Enhanced Low Cloud Representation in E3SM with Framework for Improvement by Vertical Enhancement and Future Plan

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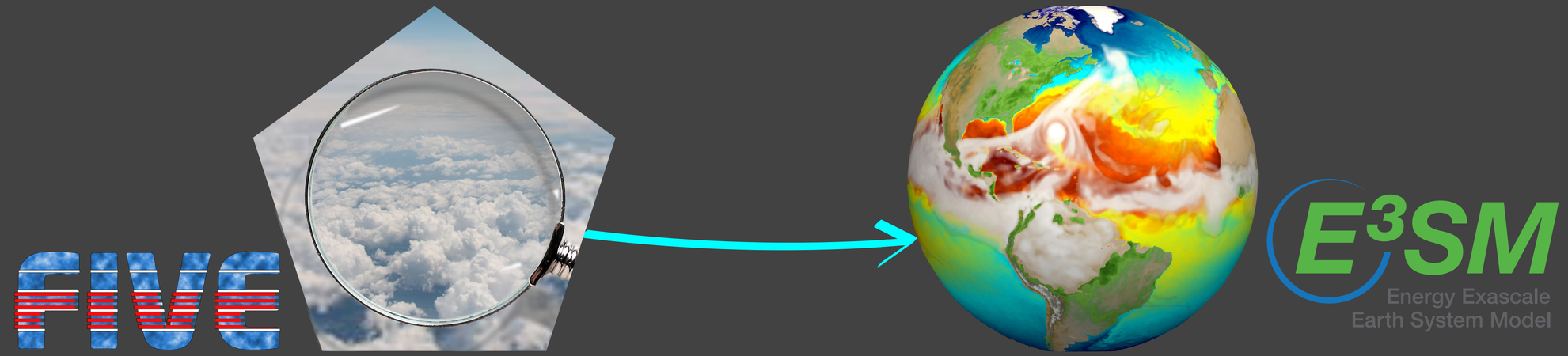

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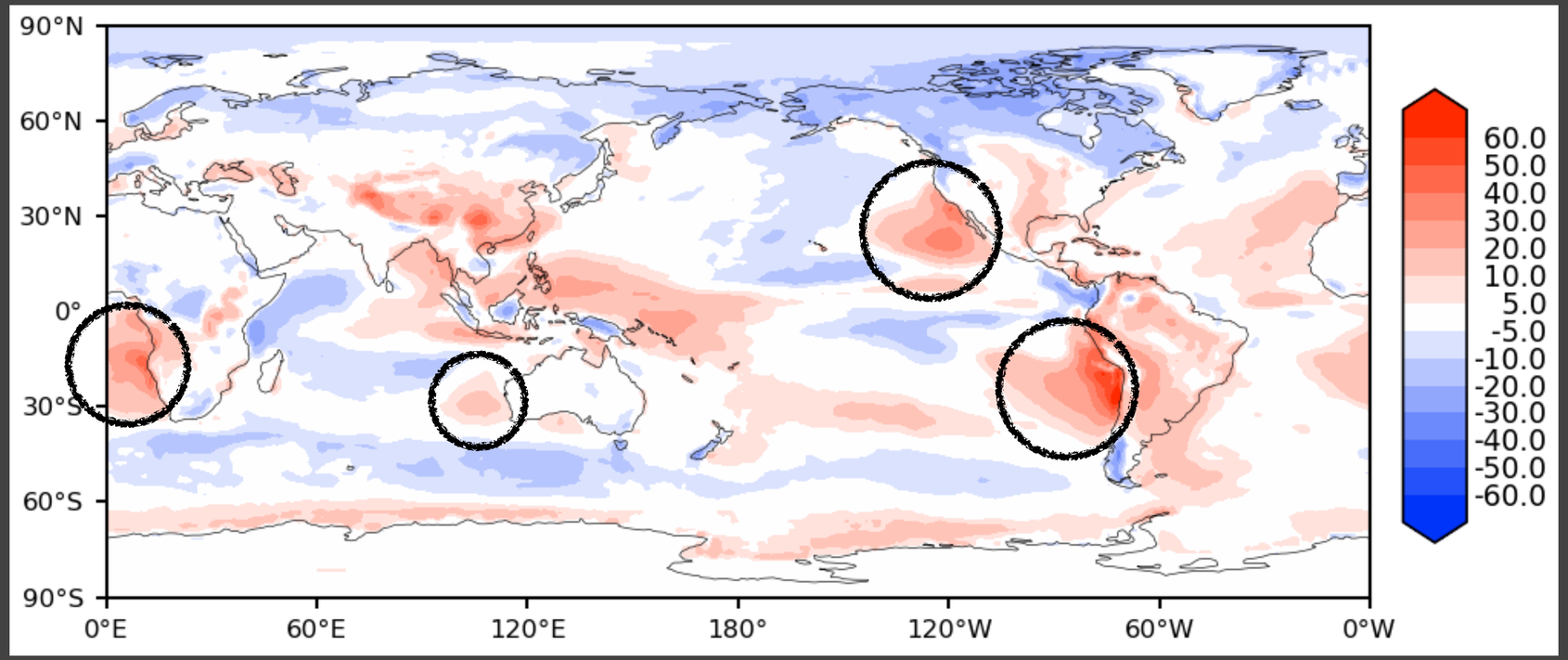
Low clouds are erroneous in global climate model.

