Parameterized Convection, Grid-Scale Clouds and Resolution Sensitivity in CAM-SE-CSLAM

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The Curious Case of Convection

Parameterized Deep Convection Less Active with Increasing Resolution


Williamson (2013)
Higher resolution simulations typically use smaller physics time-steps.

- Deep convection scheme removes instability at $\sim$ (fixed rate $\times$ $\Delta t_{phys}$)
- Grid-scale clouds remove remaining instability instantaneously

Convergence tests with fixed physics time-step,
Deep convection still less active with resolution
Deep Convection in CAM

AKA Stratiform clouds
AKA Gird-scale clouds

Schematic courtesy of AMWG
Theory...

Equations of Motion have inherent scale dependencies at hydrostatic scales

Vertical velocity scale due to the Archimedesan Buoyancy, $B_0$

$$W = \sqrt{B_0 H H / D}$$

**Assume $D \sim \Delta x$, $B_0$ and $H$ are cnst**

$$\frac{W_1}{W_2} = \frac{\Delta x_2}{\Delta x_1}$$

Orlanski 1981; Jeevanjee and Romps (2015); Herrington and Reed (2018)
Theory...

Equations of Motion have inherent scale dependencies at hydrostatic scales

Vertical velocity scale due to the Archimedean Buoyancy, $B_0$

$$W = \sqrt{B_0 H^2 / D}$$

**Assume $D \sim \Delta x$, $B_0$ and $H$ are const

$$\frac{W_1}{W_2} = \frac{\Delta x_2}{\Delta x_1}$$

Orlanski 1981; Jeevanjhee and Romps (2015); Herrington and Reed (2018)
Aqua-planets follow the scaling

\[ P(\omega)_{\text{ne}120} = \alpha P(\omega/\alpha), \]
\[ \alpha = \frac{\Delta x_{\text{ne}120}}{\Delta x} \]

<table>
<thead>
<tr>
<th>Grid name</th>
<th>( \Delta x_{\text{dyn}} )</th>
<th>( \Delta t_{\text{dyn}} )</th>
<th>( \Delta t_{\text{phys}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>ne20pg3</td>
<td>166.8km</td>
<td>450s</td>
<td>2700s</td>
</tr>
<tr>
<td>ne30pg3</td>
<td>111.2km</td>
<td>300s</td>
<td>1800s</td>
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<tr>
<td>ne40pg3</td>
<td>83.4km</td>
<td>225s</td>
<td>1350s</td>
</tr>
<tr>
<td>ne60pg3</td>
<td>55.6km</td>
<td>150s</td>
<td>900s</td>
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<tr>
<td>ne80pg3</td>
<td>41.7km</td>
<td>112.5s</td>
<td>675s</td>
</tr>
<tr>
<td>ne120pg3</td>
<td>27.8km</td>
<td>75s</td>
<td>450s</td>
</tr>
</tbody>
</table>
Global Mean Climatology

\[ \bar{\omega} = \bar{f}_u \times \bar{\omega}_u + \bar{f}_d \times \bar{\omega}_d \]
Global Mean Climatology

Pearson’s R
0.98867399
Zonal Means

Total Precipitation Rate (mm/day)

Latitude

$\mathbf{f}_d \mathbf{\Omega}_d$ (hPa/day)

Latitude

ZM Precipitation Rate (mm/day)

Latitude

Frequency of ZM-trigger

Latitude
+/- 10° Latitude

$\langle \omega \rangle > 0$

$\langle \omega \rangle > \text{bar} \langle \omega_d \rangle$
$+/\!-\! 10^\circ$ Latitude

$\langle \omega \rangle < 0$

$\langle \omega \rangle > 0$

$\langle \omega \rangle > \bar{\langle \omega_d \rangle}$

Everywhere $+/\!-\! 10^\circ$ Latitude
Conclusions

- Deep Convection Scheme is designed to produce stratiform clouds in upper-troposphere.
- The following is observed to occur in the Tropics with an increase in resolution:
  - **Magnitude** of stratiform induced resolved vertical motion increases like $\Delta x^{-1}$
  - Areal **extent** of these ‘updrafts’ **decrease**
  - Areal **extent** and **magnitude** of resolved compensating subsidence both **increase**
  - Deep convection triggers less frequently, and is highly correlated with subsidence.
- Evidence suggests the increase in resolved subsidence dries and stabilizes the Tropics, reducing convective triggering.
- Consistent with tropical drying over the W. Pacific Warm Pool at high resolution (Bacmeister et al. 2014, see Xiaoning’s talk later).

Resolution sensitivity has a simple origin: higher resolution grids support tighter gradients.