Progress toward Adaptive Vertical Grid Enhancement in E3SM

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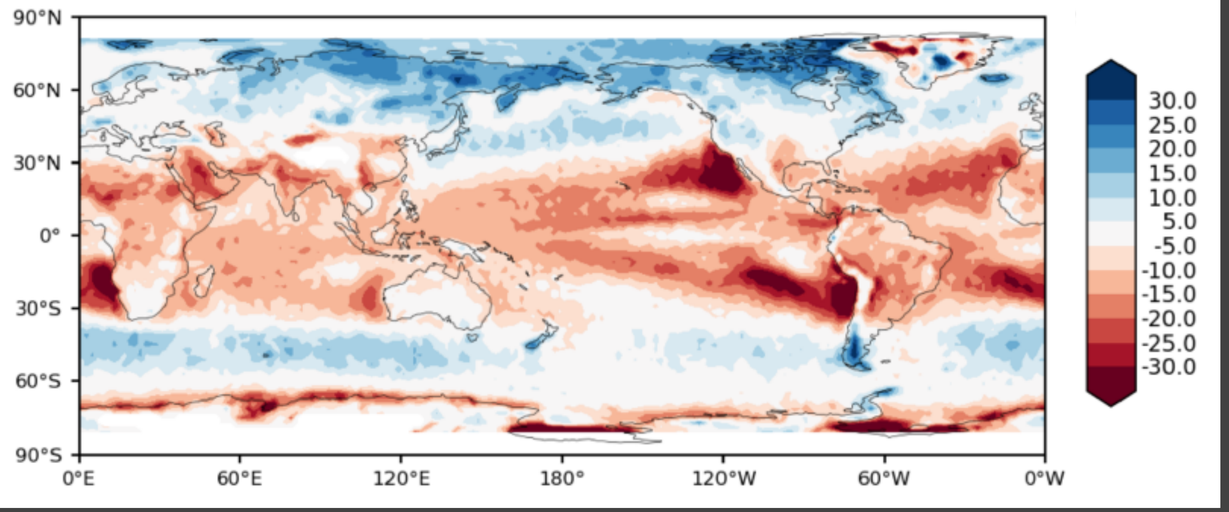
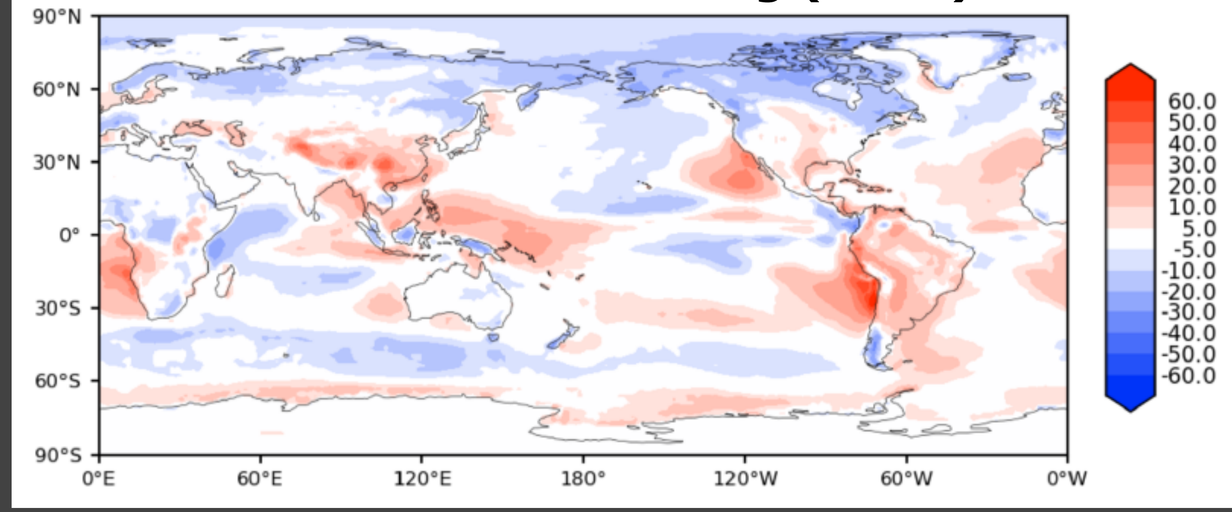
Low clouds are largely missed in E3SM v1.

E3SM Control – CALIPSO-GOCCP
Low cloud amount



E3SM Control – CERES-EBAF
Shortwave cloud forcing (Wm^{-2})



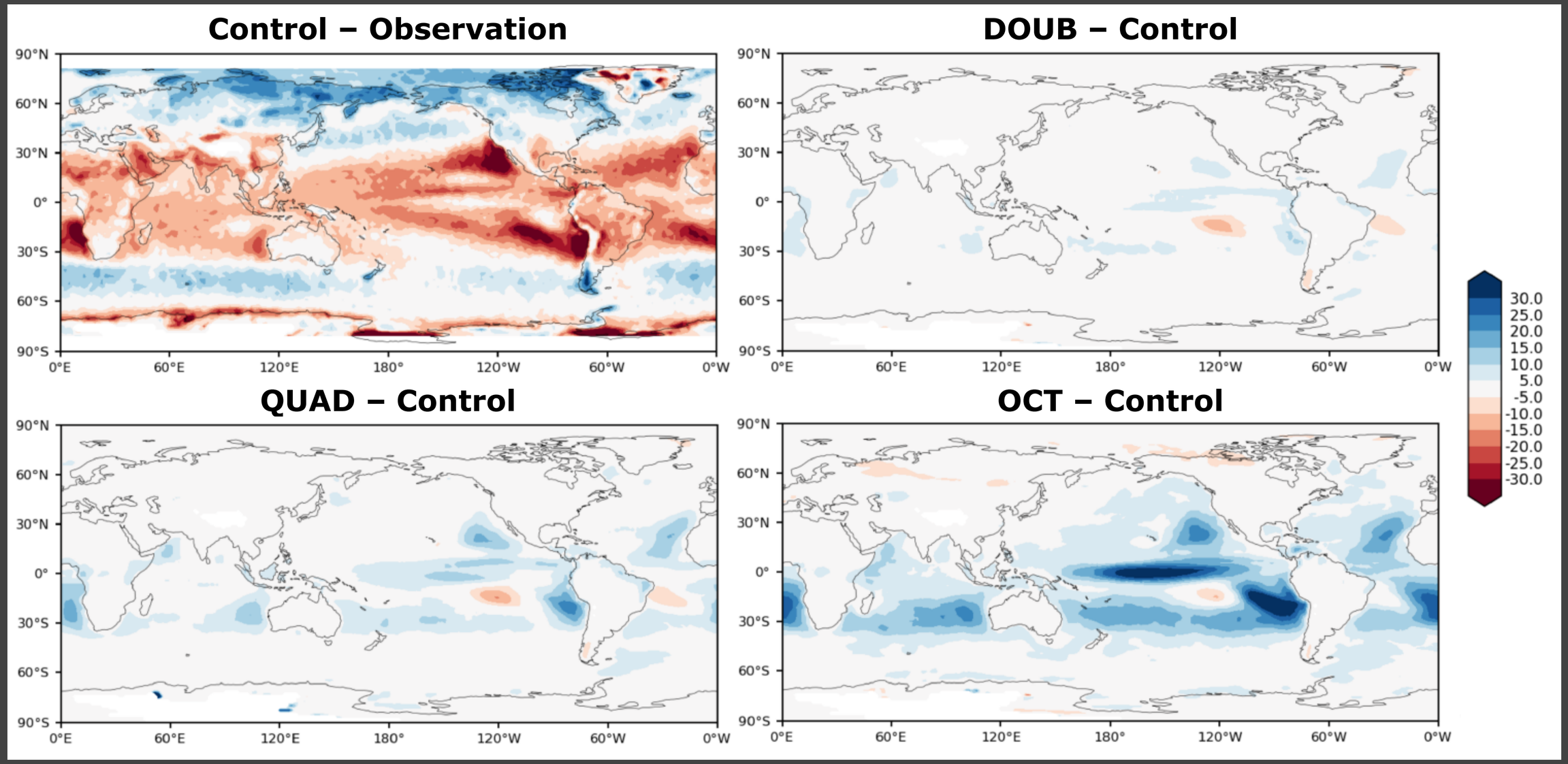
E3SM Control: 1 degree mesh, 72 levels, 10 years

Does vertical resolution matter?

