Evaluating the Physics at a Lower Resolution in CAM-SE-CSLAM

Advanced Study Program
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Collaborator: Steve Goldhaber

Ph.D Advisor: Kevin A. Reed
(MWIR, in review)

\textbf{Dynamics}

\begin{align*}
np &= 4 \\
\text{CSLAM} &= 3 \times 3
\end{align*}

\textbf{Tracer Transport}

\begin{align*}
A_1 & \quad A_2 & \quad A_3 \\
A_4 & \quad A_5 & \quad A_6 \\
A_7 & \quad A_8 & \quad A_9
\end{align*}

\textbf{Physics}

\begin{align*}
pg &= 3 \\
pg &= 2
\end{align*}

\textbf{neXXpg3'}

\begin{align*}
A_1 & \quad A_2 & \quad A_3 \\
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\textbf{neXXpg2'}

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\end{align*}
(MWR, in review)

\[ \text{np} = 4 \]

\[ \text{CSLAM} = 3 \times 3 \]

\[ \text{pg} = 3 \]

\( \text{neXXpg3} \)

\( \text{neXXpg2} \)
Fix Dynamics, Decrease Topo Res.
(but, same smoothing radius – C92)

<table>
<thead>
<tr>
<th>Grid name</th>
<th>$\Delta x_{dyn}$</th>
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<tbody>
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<td>ne30pg2</td>
<td>111.2km</td>
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Dynamics Grid Spacing
- Hyper-Viscosity Scaling
- Topographic Smoothing Radius

Physics Grid Spacing:
- Topography lives here
- Physics evaluated here
Fix Dynamics, Decrease Topo Res.
(but, same smoothing radius – C92)
Fix Dynamics, Decrease Topo Res.
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Fix Dynamics, Decrease Topo Res.
(but, same smoothing radius – C92)
Let's talk about moisture

Need to do some tricks to conserve mass while maintaining shape preservation (CSLAM <-> pg2).

Scale the mixing ratio tendencies by **available mass**, above which does not produce local extremes (shape preserving, preserves linear correlations and mass).

OK, now we are ready to for some CAM6 aqua-planet** results. But first, what is the expected sensitivity to grid resolution?

** Special thanks to all involved in the CESM2 Simple Models compsets
Theory...

Equations of Motion have inherent scale dependencies at hydrostatic scales

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

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

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

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

Orlanski 1981; Jeevanjee and Romps (2015); Herrington and Reed (2018)
Scaling across the board

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<tr>
<td>ne60pg3</td>
<td>55.6km</td>
<td>150s</td>
<td>55.6km</td>
<td>900s</td>
</tr>
<tr>
<td>ne120pg3</td>
<td>27.8km</td>
<td>75s</td>
<td>27.8km</td>
<td>450s</td>
</tr>
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Forcing Scale

PDF upward motion

$P(\omega_1) = \alpha \times P(\omega_0/\alpha)$ (scaled to ne120pg3)
Equations of Motion have inherent scale dependencies at hydrostatic scales

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

\[
W = \frac{W_1}{\alpha}, \quad \alpha = \frac{\Delta x_2}{\Delta x_1}
\]

Orlanski 1981; Jeevanjee and Romps (2015); Herrington and Reed (2018)
ne20pg3 v. ne30pg2: are they the same?

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PDF upward motion

\[ P(\omega_1) = \alpha \cdot P(\omega_0/\alpha) \] (scaled to ne30pg3)

Scaled by $\Delta x_{\text{PHYS}}$
ne20pg3 v. ne30pg2: are they the same?

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PDF upward motion

$$P(\omega_1) = \alpha \times P(\omega_0/\alpha)$$
(scaled to ne30pg3)

Scaled by $\Delta x_{phys}$
ne20pg3 v. ne30pg2: are they the same?

