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A 2-D framework for accelerating the development of physics schemes in high resolution global modeling

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Motivation:

Development & assessment new schemes in high-resolution simulation are TOUGH!

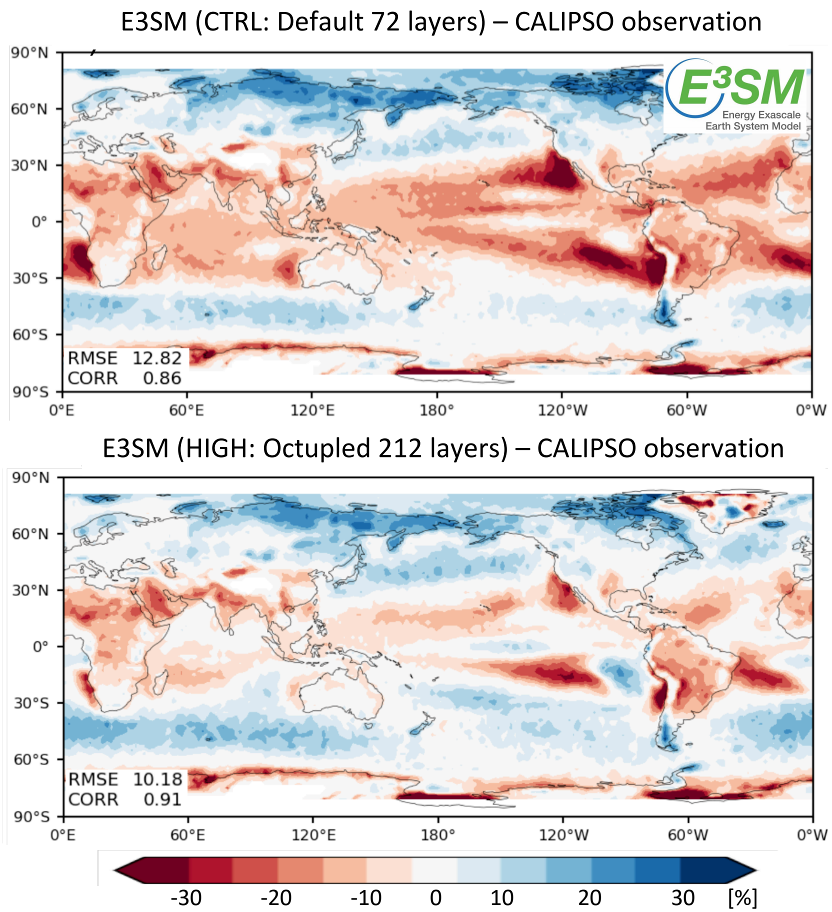


Figure 1: Difference of low cloud amounts. In HIGH case, the vertical resolution below 700 hPa was octupled relative to the CTRL, and the total number of vertical layers was 212 layers. From Bogenschutz et al. (2020, submitted) The Energy Exascale Earth System Model (E3SM) is a new climate model developed by DOE.

High-resolution simulation is now a trend in global cloud system resolving models. Because resolution improvement can bring a better numerical solutions and a better representation of physics schemes. As shown in left figures, a representation of low-level shallow clouds becomes much better by improvement of vertical resolution.

However, the cost of computations and output data are increasing enormously at the same time. This becomes more serious in the development stage because numerous experiments are required to assess the performance of new schemes, and the performance should be assessed in a similar domain and a similar resolution to the target simulations.

We approach this problem by applying a 2-D framework that simulates many types of clouds with a small cost.

