A first look at multi-resolution CAM-MPAS AMIP simulations

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Thanks also to Mark Taylor (CAM-SE results) and Peter Lauritzen (topography)
We don’t know the best way to obtain regional climate information.

Limited area or regional climate models

Global Uniform Resolution (Low and High Resolution)

Global Variable Resolution or “Multi-Resolution”

The regional chapter in the IPCC AR4 was based mostly on global uniform resolution.
How can we evaluate the “added value” of our high resolution region in the variable resolution simulation?

• Can we “match” the high resolution quasi-uniform simulation (the “truth”)? (or even resemble it?)
• Is there an “upscale” effect from the VR high resolution region to the rest of the VR simulation?
• How are the physical parameterizations working (or not) inside and outside of the VR high resolution region?

And how does CAM-MPAS compare with other dycores?
Experiments

- **Held-Suarez (H-S):** simplified physics, dry: dynamically induced circulation is not influenced by interactions with the physical parameterizations.

- **Aquaplanet (APEs):** full model physics but prescribed zonally symmetric SSTs, no sea ice, no land, perpetual equinox: we expect zonal and hemispheric symmetry.

- **AMIP:** 1999-2009, first year discarded for spin-up, T341 physics settings from ORNL.

- **Model for Prediction Across Scales Atmosphere (MPAS-A):** Dynamical Core coupled to CAM by LLNL (Art Mirin, Dan Bergmann, Jeff Painter)
  - unstructured conforming grid
  - most cells are hexagonal
  - hydrostatic, finite volume approach
  - all simulations use CAM4 physics
  - unsmoothed topography provided by Peter Lauritzen.
## CAM-MPAS simulations

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Hyper-diffusion</th>
<th>Physics time step (APE/AMIP) (seconds)</th>
<th>Dynamics time step (seconds)</th>
<th>Simulation Length (years) Run/analysis length</th>
</tr>
</thead>
<tbody>
<tr>
<td>~240km (10242 cells)</td>
<td>5e15</td>
<td>600/900</td>
<td>100</td>
<td>5/4.5 11/10 (1999-2009)</td>
</tr>
<tr>
<td>~30km (655362 cells)</td>
<td>5e12</td>
<td>600/900</td>
<td>100</td>
<td>5/4.5 11/10 (1999-2009)</td>
</tr>
<tr>
<td>VR x8 ~30 to ~240km (65538 cells)</td>
<td>Scaled by mesh density from 5e15 to 5e12</td>
<td>600/900</td>
<td>100</td>
<td>5/4.5 11/10 (1999-2009)</td>
</tr>
</tbody>
</table>

All simulations use CAM4 physics/no resolution tuning is performed. Aquaplanet simulations use CAM4 aquaplanet use-case, AMIP use settings from T341 (ORNL).
Variable Resolution (VR) CAM-MPAS

In the VR simulation, we span the grid spacing range of our QUR simulations: 30-240km

High resolution region is continental scale (typical RCM domain), 60 degrees N/S, E/W.
90% of grid points are in the high resolution region – cost is 10% of QUR
Undesirable zonal asymmetry is present in VR simulation.
VR Gill Response

Precipitation departure from zonal mean (shaded) mm/day and 200 hPa eddy streamfunction m² s⁻¹, divided by 10⁶

200 hPa eddy velocity potential m² s⁻¹, divided by 10⁶

Bottom: Jin and Hoskins (1995) Fig. 2c
Precipitation departure from zonal mean (shaded) mm/day and 200 hPa eddy streamfunction m$^2$ s$^{-1}$, divided by 10e6

200 hPa eddy velocity potential m$^2$ s$^{-1}$, divided by 10e6
Blame it on the rain?

