Adaptive Vertical Grid Enhancement for E3SM

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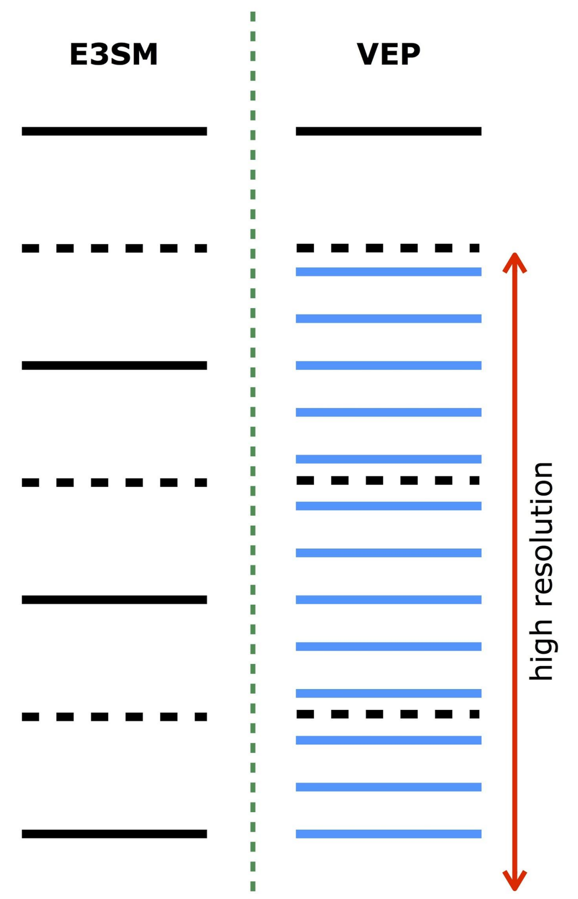
1. Project Overview

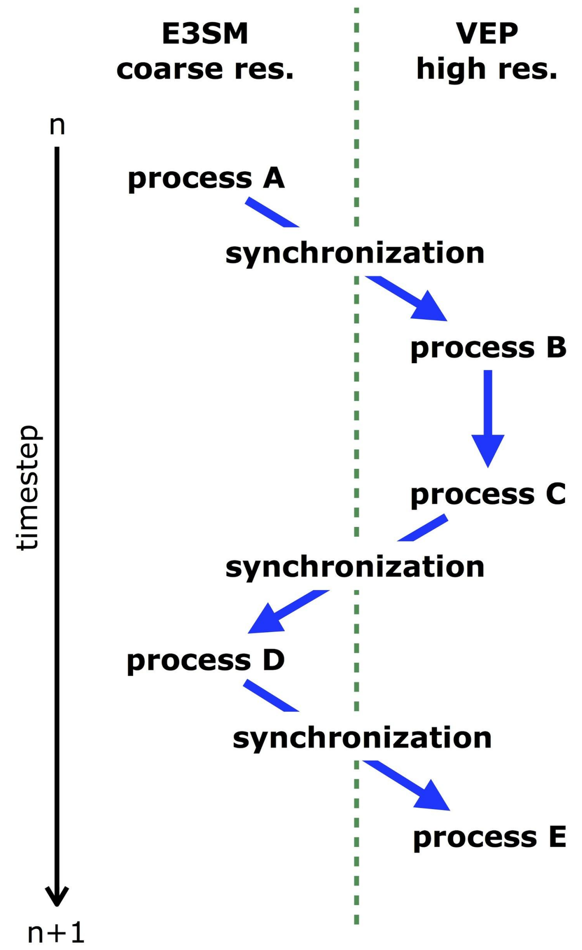
Thin clouds, i.e., stratocumulus and cirrus clouds, are poorly represented even in state-of-the-art global models like E3SM. This SciDAC project aims to ***improve representation of boundary layer clouds, as well as cirrus clouds, by implementing a new computational framework called Framework for Improvement by Vertical Enhancement (FIVE; Yamaguchi et al. 2017) into E3SM***. FIVE is a novel method that contains elements of the nested grid method, the multigrid method, and the multiscale modeling framework, and is based on the fact that improvement of representation of these clouds can be gained by simulating them with high vertical resolution. Our goal is not only to implement FIVE into E3SM, but also to ***evolve FIVE into a computationally efficient version by adding a capability of dynamically adapting vertical resolution depending on the atmospheric state (Adaptive Vertical Grid; AVG)***.



