A moist variant of the Held-Suarez test for atmospheric model dynamical core intercomparison

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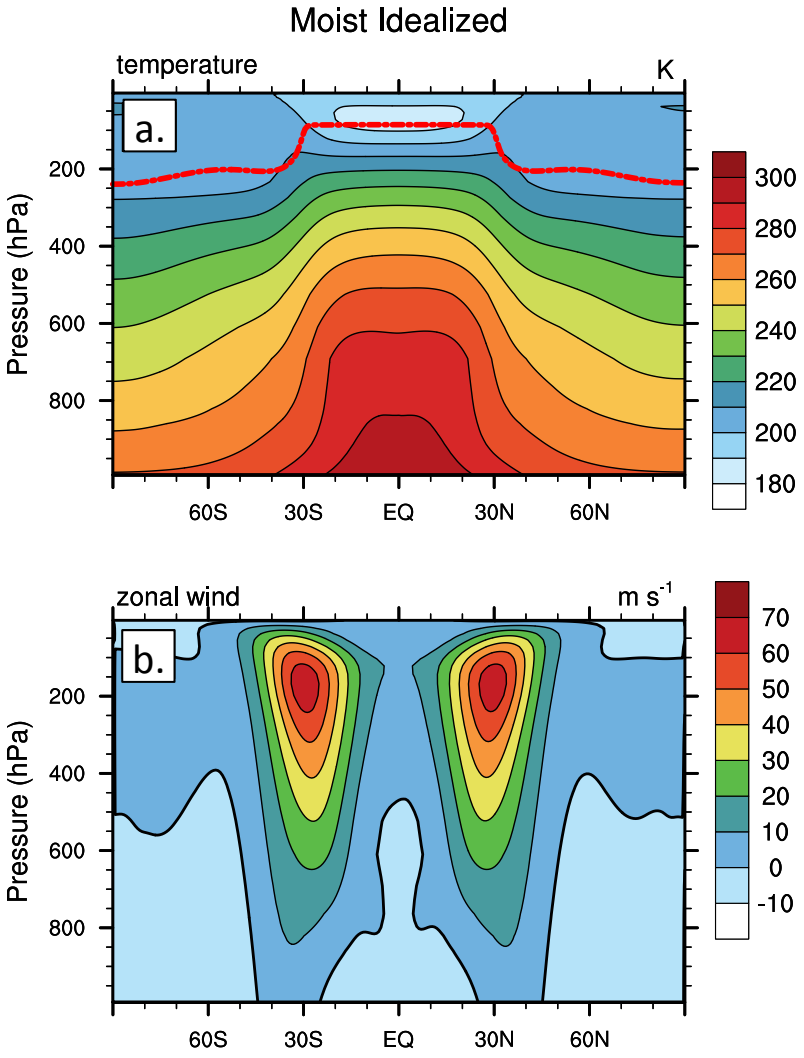
Dry physics modified from Held and Suarez (1994)

- Newtonian temperature relaxation
- Boundary layer mixing of momentum
- Surface friction for momentum

Moist physics modified from Reed and Jablonowski (2012)

- Prescribed sea surface temperature
- Surface fluxes of latent and sensible heat
- Boundary layer mixing of temperature and moisture
- Large-scale condensation and precipitation



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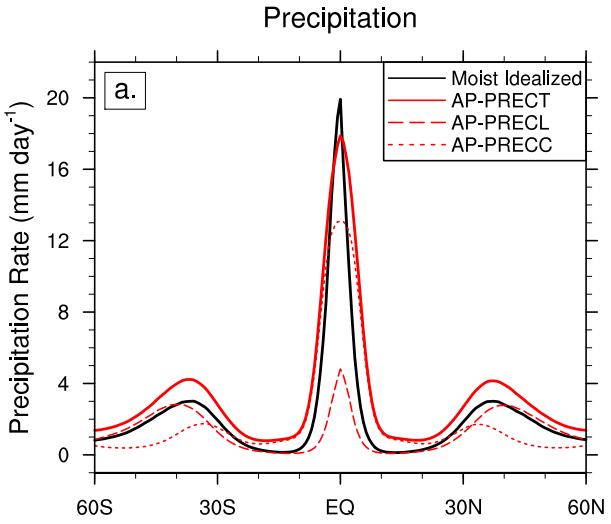

