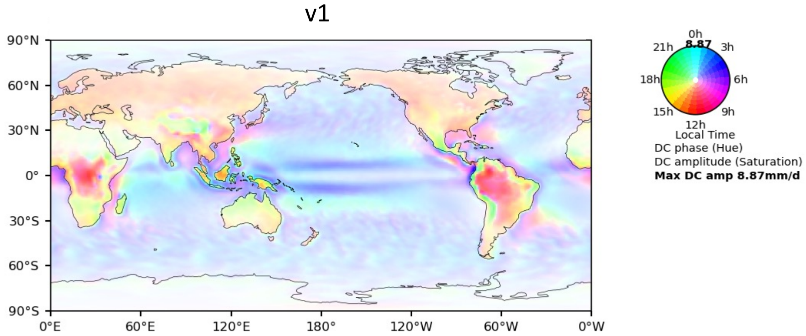


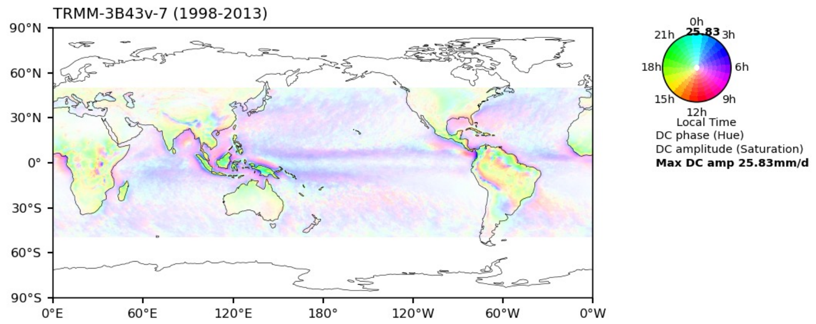




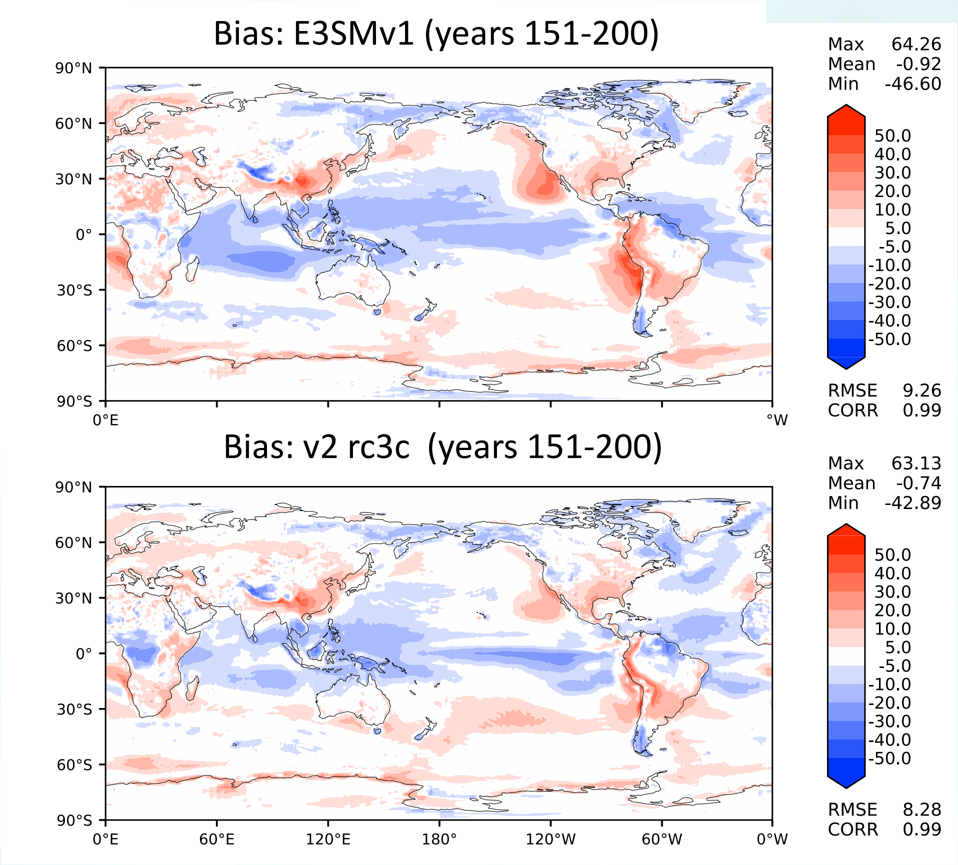
Improved precipitation diurnal cycle







Coupled (piControl) simulations: reduced TOA radiation bias

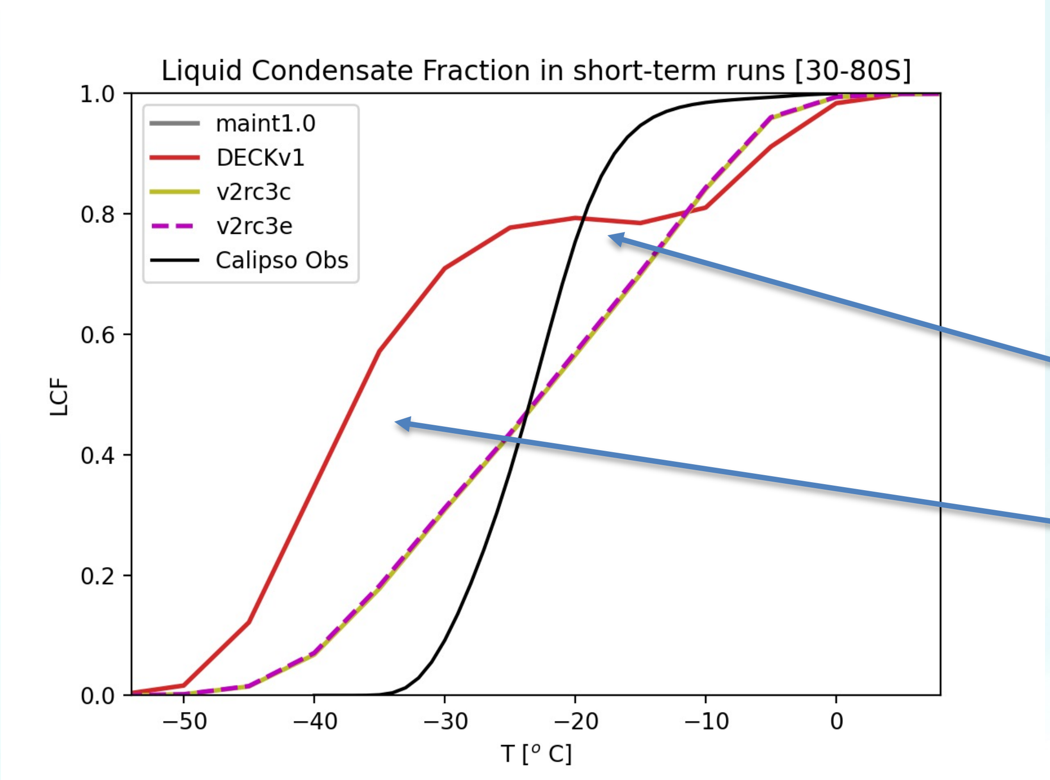


Annual mean net radiation at top-of-atmosphere (TOA) compared to CERES-EBAF Ed 4.1.

Improvements compared to v1:

- Equatorial Pacific and Indian ocean.
- Biases over stratocumulus regions (West of N and S American continents, west of African continent).
- Overall RMS error.