	Levels	E3SM timestep (s)	Micro. & turb. timestep (s)	Deep conv. timescale (s)	Simulated year per day (1024 cpus)
Control	72	1800	300	3600	4.6
DOUB	93	900	300	3600	2.5
QUAD	123	600	200	3600	0.83
OCT	194	300	100	600	0.125 (1.5 months)

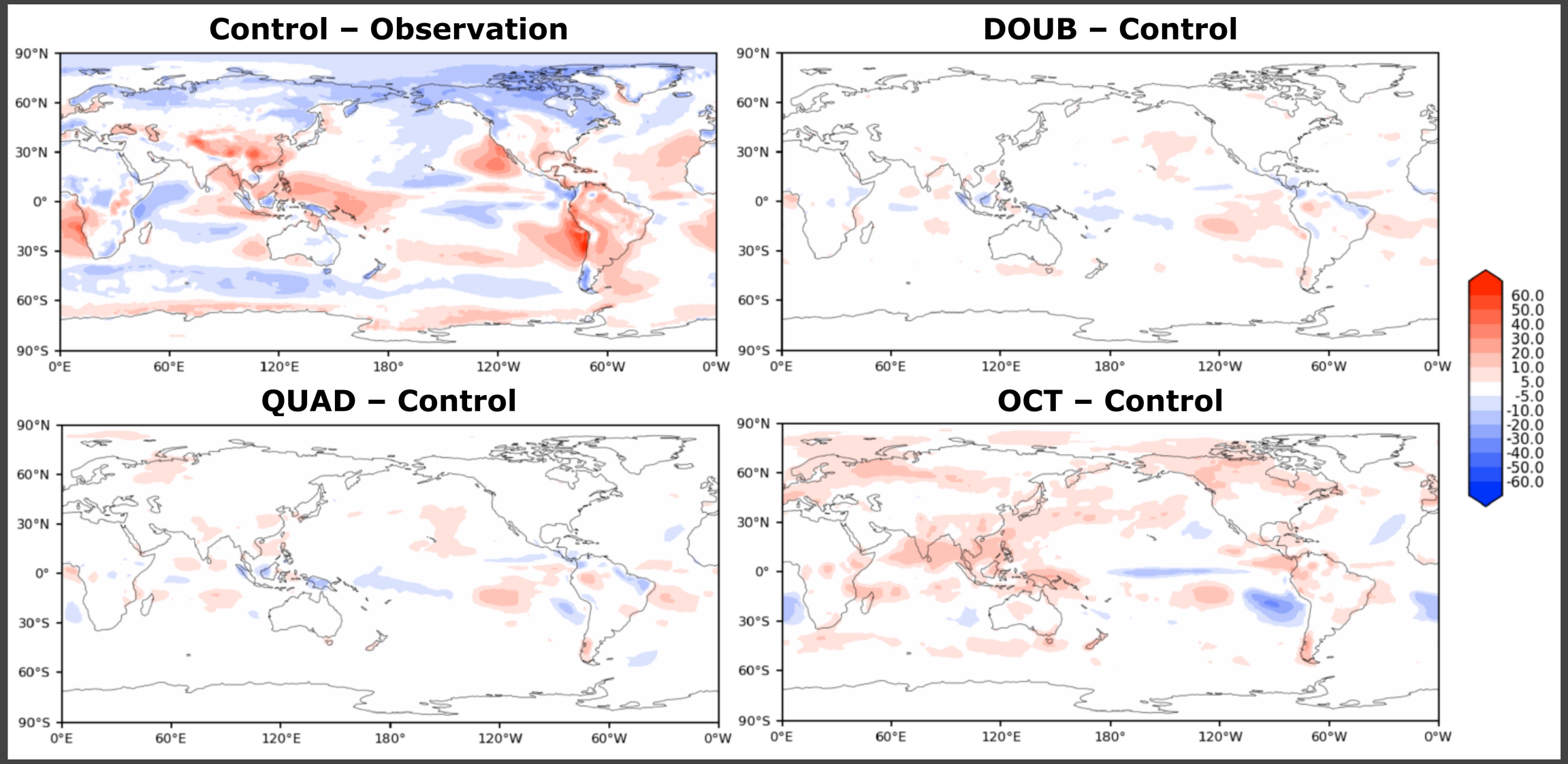
Vertical resolution is increased below 700 hPa.
Deep convective timescale is adjusted for OCT in order to maintain radiative balance.

Low cloud amount increases as vertical resolution is increased.



blue: more low cloud than Control

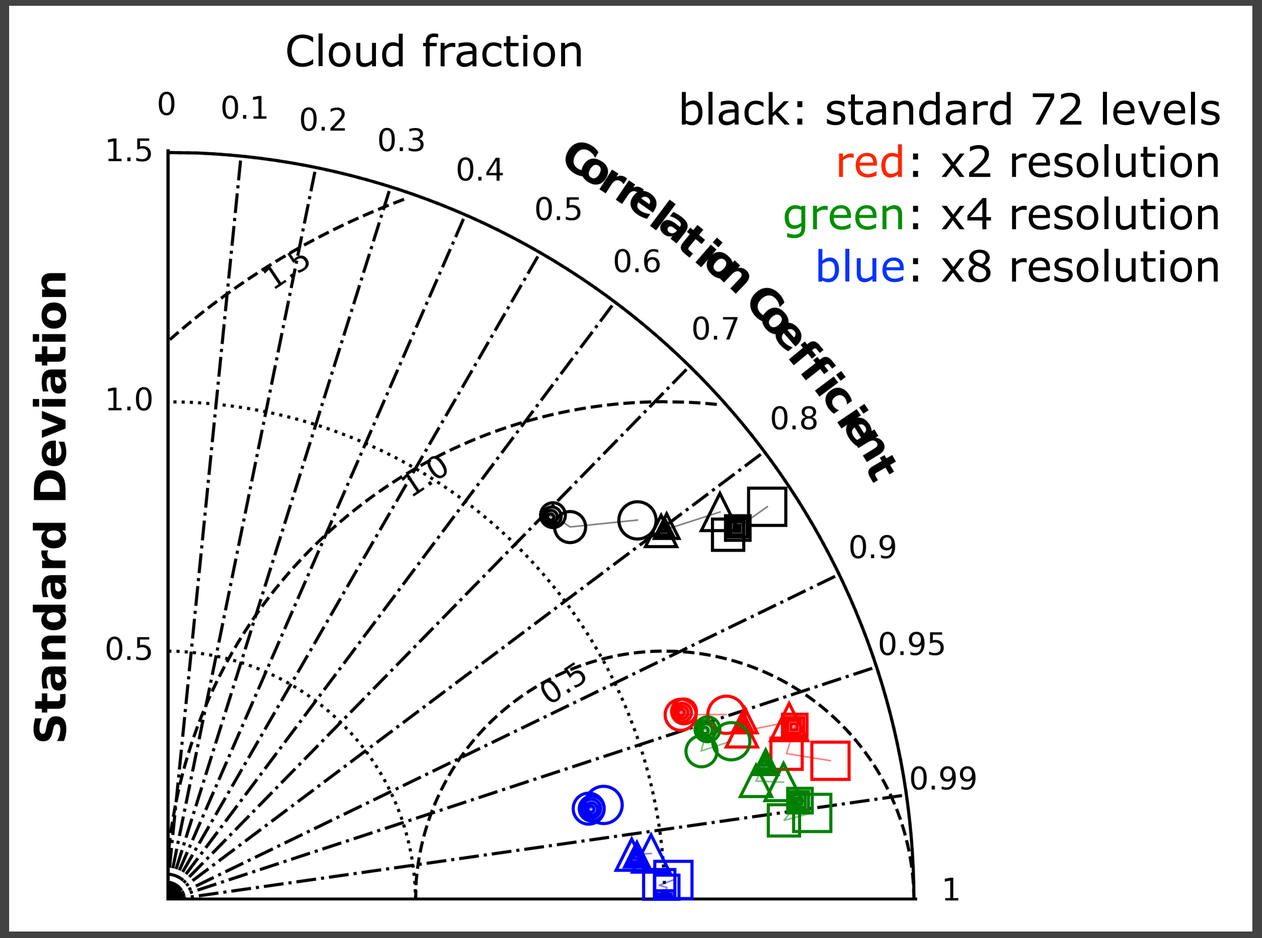
SWCF improves as vertical resolution is increased.



red: less reflective than Control blue: more reflective than Control

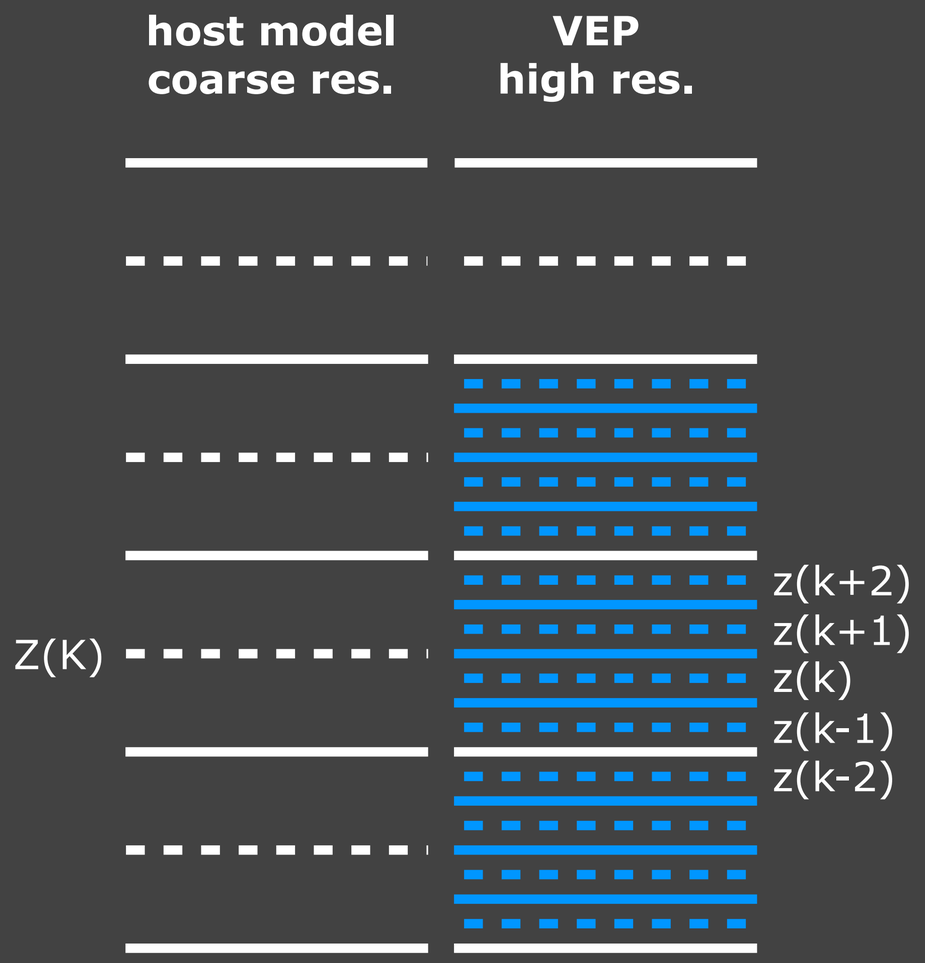
E3SM single column model tends to converge at high vertical resolution.