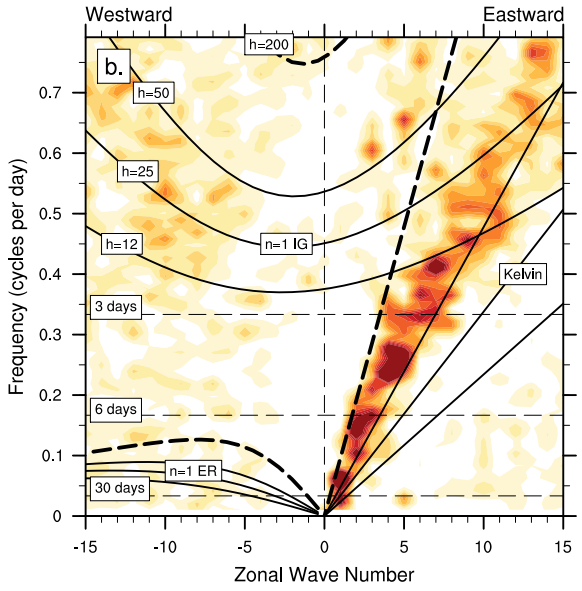

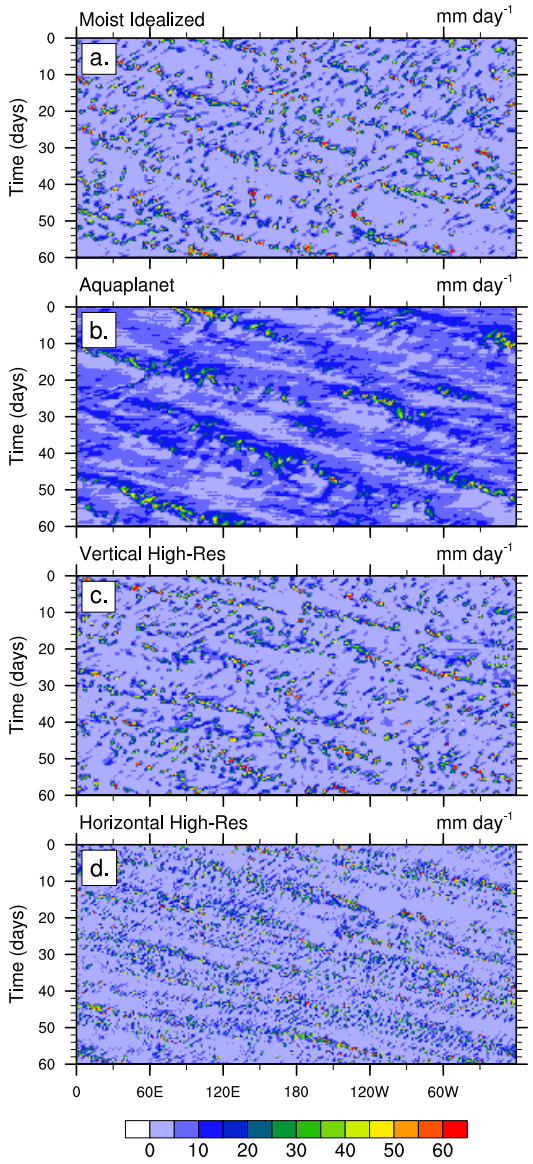

- Simple large-scale precipitation is sufficient to generate typical average precipitation distribution
- Even without convection parameterizations, Kelvin waves are present in equatorial regions
- The results using simplified moist physics are comparable to full physics simulations
- The test case is suitable for dynamical core intercomparisons with an idealized moist atmosphere

A Moist Variant of the Held-Suarez Test for Atmospheric Model Dynamical Core Intercomparisons

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PDEs — The Workshop on Partial Differential Equations on the Sphere

Background

Simplified test cases are essential for testing the performance of the dynamical core the solves that fluid-flow equations. Idealized tests allow analysis of underlying numerical techniques of dynamical cores without effects from the physical parameterizations. The newly moist idealized test case is based on the idealized test for dry dynamical cores by Held and Suarez (HS). The inclusion of moisture is important when considering physics-dynamics coupling processes, such as the transport and release of latent heat.

This new moist HS test uses simplified moist processes modified from Reed and Jablonowski and an ocean-covered planet to include the impact of moisture. Simulations of the moist idealized test case are compared to aquaplanet simulations. The moist idealized test case successfully reproduces many features of the general circulation, including precipitation distribution and convectively coupled equatorial waves, with simplified moist physics and a computationally efficient model setup.

Moist Idealized Physics

- Based on the Held and Suarez (1994) dry test case for dynamical cores
  - Modified Newtonian relaxation toward a prescribed temperature profile
  - Rayleigh damping of low-level horizontal winds
- Simplified moist physics modified from Reed and Jablonowski (2012)
  - Prescribed sea surface temperature profile
  - Large-scale condensation and precipitation
  - Boundary layer turbulence for temperature and moisture
  - Latent and sensible heat fluxes at the surface
- Moist idealized test case compared to CAM-SE aquaplanet simulations that use full physical parameterizations

	Global Precip. (mm/day)	Equator Precip. (mm/day)	Global Temp. (K)	Global Total Energy (10^9 J/m^2)
Moist Test: 110km L30	2.108	20.16	246.36	2.563
Moist Test: 110km L59	2.110	19.72	246.28	2.562
Moist Test: 55km L30	2.256	25.94	246.90	2.569
Aquaplanet	3.214	17.85	246.94	2.572

Table 1: Summary of weighted average precipitation, temperature, and column integrated total energy for all simulations.