At $\Delta x_{\text{PHYS}} / \Delta x_{\text{DYN}} = 1.5$, ‘D’ can only be proportional to $\Delta x_{\text{PHYS}}$ if hyper-viscosity coeff. scales with $\Delta x_{\text{PHYS}}$

PDF upward motion

$$P(\omega_1) = \alpha \times P(\omega_0 / \alpha)$$
(scaled to ne30pg3)
The Ambiguity of the Grid-Scale

Velocity Scale is insensitive to small departures of $\Delta x_{\text{PHYS}}$ from $\Delta x_{\text{DYN}}$ due to the efficiency of hyper-viscosity operators near the grid-scale.

Example hyper-viscosity response function near the grid scale (Whitehead et al. 2011)
Low vs. High order mapping

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*low order mapping ( bilinear in pg2->dyn, PCoM in CSLAM<->pg2 )

Forcing Scale (on phys)

Forcing Scale (on dyn)
Low vs. High order mapping

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*low order mapping (bilinear in pg2->dy, PCoM in CSLAM<->pg2)

Forcing Scale (on dyn)

PDF upward motion
Low vs. High order mapping

Due to the high-order mapping, the forcing scale in neXXpg2 is very similar to neXXpg3
What about the mean state?

Mass weighted, area averages +/- 10 deg from equator, 1 year means

\[ \bar{\omega} = \bar{f}_u \ast \bar{\omega}_u + \bar{f}_d \ast \bar{\omega}_d \]

Blue = neXXpg2  Diamond : zm_conv_cin = 5
Red  = neXXpg3  Cross : zm_conv_cin = 1
What about the mean state?

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What about the mean state?
What about the mean state?

Bacmeister et al. (2014) finds the double-ITCZ doubles-down going from 1 deg. ->0.25 deg in a PD run.
Conclusions

• Noise from topography is reduced in neXXpg2, relative to neXXpg3
  • $1.5 \Delta x_{\text{DYN}}$ control volumes smooth noisy boundary nodes
  • each control volume has an equal sampling of node types

• In aqua-planets, $W$, and therefore Forcing Scale (‘D’), do not scale with $\Delta x_{\text{PHYS}}$, but rather $\Delta x_{\text{DYN}}$. This is in part due to h.o. mapping of phys. tendencies, but primarily a result of ambiguity in the ‘near grid-scale’ thanks to hyper-viscosity
  • Here, $\Delta x_{\text{PHYS}} / \Delta x_{\text{DYN}}$ is no greater than 1.5
  • Williamson (1999) takes it to $\sim 2.5$, where it does seem like $\Delta x_{\text{PHYS}}$ is influencing $W$ in a substantial way

• After optimization of the mapping code
  • 25% cost savings in CAM6
  • Would ne60pg2 be in reach of widespread use?
    (6X more expensive than ne30pg3, instead of 8X)
### Grid Spacing

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**Dynamics Grid Spacing**
- Hyper-Viscosity Scaling
- Topographic Smoothing Radius

**Physics Grid Spacing**
- Topography lives here
- Physics evaluated here
Fix Topography, Increase Dynamics

(but, same smoothing radius – C138)

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- same topography file (same smoothing radius, C138)

- Increase dynamics resolution from 166.8 km -> 111.2 km (viscosity coefficients scaled)
Scaling ‘D’ with $\Delta x_{\text{DYN}}$: idealized test

Simple rising moist plume experiments (Herrington and Reed 2018)
Scaling ‘D’ with $\Delta x_{\text{DYN}}$ : idealized test

Simple rising moist plume experiments (Herrington and Reed 2018)

Vary ‘D’ in proportion to $\Delta x_{\text{DYN}}$:

*Grey lines,

$$W_2 = W_1 \times \Delta x_1 / \Delta x_2$$
Sensitivity to ‘D’ at fixed $\Delta x_{\text{DYN}}$

Simple rising moist plume experiments (Herrington and Reed 2018)

*Grey lines, $W_2 = W_1 \frac{\Delta x_1}{\Delta x_2}$*