RICO (precipitating trade cu)



Framework for Improvement by Vertical Enhancement (FIVE)

- Vertically Enhanced Physics (VEP)
  - Create a separate computational domain, in which prognostic variables are allocated on a locally (e.g., PBL, cirrus) high resolution vertical grid.
  - High resolution information is kept at all times.
  - Selected processes (microphysics, radiation, turbulence, vertical advection) are computed on the locally high resolution grid (VEP grid).



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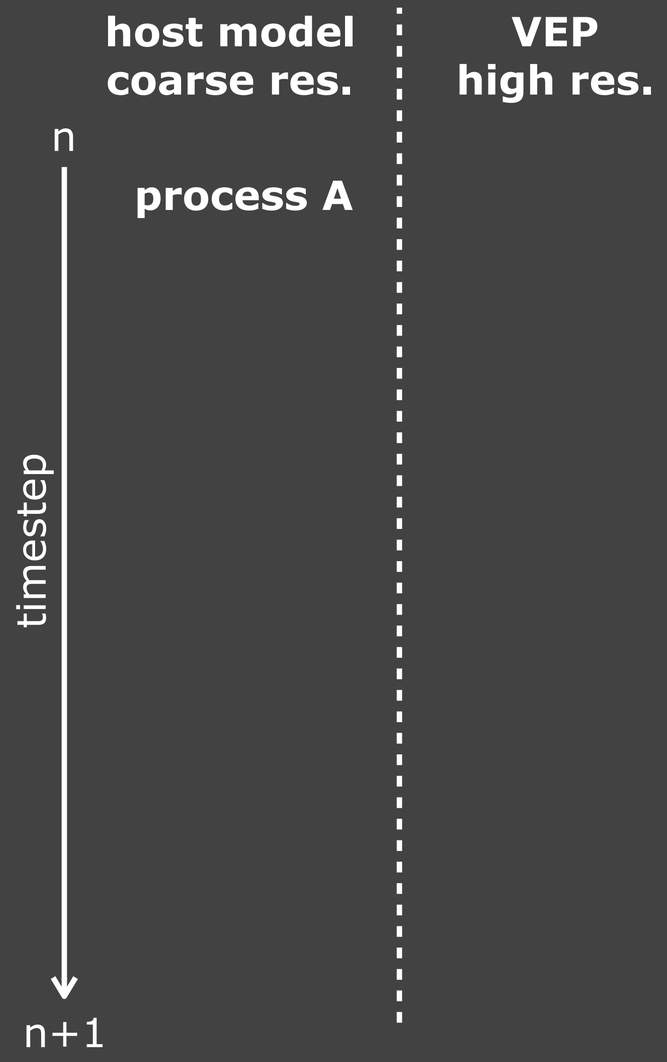

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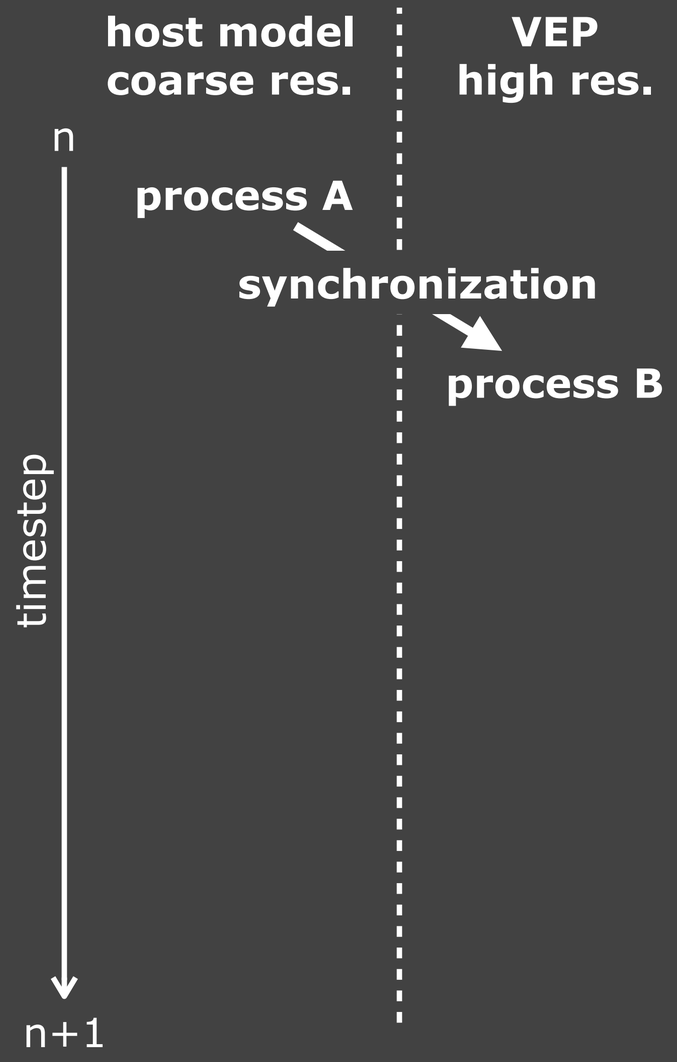

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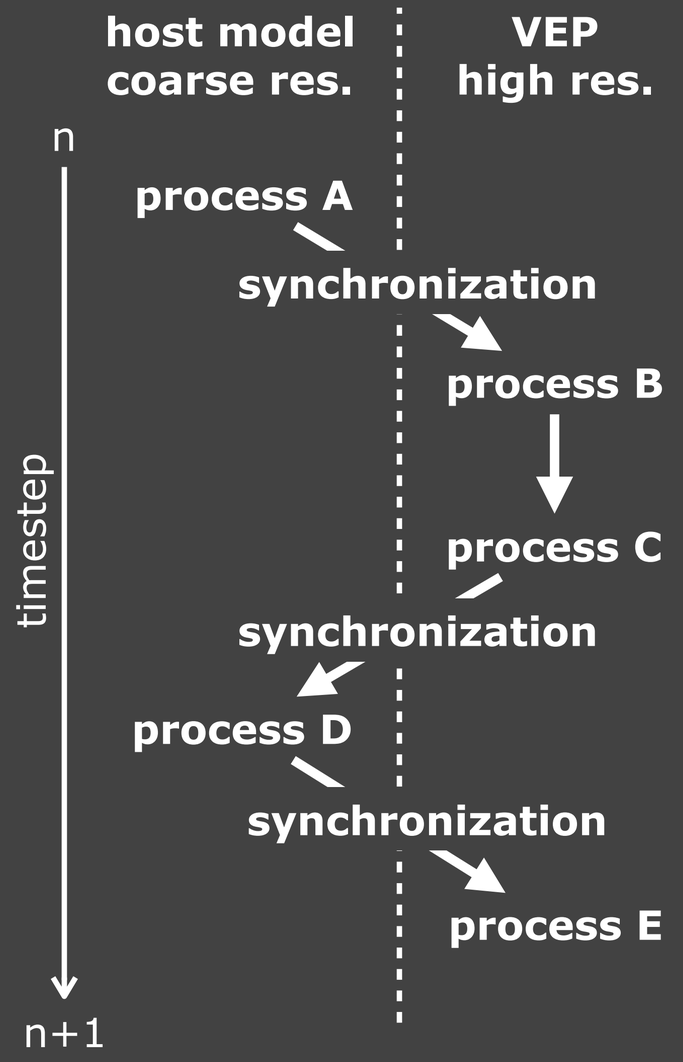
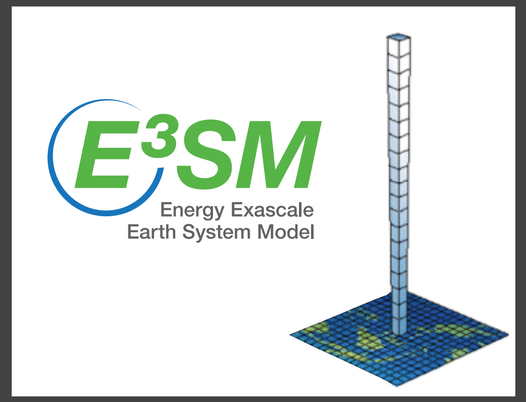
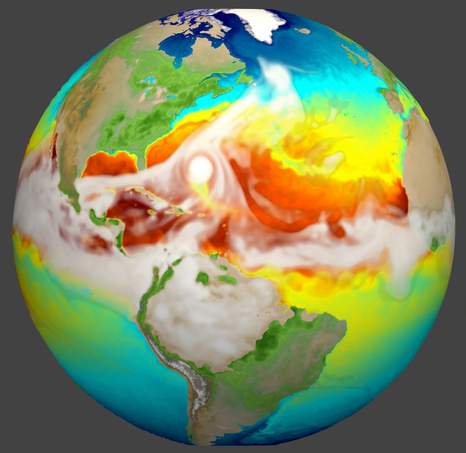
- Yamaguchi et al. (2017)



We are implementing FIVE into E3SM.



