Intercomparison of numerical methods in climate simulations with idealized moisture parameterizations

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Background

Idealized test cases for dynamical cores are used to:

- Analyze the impacts of underlying numerical techniques without effects from physical parameterizations
- Compare different dynamical cores within the same modeling framework

Important features for an idealized test case:

- Use limited or no physical parameterizations
- Able to recreate *quasi-realistic* climate conditions
- Computationally efficient

Modeling community needs moist dynamical core test cases of intermediate complexity

- Moisture transport and latent heat release are important for physics-dynamics coupling processes
- Moist idealized test cases are needed to bridge the gap between dry dynamical core test cases and full physics simulations

Test Case Design

Based on the Held and Suarez (1994) dry test case for dynamical cores

- Modified Newtonian relaxation toward a prescribed equilibrium temperature profile
- Rayleigh damping of low-level horizontal winds

Utilizes simplified moist physics modified from Reed and Jablonowski (2012)

- Prescribed sea surface temperature profile
- Boundary layer turbulence for temperature and moisture
- Latent and sensible heat fluxes at the surface
- Large-scale precipitation

Compared to aquaplanet simulations

- Full physics with and without deep convection
- Prescribed bulk aerosols

Dynamical Cores

Numerical method used to solve fluid and thermodynamic partial differential equations

Spectral Element (SE)

- Spectral functions solved on each element with Runge-Kutta multi-step time scheme

Finite Volume (FV)

- Finite volume with multi-step time scheme and good conservation

Eulerian Spectral Element (EUL)

- Eulerian spectral transform with leapfrog time scheme

Semi-Lagrangian Spectral Element (SLD)

- Lagrangian spectral transform with periodic backward remapping

Dynamical Core	Resolution	Δx (km)	Physics Δt (s)	Dynamics Δt (s)	Diffusion
SE	ne30np4	110	1800	300	∇^4 hyper-diffusion
FV	1x1°	110	1800	180	∇^2 divergence damping
EUL	T85	156	1800	600	∇^4 hyper-diffusion
SLD	T85	156	1800	1800	*implicit*

References

Held, I. M. and M. J. Suarez, 1994: A proposal for the intercomparison of the dynamical cores of atmospheric general circulation models. *Bulletin of the American Meteorological Society*, **75 (10)**, 1825–1830.

Reed, K. A. and C. Jablonowski, 2012: Idealized tropical cyclone simulations of intermediate complexity: a test case for AGCMs. *Journal of Advances in Modeling Earth Systems*, **4 (2)**.

