Dynamical core intercomparison using a moist variant of the Held-Suarez test case in CAM5

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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:

- 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
- 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
- Moist idealized test case compared to aquaplanet simulations on all four dynamical cores
  - Full physics with and without deep convection
  - Prescribed bulk aerosols

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*

Kinetic Energy Spectrum

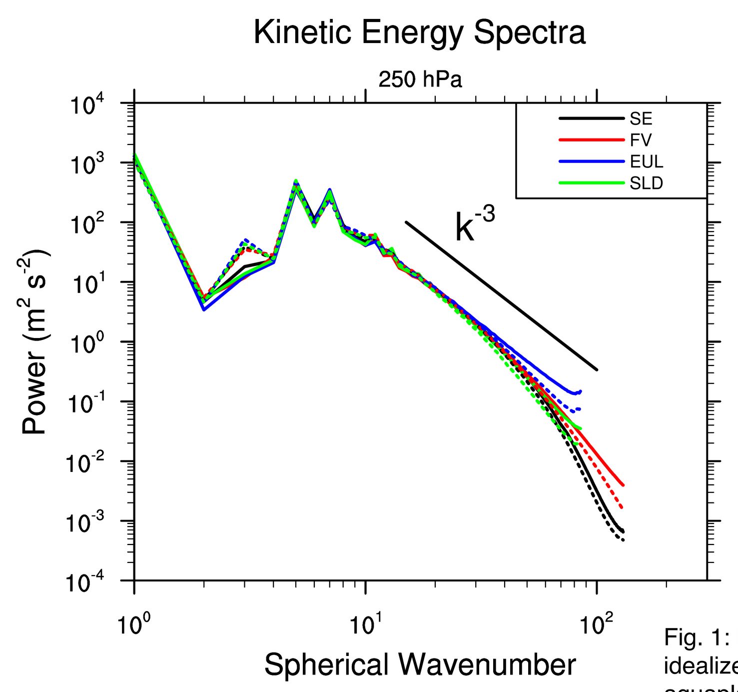

Fig. 1: Kinetic energy spectra for the moist idealized test cases (solid lines) and aquaplanet simulations (dotted lines).

- Both the aquaplanet simulation and moist test case produce reasonable spectra
- Aquaplanet is slightly more diffusive for each dynamical core

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)**.

Thatcher, D. R. and C. Jablonowski, 2014: A moist variant of the Held-Suarez test for atmospheric model dynamical cores: Aquaplanet comparison and sensitivity analysis. *In review*