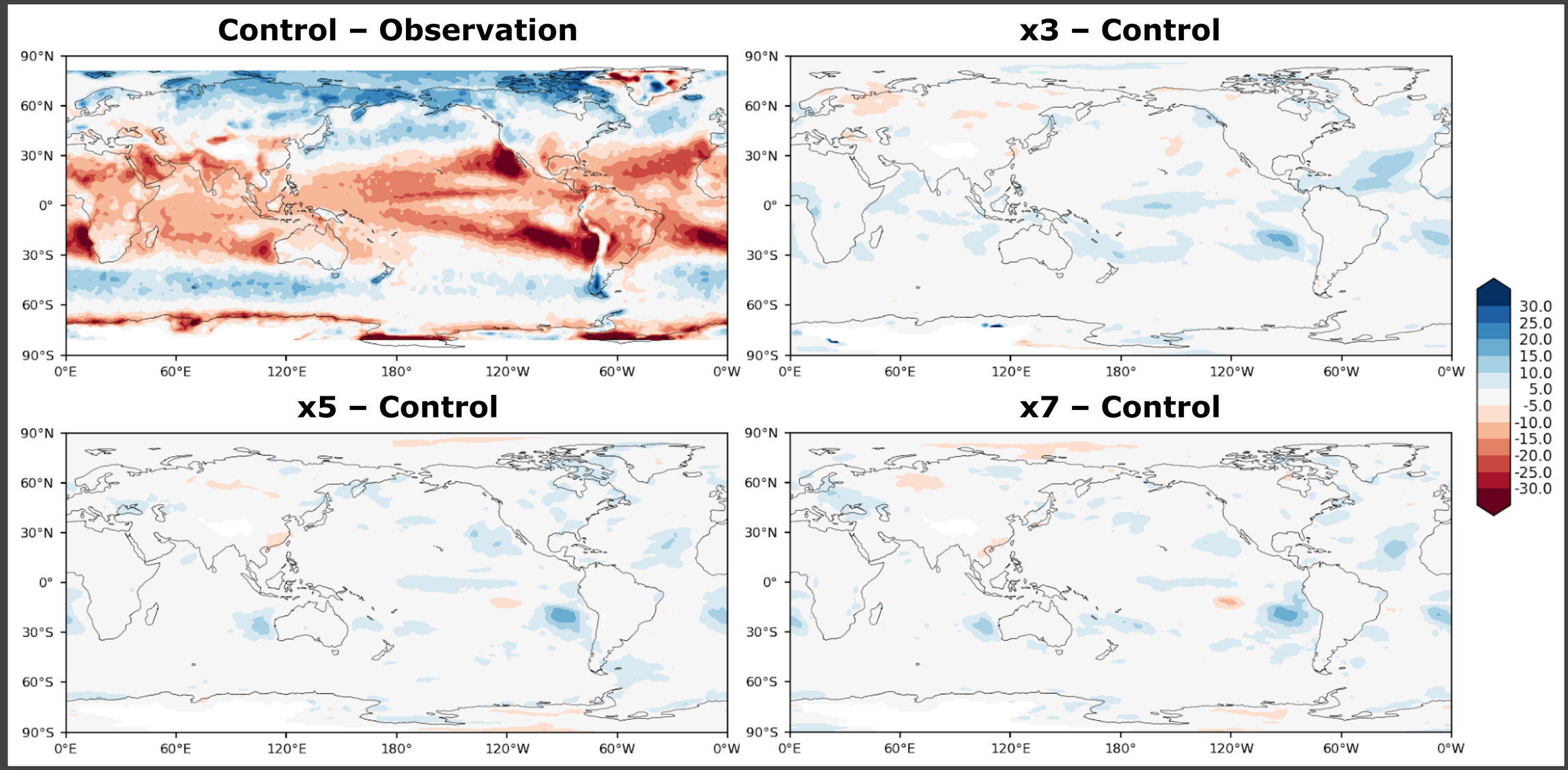


E3SM
Energy Exascale
Earth System Model

So far, microphysics, radiation, turbulence have been implemented (**pre-alpha version**).
Large scale vertical advection has been under implementation.

pre-alpha E3SM-FIVE increases low cloud amount.

2-year run



(Future version will enhance VEP resolution by 2^n, instead of inserting 2^n levels within a host model layer.)

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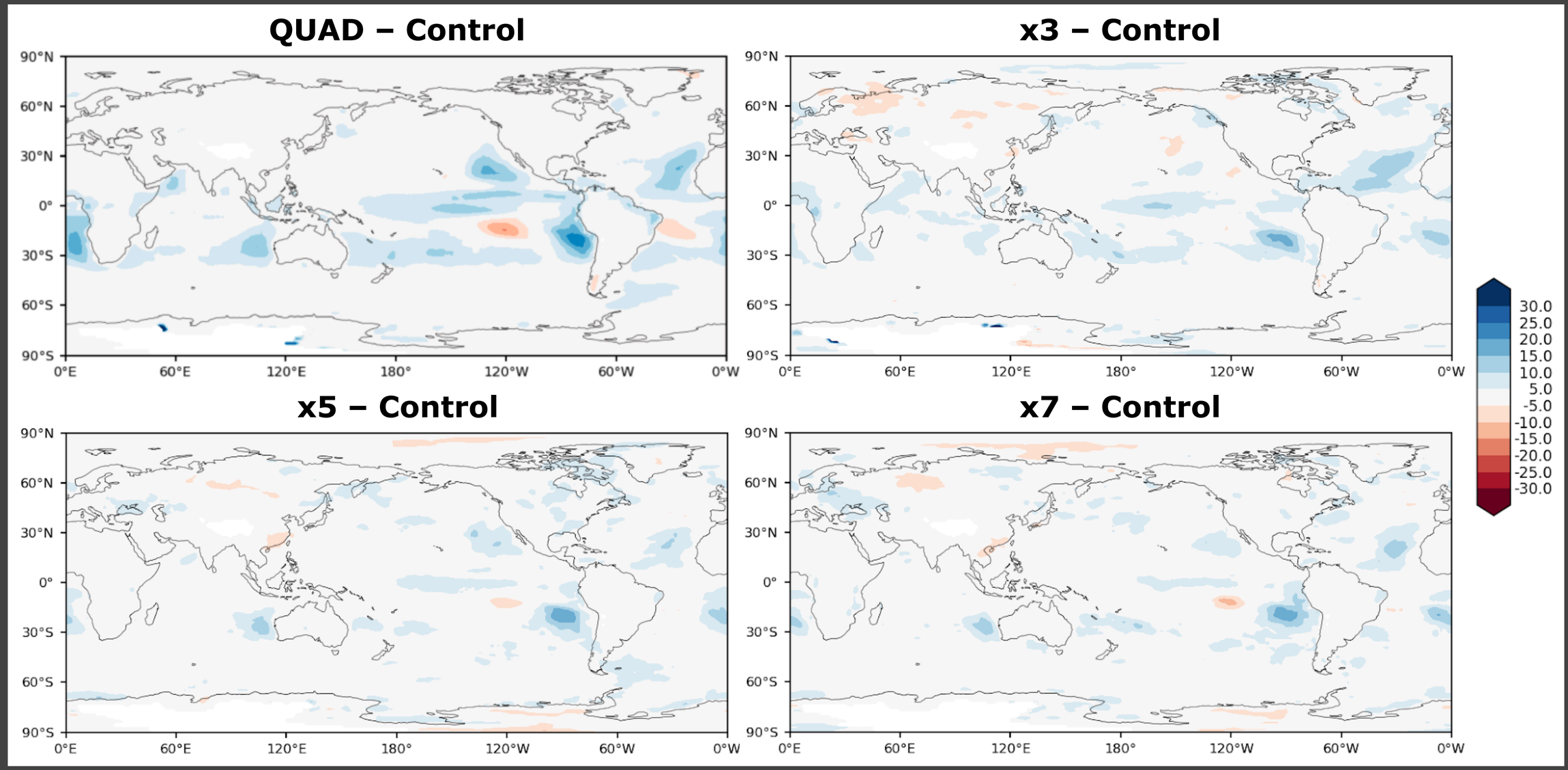

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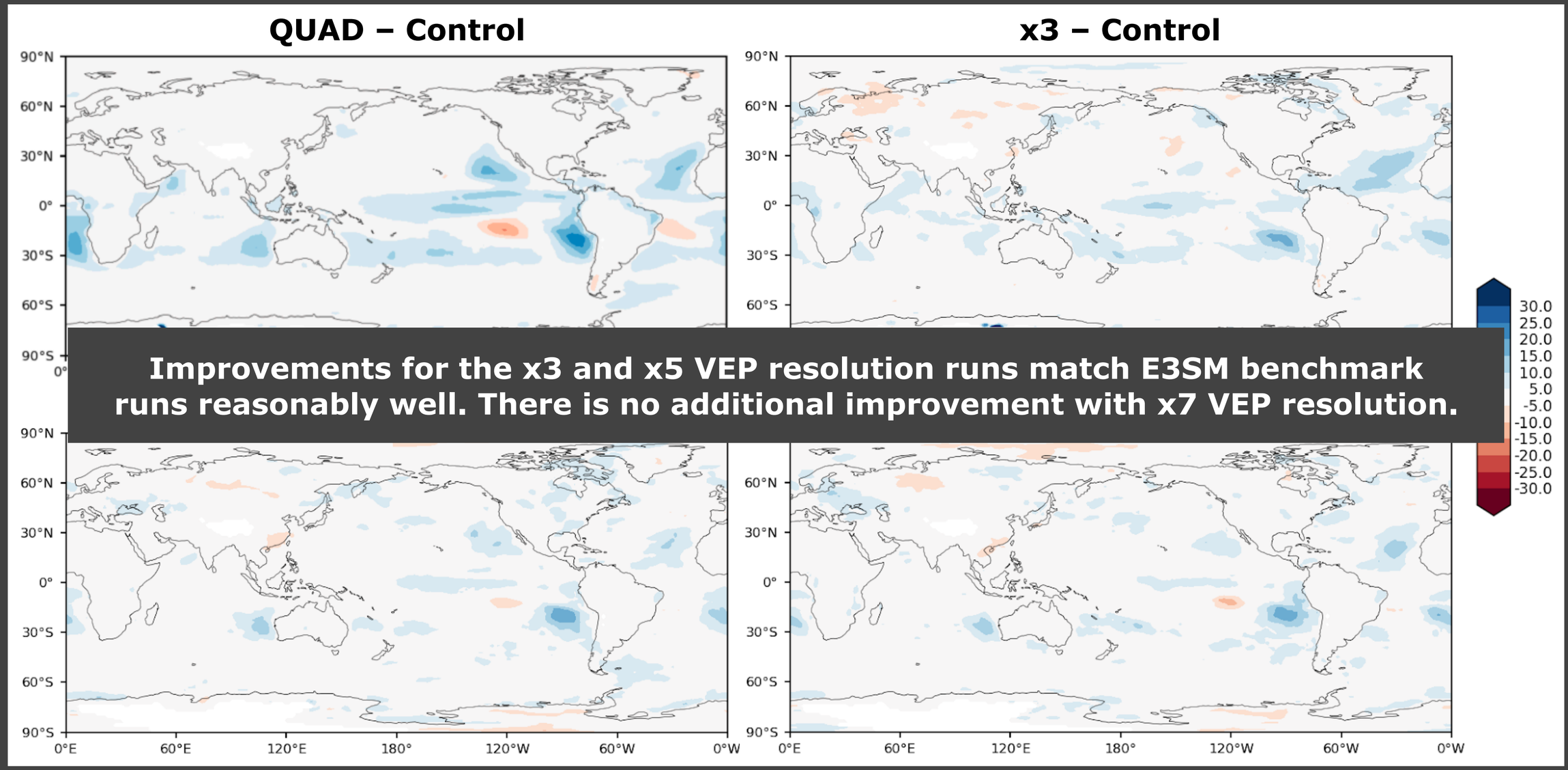