Vertical Velocity

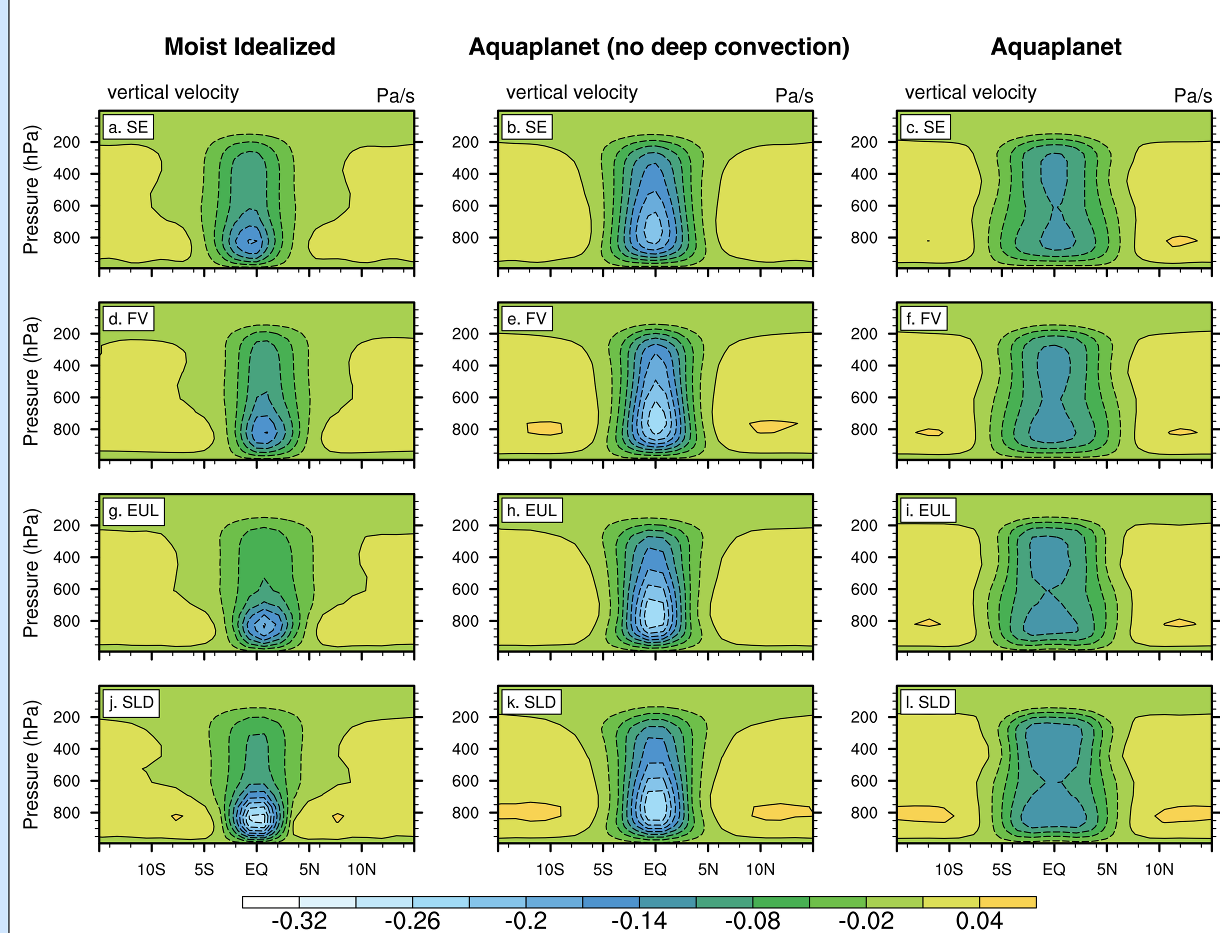

Fig. 2: Time-mean zonal-mean vertical pressure velocity in the tropic (±15°).

- As physical parameterization complexity *increases*, equatorial updrafts:
  - Widen across the equator and weaken
  - Become more uniform with height

- The moist idealized test (least complex) reveals differences attributed to the dynamical core
  - Complex physics mask effects of the dynamical core in aquaplanet simulations (both with and without deep convection)