Vertical Velocity

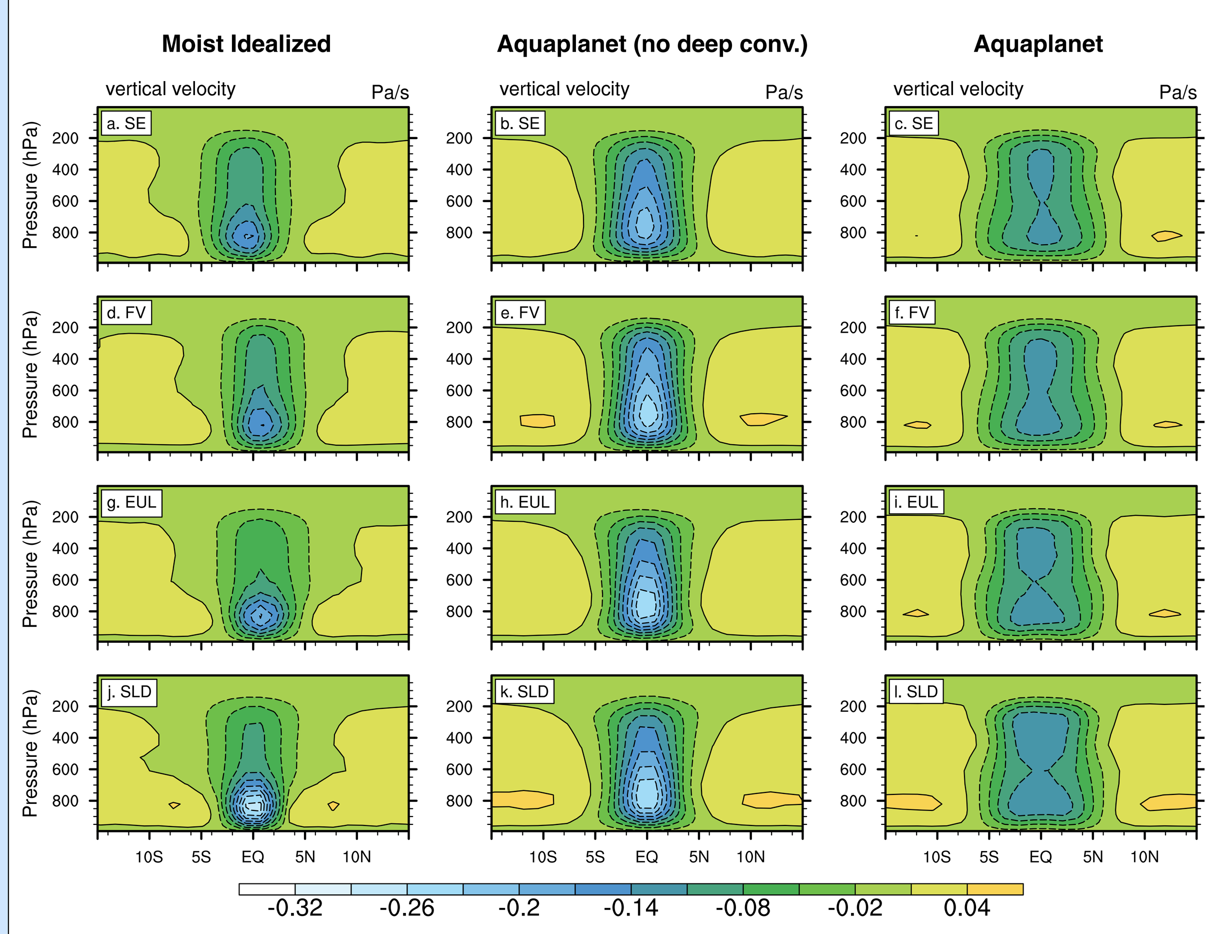

Fig. 2: Vertical pressure velocity for the moist idealized test case (left), aquaplanet simulation without deep convection (middle), and aquaplanet simulation with full physics (right).

