Modal Aerosol Treatment in CAM: Evaluation and Indirect Effect

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Current Aerosol Treatment in CAM3

- sulfate
- ammonium
- nitrate
- secondary organic carbon
- hydrophobic black carbon
- hydrophilic organic carbon
- sea salt 1
- sea salt 2
- sea salt 3
- sea salt 4
- soil dust 1
- soil dust 2
- soil dust 3
- soil dust 4
Current Weaknesses in CAM

- Aerosol species are externally mixed (individual particles are composed of only a single species).
- Their size distribution is prescribed (number is diagnosed from the predicted mass).
  - Processes that should only affect mass (condensation, chemistry) also affect number.
  - Processes that only affect number (nucleation, coagulation) are neglected.
- Hydrophobic carbon ages to hydrophilic with prescribed timescale
Benchmark Aerosol Treatment for CAM4

Aitken number water sulfate ammonium secondary OC sea salt

Accumulation number water sulfate ammonium secondary OC hydrophobic OC BC sea salt

Fine Soil Dust number water soil dust sulfate ammonium

Fine Sea Salt number water sea salt sulfate ammonium

Primary Carbon number hydrophobic OC BC

Coarse Soil Dust number water soil dust sulfate ammonium

Coarse Sea Salt number water sea salt sulfate ammonium

All modes log-normal with prescribed width.

Total transported aerosol tracers: 38

Cloud-borne aerosol predicted but not transported.
New Processes

• New particle formation
• Coagulation within, between modes
• Dynamic condensation of trace gas (H2SO4, NH3) on aerosols
• Water uptake to internally mixed particles
• Intermode transfer (renaming) due to condensation, coagulation, and cloud chemistry
• Aging of primary carbon to accumulation mode based on sulfate coating from condensation & coagulation
• Aerosol number emissions
• Aerosol activation
Revised Processes

• **Wet scavenging (stratiform & convective cloud)**
  - In-cloud rainout based on activated (cloud phase) aerosol;
  - Below-cloud impaction scavenging rates (mass & no.) using a look-up table (wet size, precipitation rate).

• **Size-dependent dry deposition (Zhang et al., 2001)**

• **Cloud sulfur chemistry**
  - Sulfate mass produced distributed to modes based on number of activated aerosols in modes.
  - Include contribution from H2SO4 (g) uptakes
  - NH3 dissolution on pH

• **Optical properties of internally-mixed hydrated aerosol.**

• **Emissions of sea salt with diameters of 0.02-1.0 um from Martensson et al. (2003)**
CAM Simulations (CAM3.5.03)

- Modal aerosol (1.9x2.5), 3 years
  - benchmark present-day (PD) simulations
  - benchmark pre-industrial (PI) simulations

- Bulk aerosol (1.9x2.5), 3 years, present-day (PD) simulations

- Same emissions (OC, BC, DMS, SO2, SO4) for PD
- Same emission schemes (dust and coarse sea salt)
  - ultrafine sea salt emission for Modal aerosol
- Same oxidant fields for PD and PI (Modal and Bulk)

We can specify different MOZART chemistry mechanisms in the pre-processor to enable aerosol-chemistry coupling
BC Column Burden

Primary carbon mode

Accumulation mode

Modal

CB1

CB2

Bulk

mg/m²

0.01 0.05 0.2 1 2.3

0.02 0.1 0.5
BC zonal mean

Primary carbon mode

Accumulation mode

Modal

CB1 CB2

Bulk

aerosol hygroscopacity

0.001 0.002 0.005 0.01 0.02 0.05 0.1 0.2 ug/kg
## BC Budgets (Modal)

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Accum.</th>
<th>Total</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission (Tg/yr)</td>
<td>6.8</td>
<td></td>
<td>6.8</td>
<td>10-19</td>
</tr>
<tr>
<td>Dry deposition (Tg/yr)</td>
<td>0.7</td>
<td>1.6</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Wet deposition (Tg/yr)</td>
<td>0.0</td>
<td>4.5</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Total sink (Tg/yr)</td>
<td></td>
<td></td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>Burden (Tg)</td>
<td>0.024 (0.02)</td>
<td>0.084 (0.086)</td>
<td>0.11 (0.11)</td>
<td>0.13-0.29</td>
</tr>
<tr>
<td>Lifetime (days)</td>
<td></td>
<td></td>
<td>5.8</td>
<td>3.9-8.4</td>
</tr>
</tbody>
</table>