General Circulation

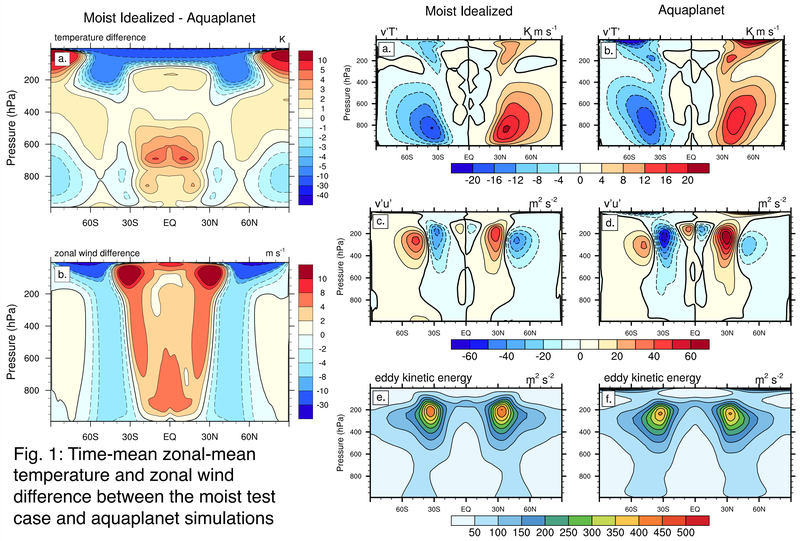


Fig. 1: Time-mean zonal-mean temperature and zonal wind difference between the moist test case and aquaplanet simulations

Fig. 2: Comparison of the latitude-pressure profile of eddy values for moist idealized (left) and aquaplanet (right) for time-mean, zonal-mean eddy variance of meridional flux of temperature $v'T'$, eddy variance of meridional flux of zonal momentum $v'u'$, and eddy kinetic energy. The test case matches the structure and magnitude reasonably well, except in the stratosphere.

Precipitation

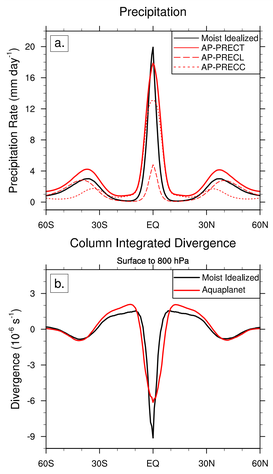


Fig. 3: (a) precipitation rate and (b) column integrated divergence.

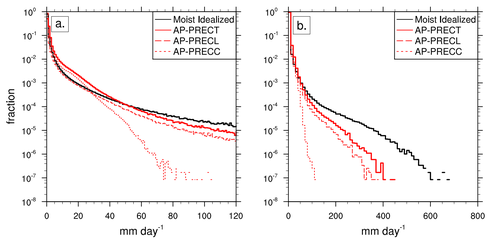
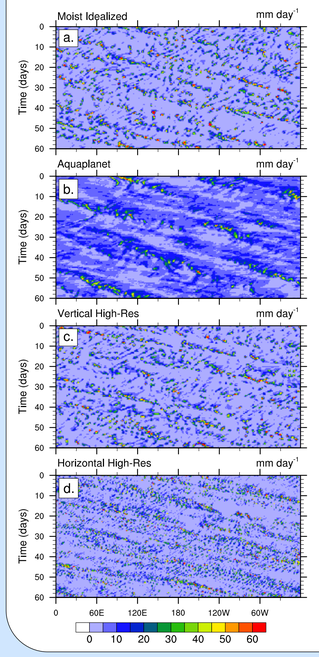


Fig. 4: Fraction of precipitation rate in 1 and 10 mm/day bins.

- Moist idealized test precipitation is only large-scale and depends on low-level convergence (Fig. 3b)
  - Overall rates are comparable to aquaplanet total (AP-PRECT), the sum of convective (AP-PRECC) and large-scale (AP-PRECL) precipitation
- Due to its large-scale nature, the test case builds up more moisture in the atmosphere and precipitates in high-rate events as the entire grid cell reaches saturation (Fig. 4)

Wave Activity

Fig. 5: Hovmöller diagram of precipitation rate (5S-5N) for the (a) moist idealized test, (b) aquaplanet, and the moist test with increased (c) vertical and (d) horizontal resolution.