200 hPa eddy velocity potential m² s⁻¹, divided by 10e6

Full CAM4 physics

Held-Suarez
Years 3-4 of integration
(1800 day integration normal)
Asymmetry depends on Fine: Coarse Mesh Ratio and Fine Mesh Region Location

X8 (30km->240km)  X4 (30km->120km)

200 hPa eddy velocity potential m² s⁻¹, divided by 10e6
CAM-MPAS AMIP Simulations

- Are they CAM-like?
- Can we match the QUR 30km simulation in the VR region? Is there an upscale effect? Do we see the same responses to the mesh as in aquaplanet?

Simulations: 30km QUR, 240km QUR
30->240km VR centered at 90W, 30N
Is CAM-MPAS CAM-like?
Annual temperature (K), DJF zonal winds (m/s), 2000-2008

ANN CROSS SECTION ZONAL TEMPERATURE

2000-2008 averages

CAM-SE simulation graphics courtesy of Mark Taylor
Is CAM-MPAS CAM-like?
Annual Precipitation (mm/day), 2000-2008

Noisier, weaker Atlantic ITCZ
stronger western Pacific convection

CAM-SE data courtesy Mark Taylor
Annual precipitation appears similar over the VR HR region and the QUR HR simulations.
The real world is not zonally symmetric so we analyze the AMIP simulations differently to evaluate the VR error.

\[
GHR - GVR = (GHR - GLR) - (GVR - GLR)
\]

\[
30km - VR = (30km - 240km) - (VR - 30km)
\]

• GHR: Quasi-uniform 30km resolution grid
• GLR: Quasi-uniform 240km resolution grid
• GVR: Variable resolution grid 240km -> 30km
Differences are smaller between 30km and VR than between 30km and 240km in HR region.

\[
\text{30km-VR} \\
\text{“Error”} \\
\text{=} \\
\text{30km-240km Resolution Effect} \\
\text{minus} \\
\text{VR-240km Upscale/Downscale}
\]

2000-2008 averages
Breaking down the resolution and mesh effects: 200 hPa Eddy Velocity Potential Differences \( (m^2 s^{-1}, \text{divided by } 10^6) \)

30km-VR
"Error"

= 

30km-240km
Resolution Effect

minus

VR-240km
Upscale/Downscale

2000-2008 averages
AMIP and APE upscale effects are similar.
Summary

• Aquaplanet/Held-Suarez: Asymmetry in VR simulations appears to be introduced by physics; magnitude of response depends on mesh fine:coarse ratio and location of high resolution region

• AMIP
  – Basic comparisons show CAM-MPAS behaves like other dycores.
  – Comparisons between 30km and VR simulations show smaller differences in high resolution region compared to 240km simulation
  – VR simulation shows same upscale effects found in APE simulation.
  – There are still big issues to resolve: Noisiness in precipitation field, \( \text{RESTOM} \neq \text{RESSURF} \ (\approx 5 \text{ W m}^{-2}, \text{RESTOM} > \text{RESSURF}) \)

• Future: further evaluation, fixes for issues, moving to CAM5 physics via nonhydrostatic version on CESM trunk (NCAR/MMM)

Issues to resolve: noise in precipitation fields, particularly at coarser (120, 240km) resolution

2x APE dissipation (1e15)

March 1999 precipitation, 120km
Why does the precipitation field look noisier at 2x?

½x APE dissipation (2.5e14)
Conservative Remapping

Figure 1: Illustration of our gridding methodologies using the CNRM model as an example. For each method, the CA average is the area-weighted average of all colored cells.

From Caldwell (2010)
Diabatic Heating Anomaly

Cross section averaged from 5S to 5N
U (vectors) and Q (shaded)

Temp tendency due to moist processes (K/day)

Cross section averaged from 5S to 5N
U (vectors) and Q (shaded)

High-res region

Temp tendency due to moist processes (K/day)

30km

240km

VR

VR EQ

240km
Are you really sure you can blame it on the rain?

Cross-sections of U and V

30km QUR – 240km QUR
Errors show seasonal variability.

JJA DJF

2000-2008 averages