Precipitation Rate

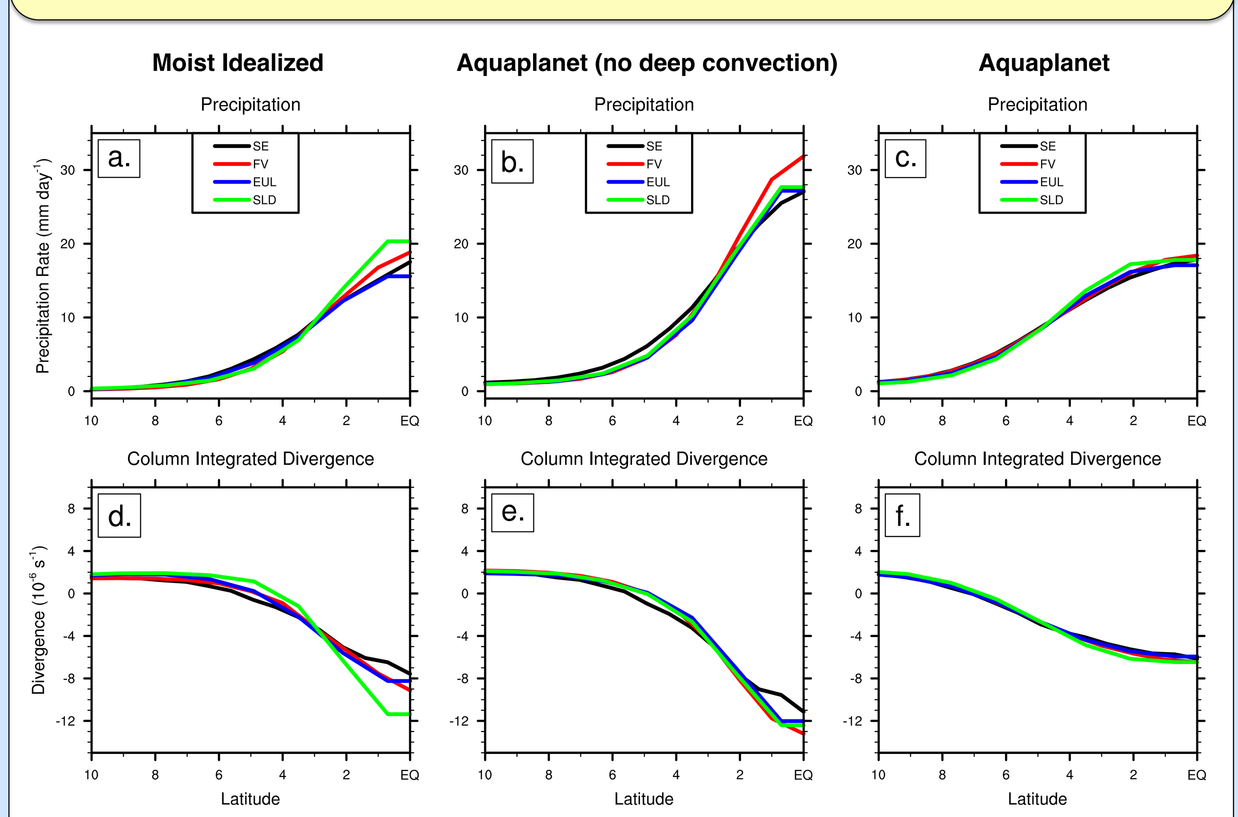

Fig. 3: Average precipitation rate (top) and column integrate divergence from the surface to 800 hPa (bottom).

- Idealized moist physics show impacts of the dynamical core on precipitation rate

- Average tropical precipitation is consistent across all dynamical cores, despite differences in equatorial precipitation

- Average large-scale precipitation rate (global and tropical) for the moist idealized test is comparable to aquaplanet simulation without deep convection

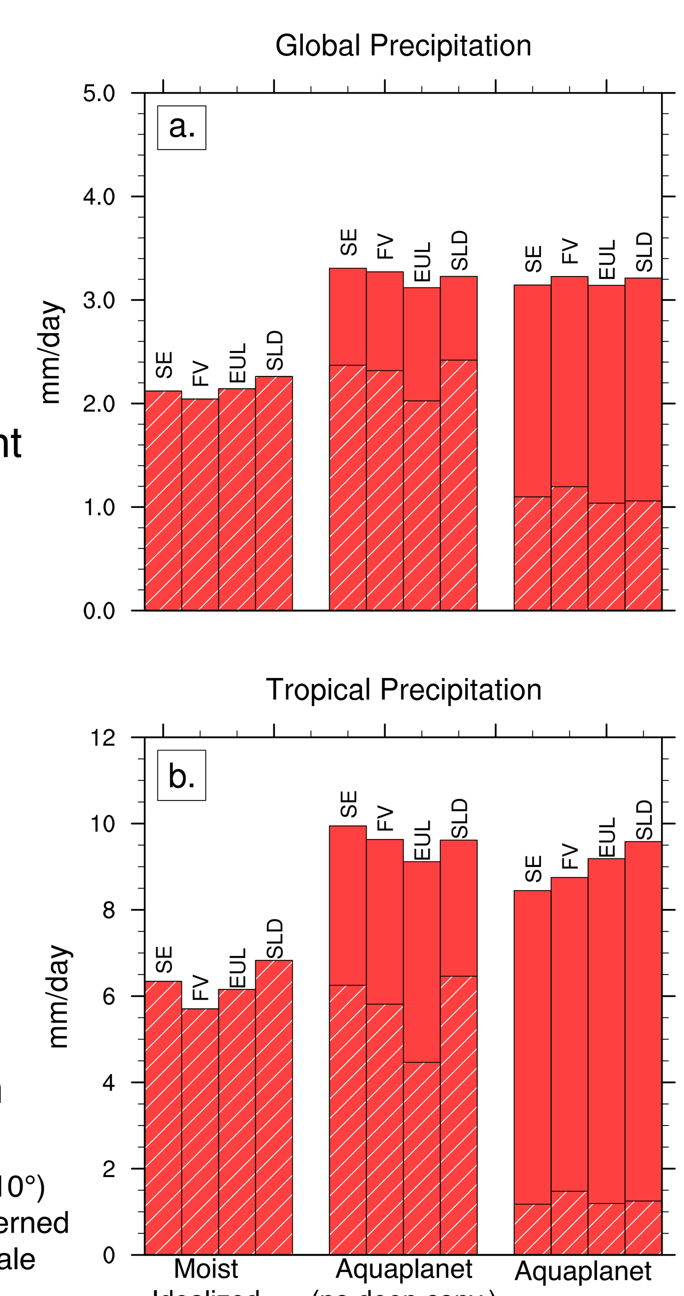

Fig. 4: (a.) global and (b.) tropical (±10°) average precipitation. Solid and patterned bars denote convective and large-scale precipitation, respectively.