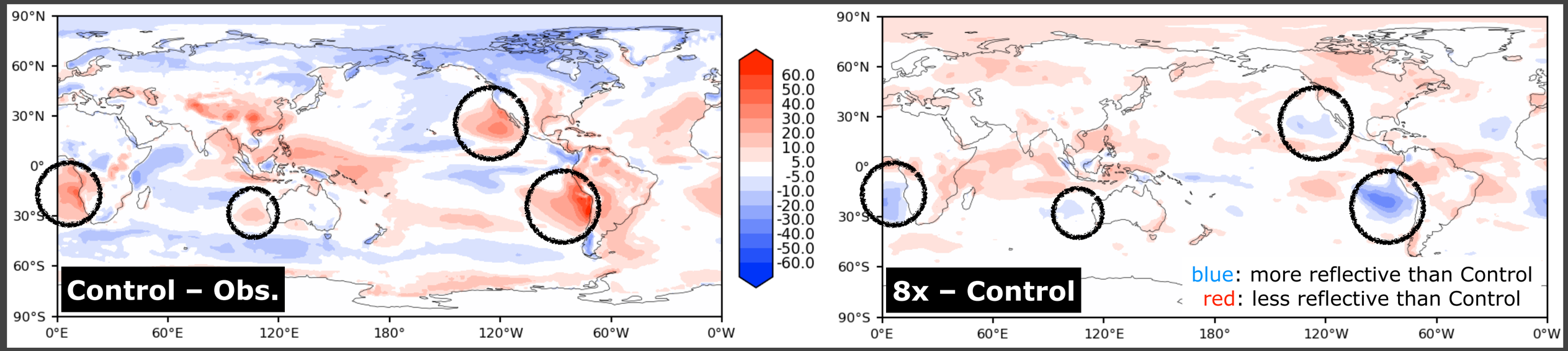
E3SM Control (1° mesh, 72 levels) – CERES-EBAF
Shortwave cloud radiative effect (Wm^{-2})



Red shading indicates areas where clouds are not reflective enough.

Representation of low clouds is improved with high vertical resolution.

8x: 8 time high resolution below 700 hPa (Δz~15 m between 900 hPa and 850 hPa; 135 m for Control), ~19 times more expensive