← **Fig. 1**
In addition to the E3SM vertical grid, FIVE additionally constructs partially high resolution vertical level and allocates prognostic variables separately from E3SM. Selected processes are computed on this high resolution grid, termed the Vertically Enhanced Physics (VEP).

Variables are allocated on both levels.

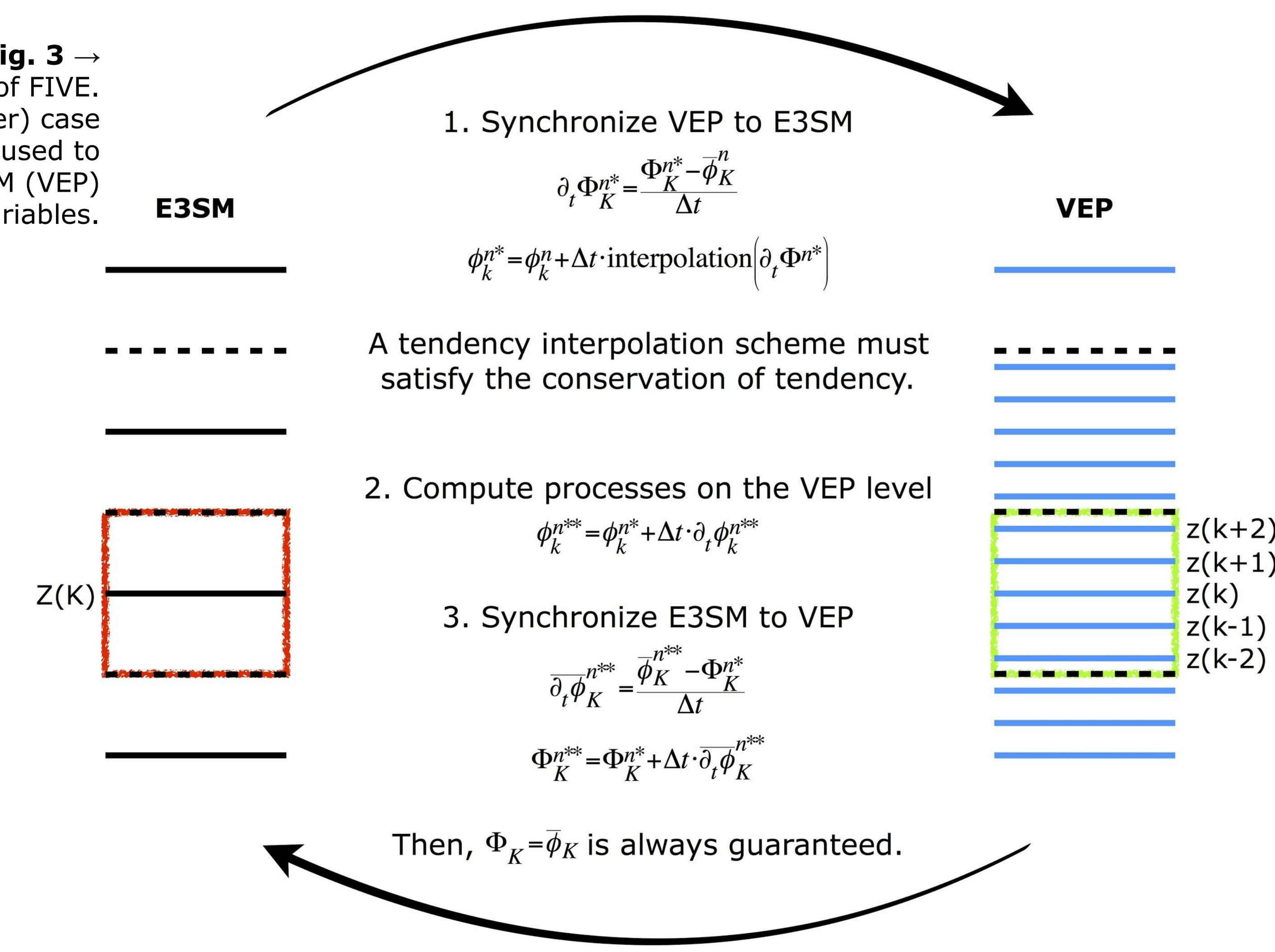
Fig. 2 →
Flowchart for process calculations over one time step for FIVE. In FIVE, selected processes, in this example process B, C, and E, are computed on VEP. Synchronization proceeds either E3SM or VEP to the appropriate partial timestep by adding tendency.