*Results from bulk model in blue*
OC Column Burden

Primary carbon mode

Accumulation mode

Modal

OC1

OC2

Bulk
OC zonal mean

Primary carbon mode

Accumulation mode

Modal

OC1

OC2

Bulk

0.005 0.01 0.02 0.05 0.1 0.2 0.5 0.7 ug/kg
## OC Budgets (Modal)

<table>
<thead>
<tr>
<th></th>
<th>Primary</th>
<th>Accum.</th>
<th>Total</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission (Tg/yr)</td>
<td>27.8</td>
<td></td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>Dry deposition (Tg/yr)</td>
<td>4.1</td>
<td>5.2</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Wet deposition (Tg/yr)</td>
<td>0.02</td>
<td>18.4</td>
<td>18.4</td>
<td></td>
</tr>
<tr>
<td>Total sink (Tg/yr)</td>
<td></td>
<td></td>
<td>27.8</td>
<td></td>
</tr>
<tr>
<td>Burden (Tg)</td>
<td>0.16</td>
<td>0.38(0.38)</td>
<td>0.54(0.46)</td>
<td>0.95-1.8</td>
</tr>
<tr>
<td>Lifetime (days)</td>
<td></td>
<td></td>
<td>7.1</td>
<td>3.9-6.4</td>
</tr>
</tbody>
</table>

Results from bulk model in blue
Dust column burden

Fine mode (0.1-2 um)

Coarse mode (2-10 um)

Modal

Emission?

Fine mode (0.1-2.5 um)

Coarse mode (2.5-10 um)

Bulk

0.1 0.5 2 10 50 200 1000 0.2 1 5 20 100 500 2000 mg/m²
## Dust Budgets (Modal)

<table>
<thead>
<tr>
<th></th>
<th>Fine</th>
<th>Coarse</th>
<th>Total</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission (Tg/yr)</td>
<td>192</td>
<td>1282</td>
<td>1474</td>
<td>(1567)</td>
</tr>
<tr>
<td>Dry deposition (Tg/yr)</td>
<td>41</td>
<td>784</td>
<td>825</td>
<td></td>
</tr>
<tr>
<td>Wet deposition (Tg/yr)</td>
<td>151</td>
<td>502</td>
<td>653</td>
<td></td>
</tr>
<tr>
<td>Total sink (Tg/yr)</td>
<td></td>
<td></td>
<td>1477</td>
<td></td>
</tr>
<tr>
<td>Burden (Tg)</td>
<td>3.0</td>
<td>6.2</td>
<td>9.2</td>
<td>(4-36)</td>
</tr>
<tr>
<td>Lifetime (days)</td>
<td>2.3</td>
<td></td>
<td>1.9-7.1</td>
<td></td>
</tr>
</tbody>
</table>

Modal: 0.1-2 um (fine), 2-10 um (coarse);  
**Bulk:** 0.1-2.5 um (fine), 2.5-10 um (coarse)
Sea salt column burden

Fine mode (0.02-1 um)
Coarse mode (1-10 um)

Modal

below-cld scavenging coefficient!

Bulk

Fine mode (0.2-1 um)
Coarse mode (1-20 um)

mg/m²
Sea salt zonal mean

- Fine mode (0.02-1 um)
- Coarse mode (1-10 um)
- Fine mode (0.2-1 um)
- Coarse mode (1-20 um)

Modal

Bulk

 ug/kg
# Sea Salt Budgets (Modal)

<table>
<thead>
<tr>
<th></th>
<th>Fine</th>
<th>Coarse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission (Tg/yr)</td>
<td>127</td>
<td>3709</td>
<td>3836(3758)</td>
</tr>
<tr>
<td>Dry deposition (Tg/yr)</td>
<td>23</td>
<td>1751</td>
<td>1774</td>
</tr>
<tr>
<td>Wet deposition (Tg/yr)</td>
<td>105</td>
<td>1979</td>
<td>2084</td>
</tr>
<tr>
<td>by below cloud</td>
<td></td>
<td>1046(149)</td>
<td></td>
</tr>
<tr>
<td>Total sink (Tg/yr)</td>
<td></td>
<td></td>
<td>3854</td>
</tr>
</tbody>
</table>

|                      |       |        |         |         |
| Burden (Tg)          | 0.62(0.63) | 5.1(11.0) | 5.7(11.6) | 4.3-12   |
| Lifetime (days)      | 0.54  | 0.19-0.99 |

Modal: 0.02-1 um (fine), 1-10 um (coarse);  
Bulk: 0.2-1 um (fine), 1-10 um (coarse)
SO4

Modal Bulk

Column burden

1.0  0.3

Zonal

sol_fraci!