Distribution of Precipitation Rate

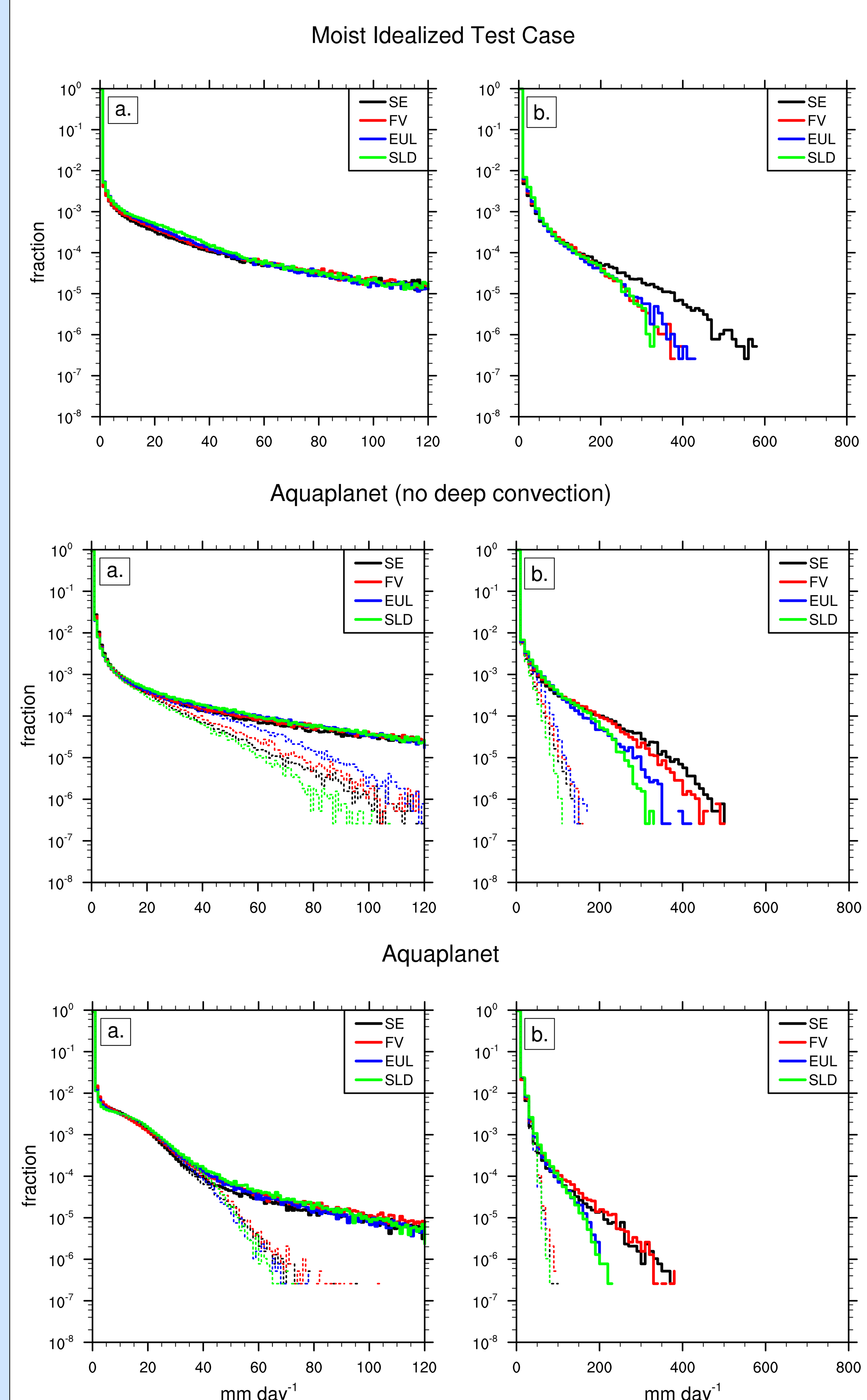

Fig. 5: Histogram of tropical precipitation rate for ±10° at low rates in 1 mm/day bins (left) and high rates in 10 mm/day bins (right). Solid and dotted lines denote total and convective precipitation, respectively.

- Convective parameterizations reduce the frequency of extreme precipitation events
  - Especially true for SE, which reaches nearly 600 mm/day in the moist idealized test

- Aquaplanet with deep convection generates two distinct regimes for extreme precipitation events
  - Precipitation extremes likely a result of slightly different resolutions
  - Convective precipitation does not show resolution sensitivity

Conclusions

Idealized test cases with simplified moist physics are important tools for understanding dynamical cores

In CAM5, replacing the full physical parameterizations with idealized moist physics reveals impacts of the underlying numerical method that are otherwise masked by the physical parameterizations

- Updrafts over the equator are weaker in more recent dynamical cores (SE and FV) than older dynamical cores (EUL and SLD)
- Stronger surface convergence and higher rainfall rates at the equator in SLD than SE
  - Average rainfall rates in the tropics are equivalent
- SE has more precipitation at extreme rates, while SLD has more precipitation at low rates

The new moist idealized test case recreates a *quasi-realistic* climate, but still shows features due to dynamical core formulation that would be hidden by complex physical parameterizations