2. Framework for Improvement by Vertical Enhancement

FIVE is summarized in Figs. 1, 2, and 3 below. In Yamaguchi et al. (2017), a prototype version of FIVE implemented into a regional model, the System for Atmospheric Modeling (SAM; Khairoutdinov and Randall 2003) coupled with the Cloud Layers Unified By-Binormals (CLUBB) turbulence parameterization (Larson and Golaz 2004), shows dramatic improvement for drizzling stratocumulus clouds in, for instance, inversion height, cloud water path, rainwater path, and various vertical thermodynamic profiles. FIVE also has the potential to improve representation of cirrus clouds and mixed phase stratocumulus. One notable advantage of FIVE is its flexibility, so that it can be used with any choice of turbulence parameterization.

Fig. 3 →
Details of FIVE. Upper (lower) case letters are used to denote E3SM (VEP) variables.



3. Adaptive Vertical Grid for VEP

The first version of E3SM-FIVE will use a stationary VEP vertical level, which will be computationally expensive for the regions where the current parameterization can reasonably represent atmospheric state with E3SM's standard 72 levels. Also, stratocumulus columns will be better represented with higher resolution than shallow cumulus columns (Fig. 4). We will develop an AVG method for VEP level so that the resolution for the VEP level dynamically adjusts to the atmospheric state. For multi-core computations, however, AVG does not guarantee reduction of computational cost due to the heterogeneous workload. Possible methods to overcome this problem include performance tuning, work stealing, and GPUs.

