An overview of recent CAM developments

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Outline

• What happens since the last CCSM meeting?
  - Changes in the CAM trunk since Breckenridge
  - New datasets for tuning and evaluation

• CAM standalone simulations
  - CAM3.5
  - Microphysics scheme
  - Radiation scheme
  - Aerosol model
  - PBL/ShCu/Macrophysics schemes ("cloud package")

• Conclusions
Changes in the CAM trunk since Breckenridge

• June 2008 (Breckenridge): Trunk = CAM3.5

• August 2008: New default microphysics (MG)

• Nov 2008: New default radiation (RRTMG)

• Feb 2009: New default aerosol model (MAM)

• Feb 2009: Completed merge between MAM and the cloud branch (UW PBL, shallow convection, macrophysics) => “CLAM branch”
New datasets for tuning

- **Tuning** = adjusting parameters (weakly constrained by obs) to achieve agreement of the **TOA radiative balance** with observations.

  TOA radiative balance: Net SW - Net LW $\sim 0$

- **CAM3.5 ⇔ ERBE dataset**

- CERES-EBAF dataset (global net TOA flux $\sim 0.9$ Wm$^{-2}$)
# Comparison of ERBE, CERES and CERES-EBAF TOA fluxes

<table>
<thead>
<tr>
<th></th>
<th>ERBE Adjusted (Trenberth, 1997)</th>
<th>CERES</th>
<th>CERES-EBAF (Loeb et al., 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Irradiance</td>
<td>341.3</td>
<td>341.3</td>
<td>340.0</td>
</tr>
<tr>
<td>LW (All-Sky)</td>
<td>234.4</td>
<td>237.1</td>
<td>239.6</td>
</tr>
<tr>
<td>SW (All-Sky)</td>
<td>106.9</td>
<td>97.7</td>
<td>99.5</td>
</tr>
<tr>
<td>Net (All-Sky)</td>
<td>0.0</td>
<td>6.5</td>
<td>0.9</td>
</tr>
<tr>
<td>LW (Clear-Sky)</td>
<td>264.9</td>
<td>264.1</td>
<td>269.5</td>
</tr>
<tr>
<td>SW (Clear-Sky)</td>
<td>53.6</td>
<td>51.1</td>
<td>52.5</td>
</tr>
<tr>
<td>LWCF (LW\text{Clear-sky} - LW\text{All-sky})</td>
<td>30.5</td>
<td>27.0</td>
<td>29.9</td>
</tr>
<tr>
<td>SWCF (SW\text{Clear-sky} - SW\text{All-sky})</td>
<td>-53.3</td>
<td>-46.6</td>
<td>-47.1</td>
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</table>
Impact of the new datasets on the tuning

The two datasets gave a different picture of where the deficiencies are
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cam3.5: parameterizations

• Microphysics: Rasch-Kristjansson (1998)
• Boundary layer: Holtslag-Boville (1993)
• Shallow convection: Hack (1993)
Where were we in cam3.5?

- Too much SWCF in the tropics
- Not enough LWCF at mid latitudes
- LWP is overestimated
- Atmosphere is too moist (especially near the sfc)

Reminder: cam3.5 was not well tuned. It was a guinea pig model for the carbon cycle.
Morrison-Gettelman microphysics

- **2-moment scheme**: prognostics variable for cloud mass and number concentration (liquid + ice).
- **Microphysical processes**: hydrometeor collection, condensation/evaporation, freezing, melting, and sedimentation.
- Explicit treatment of **subgrid cloud water variability** for calculation of the microphysical process rates.
- Diagnostic treatment of **rain and snow** number concentration and mixing ratio.
MG microphysics: LWP is reduced

CAM3.5

MG microphysics

LWP

- CAM3.5
- SSM/I

LWP

- MG micro
- SSM/I

cam3.5 overestimates LWP at mid latitudes

• LWP improves at mid latitudes
• LWP too low in the tropics (but no contribution of convective clouds)
Despite low values of LWP, the cloud forcings are reasonable.
MG microphysics allows smaller cloud droplets => brighter clouds.
Precipitable water

<table>
<thead>
<tr>
<th>Model or observations</th>
<th>Precipitable water (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVAP</td>
<td>24.6</td>
</tr>
<tr>
<td>JRA25</td>
<td>24.3</td>
</tr>
<tr>
<td>ERA40</td>
<td>24.9</td>
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<tr>
<td>cam3.5</td>
<td>25.3</td>
</tr>
<tr>
<td>MG microphysics</td>
<td>25.9</td>
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</table>

(+1.0 compared to cam3.1)
(+0.6 compared to cam3.5)

Atmosphere is too moist compared to obs and analysis

=> Impact on the clear sky LW at the TOA
Atm too moist => clear sky LW at the TOA is too low
RRTMG (Conley, Collins, Iacono et al.)