Framework Design:
A 2-D simulation with a high-resolution and a cost-efficiency

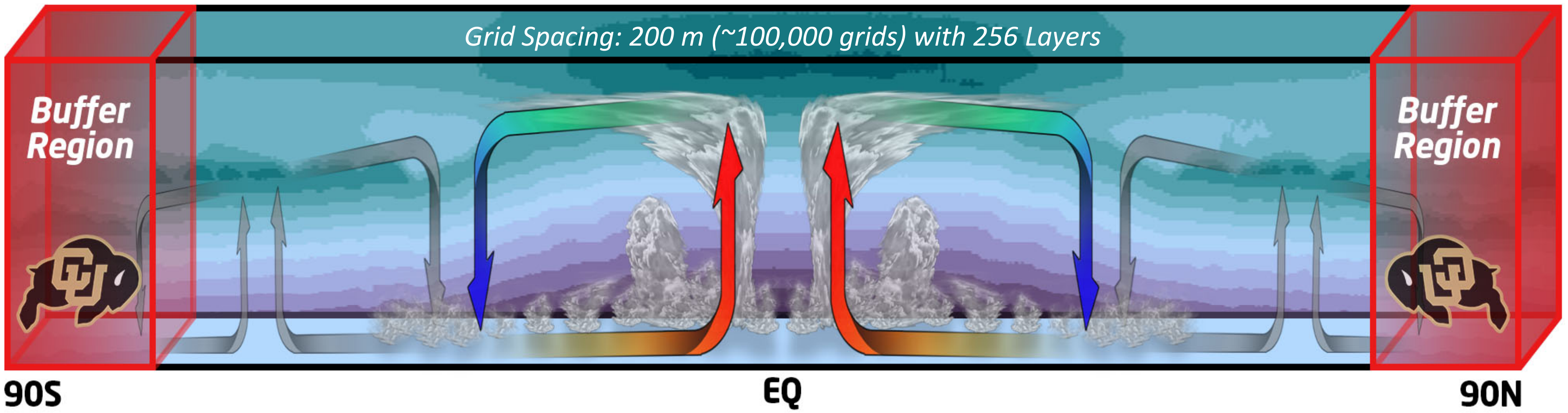


Fig. 3: illustration of 2-D Hadley circulation simulation; North-South (Y-Z) wide 2D domain.

The Hadley circulation is a good representation of the Earth's climate.

- The Hadley circulation is the primary response in the atmospheric general circulation to the global temperature distribution organized by the solar radiation.
- In the 2-D simulation, a SST represents a meridional distribution of the solar radiation income.
- A large scale circulation is organized in each hemisphere as a response to the given SST profile.

The 2-D simulation is light weight and simple, but still complicated.

- save computation and data space
- easily increase model resolution and a number of test cases
- This can simulate many types of clouds and scale interactions, which cannot be done by a single column model or a coarse-grid global model.

2-D simulation Results:

