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

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Background

Simplified test cases are essential for testing the performance of the dynamical core of atmospheric models. These tests allow analysis of underlying numerical techniques of dynamical cores without effects from the physical parameterizations. The new 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

General Circulation

- Model resolution: Aqua 110 km, 59 levels; Wet NCEP 55 km, 30 levels
- 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

Wave Activity

- Precipitation bands in all four simulations have similar slopes
- Aquaplanet has more precipitation bands than the moist idealized test case
- The moist idealized test case precipitation rate is sensitive to horizontal resolution

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

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Precipitation (mm/day)</th>
<th>Temperature (K)</th>
<th>Total Energy (TW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moist Test: 110 km</td>
<td>2.108</td>
<td>291.6</td>
<td>246.363</td>
</tr>
<tr>
<td>Moist Test: 220 km</td>
<td>2.110</td>
<td>291.9</td>
<td>246.382</td>
</tr>
<tr>
<td>Moist Test: 55 km</td>
<td>2.176</td>
<td>292.2</td>
<td>246.456</td>
</tr>
<tr>
<td>Aquaplanet: 55 km</td>
<td>3.214</td>
<td>293.5</td>
<td>246.953</td>
</tr>
</tbody>
</table>

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.

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-PREICT), the 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)

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

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 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. 6: Wave number-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 110 km 59 and (b) horizontal resolution 55 km 30.

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 new moist idealized test case 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

References