- Precipitation bands in all four simulations have similar slopes
- Aquaplanet has more precipitation at low rates (5-20 mm/day) due to convection parameterization
- The moist idealized test has a strong signal for non-convectively coupled 'dry' Kelvin waves (thick dashed line)
- Aquaplanet has some weaker signals for dry Kelvin waves

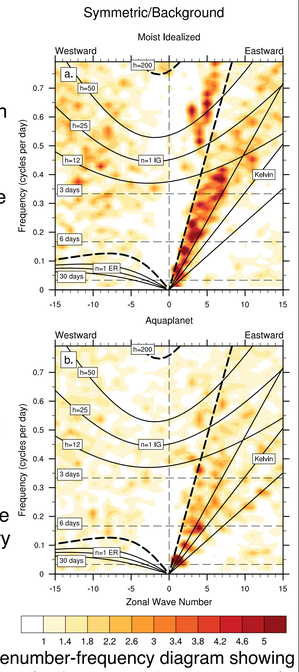


Fig. 6: Wavenumber-frequency diagram showing spectral power for the symmetric component of temperature (100 hPa, 15S-15N).

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 preparation*

Effects of Resolution

- *Note*: for increased vertical resolution the position of the lowest model level is unchanged
- Vertical resolution has little effect on precipitation rate, eddy heat and momentum transport ($v'T'$ and $v'u'$), and equatorial wave activity
- Increasing vertical resolution corresponds with increases eddy kinetic energy
- Horizontal resolution has little effect on eddy momentum transport $v'u'$ and eddy kinetic energy
- Increasing horizontal resolution leads to:
  - Decreased eddy heat transport $v'T'$
  - Decrease in dry Kelvin wave activity, while moist Kelvin wave activity strengthens slightly
  - Increased global average precipitation from 2.108 to 2.256 mm/day because individual grid cells are better able to reach saturation as the grid size decreases

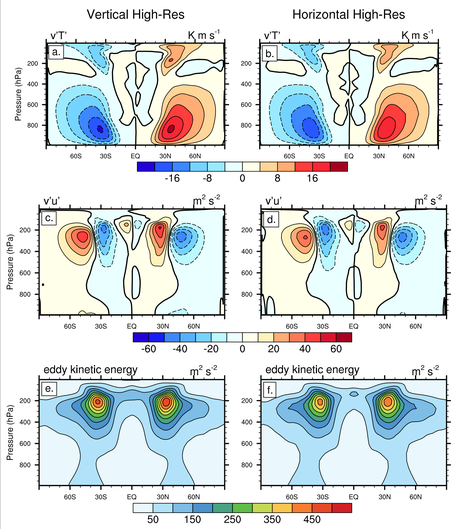


Fig. 2: Comparison of the latitude-pressure profile of eddy values for the test case with increased vertical (left) and horizontal (right) resolution for time-mean, zonal-mean eddy variance of meridional flux of temperature $v'T'$, eddy variance of meridional flux of zonal momentum $v'u'$, and eddy kinetic energy.

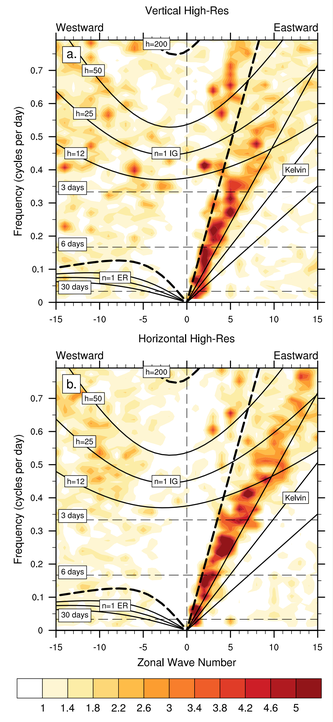


Fig. 8: Wavenumber-frequency diagram showing spectral power for the symmetric component of equatorial temperature (15S-15N) at 100 hPa for the moist idealized test with increased (a) vertical resolution 110kmL59 and (b) horizontal resolution 55kmL30.

Conclusions

- The new moist idealized test case provides a computationally efficient benchmark test of intermediate complexity
- The temperature, zonal wind, eddy kinetic energy, and eddy transport of heat and momentum are successfully recreated when compared to aquaplanet simulations
- The precipitation using only large-scale condensation is sufficient to reproduce the zonal precipitation distribution of aquaplanet simulations
  - The moist idealized test case precipitation rate is sensitive to horizontal resolution and precipitation increases with resolution
- The simplified large-scale condensation and precipitation of the moist idealized test provides sufficient convection to produce non-convectively coupled equatorial Kelvin waves in addition to convectively coupled Kelvin waves
- The test case produces a quasi-realistic climate and is therefore suitable for testing and intercomparing dynamical cores in a simplified moist setting