Adventures with CAM-CLUBB
Where we’ve been, where we’re going... and aerosol effects

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What is CLUBB?

• CLUBB = Cloud Layers Unified By Binormals

• First developed by Golaz et al. (2002), maintained by University of Wisconsin Milwaukee (Vincent Larson’s group)

• “Incomplete” third-order turbulence closure (predicting 9 second and third order moments), centered around a trivariate assumed double gaussian PDF

• Concurrently undergoing implementation into GFDL’s AM3 through CPT project

• Should provide a unified treatment of PBL and shallow convection, that drives a single microphysics scheme (Morrison and Gettelman 2008)
## Coupling CAM with CLUBB

<table>
<thead>
<tr>
<th>Physics</th>
<th>CAM5</th>
<th>CAM-CLUBB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Layer</td>
<td>Bretherton and Park (2009)</td>
<td>CLUBB</td>
</tr>
<tr>
<td>Shallow Convection</td>
<td>Park and Bretherton (2009)</td>
<td>CLUBB</td>
</tr>
<tr>
<td>Cloud Macrophysics</td>
<td>Park (2012)</td>
<td>CLUBB</td>
</tr>
<tr>
<td>Radiation</td>
<td>RRTMG (Iacono et al. 2008)</td>
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</tr>
</tbody>
</table>

- CLUBB time step is 5 minutes
- CLUBB called directly after deep convection and directly before microphysics
- Predicted vertical velocity variance used for aerosol activation
Where We’ve Been...

- CAM-CLUBB is overall competitive with CAM5 (a number of improvements, some degradations)
  - Bogenschutz et al. (2012) (Geosci. Model Dev.) documents SCM simulations
  - Bogenschutz et al. (2013) (J. Climate) submitted, documents global simulations
- Published configuration has been tested preliminarily in CESM
- CAM-CLUBB on development trunk and last CESM release (not the published configuration, yet)
Low Cloud Amount Biases

*All runs are 1 degree five-year simulations using FV dy-core*
Low Cloud Amount Biases

CAM5 - CLOUDSAT
mean = -1.26  
rmse = 12.39

CAM-CLUBB - CLOUDSAT
mean = -1.74  
rmse = 11.65

Shortwave Cloud Forcing Biases

CAM5 - CERES-EBAF
mean = -1.73  
rmse = 14.15 W/m²

CAM-CLUBB - CERES-EBAF
mean = -1.85  
rmse = 12.45 W/m²

* All runs are 1 degree five-year simulations using FV dy-core
Preliminary Coupled Simulation (CESM-CLUBB)

- 2 degree coupled simulation, using B1850 compset
- Averaged RESTOM -0.28 W/m². Can be tuned down.
- No indication of a drifting or runaway climate
- Overall climate metrics seem similar to AMIP runs
- Seems competitive with CESM, similar SST rmse
Where We’re Going...

CAM-CLUBB base code
Where We’re Going...

CAM-CLUBB base code

Sub-columns

Radiation (Bogenschutz)

Microphysics (Thayer-Calder, Bacmeister, Gettelman)
Where We’re Going...

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Sub-columns

Radiation (Bogenschutz)

Have CAM-CLUBB go deep (Chen, Gettelman, Bogenschutz)

Microphysics (Thayer-Calder, Bacmeister, Gettelman)

Monday, February 11, 2013
Where We’re Going...

CAM-CLUBB base code

Smaller development projects (i.e. testing with MG2, sub-step CLUBB & MG using “Caldwell” method, etc.)

Sub-columns

Radiation (Bogenschutz)

Have CAM-CLUBB go deep (Chen, Gettelman, Bogenschutz)

Microphysics (Thayer-Calder, Bacmeister, Gettelman)
Where We’re Going...

