A moist idealized test case: convectively coupled equatorial waves and precipitation compared to aquaplanet simulations

Diana Thatcher[1], Christiane Jablonowski[1]

[1]Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, Ann Arbor, MI

E-mail: dtatch@umich.edu

Background and Motivation

Simplified test cases are important in testing the accuracy of the dynamical core, which computes the fluid flow in atmospheric general circulation models. Dynamical cores are coupled to complex subgrid-scale physical parameterization packages, resulting in nonlinear interactions between various components of the model. Idealized tests are a computationally efficient method for analyzing the underlying numerical techniques of dynamical cores. We present an idealized test case of intermediate complexity featuring moist feedbacks

Moist Idealized Test Case Design

- Based on the Held and Suarez (1994) dry test case
  - Newtonian temperature relaxation
  - Rayleigh damping of low-level winds
- Simplified moist physics modified from Reed and Jablonowski (2012)
  - Prescribed sea surface temperature profile
  - Large-scale condensation and precipitation
  - Boundary layer turbulence
  - Surface fluxes of latent and sensible heat
- Implemented on the spectral element dynamical core of the NSF/DoE Community Atmosphere Model
  - Utilizes a cubed-sphere grid (*Fig. 1*)
- Moist idealized test case compared to aquaplanet simulations, which uses full physical parameterizations

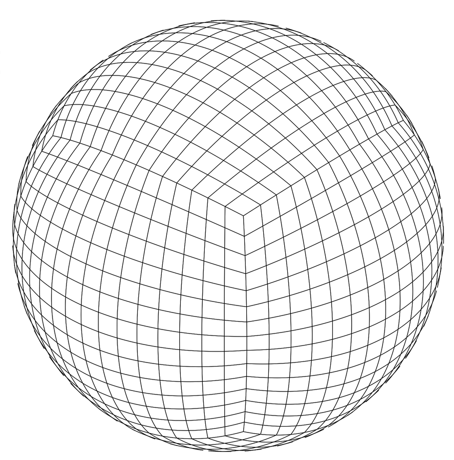
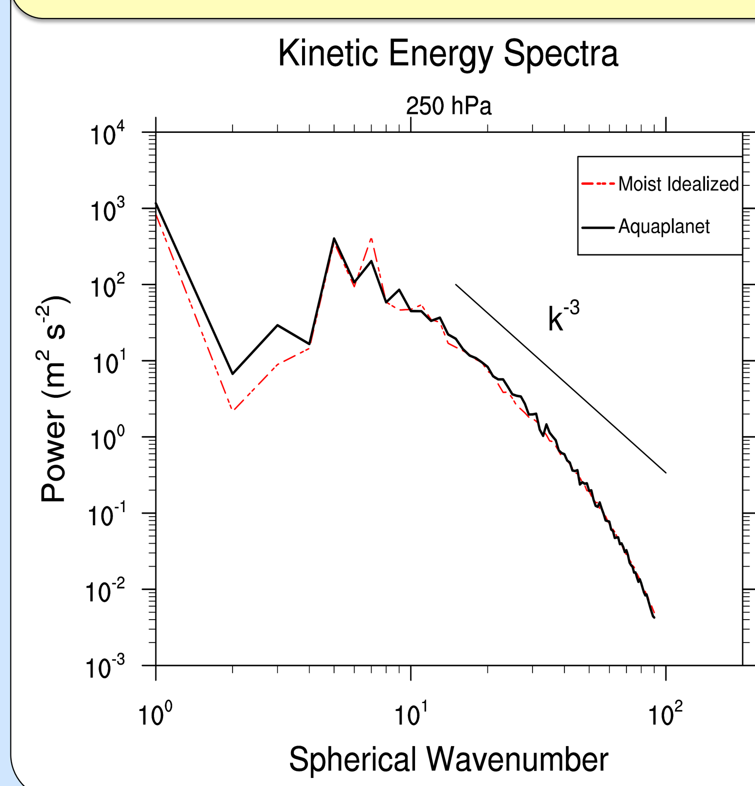


Figure 1. An example of a cubed-sphere grid

Dynamical Motions across Scales



- Kinetic energy spectra (*Fig. 2*) of both simulations follow the theoretical k^{-3} slope
- Spectra curves as it approaches the maximum resolved scale due to diffusion

Figure 2. Kinetic energy spectra for the moist idealized test (red dashed) and aquaplanet simulations (black solid). The line labeled k^{-3}, where k is the wavenumber, shows the theoretical slope based on the downscale cascade of enstrophy.