0.3
## SO4 Budgets (Modal)

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burden (Tg S):</td>
<td>0.43(0.56)</td>
</tr>
<tr>
<td>Lifetime (days):</td>
<td>3.3</td>
</tr>
<tr>
<td>Global dry deposition (Tg S/yr):</td>
<td>8.8</td>
</tr>
<tr>
<td>Global wet deposition (Tg S/yr):</td>
<td>38.7</td>
</tr>
<tr>
<td>Global SO4 sources (Tg S/yr):</td>
<td></td>
</tr>
<tr>
<td>by H2SO4 condensation</td>
<td>9.5</td>
</tr>
<tr>
<td>by H2O2</td>
<td>23.1</td>
</tr>
<tr>
<td>by O3</td>
<td>12.7</td>
</tr>
</tbody>
</table>

**SO4 burden by reservoir (%):**

- by SO4 nuclei mode: 2.5%
- by SO4 accumulation mode: 92%
- by Dust: 3%
- by Sea Salt: 2.5%

*Results from bulk model in blue*
Modal - Compared with RSMAS SO4 Data
Compared with RSMAS SO4 Data

**Modal**

```
R = 0.964557
```

**Bulk**

```
R = 0.913942
```
Modal - Compared with IMPROVE SO4 Data
Compared with IMPROVE SO4 Data

Modal

Bulk
Compared with IMPROVE BC Data

Modal Emissions?! 

Bulk Emissions?!
CCN \((S=0.1\%)\)
## Global Annual Means (Present Day)

<table>
<thead>
<tr>
<th></th>
<th>Modal</th>
<th>Bulk</th>
<th>OBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWP, g m(^{-2})</td>
<td>104.5</td>
<td>129.9</td>
<td></td>
</tr>
<tr>
<td>IWP, g m(^{-2})</td>
<td>15.5</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>SWCF, W m(^{-2})</td>
<td>-58.3</td>
<td>-53.7</td>
<td>-54.2 (ERBE)</td>
</tr>
<tr>
<td>LWCF, W m(^{-2})</td>
<td>28.0</td>
<td>27.7</td>
<td>30.4 (ERBE)</td>
</tr>
<tr>
<td>FLNTC, W m(^{-2})</td>
<td>263.0</td>
<td>262.7</td>
<td>265.0 (ERBE)</td>
</tr>
<tr>
<td>CLDTOT, %</td>
<td>52.8</td>
<td>51.8</td>
<td>67.3 (ISCCP)</td>
</tr>
<tr>
<td>CLDLOW, %</td>
<td>35.5</td>
<td>34.4</td>
<td>21.8/33.6 (ISCCP/SAGE)</td>
</tr>
</tbody>
</table>
Aerosol Indirect Effect

Present – Past Shortwave Cloud Forcing (W/m²)

Present – Past Liquid Water Path (g/m²)

Global Mean = -1.1 W/m²
Timing

MODAL 7 modes pcnst=49
MODAL 4 modes pcnst=32
CAM online aerosol pcnst=20
CAM offline aerosol ndrop
CAM offline aerosol

Timing

0 20 40 60 80 100 120
Remaining issues

- Simulation with Morrison microphysics and Modal aerosol reduces the simulated SWCF to -47 W/m², which is 7-10 W/m² too small.
- Simulations with Morrison microphysics and Mozart aerosol using the UW PBL scheme produce excessively large SWCF.
- Simulations coupling Modal aerosols with Morrison microphysics and the UW PBL scheme should be performed.
- The simpler version of Modal aerosol should be evaluated.
- Improvements in primary carbon emissions are needed.
- A secondary organic aerosol mechanism for modal aerosol is under development.
- Evaluate simulated aerosol optical depth.
THANKS!
SO4 column burden (Modal)

Accumulation mode

Associated with dust

Aitken mode

Associated with sea salt (>0.3 um)

0.01 0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 mg/m²