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A 2-D framework for accelerating the development of physics schemes in global cloud system resolving models

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Motivation: Development and assessment new schemes in high-resolution simulation are TOUGH!

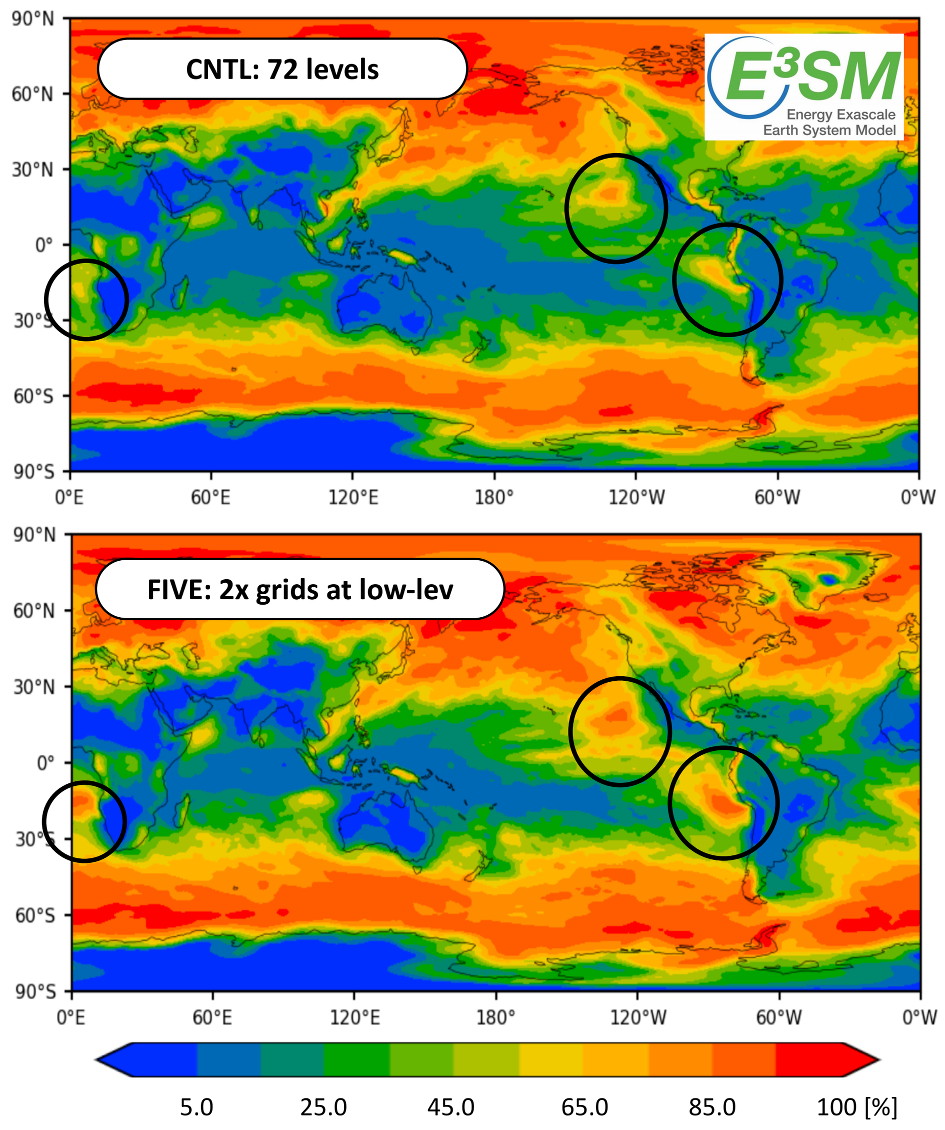


Fig. 1: Integrated Low Cloud Amount. (By Peter A. Bogenschutz at LLNL) The Energy Exascale Earth System Model (E3SM) is a new climate model developed by DOE. A 3 km horizontal mesh climate simulation with cutting-edge physics schemes is planned in the near future.