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)**.

General Circulation

- The moist idealized test case produces an reasonable general circulation when compared to aquaplanet simulations (Fig. 3)
- Similar magnitudes and structures for temperature (*a., b.*) and zonal wind (*c., d.*), including strong westerly jets in the upper troposphere
  - Tropopause occurs around the same height (red lines in a,. b.)
- Magnitudes of eddy variance of meridional heat transport (*e., f.*) are similar
- Structural differences in the eddy variance of meridional heat transport are likely the result of different boundary layer turbulence schemes

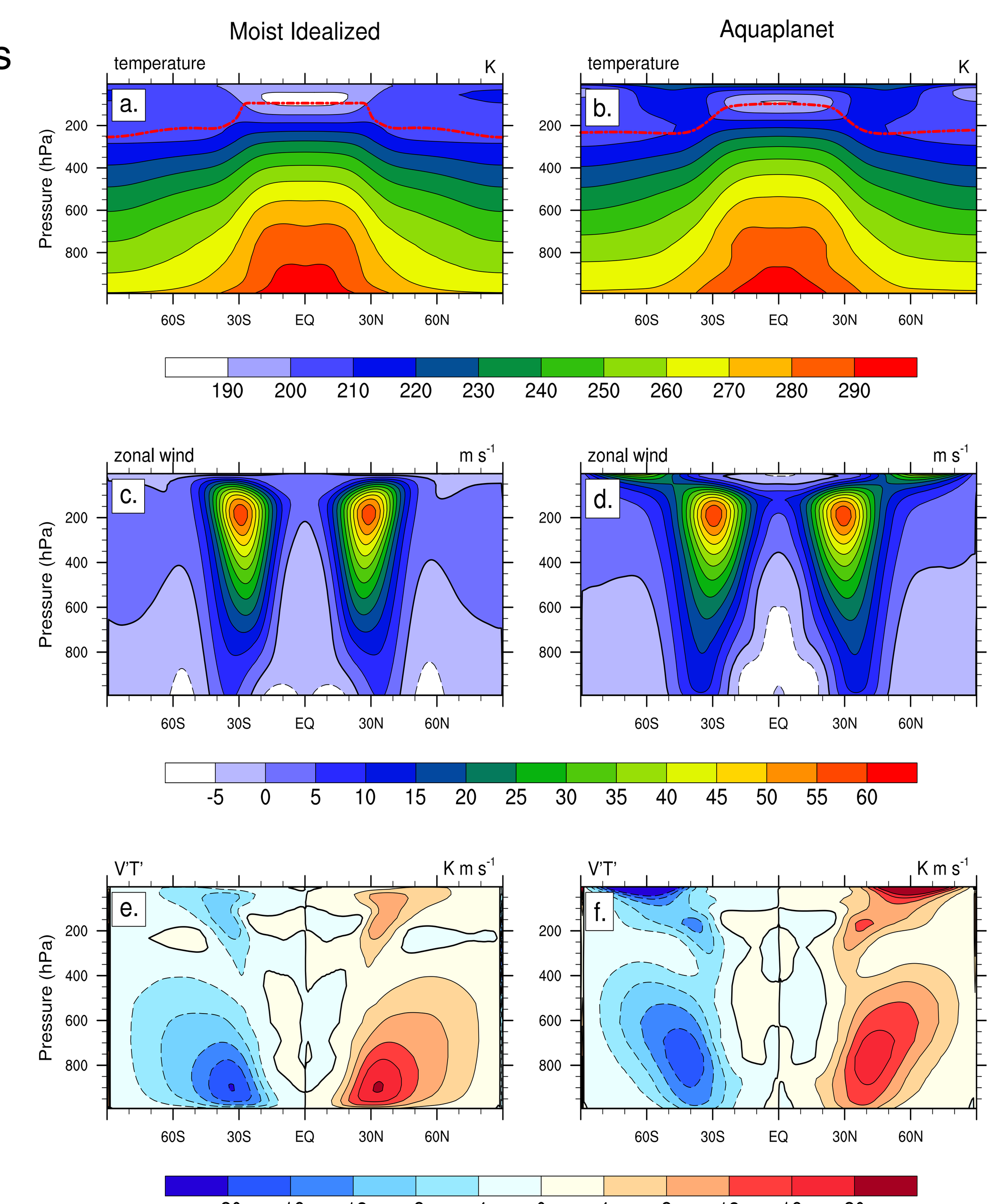


Figure 3. Comparison of moist idealized test and aquaplanet general circulation for time-mean zonal-mean temperature (a., b.) , zonal wind (c., d.), eddy variance of meridional flux of temperature *v'T'* (e., f.). The red dashed line in (a., b.) indicates the location of the tropopause.

Convectively Coupled Equatorial Waves

- Convectively coupled equatorial waves (*Fig. 4*) are prominent in both moist idealized (*a.*) and aquaplanet (*b.*), especially Kelvin waves
  - Moist idealized Kelvin waves have slightly larger equivalent depth
- Moist idealized contains weak eastward and westward inertio-gravity waves
- Convective parameterizations are not necessary to generate convectively coupled equatorial waves