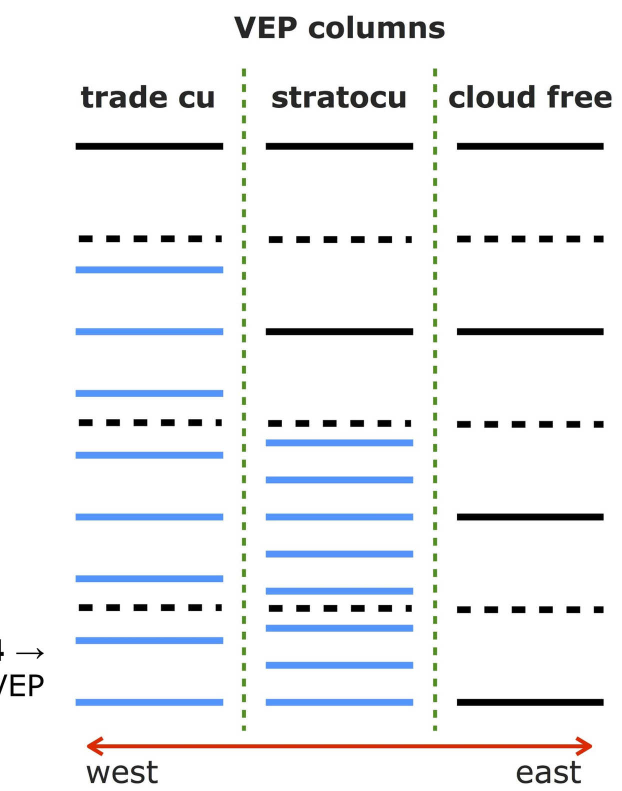


Fig. 4 →
Schematic for AVG for VEP

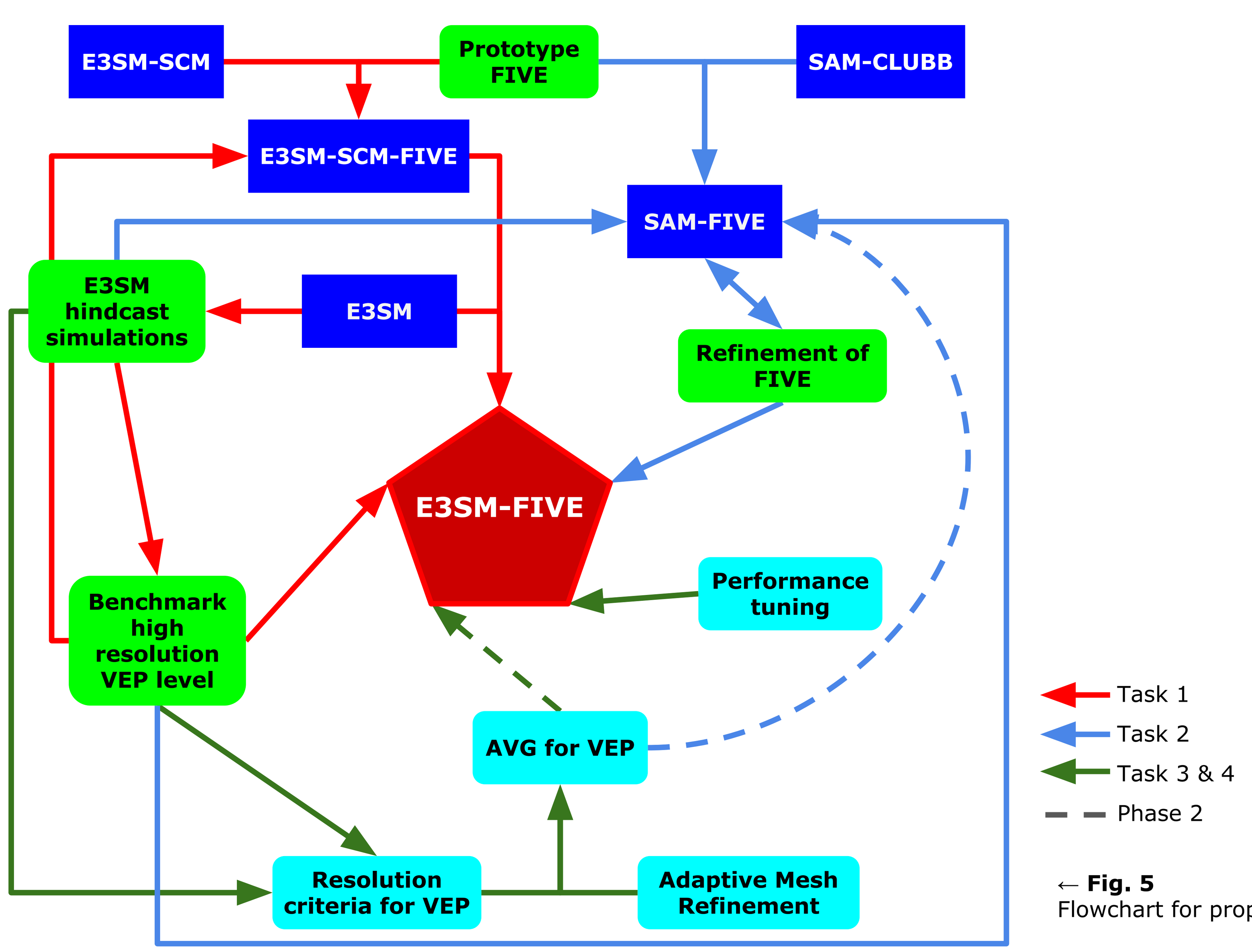
4. Resolution Criteria for AVG

AVG requires decision criteria to adjust VEP resolution based on the current and very near future atmospheric state. Development of the resolution criteria for AVG will use information that would be available when FIVE is used on the fly (i.e., E3SM as well as VEP information). We will test a number of ideas ranging from lower tropospheric stability and boundary layer classification schemes to machine learning and a statistical emulator to develop these criteria.