- **Correlated-k code** for gases in LW and SW
- **Monte Carlo Independent Column Approximation** for clouds
- New liquid and ice **cloud optics**
- Greater **accuracy** than CAMRT relative to LBL calculations
### RRTMG: TOA clear-sky longwave bias

Because of the clear-sky bias, we will have a low LWCF (to achieve the TOA balance)

\[
\text{LW}_{\text{All-sky}} + \text{SW}_{\text{All-sky}} = 0.9
\]

\[
\text{LWCF} = \text{LW}_{\text{Clear-sky}} - \text{LW}_{\text{All-sky}}
\]

<table>
<thead>
<tr>
<th>Dataset/model</th>
<th>Clear-sky LW (W/m²)</th>
<th>Diff with ERBE (W/m²)</th>
<th>Diff with CERES (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERBE</td>
<td>264.4</td>
<td>0</td>
<td>-5.1</td>
</tr>
<tr>
<td>CERES-EBADF</td>
<td>269.5</td>
<td>5.1</td>
<td>0</td>
</tr>
<tr>
<td>cam3.1</td>
<td>264.3</td>
<td>-0.1</td>
<td>-5.2</td>
</tr>
<tr>
<td>cam3.5</td>
<td>263.1</td>
<td>-1.3</td>
<td>-6.4</td>
</tr>
<tr>
<td>MG micro</td>
<td>262.3</td>
<td>-2.1</td>
<td>-7.2</td>
</tr>
<tr>
<td>RRTMG</td>
<td>258.3</td>
<td>-6.1</td>
<td>-11.2</td>
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<tr>
<td>RRTMG</td>
<td>22.4</td>
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</table>
RRTMG: Temperature

RRTMG reduces cold T bias at the tropopause
Modal Aerosol Model (Ghan, Liu et al.)

- Prognostic modal aerosol treatment (with 3 modes)

- Predicts aerosol mass and number, and internal mixing between aerosols.

- New processes: new particle formation (upper troposphere and BL), coagulation within and between aerosol modes, condensation of water vapor and trace gas on aerosols, aging of primary carbon to accumulation mode, secondary organic aerosol formation, and aerosol activation.

- More realistic representation of aerosol properties and more accurate estimation of aerosol direct and indirect forcing
Aerosol: direct and indirect effect

**Direct effect**
- Aerosols scatter and absorb solar and infrared radiation

**Indirect effect**
- If aerosols increase, number of cloud droplets increase
  - Droplet size decrease
  - For same LWP, clouds are brighter

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<th>Direct effect W/m²</th>
<th>Indirect effect W/m²</th>
</tr>
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<tbody>
<tr>
<td><strong>MAM</strong></td>
<td>-0.56</td>
<td>-1.2</td>
</tr>
<tr>
<td><strong>MAM + droplet # limiter</strong></td>
<td>-0.49</td>
<td>-0.6</td>
</tr>
<tr>
<td><strong>IPPC values</strong></td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>-0.7 [-1.8 to -0.3]</td>
</tr>
</tbody>
</table>
SO$_4$ compared with RSMAS data

(Courtesy Xiaohong Liu)
UW PBL, shallow convection, macrophysics (Park and Bretherton)

- Turbulence scheme includes explicit entrainment at the top of the PBL and explicit interaction between cloud, radiation and turbulence.

- Shallow convection: cloud-base mass flux based on surface TKE and convection inhibition near cloud base

- New macrophysics treatment

Cloud + MAM = CLAM branch
UW scheme: SWCF, JJA

UW scheme:
- Improves SWCF in stratocumulus deck (magnitude and location)
- doesn’t use “Klein line”

TOA SW cloud forcing

**cam3.5**

mean = -51.41 W/m²

**UW PBL/ShCu/Macrophysics**

mean = -52.13 W/m²

**CERES-EBAF**

TOA SW cloud forcing

mean = -45.04 W/m²

Min = -156.06 Max = 94.38
PBL in stratocumulus regions

UW scheme:
better representation of the PBL
in stratocumulus region
(here: compared to EPIC 2001 cruise)

(Hannay et al., J Climate, 2009)
Shallow convective mass flux at cloud base, ANN

UW Sh/Cu

Hack scheme

Cumulus

Stratus

(UW scheme: better representation of cumulus regions)

(Courtesy Sungsu Park)
The CLAM branch versus observation

**SWCF**

TOA SW cloud forcing
mean = -52.43 W/m²

**CERES2**

TOA SW cloud forcing
mean = -47.07 W/m²

Min = -120.79 Max = 3

**LWCF**

TOA LW cloud forcing
mean = 20.55 W/m²

**CERES2**

TOA LW cloud forcing
mean = 29.90 W/m²

Min = -0.92 Max = 86.90

**ANN**

TOA LW cloud forcing
mean = 20.55 W/m²

Min = -0.92 Max = 86.90

**ANN**

TOA LW cloud forcing
mean = 20.55 W/m²

Min = -0.92 Max = 86.90

**SWCF:** too high (especially in deep convection)

**LWCF:** too low (especially at mid latitudes)
The CLAM branch

**Example of trade-offs**

In the CLAM branch, we **reduced** the SWCF in deep convective area

- by increasing the **autoconversion of rain** but this is also significantly reduced the LWP

- by decreasing the **autoconversion size threshold for cloud ice to snow** but this also **reduced** the LWCF

LWP is too low
Tuning challenges

- Radiation
  - Aerosol direct effect
  - Prognostic aerosols
  - Microphysics
    - droplet #
    - droplet size
  - activation sedimentation scavenging

- #, q_l, q_{ice}

Indirect effect
Conclusion

- **New dataset: CERES-EBAF**
  Significant change in the clear sky LW and SCWF

- **MG Microphysics:**
  MG improves LWP with realistic cloud forcing

- **Radiation (RRTMG)**
  greater accuracy relative to LBL calculations bias in the clear-sky LW

- **Modal aerosol (MAM)**
  realistic aerosol direct/indirect effect
Conclusion

• **UW PBL/ShCu/Macrophysics:**
  More realistic physics.
  Improves stratocumulus deck and cumulus area.

• **Challenging tuning because of feedbacks** between radiation, aerosols and microphysics.
Thanks !