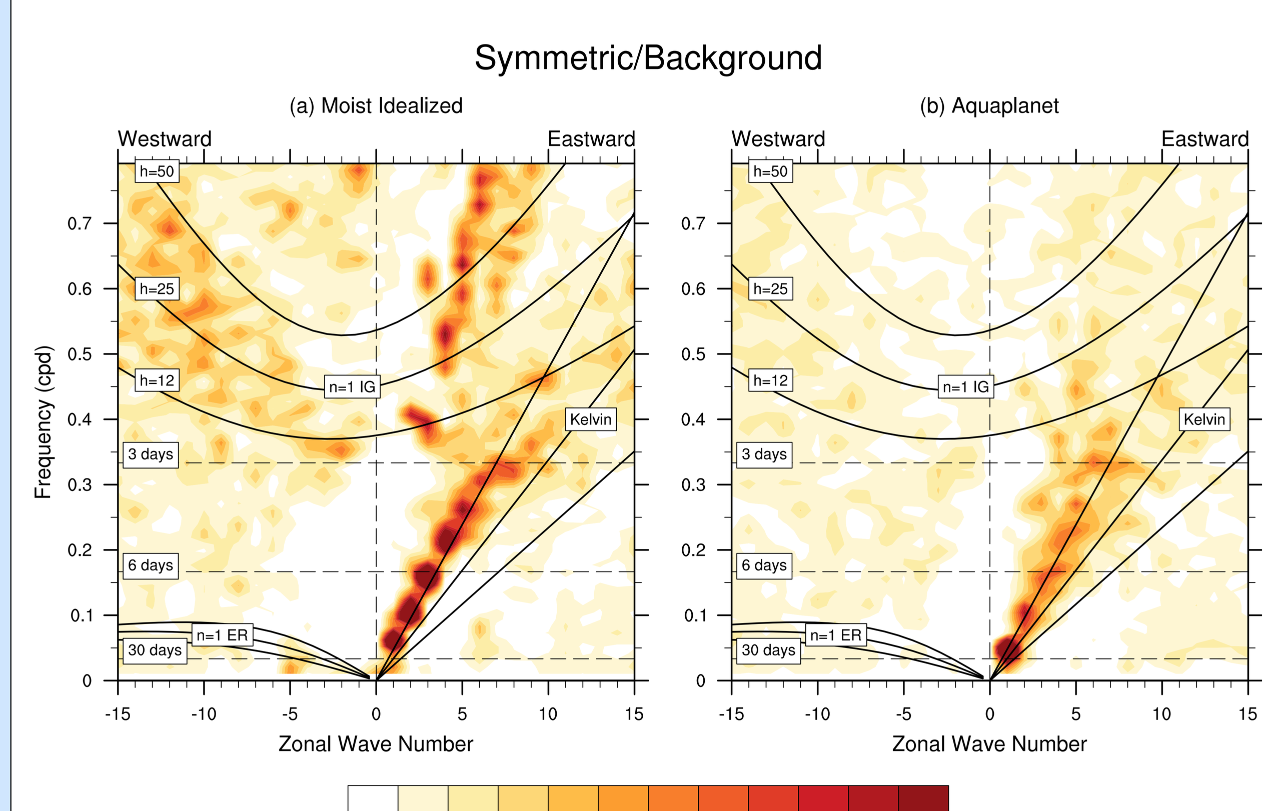


Figure 4. Spectral powers for the symmetric component of temperature near the equator (15°S-15°N) at 100 hPa for (a.) moist idealized and (b.) aquaplanet.

Precipitation

- Precipitation rate (*Fig. 5*) differs significantly because aquaplanet has convective (PRECC) and large-scale (PRECL) precipitation
  - Convective parameterizations allow precipitation in grid boxes that do not reach saturation
  - Convective precipitation creates a wider precipitation peak over the equator and higher precipitation rates in the subtropics, where large-scale saturation occurs less often