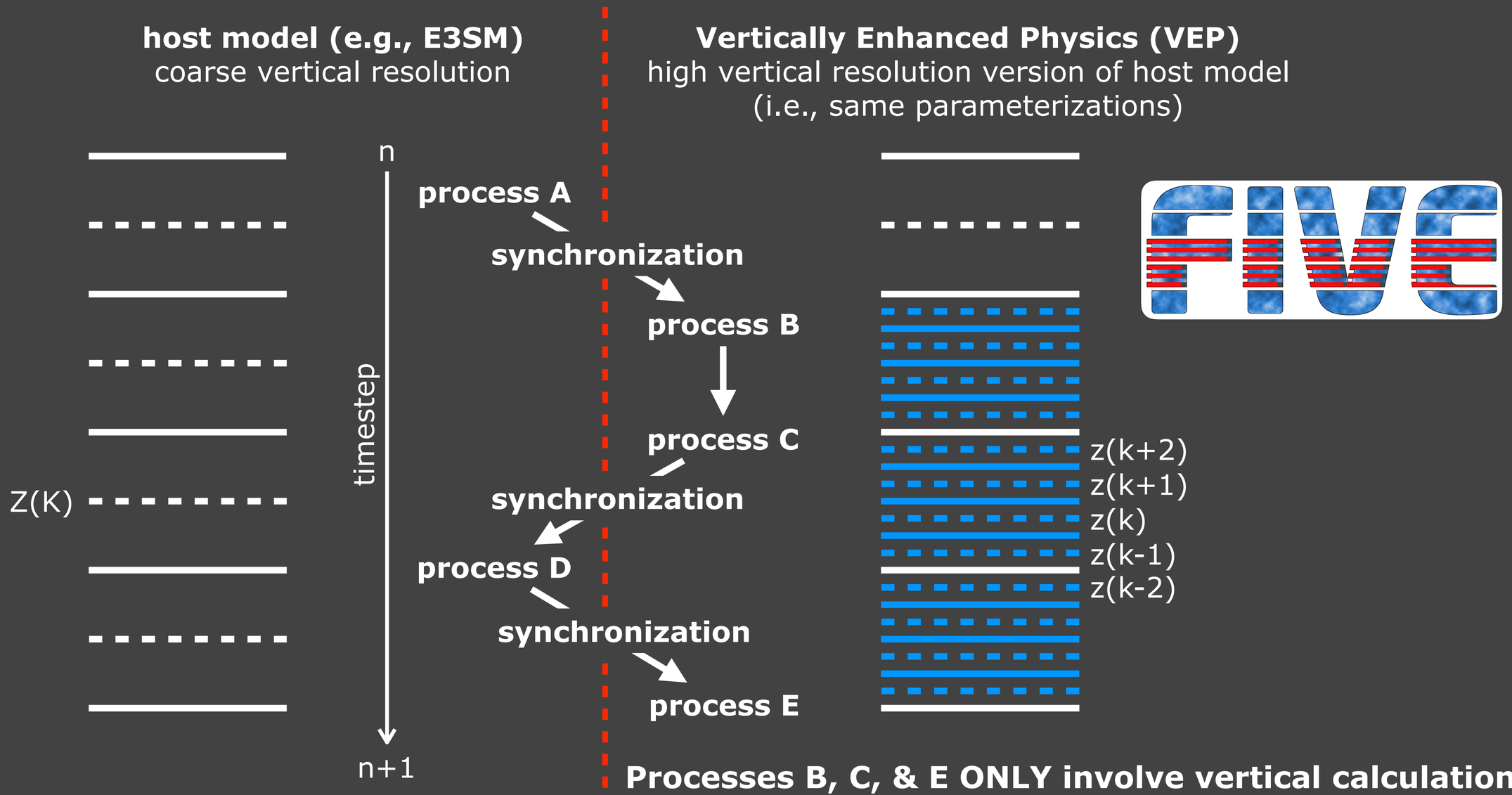


Large impacts with LES-like vertical resolution

Blue shading inside circles indicates where bias is being corrected.

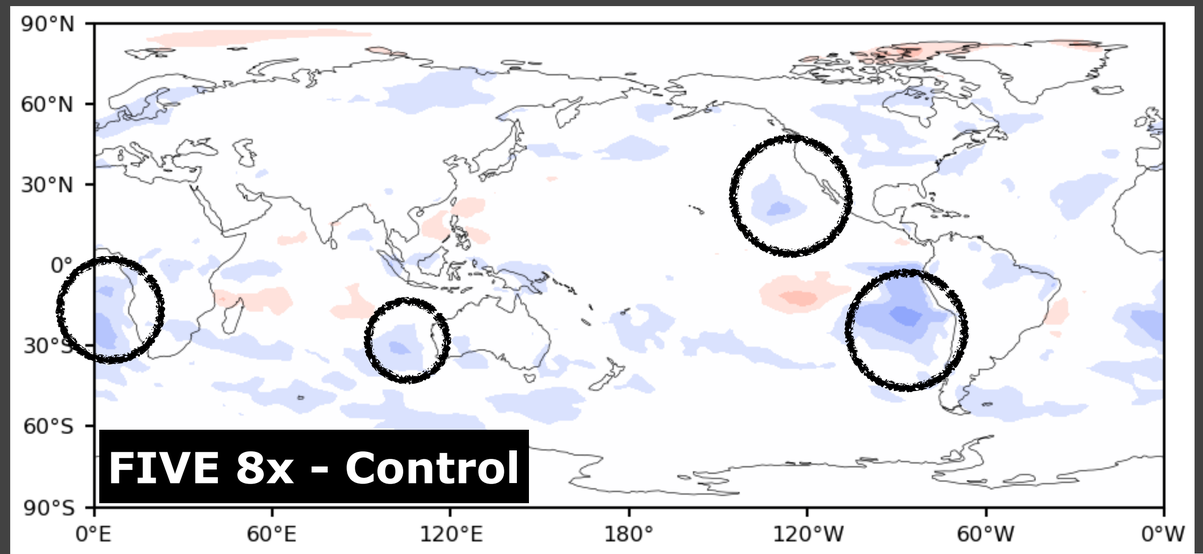
Bogenschutz et al. (2020, in review)

Framework for Improvement by Vertical Enhancement (FIVE)

