High-resolution simulations using CAM (4 and 5)

Julio Bacmeister

With lots of help - will try to cite at appropriate places

Thanks to: Warren Washington, Jim Hack and DoE for computer time at ORNL

AMWG Meeting February 16, 2011
Outline

1) Rough description of “quarter degree” configurations

2) CAM4 and CAM5 resolution sensitivity (2 vs ¼ degree)
   - CAM4 clouds are more sensitive

3) Means, variability and statistics
   - Mixed bag

4) Precipitation loading effects
   - Seem to be important
High resolution 0.23x0.31 configurations

CAM4: out-of-the-box

CAM4-ice: *Ice cloud radii dependence on T changed* , **(with Cecile Hannay and Rich Neale)**

CAM5: fully prognostic aerosols

CAM5-BAM: *using prescribed bulk aerosols. (2x speed-up)* (thanks to Andrew Gettelman)

* $r_e=25 \mu \text{m}$ for $T<224K$ linear decrease to $10 \mu \text{m}$ at $T=273K$

**Used in 1989-2005 AMIP run and future time slice**
Sensitivity to horizontal resolution
(or time step?)
Well tuned at 2 degree resolution.
Drops sharply at 0.25 -- esp. in storm tracks
(30% global decrease, factor of two in midlatitudes)
CAM 5 LWCF

Starts with more bias at 2 degree but
Less sensitive to resolution in midlatitudes
CAM4 clouds tend to go away at high resolution.

Mid and high-level clouds decrease by a factor of two.
CAM5 clouds are nearly insensitive to resolution

... small decrease in mid and high-levels
<table>
<thead>
<tr>
<th>Model</th>
<th>LWCF (Wm⁻²)</th>
<th>SWCF (Wm⁻²)</th>
<th>CLDMED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 deg</td>
<td>¼ deg</td>
<td>2 deg</td>
</tr>
<tr>
<td>CAM4</td>
<td>30</td>
<td>21</td>
<td>-54</td>
</tr>
<tr>
<td>CAM4-ice</td>
<td>29</td>
<td>29</td>
<td>-49</td>
</tr>
<tr>
<td>CAM5</td>
<td>22</td>
<td>18</td>
<td>-50</td>
</tr>
<tr>
<td>CAM5-BAM</td>
<td>18</td>
<td>-52</td>
<td></td>
</tr>
</tbody>
</table>
Analysis of high frequency cloud output from CAM4 at T85 and T341

One month (January) of hourly instantaneous output

Thanks to John Truesdale and Julie Caron
Blue curves are means over “cool” ocean points (273K<T_{sfcair}<292K)
Most of midlatitude decrease in LWCF takes place over cool oceans.
Joint PDFs of cloud fraction and LWCF over cool ocean

(overlying high cloud <0.1)
Joint PDFs of cloud fraction and LWCF over cool ocean

Lots of fractions ~1.0 at **lower** resolution

(overlying high cloud <0.1)
Means, diurnal cycle, TCs
Precipitation patterns are relatively insensitive to resolution.
Precipitation patterns are relatively insensitive to resolution.

Some improvement: SE US winter precip up, NE tropical Pacific down. (Orography?)
Precipitation patterns are relatively insensitive to resolution

Some degradation – *ITCZs intensified, more “doubled”*

**CAM5 2°**

**CAM4 2°**

**CAM5 ¼°**

**CAM4 ¼°**

**GPCP**

**DJF**
Thanks to Rich Neale

Diurnal cycle of precip shows some improvement with resolution
All storms June 1, 2005 to November 1, 2006
Shading - moist entropy $s$; 
solid contours - angular momentum 
dashed contours – wind speed $V$

$$s = c_p \log(T) - R \log(p) + \frac{Lq}{T}$$
(e.g. Emanuel, 2003)
Large-scale rain dominates in cores of intense simulated cyclones.

Large-scale, total convective, shallow convective rain (50km)$^2$ average along tracks of top 12 storms from CAM5.
Precipitation Intensity Distributions and Extremes
PDFs of tropical precipitation (30S-30N) rates Aug 2005

Intensity (mm d⁻¹)
PDFs of tropical precipitation (30S-30N) rates Aug 2005

CAM5 - convective contribution (deep and shallow)

TRMM-3B42
PDFs of tropical precipitation (30S-30N) rates Aug 2005

Intensity (mm d⁻¹)

CAM5 - convective contribution (deep and shallow)

CAM5-NDC

TRMM-3B42
PDFs of tropical precipitation (30S-30N) rates Aug 2005

CAM5 - convective contribution (deep and shallow)