Improvements for the x3 and x5 VEP resolution runs match E3SM benchmark runs reasonably well. There is no additional improvement with x7 VEP resolution.

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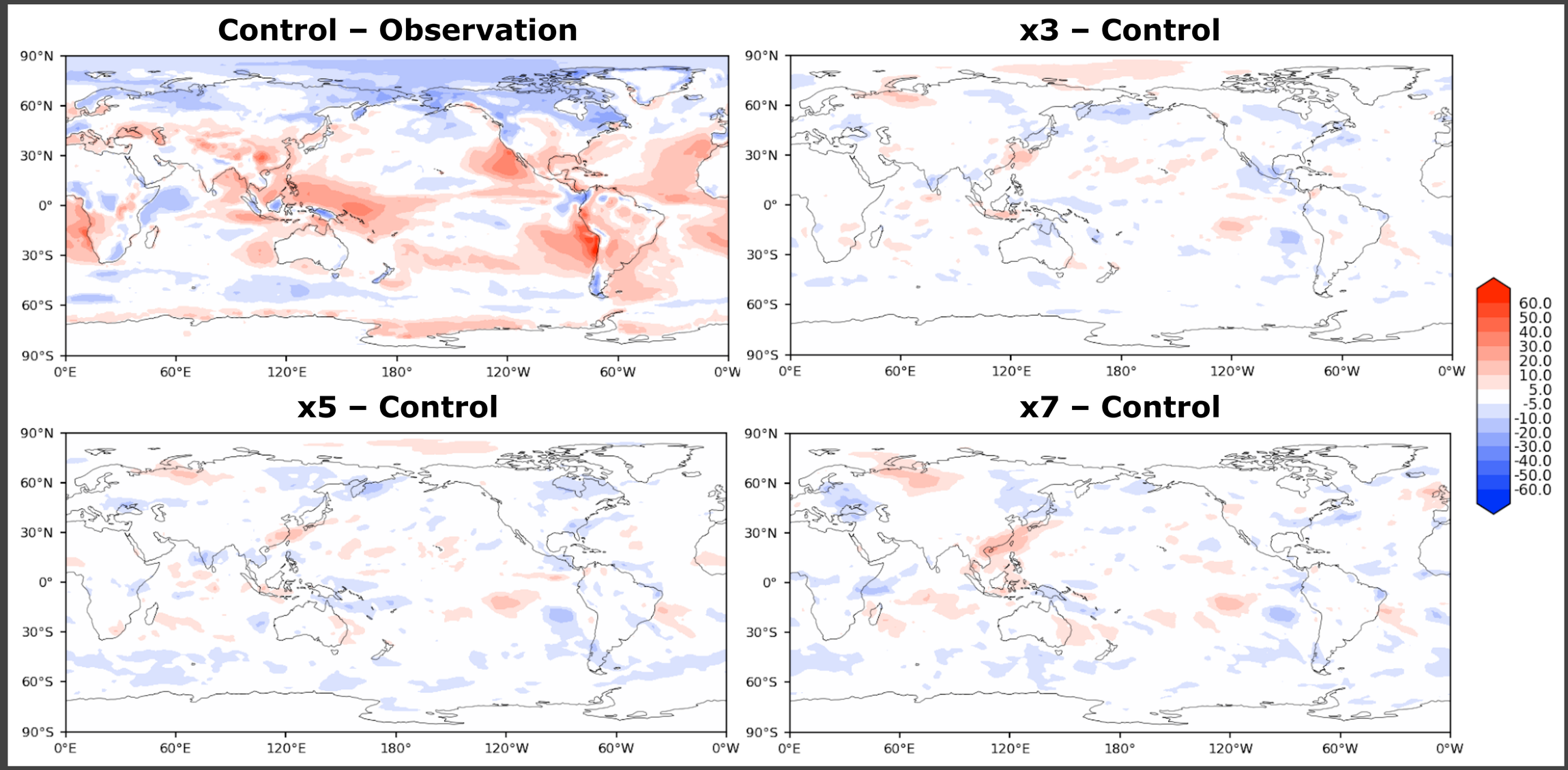

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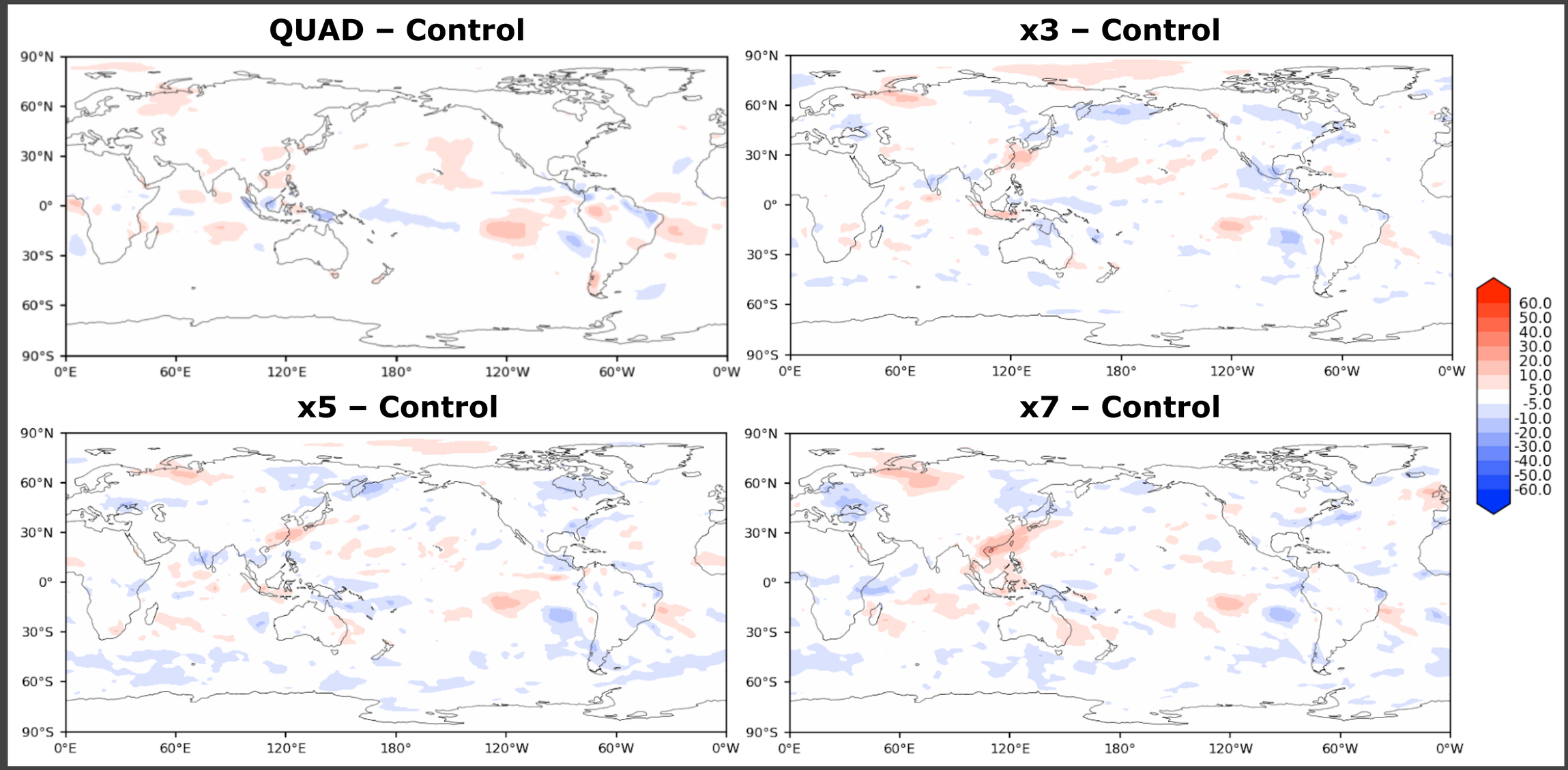