- Histogram of precipitation rate (*Fig. 6*) shows that moist idealized has fewer low-rate events (*a.*), but more high-rate events (*b.*)
- Lack of convection allows moisture in the moist idealized case to build-up and precipitate out in extreme events with high precipitation rates

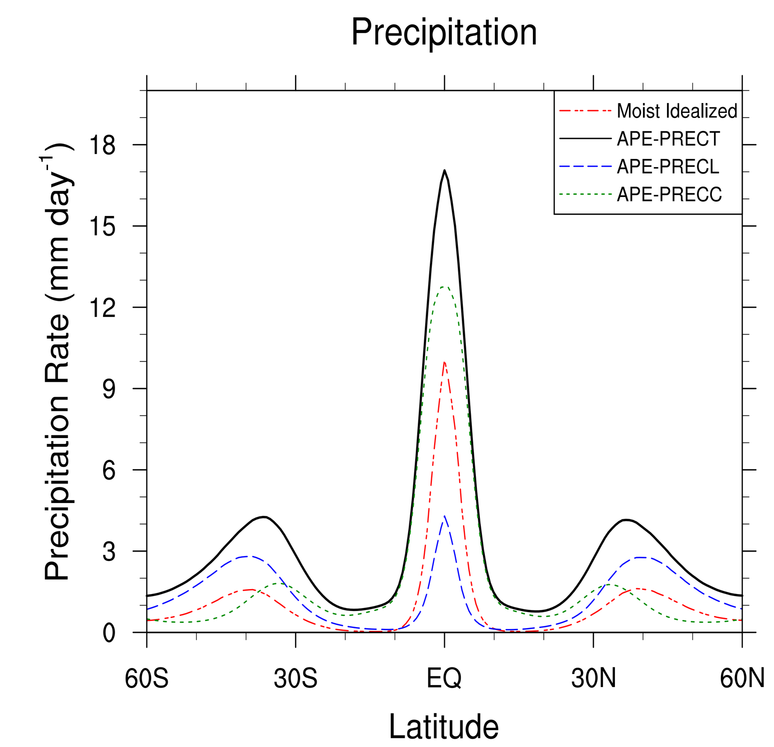


Figure 5 (right). Precipitation rate for moist idealized (red dash-dot line) and aquaplanet (APE) total precipitation (PRECT – black solid) along with the two components of total precipitation: large-scale (PRECL – blue dashed line), and convective (PRECC – green dotted line) precipitation in mm/day between 60° S and 60° N.