Too many extreme precip rates?
PDFs of tropical precipitation (30S-30N) rates Aug 2005

Intensity (mm d\(^{-1}\))

CAM5 - convective contribution (deep and shallow)

Frequency

<20 mm d\(^{-1}\)

>500 mm d\(^{-1}\)

>1000 mm d\(^{-1}\)

CAM5 - convective contribution (deep and shallow)

TRMM-3B42

CAM5-NDC
ALL

<20 mm d⁻¹

>500 mm d⁻¹

>1000 mm d⁻¹

Global mean = 3.09 mm d⁻¹

Global mean = 1.55 mm d⁻¹

Global mean = 0.10 mm d⁻¹

Global mean = 0.02 mm d⁻¹

CAM5a February 2006
TRMM 3B42 February 2006
Instantaneous precipitation rates are related to instantaneous convergence.

A couple of days in the tropics
Pressure in a non-hydrostatic WRF experiment

Effects of condensate loading

(WRF results provided by Aiguo Dai)
Dashed lines show 50x50 gp (25km x 25km) squares used to coarse grain WRF fields to produce “high-res AGCM” fields.
Hydrostatic Balance w/ and w/out condensate loading

\[ \pi_{hyd} = \int_{z}^{z_{top}} \frac{g}{c_p \Theta_{\{v,cond\}}} \, dz' + \pi_{top} \]

\[ p_{hyd} = p_{00} \pi_{hyd}^{1/\kappa} \]

w/out loading:

\[ \Theta_{v} = \Theta(1 + 0.61q) \]

with loading:

\[ \Theta_{cond} = \Theta\left(1 + 0.61q - q_{liq} - q_{ice} - q_{rain} - q_{grouop} - q_{snow}\right) \]
Net loading at surface (in Pa) as a function of surface precipitation rate.

\[ D_{\text{prec}} = 7000 \text{m} \]

\[ w_{\text{fall}} = 2.5 \text{ m s}^{-1} \]

Dashed red line shows net parameterized pressure loading from precipitating condensate as implemented in CAM5.
PDFs of tropical precipitation (30S-30N) rates Aug 2005

Parameterized precip loading in CAM5 (green line) removes extreme rates

Intensity (mm d⁻¹)

Frequency

CAM5 control

CAM5+parameterized precip loading
PDFs of tropical precipitation (30S-30N) rates Aug 2005

Parameterized precip loading in CAM5 (green line) removes extreme rates

Intensity (mm d\(^{-1}\))

Frequency

TRMM-3B42
CAM5 control
CAM5-NODC
CAM5+precip loading
CAM5+precip loading
Annual mean precipitation

**CAM5 control**

**w/ parameterized precipitation loading**

*Bad news: TC number also decreases*
Summary

CAM5 clouds somewhat less sensitive to resolution. CAM4 counterintuitively produces more fractions \( \sim 1 \) at low resolution than at high resolution.

In terms of climate means and statistics, impact of high resolution is mixed.

- some biases worsen, e.g., Pacific ITCZs
- some improve: SE US precip, diurnal cycles in some regions
Summary (cont.)

- Encouraging tropical cyclone climatologies and structures with CAM5 at 0.23x0.31 (Note: large-scale rain rather than convective appears to dominate tropical cyclone dynamics)

- Extreme precipitation (>500 mm d⁻¹ at 25² km²) events are probably too common. Parameterized condensate loading seems to help

⇒ Climate models at high-resolution may not be able to postpone adding consistent prognostic precipitation, including pressure effects

    More important than adding non-hydrostatic effects.

“Middling” precip (5-20 mm d⁻¹) is also too common – directly produced by convective parameterization(s)
Future Work

Add correct condensate loading along with prognostic precipitation to CAM (might need extra convective treatment)

Longer CAM5 integrations (with prescribed MAM?)

Compare CAM4 and CAM5 TC climatologies
The NESL Mission is:
To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

NCAR is sponsored by the National Science Foundation
Diagnosed hydrostatic surface pressure with and without condensate loading vs. coarse grained WRF surface pressure

Condensate loading matters – even in (25 km)$^2$ grid boxes
Net loading at surface (in Pa) as a function of surface precipitation rate
Parameterized precipitation loading

Surface precip rate $R_{\text{surf}}$ used to diagnose precipitating condensate density $\rho_{\text{prec}}$

\[ p_{\text{prec}}(x, y, z, t) = \frac{R_{\text{surf}}(x, y, t)}{w_{\text{fall}}} + \int_{z}^{7000m} g\rho_{\text{prec}} \, dz' \]

Extra condensate pressure is added to “real” model pressure right before horizontal gradients are calculated, then removed.