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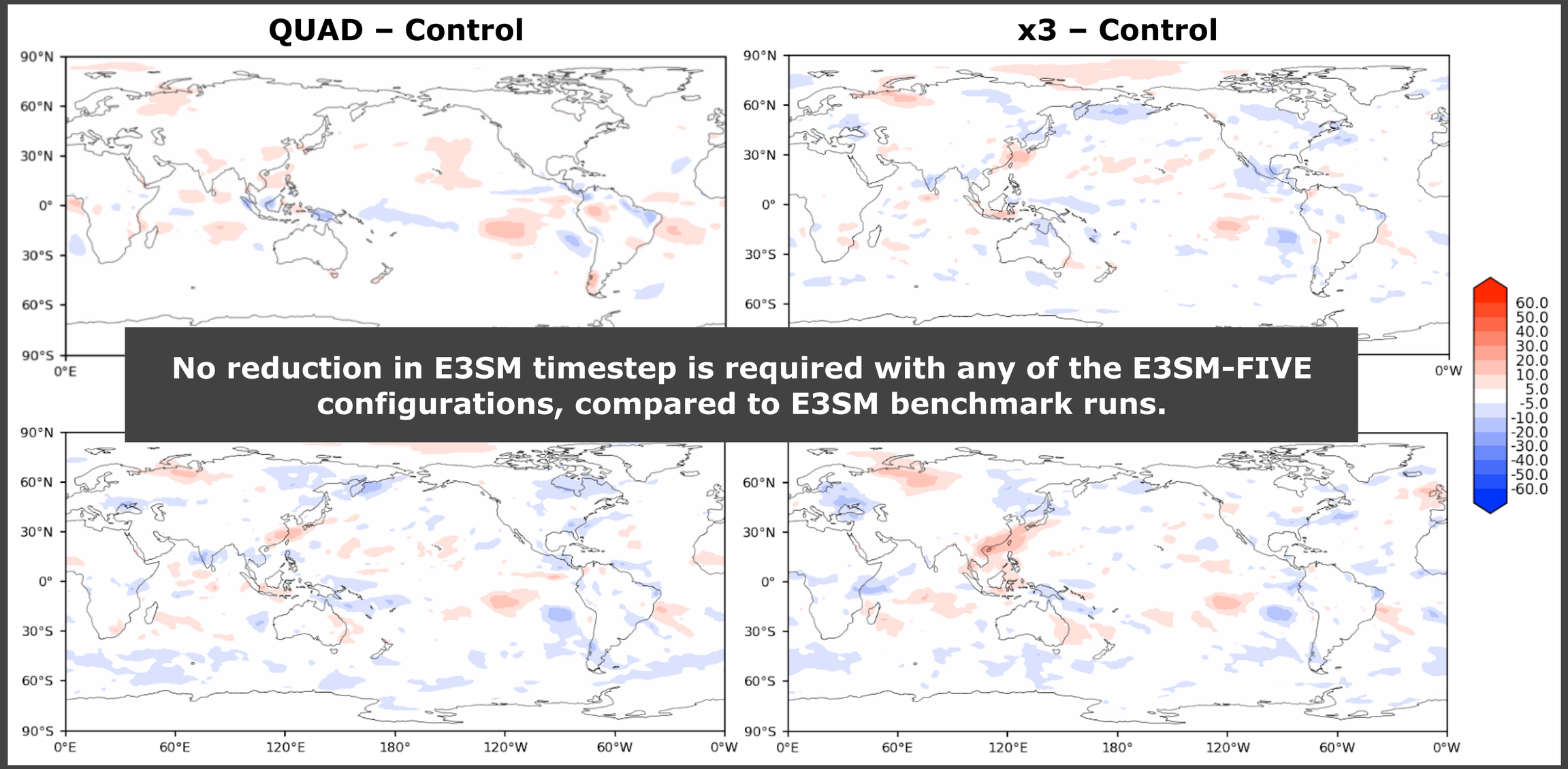
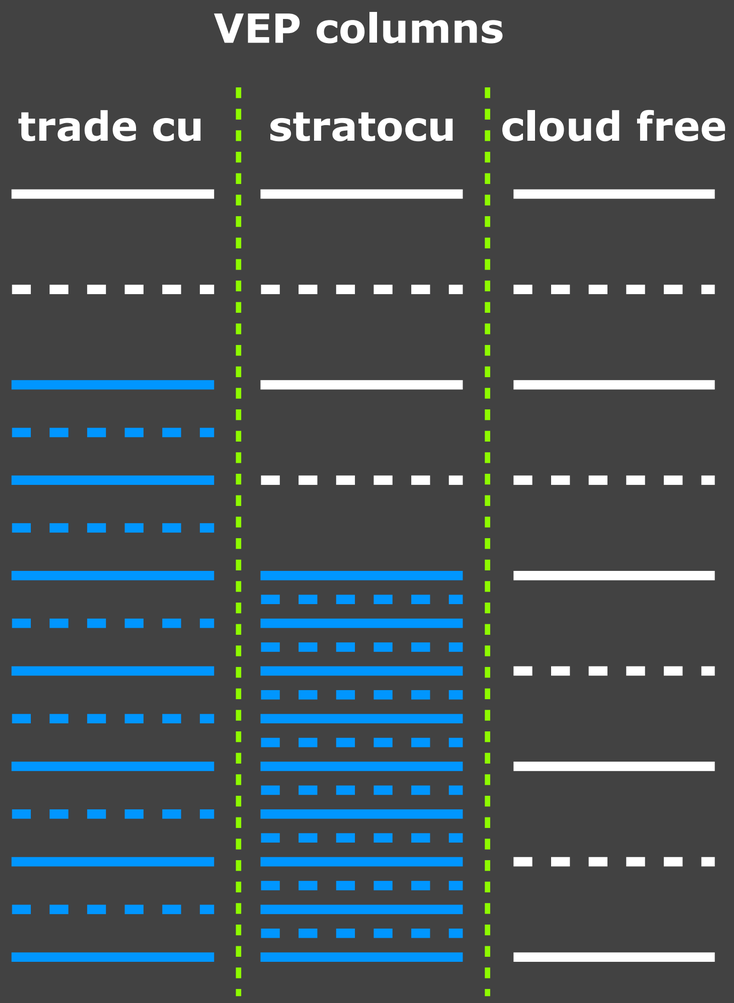


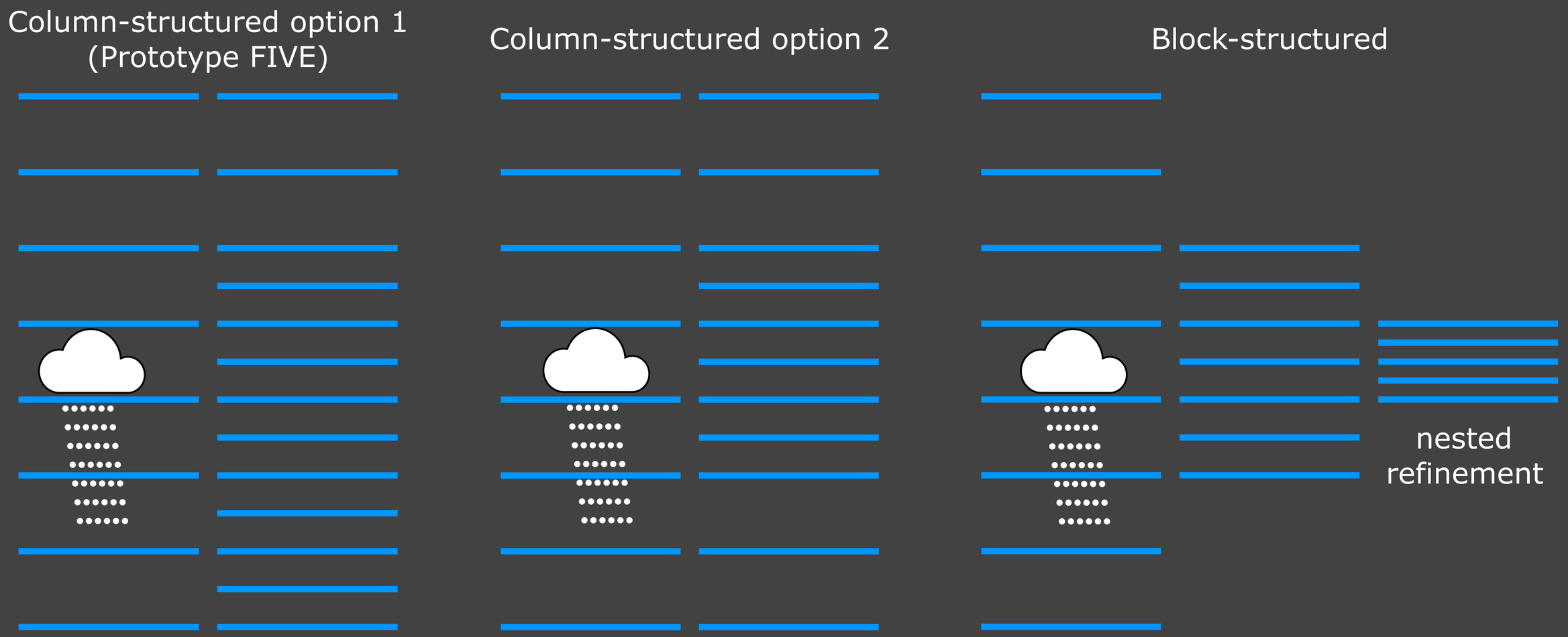
No reduction in E3SM timestep is required with any of the E3SM-FIVE configurations, compared to E3SM benchmark runs.

Adaptive vertical grid for VEP

- Computational cost may be reduced if vertical resolution of VEP is dynamically adjusted based on the atmospheric state (Adaptive Vertical Grid; AVG).
- Resolution criteria for AVG will be developed with machine learning / statistical methods.
- Load balancing problems will be mitigated by various optimization techniques (performance tuning, work stealing, GPU).