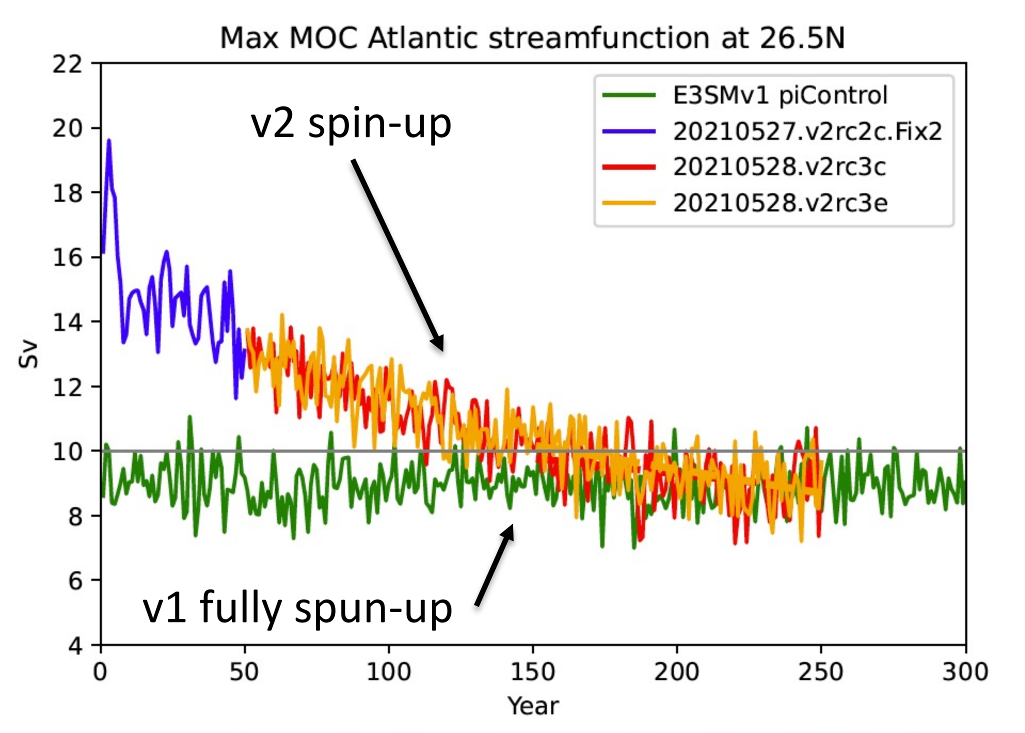
Improved cloud phase partitioning



- Removed unrealistic plateau.
- More realistic liquid condensate fraction (LCF) at lower temperature.