The Hadley circulation and corresponding clouds in the 2-D simulation

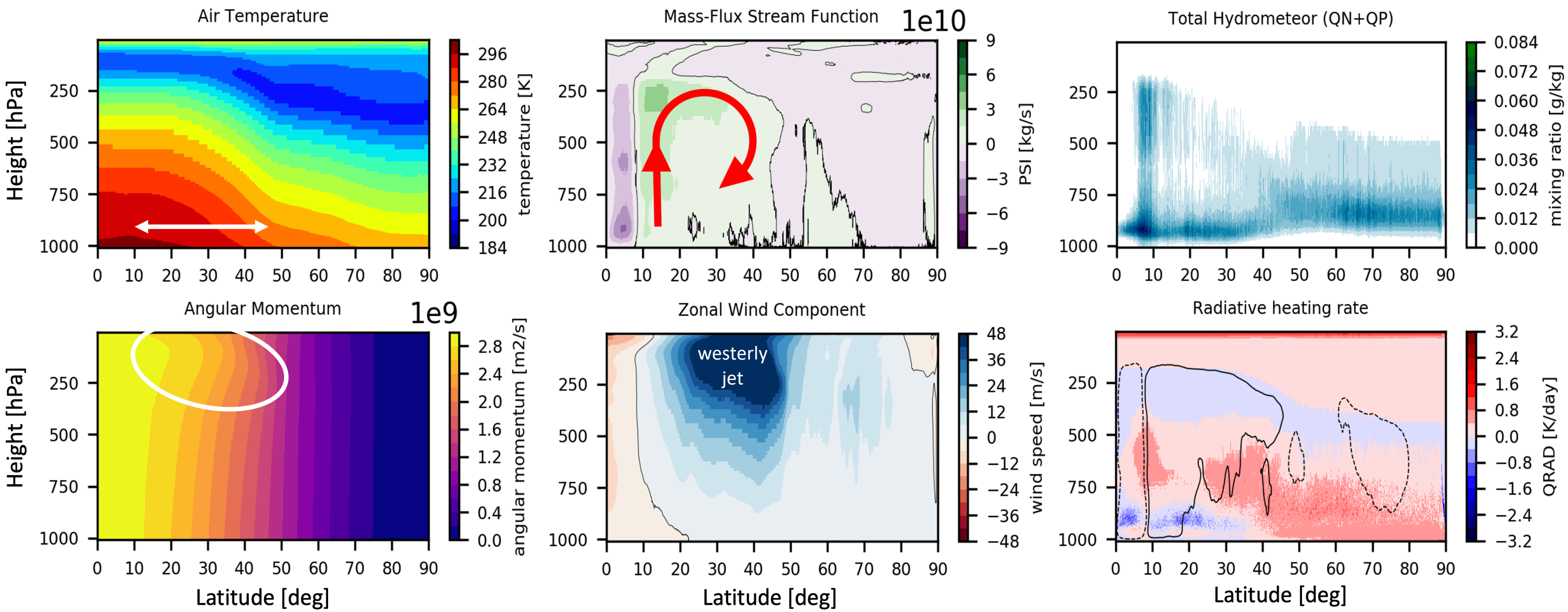


Fig. 4: Meridional-vertical cross section of the last 700 day mean of 1000 days time integration for 4 km horizontal grid spacing and 128 vertical levels with 35 m layer interval up to 2 km height. Only 4 nodes of DOE's supercomputer was used for 300 h wall-clock time. This efficiency is an advantage of 2D simulation.

The 2-D framework can simulate a large-scale circulation and corresponding convective clouds through full physics components.

This framework has a lot of potentials to be applied to various sciences:

- SST sensitivity of the large scale circulation and clouds
- Multi-Interactions between cloud, aerosol, and largescale circulation

2-D simulation Results:
Resolution dependencies for effective radius of cloud liquid water