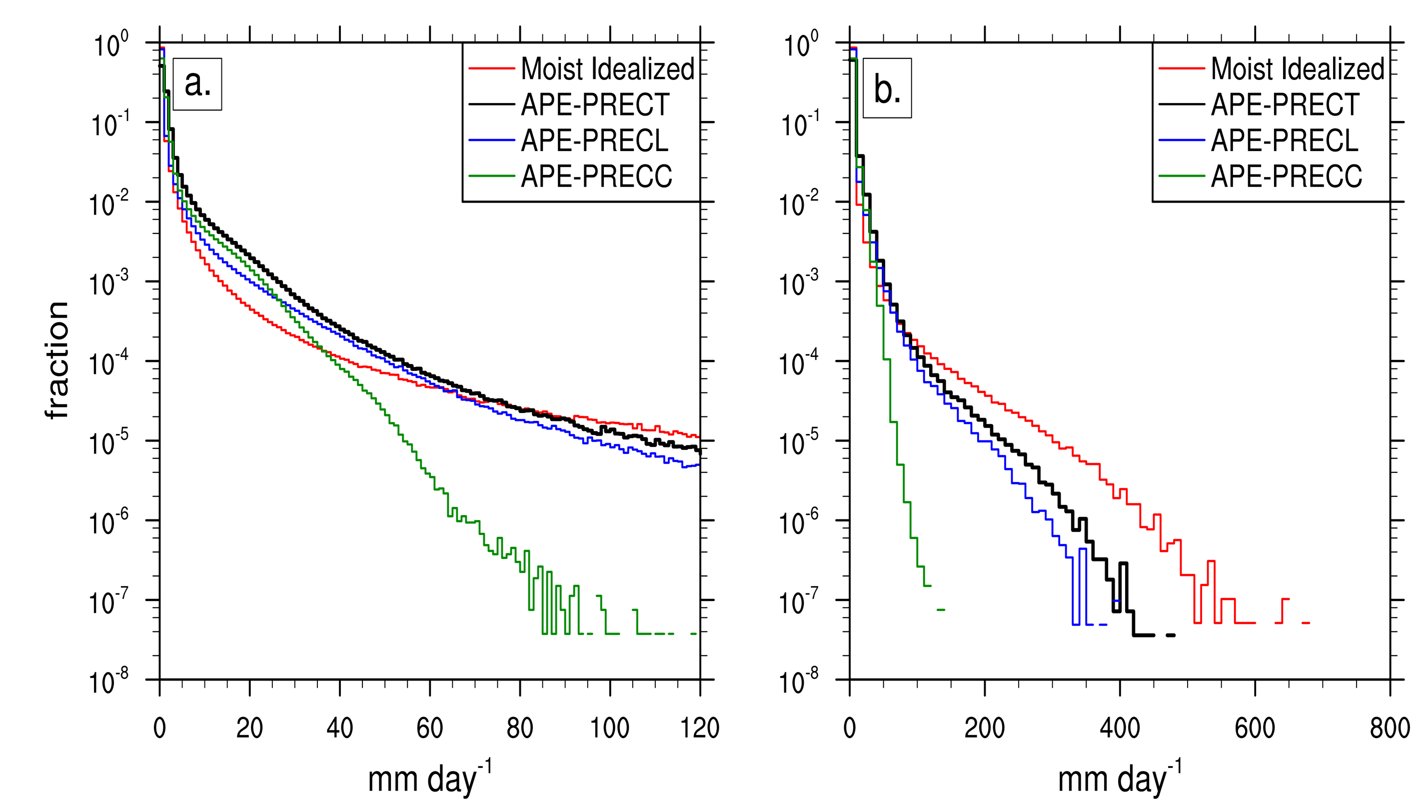


Figure 6. Histogram of precipitation rate for moist idealized (red) and aquaplanet (APE) total (PRECT - black), large-scale (PRECL - blue), and convective (PRECC - green). (a.) precipitation rate from 0 to 120 mm/day with 1 mm/day bins. (b.) precipitation rate from 0 to 800 mm/day with 10 mm/day bins.

Conclusions

- The new moist idealized test case provides a benchmark test of intermediate complexity
- The kinetic energy spectrum and the general circulation are successfully recreated when compared to aquaplanet simulations
- The large-scale condensation and precipitation provides sufficient convection to produce equatorial Kelvin waves
- The latitudinal distribution of precipitation agrees with the large-scale precipitation of aquaplanet
- High-rate events, though more numerous than in aquaplanet, are a significantly smaller fraction of the total number of events compared to low-rate events, therefore the average precipitation rate is lower than aquaplanet