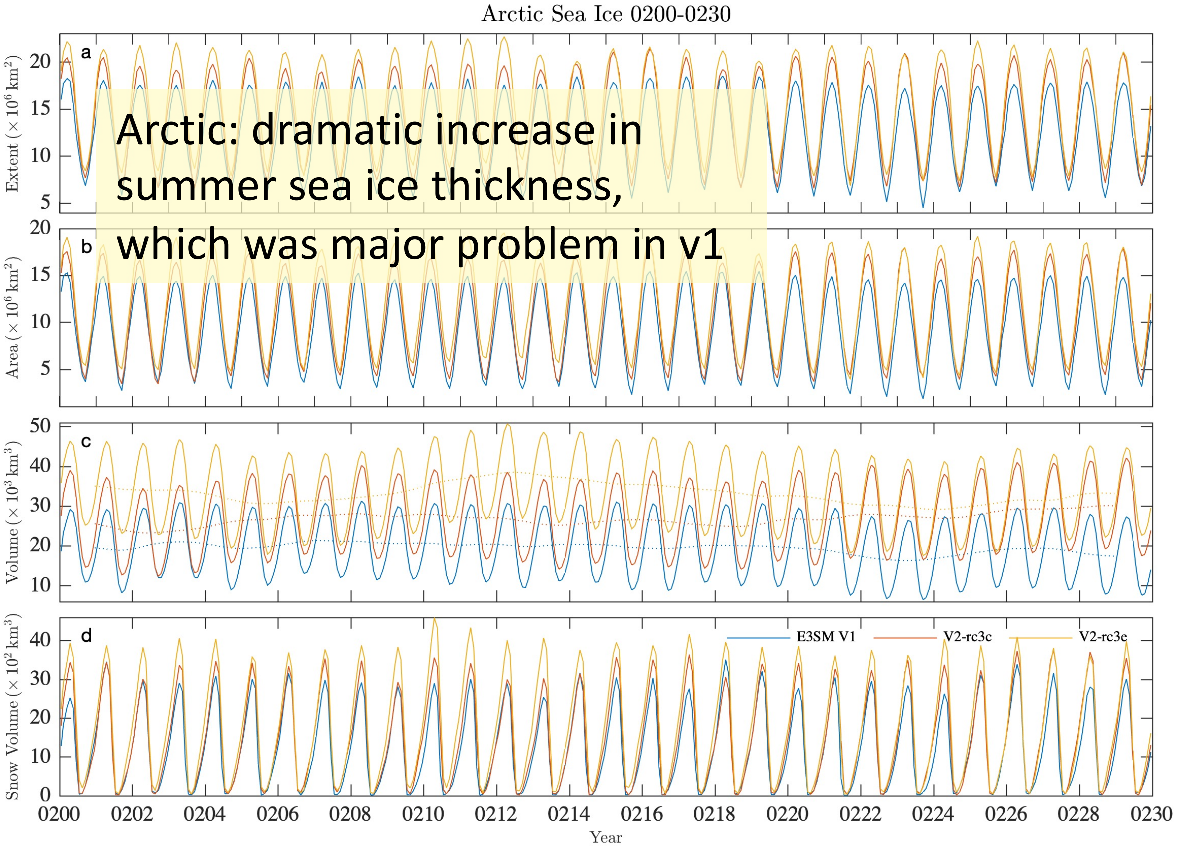
AMOC: v2's White Whale

- AMOC was very weak in v1 and remains weak in v2:
  - Tried numerous things: tuning, GM changes, a resolved Atlantic mesoscale eddy mesh
- MPAS-O is quite sensitive to forcing.
- Best v2 AMOC was due to bugs in new land features.



Key v2 Sea Ice and Ocean-Ice Coupling Improvements

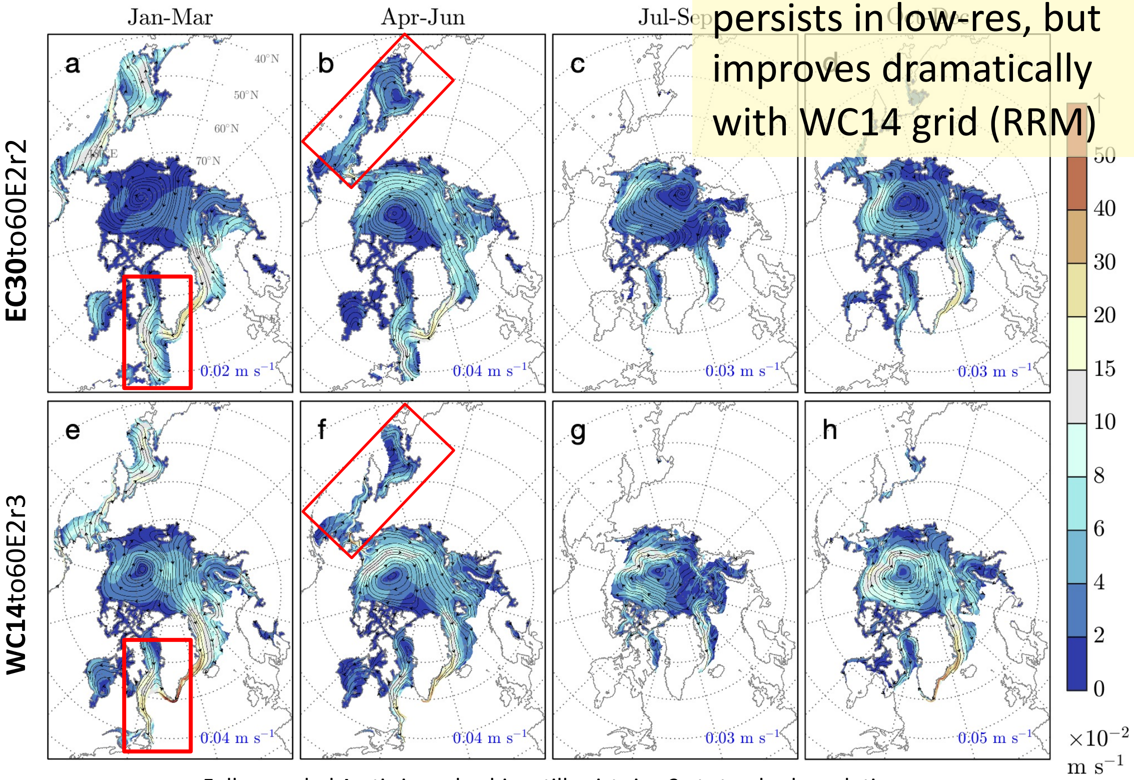
1. Fixed key frazil bug accounting for ~0.1Wm^{-2} heat leak globally, resulting in **thicker sea ice in v2**.
2. Homogenization of **snow radiative transfer** over land and sea ice (SNICAR_AD)
3. Sophisticated **snow morphology** over sea ice (including 5 snow layers)
4. Harmonization of **sea ice basal temperature** with the ocean equation of state.