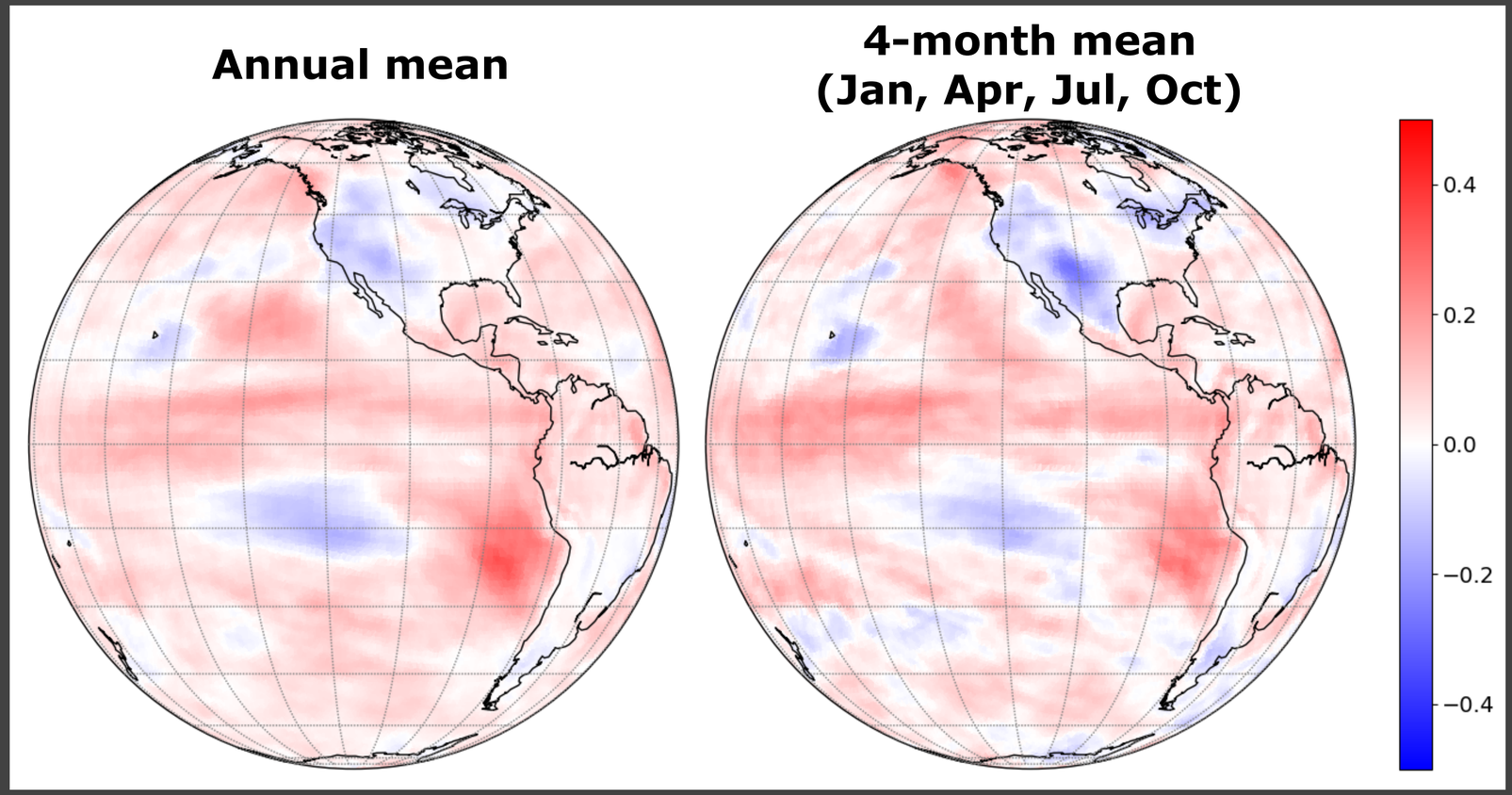


Column-structured AVG or block-structured AVG?



easy	implementation	difficult
low	efficiency	high
accurate	flux	less accurate

Resolution criteria: Very short term SCM simulations



Low cloud fraction

- The decision criteria consider near future boundary layer state from available information.
- A good data base is required.
  - Size of data (many locations & timing)
  - Duration of SCM (cost)
- SCM is extensively used in the replay mode. Large scale state follows Control.
- 6-hour SCMs were performed for total of 12,000 locations in Eastern Pacific and timings in Jan/Apr/Jul/Oct in a year with the Control and QUAD resolutions.

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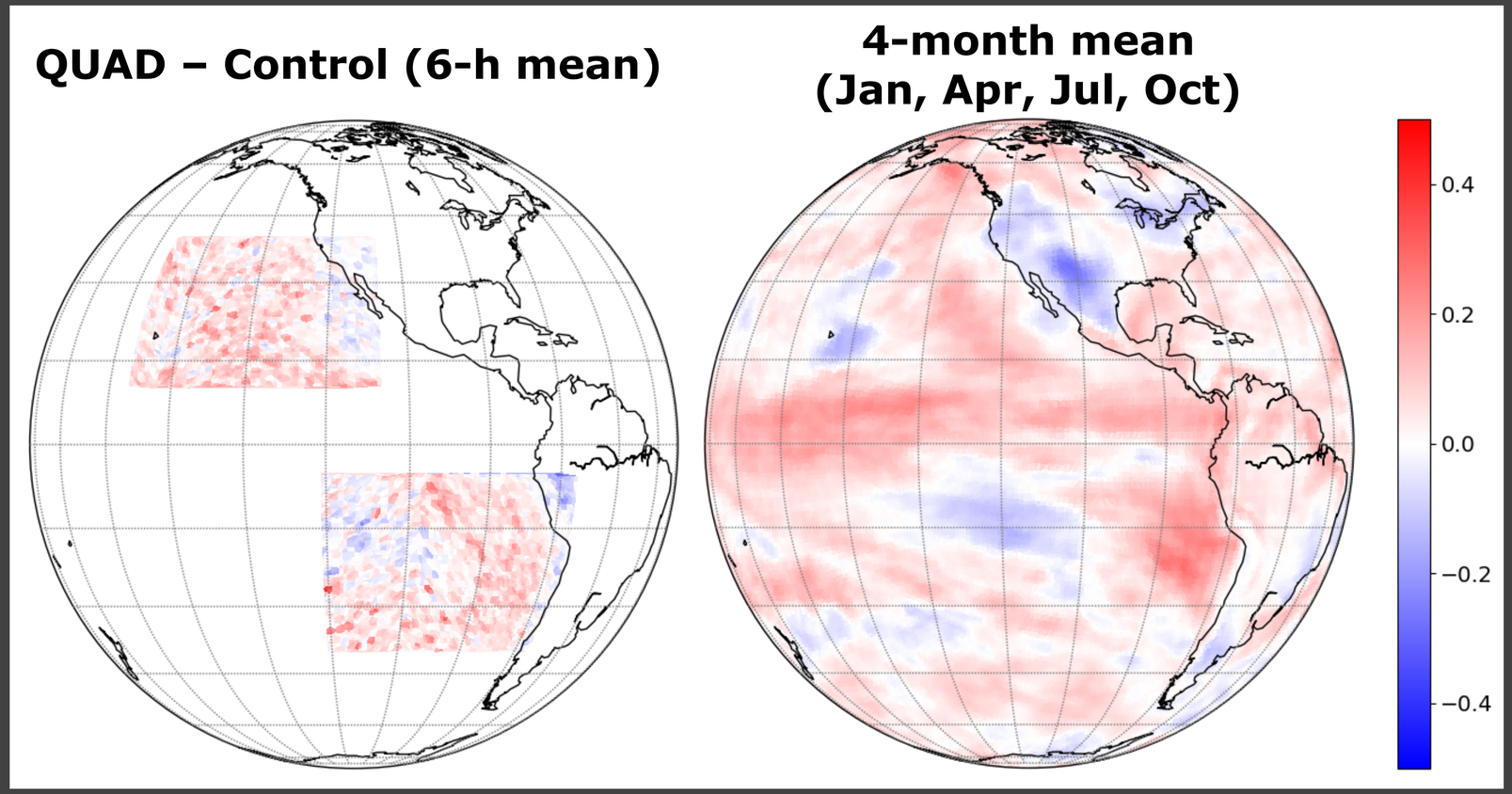