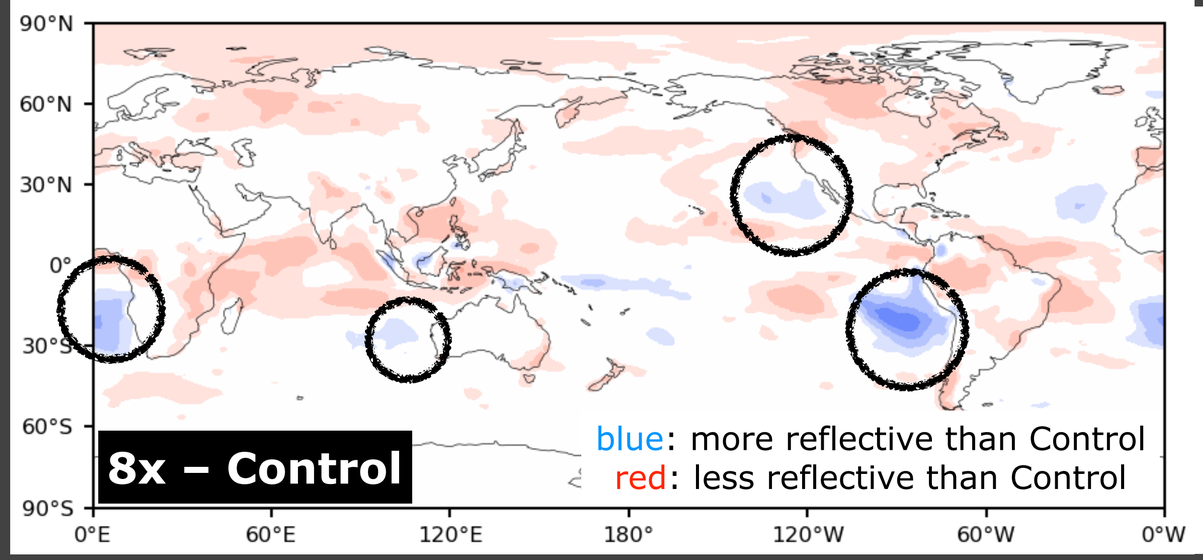


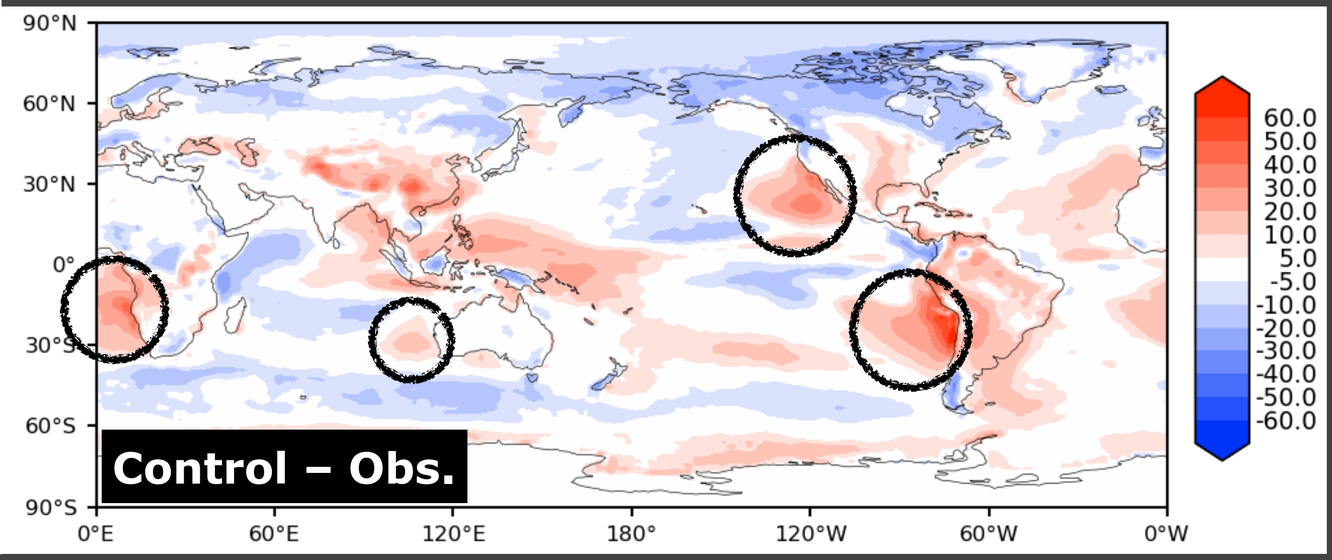
Yamaguchi et al. (2017)

FIVE provides the benefit of high vertical resolution.



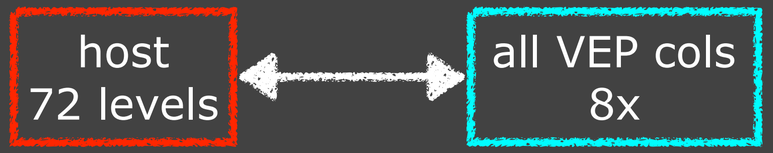
- FIVE 8x (not optimized) is ~4.3 times faster than E3SM 8x (i.e., FIVE 8x is ~4 times more expensive than Control).
- Coastal stratocumulus and mixed-phase stratocumulus are not improved.
- Lee et al. (2020, in review)



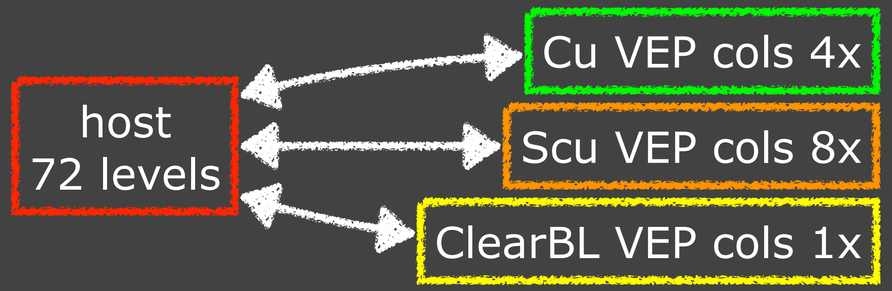


Adaptive Vertical Grid (AVG) to reduce cost

Current FIVE
Auxiliary refined mesh is the same everywhere.