Dashed lines are 12-month filtered sea ice volume

Key v2 Sea Ice and Ocean-Ice Coupling Improvements

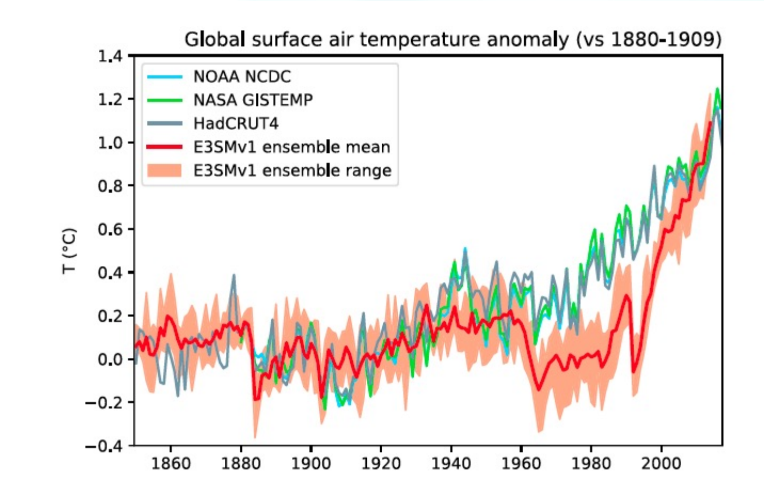
5. **Removal of sea surface height filtering** previously needed to damp high-frequency coupling.
6. **Removal of checkerboarding in sea ice ocean melt terms** associated with ocean advection bug.
7. Solidified ocean eddies/eddy parameterization as a primary driver of an accurate sea ice edge and sea ice drift speed.
8. Improvement of **analysis tools** for quick diagnosis of coupling inconsistencies between model components.



Labrador sea-ice bias persists in low-res, but improves dramatically with WC14 grid (RRM)

Fully-coupled Arctic ice-edge bias still exists in v2 at standard resolution, but is rectified on the WC14 (RRM) ice-ocean mesh

What about the E3SM “pot-hole”?



Golaz et al. (2019)

For v2, expecting:

- Smaller (magnitude) aerosol-cloud forcing.
- Weaker cloud feedback. Smaller sensitivity?

Will it be enough to fill the pot-hole?

- Probably not but should get better.

Config	**Cess feedback** (W/m^2 per K)	**net cloud feedback**	**ERFaer_tot**
v2rc1c	-1.612	0.104	-1.327
v2rc1e	-1.555	0.116	-1.327
maint-1.0	-1.372	0.251	-1.6

v2 : Improved user experience

- Significant efforts bringing back some sanity into **compset naming convention**: no more AV1C04-P2!
- Simplified **run e3sm script**.
- Continued improvements to diagnostics (**MPAS-Analysis**, **E3SM Diags**)
- Post-processing toolchain: **zppy**
  - Getting closer to “Set it and forget it!”
- Documentation: Running E3SM step-by-step guide
  - Everyone who wants it should be able to get the model running in one afternoon.

v2 Water Cycle simulation campaign

- **Low-res**
  - DECK
    - Pre-industrial control (500 years)
    - Abrupt 4xCO_2 (150+ years)
    - One percent CO_2 per year (150 years)
    - AMIP
  - Historical simulations: focus on DOE actionable science
    - How large an ensemble?
  - Subset of CFMIP/RFMIP (jointly with RGMA)
  - ...
- **RRM**
  - DECK + historical (?)
- Anything beyond requires a **simulation champion** with a plan (and paper).