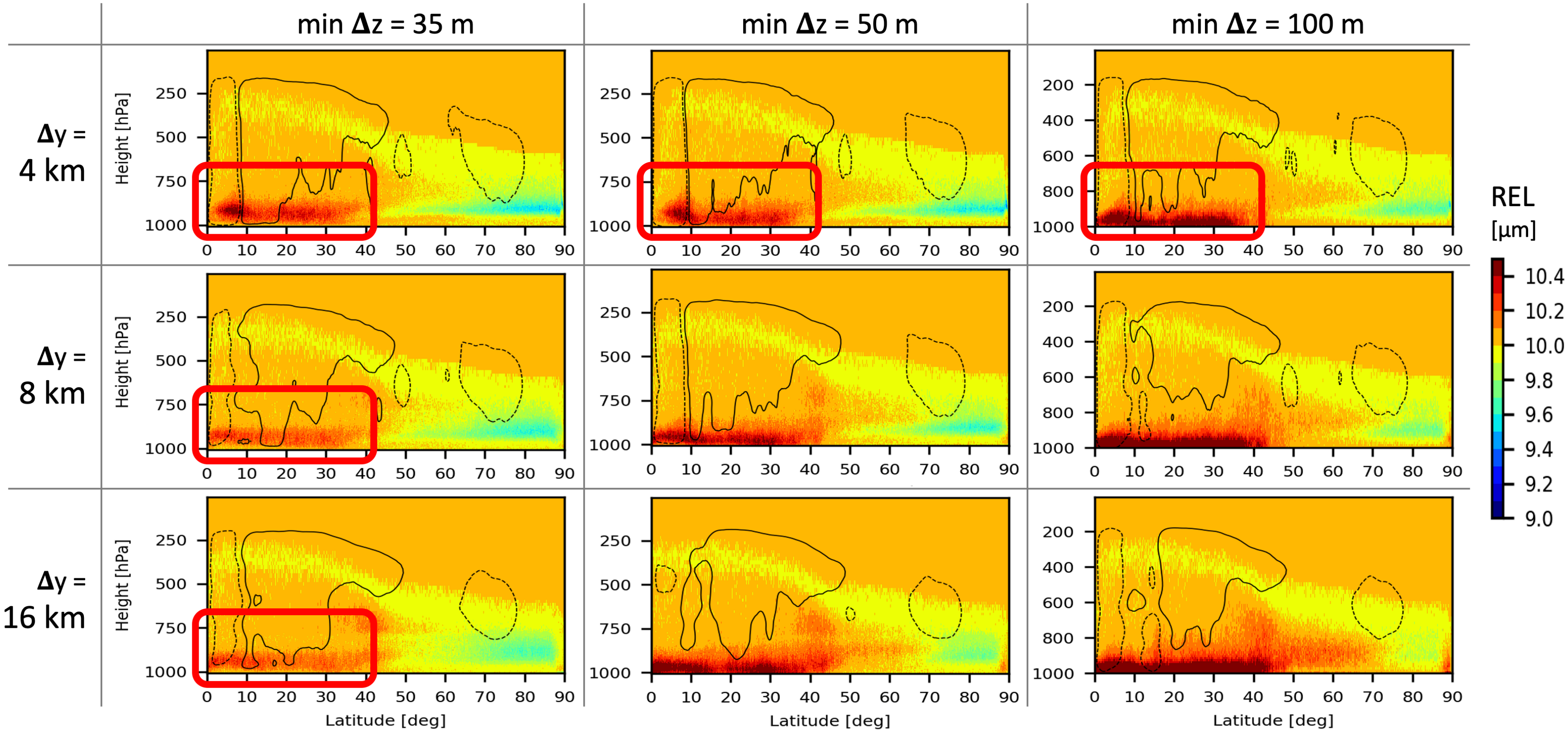


Fig. 5: Meridional-vertical cross section of the last 700 day mean of 1000 days time. Columns show different vertical resolutions and rows show different horizontal resolutions. The number of vertical layer is 128 for all vertical grid arrangement, but the layer interval below 2 km height is different.

This resolution dependency implies that both horizontal- and vertical-resolutions are necessary to represent clear regimes for deep convection and shallow convections.

Further development:
A parallelized-FIVE to improve vertical resolution with the smallest cost

FIVE: Framework for improvement by vertical enhancement (Yamaguchi et al., 2017) is a method to enhance vertical resolution. A part of physics schemes which are sensitive to the vertical profiles are only calculated in a high vertical resolution. Furthermore, we are **developing an efficient implementation of FIVE for a massive parallel computer; that is a Parallelized-FIVE!**

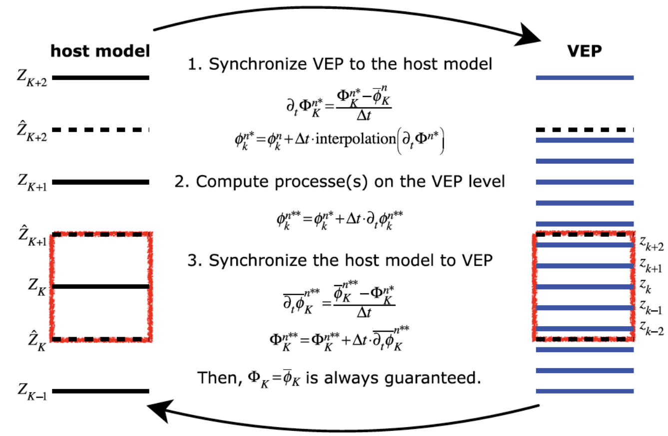
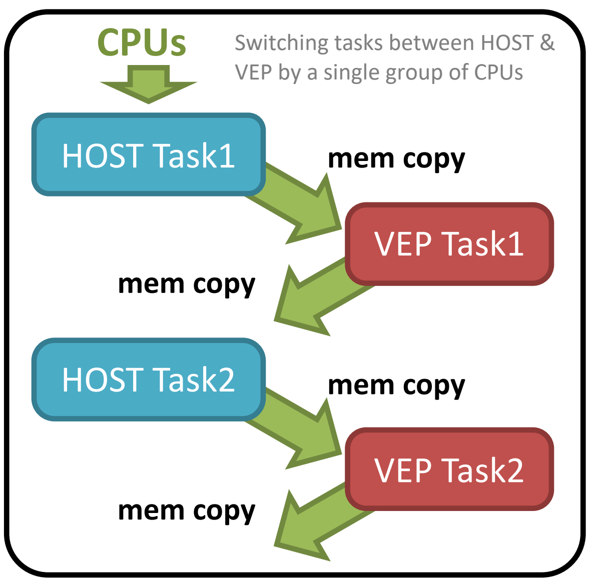
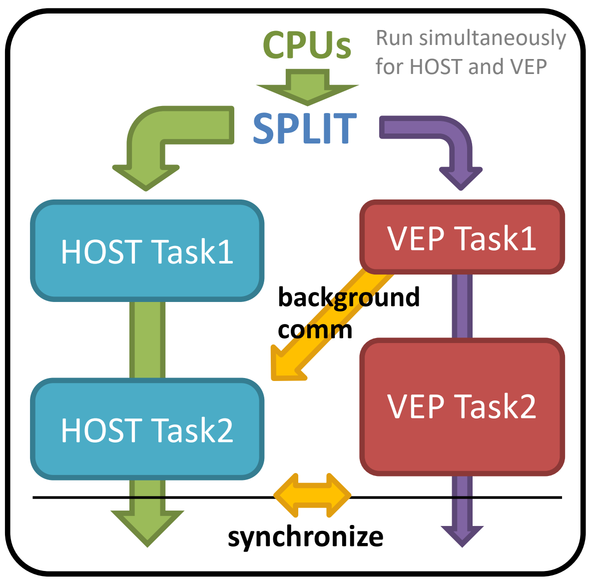