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

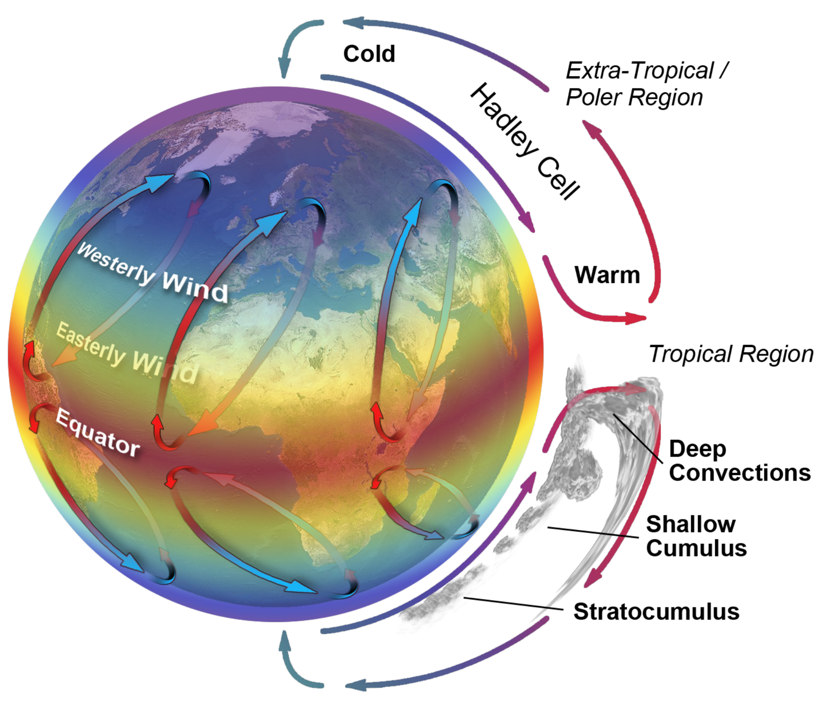


Fig. 2: illustration of Hadley circulation

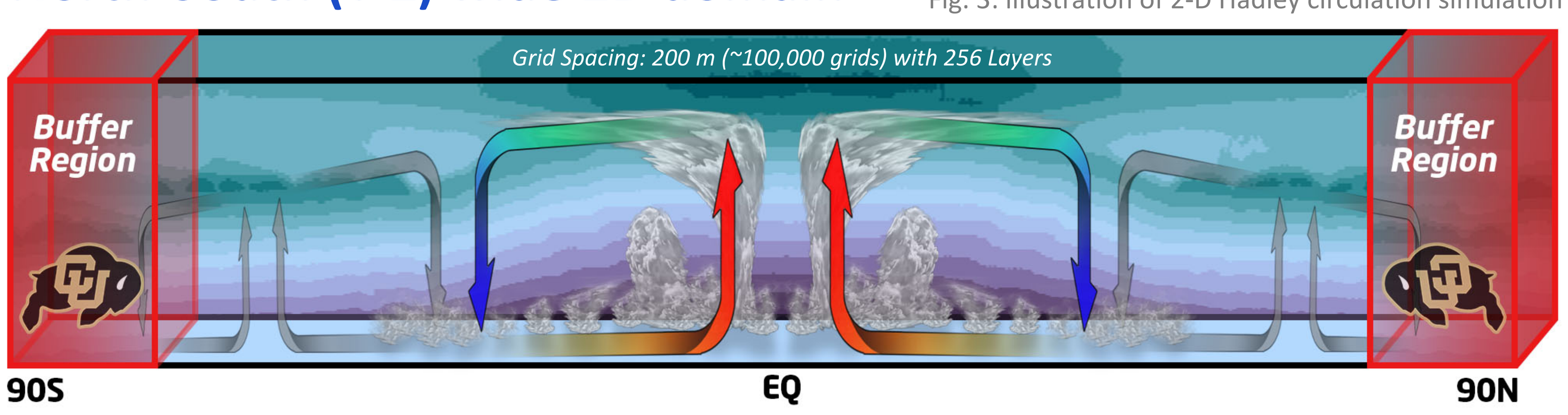
Hadley circulation

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 2D simulation, a sea surface temperature (SST) represents a meridional distribution of the solar radiation income. A large scale convective circulation is organized in each hemisphere as a response to the given SST profile, that is the ideal Hadley circulation.

North-South (Y-Z) wide 2D domain

Fig. 3: illustration of 2-D Hadley circulation simulation



Light weight

- save computation and data space
- easily increase model resolution and a number of test cases

Simple, but still complicated

- 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.

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	Δy = 8 km (2,560 grids); minimum Δz = 35 m; 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 Δt = 10 s
Initial/Boundary	ERA-5 (resolution 31 km; zonal mean & 10 years mean from 2001 to 2011)

* Red colored schemes are newly ported for this project.

Preliminary Results: The Hadley circulation and corresponding clouds are simulated in the 2-D.