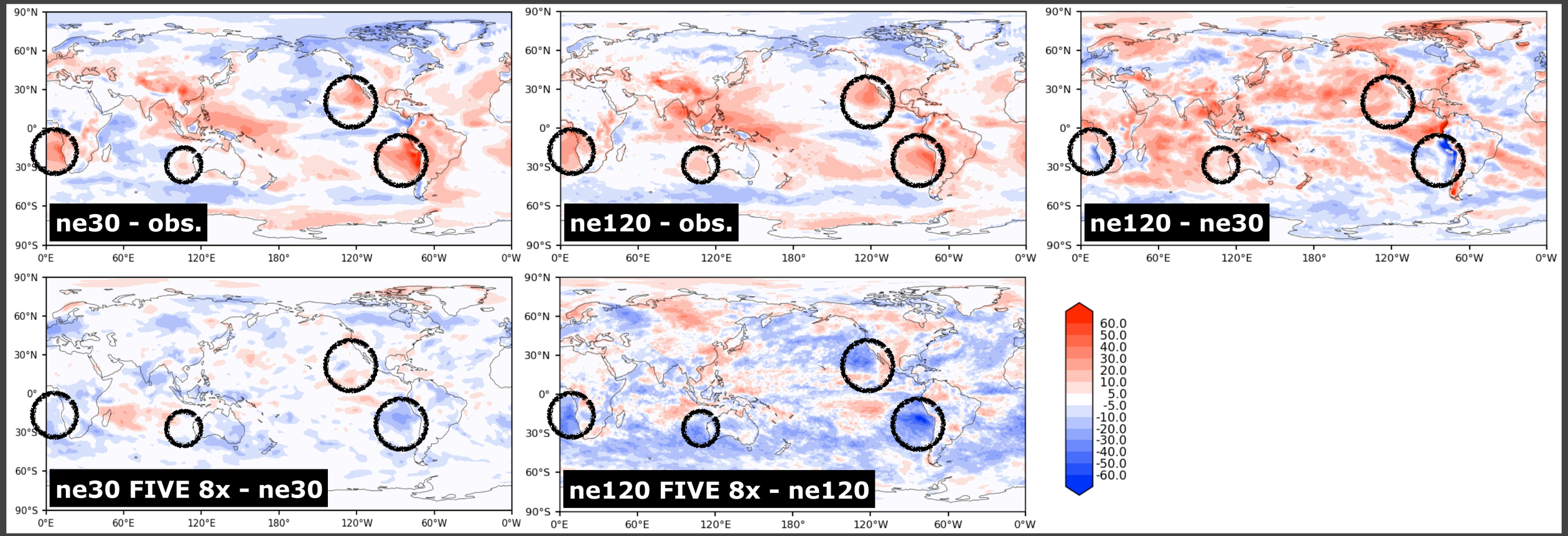


AVG FIVE
Adjust refined mesh to match local conditions



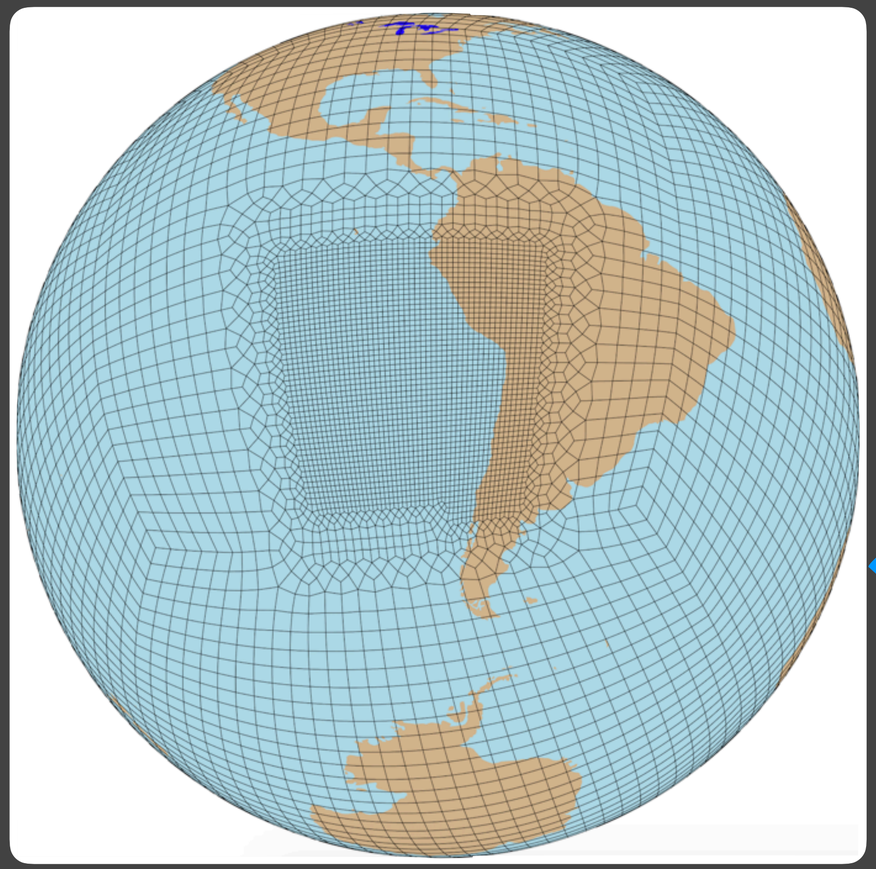
- AVG possibly provides the benefit of high vertical resolution and reduces further computational cost associated with FIVE.
- E3SM-FIVE single column model has been used to develop the AVG module/code.
- A research has been conducted to understand statistical relationship between low cloud amounts and its control factors (e.g., lower tropospheric stability) for various VEP level configurations and observation (Chen et al. 2020 in preparation). This study has provided us information to develop a scheme that effectively configures the VEP levels.
- Once the AVG code is ported to E3SM-FIVE, we will first use geographically specified VEP levels based on climatology (independent of time) to develop a configuration method.
- We will assess E3SM-FIVE AVG in terms of low cloud representation and computational cost.