Fig. 5: an outline of FIVE (from Fig. 1 in Yamaguchi et al. 2017)

Serial procedure for one step



Parallel procedure for one step

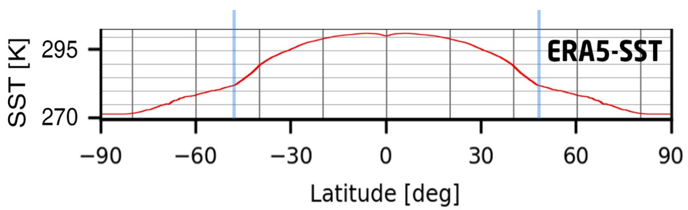


- **Split allows us to tune CPUs number** for each tasks of HOST and VEP to gain the best computational performance. It is also capable to GPUs.
- The elapsed time for interpolation and **communication between HOST and VEP can be hide** behind other computations.

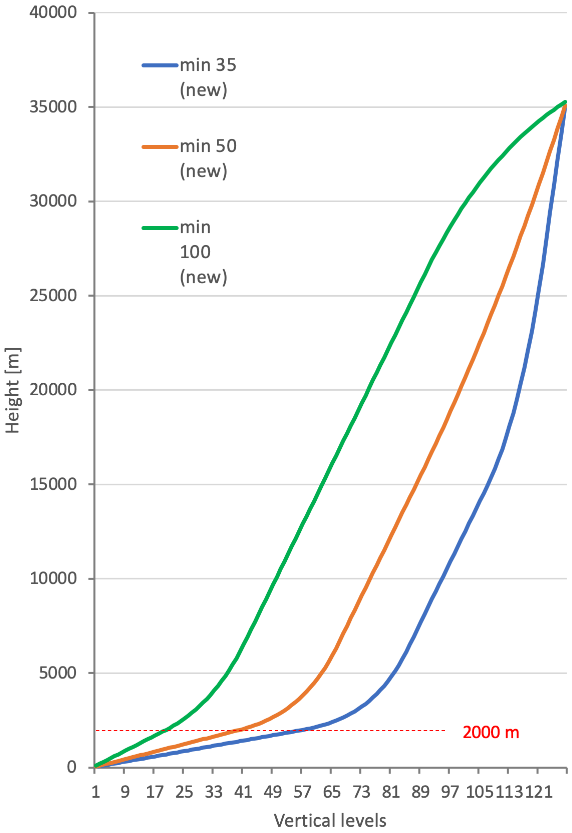
Appendix:
Settings for the 2D Hadley circulation simulation

Grid and model component settings

Items	Settings
Atmospheric Model	SAM (System for Atmospheric Modeling; Khairoutdinov and Randall, 2003)
Domain Settings	Y-Z 2-D domain; 90ºN to 90ºS; model top is 35 km
Grid Spacing	**Δ**y = 16 km, 8 km, 4 km, 2 km; 128 vertical levels
Micro-Phys Scheme	P3 (Predicted Particle Properties; Morrison and Milbrandt, 2015)
Radiation Scheme	RRTMG (The Rapid Radiative Transfer Model for GCMs; Iacono et al, 2008)
Turbulence Scheme	SHOC (Simplified Higher-Order Closure; Bogenschutz and Krueger, 2013)
Integration Period	1000 days with **Δ**t = 10 s
Initial/Boundary	ERA-5 (resolution 31 km; zonal mean & 10 years mean from 2001 to 2011)



Boundary condition of the mean SST based on ERA5: Note that the north hemisphere profile was copied to the south hemisphere to make a completely mirror condition.



Vertical grid arrangements; the number of vertical layer is 128 for all grid arrangement, but the minimum interval is 35 m, 50 m, and 100m, respectively.