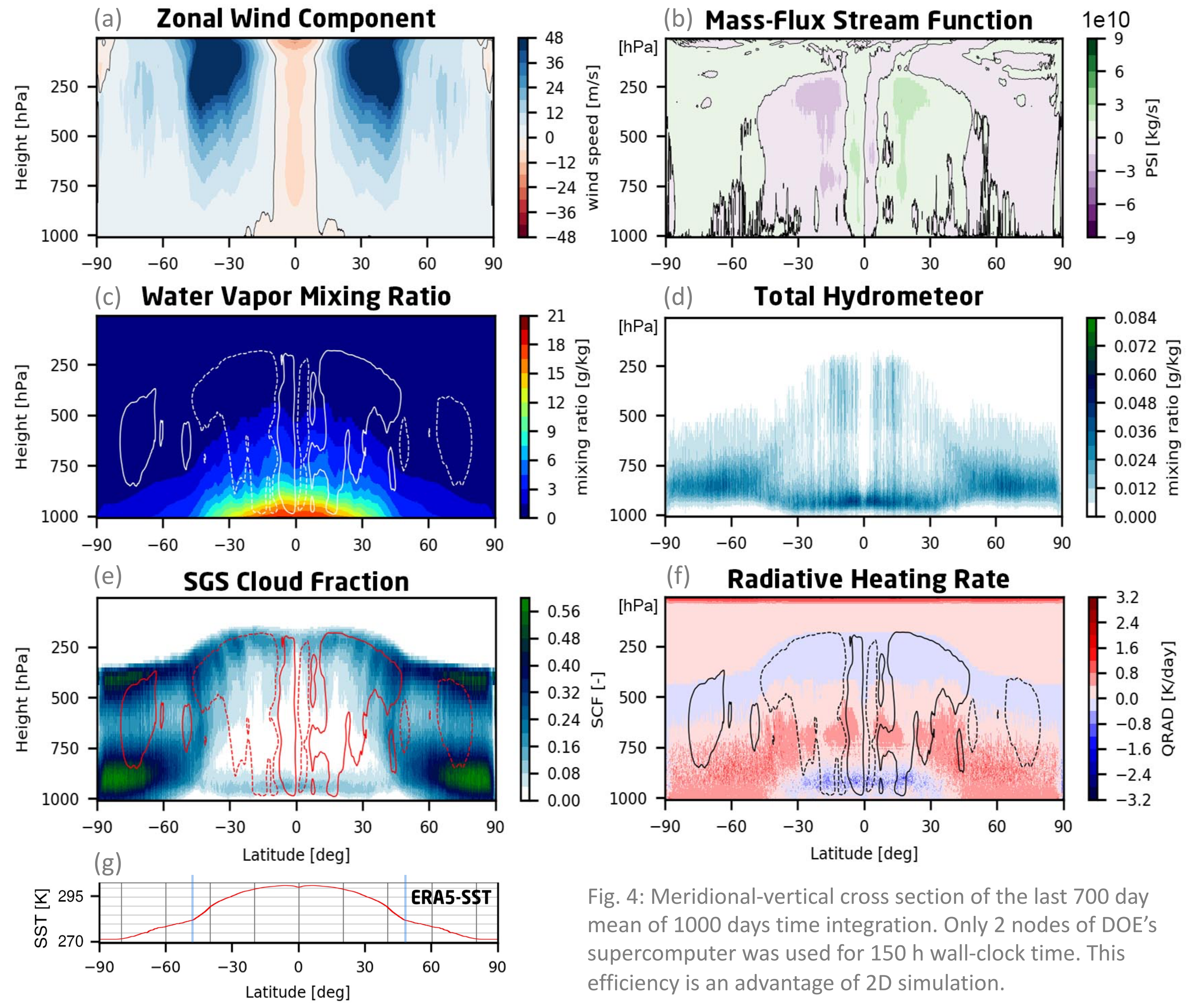


Fig. 4: Meridional-vertical cross section of the last 700 day mean of 1000 days time integration. Only 2 nodes of DOE's supercomputer was used for 150 h wall-clock time. This efficiency is an advantage of 2D simulation.

The 2-D framework can simulates a large-scale circulation and a variety of clouds with full physics. This framework has a lot of potentials to be applied to various sciences:

- SST sensitivity: How does the circulation change as SST profile is altered?
  - simulations by changing a SST profile which are derived from the CMIP6 data
- Multi-Interactions between cloud, aerosol, and largescale circulation
  - investigate differences in cloud representations in various aerosol conditions