Coastal stratocumulus appears with ne120 and FIVE.



- ne120 (25 km mesh) produces some of coastal stratocumulus
- ne120 with FIVE significantly improves subtropical low clouds including coastal stratocumulus.
- Lee et al. at PS-2 Atmosphere

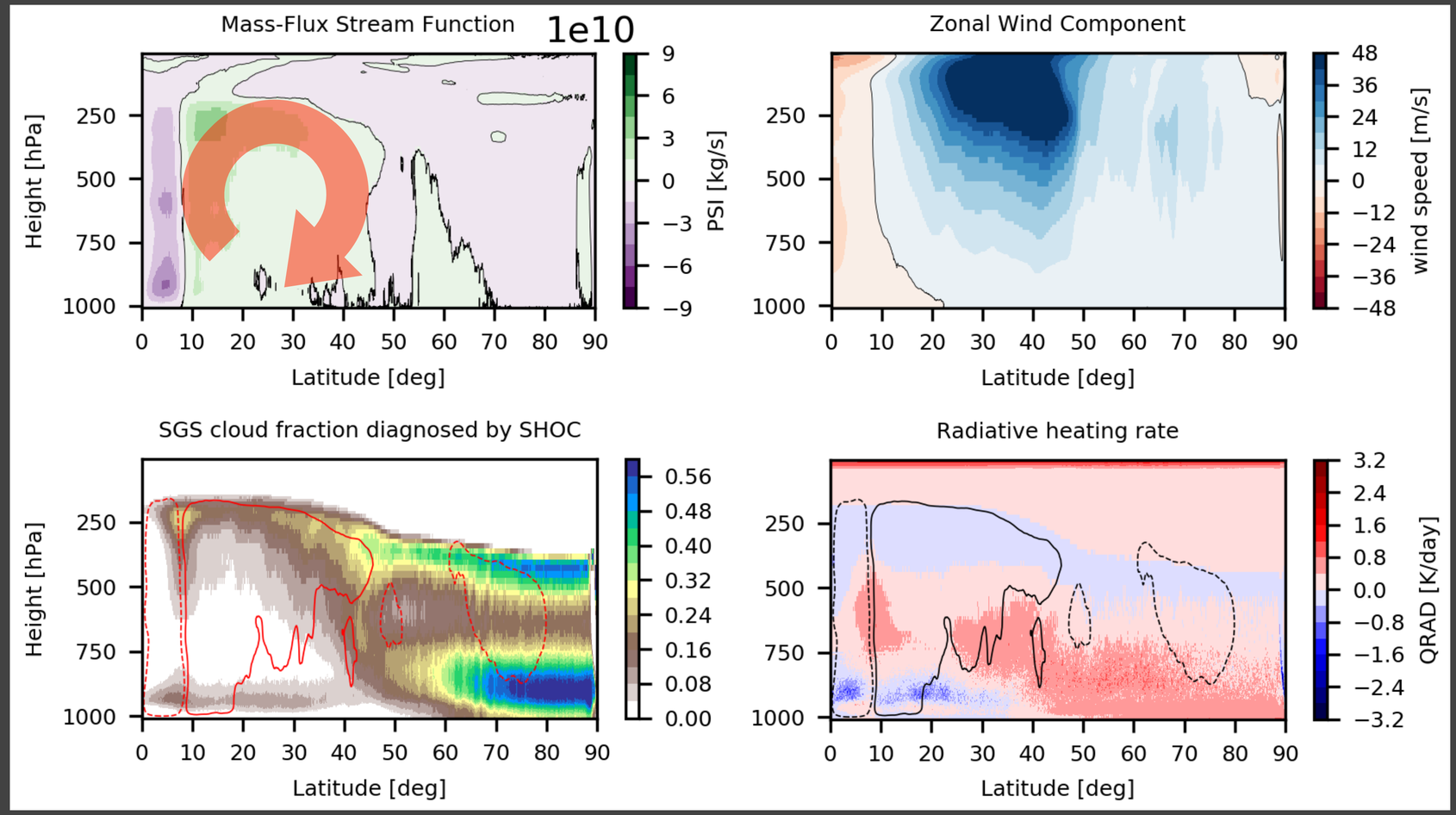
Regionally Refined Model + FIVE = New 3D mesh refinement