5. Path to E3SM-FIVE

This project consists of 4 tasks:

Task 1 implements FIVE into the E3SM single column model, followed by E3SM.
Task 2 refines the existing FIVE.
Task 3 works on computational aspects of AVG.
Task 4 develops resolution criteria for AVG.



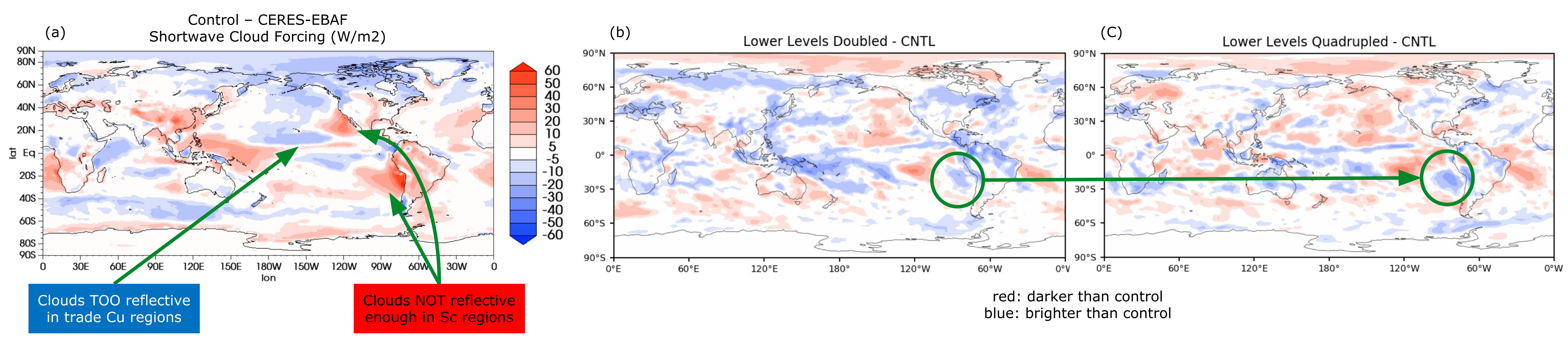
← **Fig. 5**
Flowchart for proposed tasks.

6. Preparation for a Benchmark High Resolution Hindcast Simulation

Fig. 6a shows bias in shortwave radiative forcing for a 2-year simulation of the current E3SM with its standard 72 levels and 1 degree mesh. The stratocumulus regions are too dark and the trade cumulus regions are too bright. Fig. 6bc shows improvement in these regions by simulating with doubled and quadrupled vertical resolution below 700 hPa. Increasing vertical resolution in the boundary layer generally results in more reflective marine stratocumulus and less reflective trade cumulus. We are confident that E3SM-FIVE can replicate these results, at reduced cost. An experiment with octupled resolution as well as the same experiment for high clouds at levels 400 hPa to 50 hPa are currently running.

All simulations were run using 1024 processors. The runs with quadrupled and octupled cases required changes in the host and CLUBB timestep for a stable run. A sensitivity test to timestep for the standard configuration will be carried out in order to elucidate any potential differences that are coming from changing the time step. Below is a summary for timesteps and numerical cost.

Standard (model timestep: 1800 s, CLUBB & microphysics timestep = 300 s); 72 layers; 4.6 simulated years per day.
Doubled (model timestep: 1800 s, CLUBB & microphyscis timestep = 300 s); 93 layers; 2.5 simulated years per day.
Quadrupled (model timestep: 600 s, CLUBB & microphysics timestep = 200 s); 123 layers; 0.83 simulated years per day.
Octupled (model timestep: 300 s, CLUBB & microphysics timestep = 100 s); 194 layers; 0.125 simulated years per day.



↑ **Fig. 6**
Results from 2-year simulation with various vertical resolutions below 700 hPa.

References

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