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

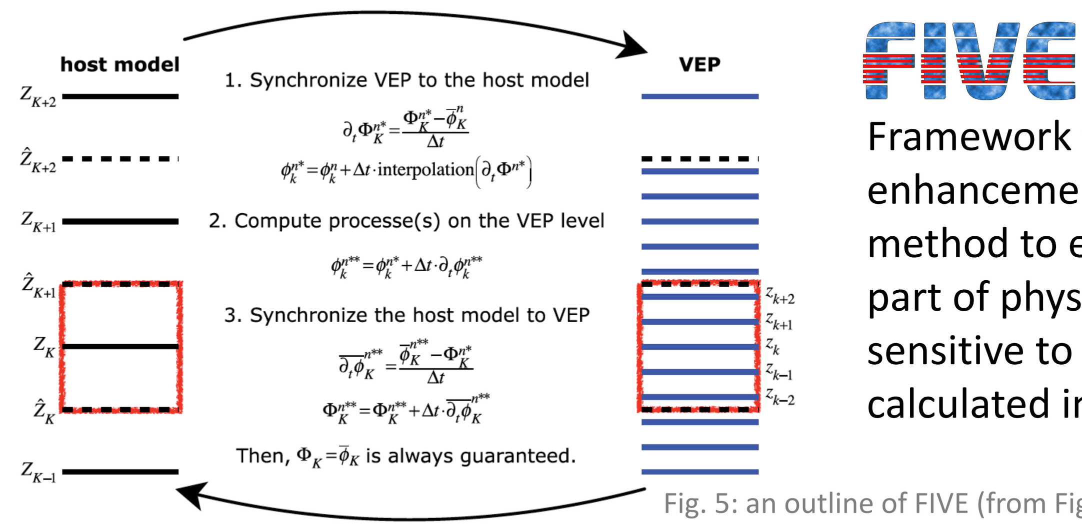


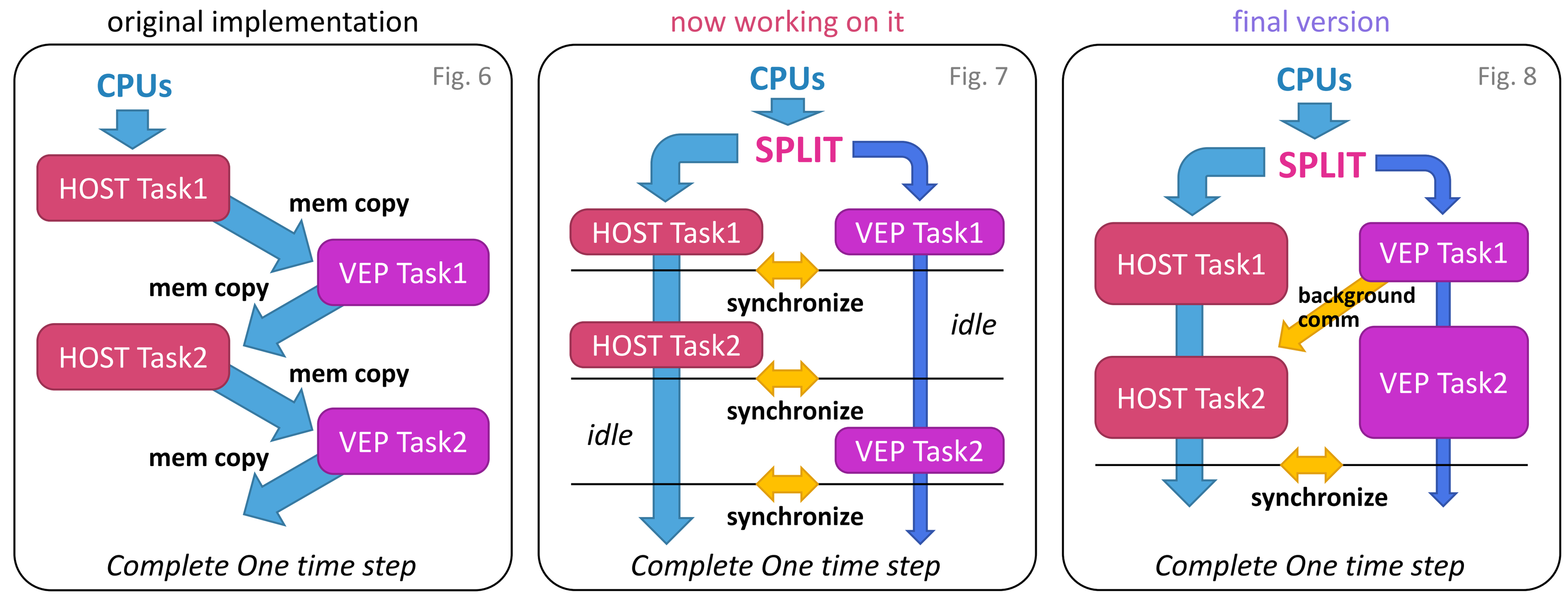
Fig. 5: an outline of FIVE (from Fig. 1 in Yamaguchi et al. 2017)

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.

Seek an efficient implementation of FIVE on supercomputer

Serial procedure — original implementation | Parallel procedure (TS) — now working on it | Parallel procedure (HVPS) — final version



Switching tasks between HOST and VEP by a single group of CPUs.

Create two groups of CPUs; which are assigned to a different task.

Run simultaneously, minimize the elapsed time of the total process.

- 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.

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SHOC was imported from SAM-SHOC code, which is a branch off of SAM6.10.3, by courtesy of P. Bogenschutz. P3 was imported from the Github repository of SAMUWgh, by courtesy of P. Blossey.