CAM-CLUBB base code

- Smaller development projects (i.e. testing with MG2, sub-step CLUBB & MG using “Caldwell” method, etc.)
- Sub-columns
  - Radiation (Bogenschutz)
  - Microphysics (Thayer-Calder, Bacmeister, Gettelman)
  - Have CAM-CLUBB go deep (Chen, Gettelman, Bogenschutz)

Science:
- Aerosol Effects
- Climate sensitivity
- Coupled simulations (etc.) (Bogenschutz, Gettelman, Morrison)

Monday, February 11, 2013
Aerosol Indirect Effect
Global Averages

<table>
<thead>
<tr>
<th>Simulation</th>
<th>RFP</th>
<th>( \Delta \text{SWCF} ) (present day - preindustrial)</th>
<th>( \Delta \text{LWCF} ) (present day - preindustrial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAM5 30L</td>
<td>-1.5</td>
<td>-1.7</td>
<td>+0.4</td>
</tr>
<tr>
<td>CAM-CLUBB 30L</td>
<td>-1.6</td>
<td>-1.8</td>
<td>+0.4</td>
</tr>
</tbody>
</table>

* All units W/m²

- CAM-CLUBB has roughly same AIE as CAM5 (albeit, bit higher estimates)
- Since CAM-CLUBB and CAM5 have very different formulations of turbulence/clouds, one could easily conclude that this is exclusively a microphysics problem
- But let’s examine this further...
Aerosol Effects in AM3-CLUBB

From Guo et al. (2011)
Aerosol Effects in AM3-CLUBB

From Guo et al. (2011)

Solid curves: AM3-CLUBB
Dashed curves: LES

Questions:

1) Can CAM-CLUBB and/or CAM5 replicate this?
2) What vertical/temporal resolution is required?
3) Does sub-stepping CLUBB/macrophysics in concert with MG help replicate this behavior for CAM-CLUBB/CAM5?
DYCOMS2-RF01
(Sc with very dry free troposphere)

- At operational configuration, excessive sensitivity to lower Nd’s for CAM-CLUBB
- CAM5, much less sensitivity but no sign reversal of LWP at higher Nd’s
DYCOMS2-RF01
(Sc with very dry free troposphere)

- 60 layer grid helps reduce LWP sensitivity to Nd, but still too large & robust no sign reversal
- CAM-CLUBB still much more sensitive than CAM5
DYCOMS2-RF01
(Sc with very dry free troposphere)

- 90 layer grid:
  - CAM5 still fairly sensitive & no sign reversal (insensitive to time step)
  - CAM-CLUBB, sign reversal and reduced sensitivity
  - What does it take to get CAM-CLUBB to replicate this behavior at 30 L?
Reducing time step reduces LWP sensitivity to Nd.

CAM-CLUBB is able to capture the LWP sign reversal with small dt (anything from 3 min or finer).

3 min and 60 s time step is too expensive for global simulations.

Can sub-stepping CLUBB and MG produce comparable results (i.e. Caldwell method)?
Substepping CLUBB/MG together at five minutes actually worsens sensitivity

CAM5... No big changes

Solid curves: CAM-CLUBB

Dashed curves: CAM5

\( dt = 20 \text{ min} \) (no subcycle)

\( dt = 20 \text{ min} \) (5 min subcycle)
DYCOMS2-RF01
(Sc with very dry free troposphere)

- Substepping CLUBB/MG at 2.5 minutes, leads to reduced sensitivity and hints of LWP sign reversal
- Virtually no changes for CAM5
- Why is CAM-CLUBB more responsive to sub-stepping?
  - CAM5 substeps only macrophysics and MG
  - CLUBB is unified parameterization therefore turbulence/entrainment is evolving with MG, along with macrophysics

Solid curves: CAM-CLUBB
Dashed curves: CAM5

All curves = 30 Layers

Liquid Water Path

- $dt = 20$ min (no subcycle)
- $dt = 20$ min (5 min subcycle)
- $dt = 20$ min (2.5 min subcycle)
Summary & Future AIE Work

- CAM-CLUBB is very much alive and with fruitful development ahead
- Competitive with CAM5, appears to behave in coupled simulations
- More validation needed for climate variability
- Concerning aerosol effects, preliminary experiments raise more questions than answers.
  - Probably not exclusively a microphysics problem (but likely part of it)
  - To what degree are the different entrainment formulations between CLUBB and UWMT playing a role in different LWP responses?
  - What are the effects of sub-cycling CLUBB/MG on global AIE?
  - What will the effect of prognostic precip (and activation fix) be for CAM5 and CAM-CLUBB?