FIVE

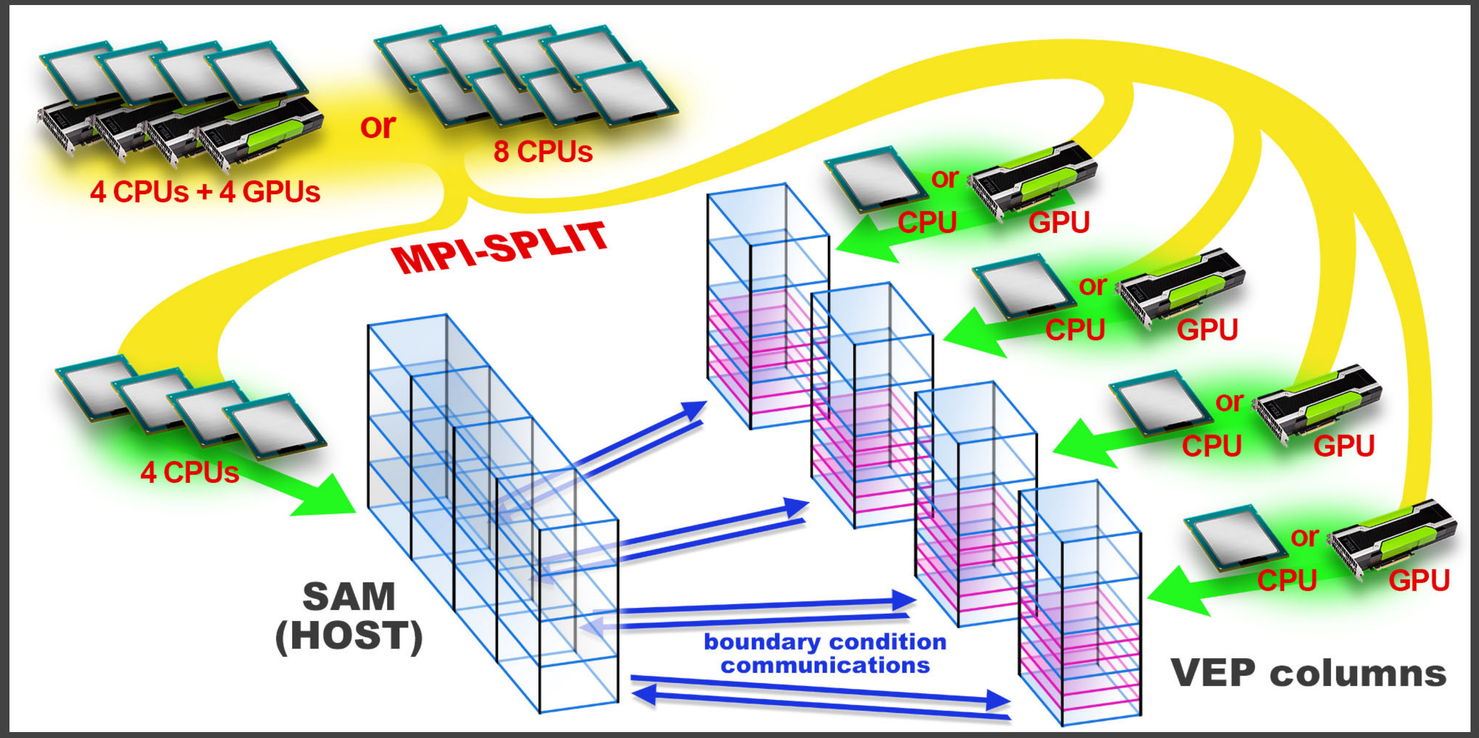
How to assess usefulness of FIVE for global storm resolving model (E3SMv4)?

- Our answer: 2D Hadley circulation modeling
- For Δy=2 km, the 2D Hadley circulation model would be **~5000 times faster** than GSRM.
- System for Atmospheric Modeling (SAM; Khairoutdinov and Randall 2003) coupled with E3SMv4 physics (SHOC, P3, RRTMG)
- Yoshida et al. (2020, in preparation)
- Yoshida et al. at PS2-Atmosphere



Last 700 days mean of 1000 day time integration
Δy=4 km, 128 levels with Δz=35 m below 2 km