New for v2!

Analysis Highlights (subset)

Subtropical Eastern N Pacific SST bias in E3SM v1

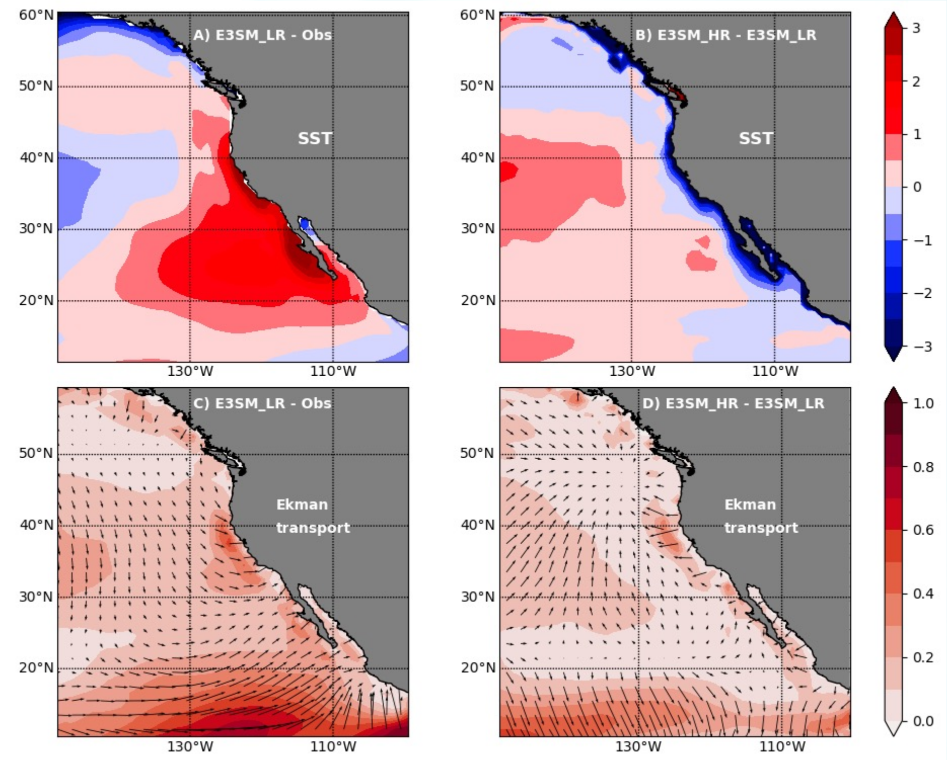


Figure: (A) Annual mean SST (^oC) bias in E3SM_LR. (B) Difference in annual mean SST between E3SM_HR and E3SM_LR. (C-D) As in A-B but for Ekman transport (m^3s^{-1}). In panels C and D, the color in the background represents the magnitude of vector differences.