- 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

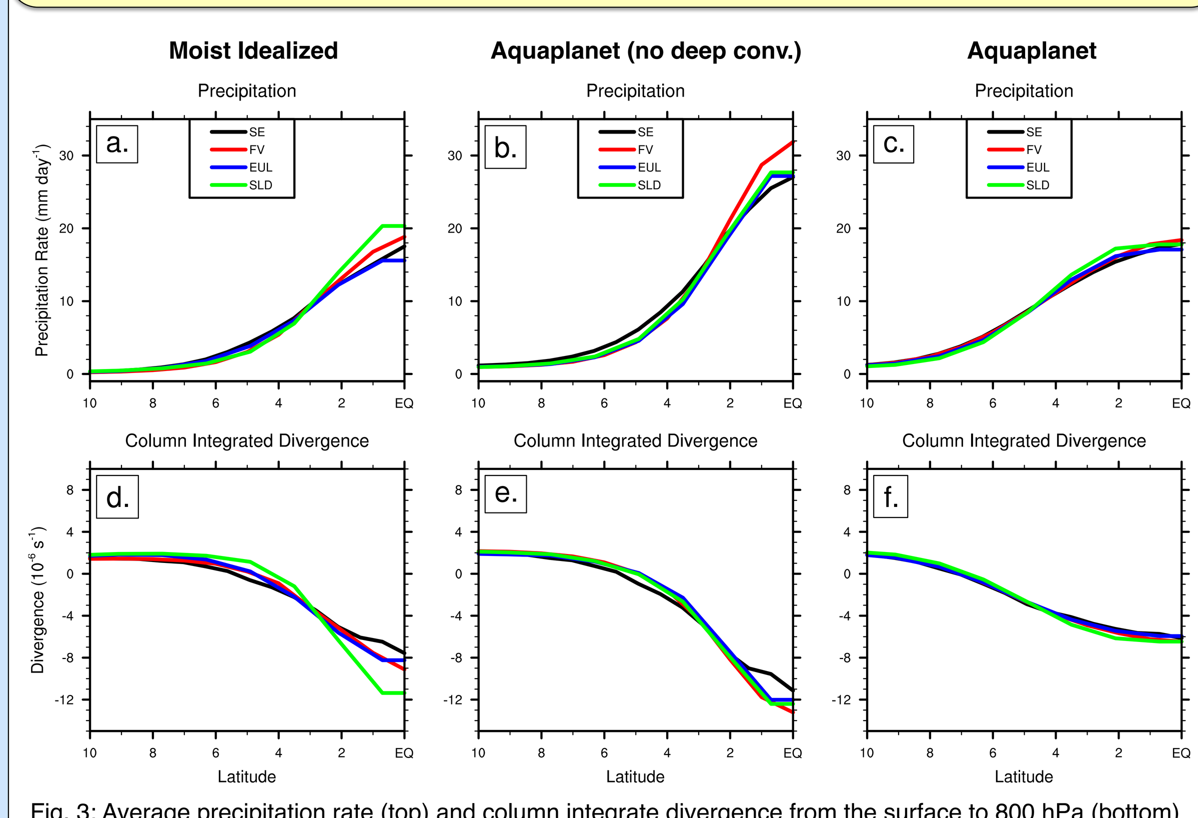

Fig. 3: Average precipitation rate (top) and column integrate divergence from the surface to 800 hPa (bottom) for the moist idealized test case (left), aquaplanet simulation without deep convection (middle), and aquaplanet simulation with full physics (right).

- Impacts of the dynamical core on precipitation rate become apparent in when idealized moist physics are used
- Average large-scale precipitation rate (global and tropical) for the moist idealized test is comparable to aquaplanet simulation without deep convection

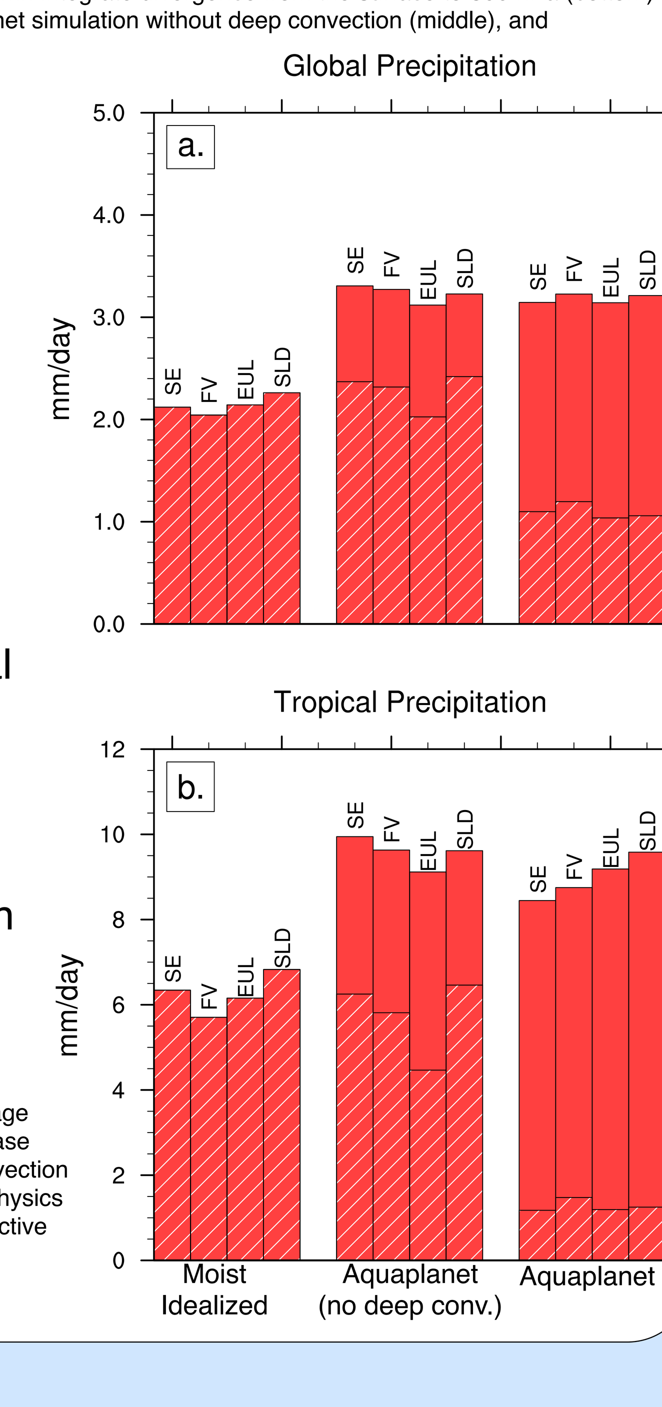

Fig. 4: (a.) global and (b.) tropical (±10°) average precipitation rate for the moist idealized test case (left), aquaplanet simulation without deep convection (middle), aquaplanet simulation with full physics (right). Solid and patterned bars denote convective and large-scale precipitation, respectively.