New FIVE implementation strategy to achieve maximum efficiency



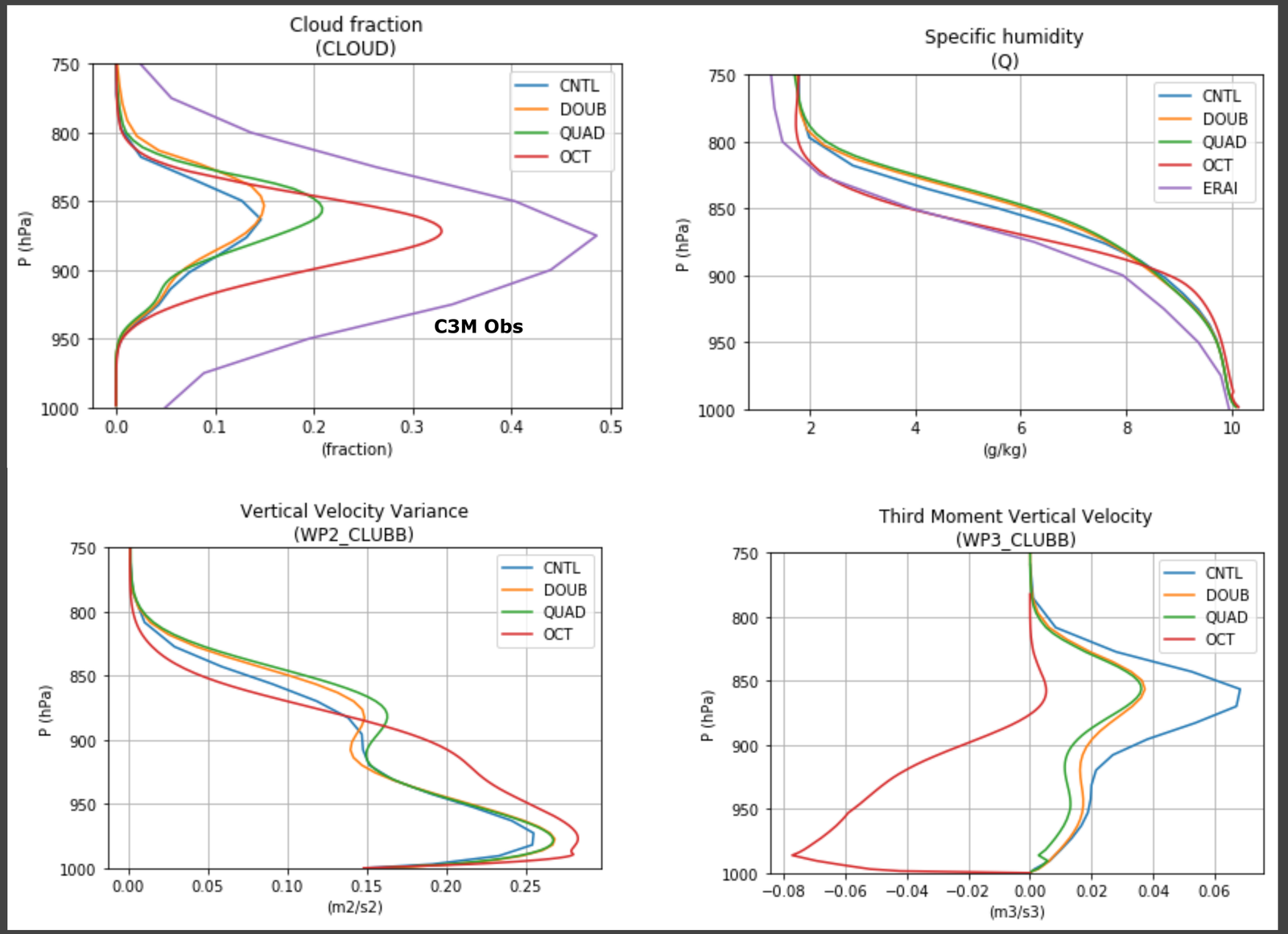
Simultaneously computing SAM and VEP whenever possible

Summary

- FIVE improves the representation of the subtropical low cloud in E3SM.
- The development of AVG is ongoing. Performing a global simulation with geographically specified VEP levels based on climatology is the next step.
- Coastal stratocumulus appears with high horizontal resolution and FIVE. A combination of RRM and FIVE is a new variant of 3D mesh refinement.
- Mixed-phase low clouds will be studied with E3SM, E3SM-SCM, and SAM LES.
- 2D Hadley circulation model has been developed to assess the benefit of FIVE for GSRM (e.g., E3SMv4). New FIVE implementation strategy is proposed and the implementation of FIVE into the 2D Hadley circulation model is ongoing.

Profiles and turbulence from SE Pacific region

- OCT (8x) simulation produces a thicker cloud, is more turbulent, less decoupled, and with **negative** vertical velocity skewness.
- OCT (8x) simulation shows signs of a sharper inversion near Scu top, suggesting that **LES vertical resolution is required** for realistic simulation of marine Scu.



Implementation of AVG into E3SM-FIVE SCM

- Different from “normal” AMR because we take advantage of existing FIVE implementation in E3SM SCM
  - Stitch together coarse and fine levels: Parameterizations are not coded to compute partial levels.
  - “Unstructured” composite mesh
  - Allows for more flexibility in refinement ratios than “normal” AMR
- Implemented in the branch of the FIVE version of E3SM
- Currently testing in E3SM-FIVE SCM to
  - Determines effectiveness
  - Understand properties of AMR/FIVE