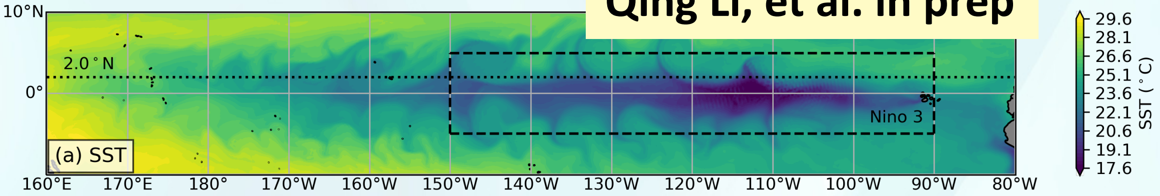
1) In the fully-coupled simulation at the low resolution (E3SM_LR), the SST bias is strongest near the coast. In the high-resolution version (E3SM_HR), the **coastal SST bias improves considerably** while the offshore bias remains largely unaffected.
2) Relative to E3SM_LR, the representation of **alongshore winds, and consequently, the nearshore Ekman transport and upwelling are improved** in E3SM_HR. This leads to an alleviation of the coastal SST bias in E3SM_HR.
3) **Away from the coast, the SST bias is mainly caused by errors in surface fluxes, which are less affected by changes in model resolution.** Further, these results based on E3SM can be generalized to CMIP6/HighResMIP suite of models, highlighting their broad nature.

Karthik Balaguru

JGR in review

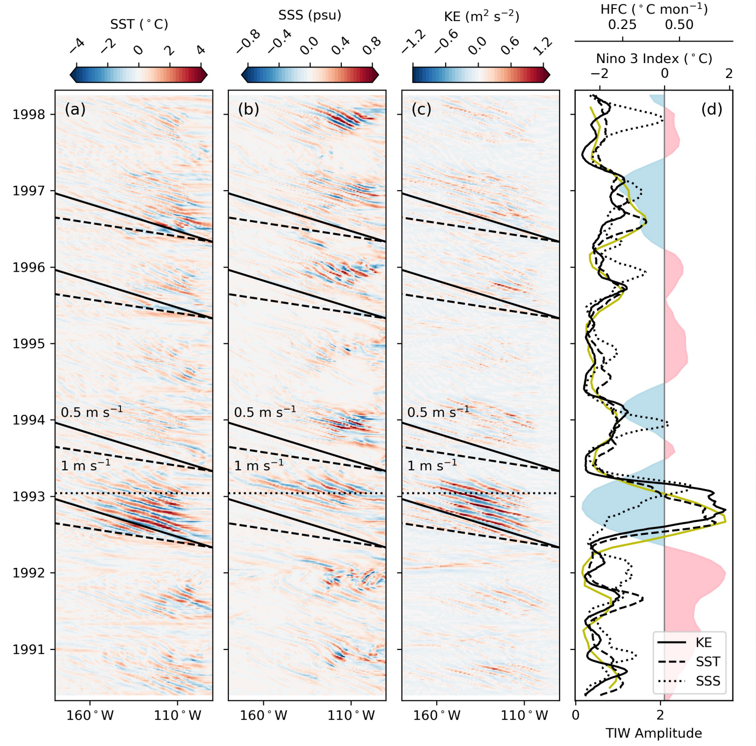
TIWs in E3SM

Qing Li, et al. in prep

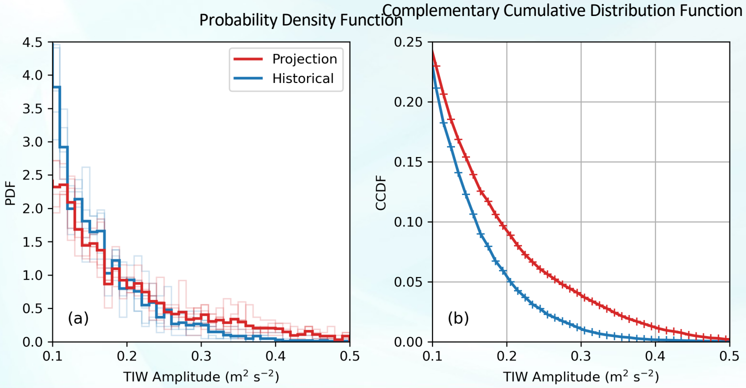


Historical vs. Projection

- Tropical instability waves (TIWs) are better resolved in standard resolution E3SM than other CMIP6 models
- Compared historical to projection simulations
- Strong TIWs are more frequent in a warmer climate
- Consistent with stronger ENSO amplitude in a warmer climate in E3SM



Propagation of TIWs shown by SST, SSS and KE



Distribution of TIW amplitude in surface kinetic energy

Thank you!