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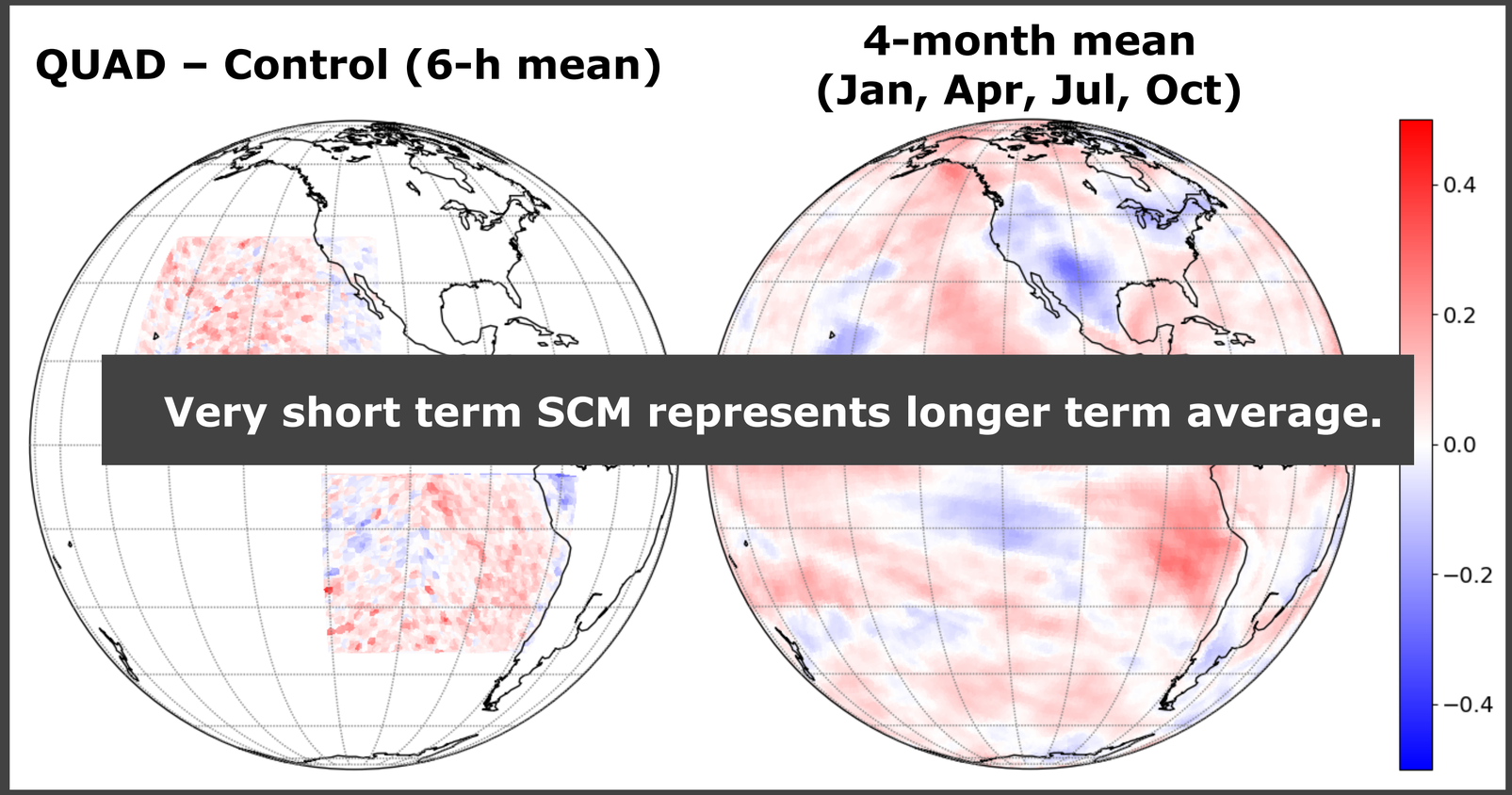

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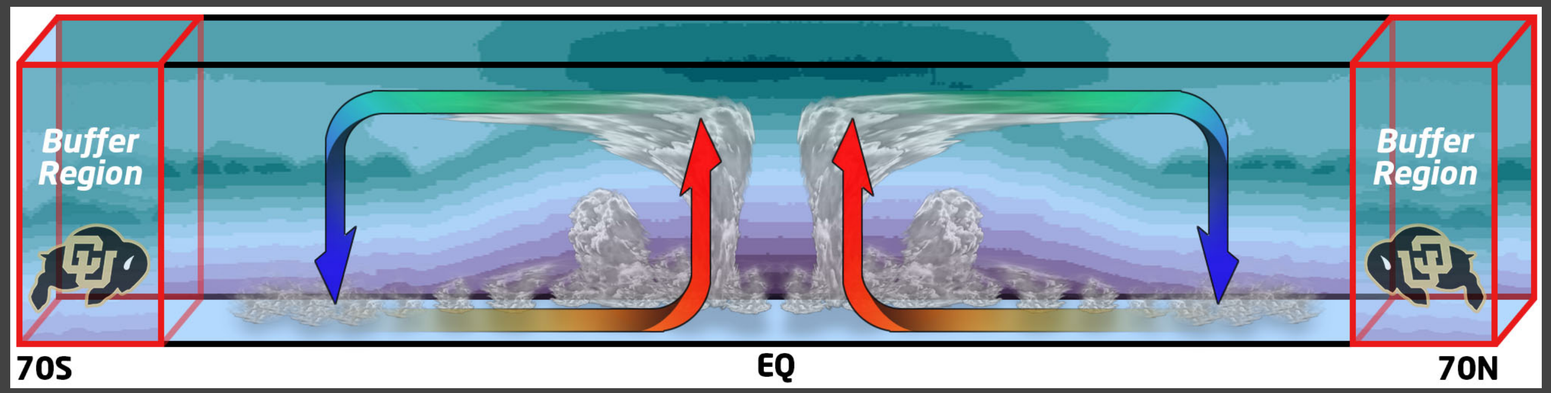
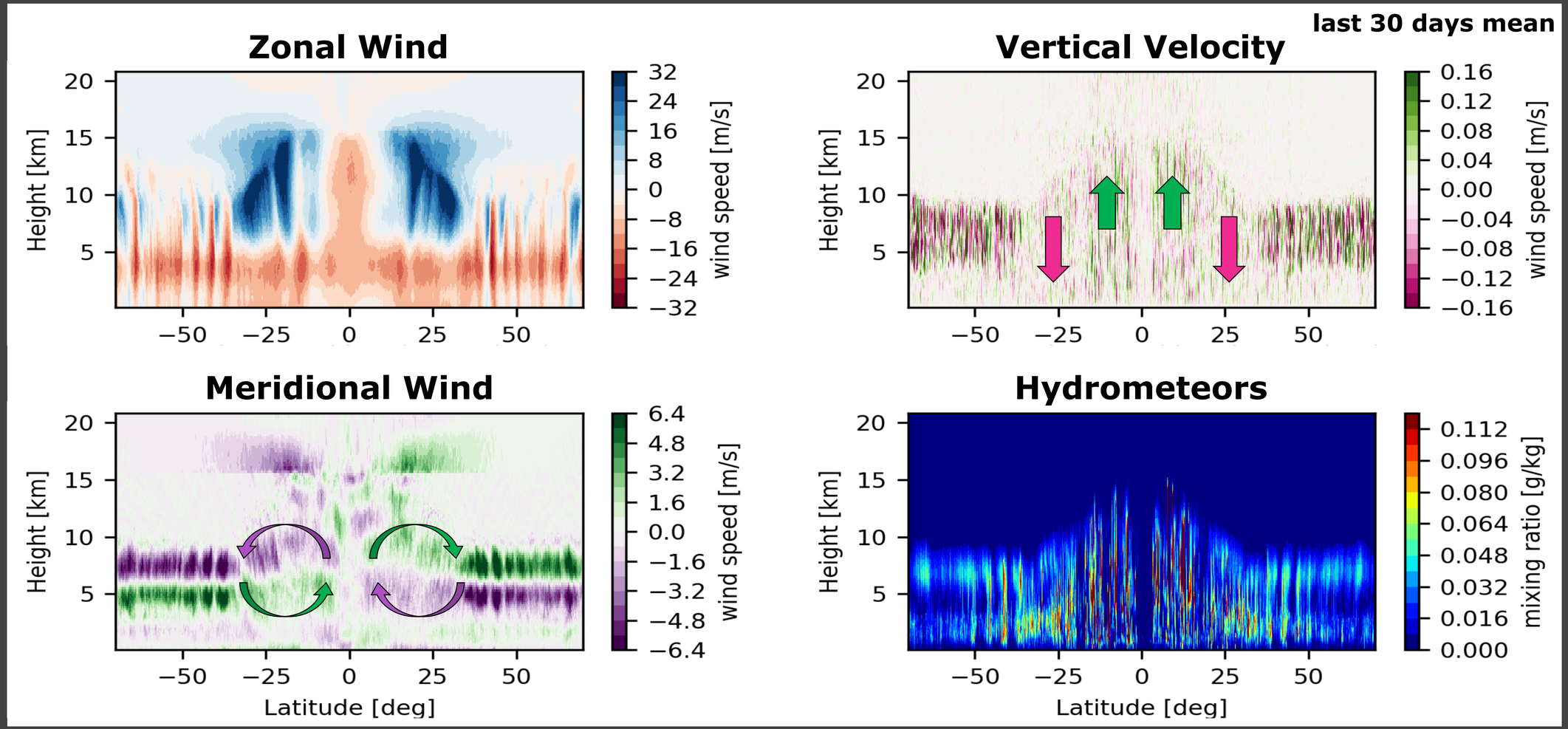
Does FIVE work at high horizontal resolution, O(a few km)?



- Next generation E3SM v4 targets 3 km horizontal resolution.
- FIVE will be tested with a regional modeling framework simulating the Hadley circulation with a channel domain with a few km resolution.
- This framework will also be used to refine the FIVE methodology.
- System for Atmospheric Modeling (SAM; Khairoutdinov and Randall 2003) has been upgraded
  - E3SM v4 physics (SHOC, P3)
  - North-South 2D mode
  - Open lateral boundary conditions
  - Initialization with real data, e.g., ERA5

A realistic Hadley circulation in the 2D framework at remarkably small cost



- 50 days of time integration (Δx = 2 km, 128 levels) can be done with 4 days of CPU time with 512 cores.
- Initial condition is at rest; the Hadley circulation appears by 20th day.

Summary of the first year

- E3SM with high vertical resolution in boundary layer improves low cloud properties.
- pre-alpha E3SM-FIVE
  - No reduction of E3SM timestep is required.
  - Improvements in the low clouds match E3SM benchmark runs reasonably well.
  - Coupling large-scale vertical advection to VEP is progressing toward an alpha version
- Research & development for AVG is ongoing.
- SAM has been upgraded to evaluate benefit of FIVE for E3SM v4 by simulating the Hadley circulation in 2D.