Distribution of Precipitation Rate

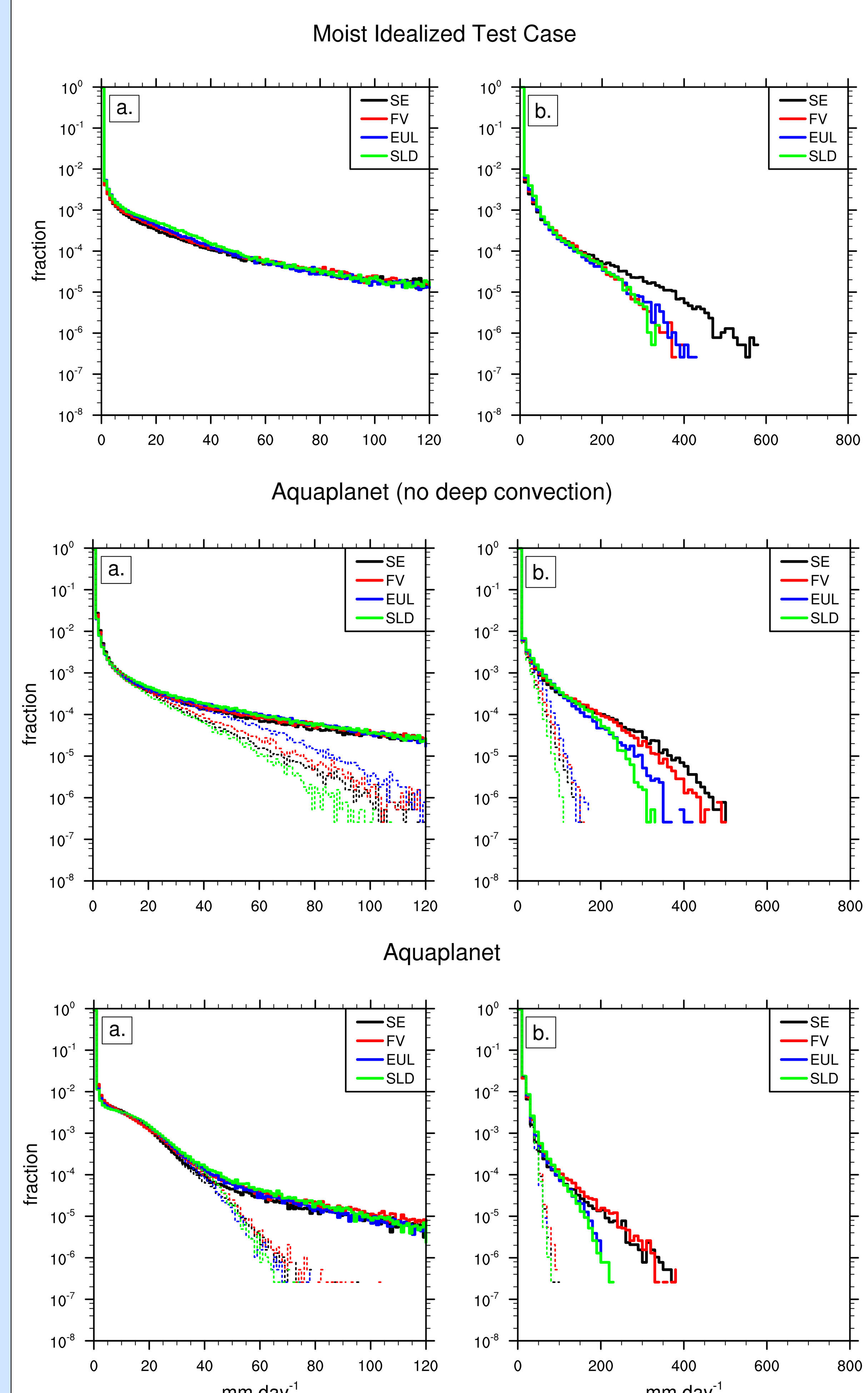

Fig. 5: Histogram of tropical precipitation rate for ±10° at low rates in 1 mm/day bins (left) and high rates in 10 mm/day bins (right) for the moist idealized test case (top), aquaplanet simulation without deep convection (middle), and aquaplanet simulation with full physics (bottom). Solid and dotted lines denote total and convective precipitation, respectively.

- The inclusion of convective parameterizations reduces 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
  - EUL and SLD: low precipitation rates (< 200 mm/day)
  - SE and FV: high precipitation rates (< 400 mm/day)

Conclusions

- Idealized test case 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 dynamical core 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