Update on Latest Aerosol Developments in CESM2

Xiaohong Liu  
University of Wyoming  
Texas A&M University (9/1/2019)

Zheng Lu, Hunter Brown, Yunpeng Shan (Univ. Wyoming)  
Rahul Zaveri, Hailong Wang, Balwinder Singh, R.C. Easter (PNNL)  
Louisa Emmons, Simone Tilmes, Francis Vitt (NCAR)
Outline

- Nitrate aerosol
- Brown carbon
- Improved treatment of wet scavenging of aerosols by deep convection
Motivation

- Nitrate aerosol (NO$_3$): a significant source of anthropogenic aerosols [IPCC]
- Nitrate aerosol (NO$_3$):
  - Similar radiative forcing compared to SO$_4$ [Adams et al., 2001]
  - Important for tropospheric chemistry [Liao et al., 2003]
  - More important in future with reduction of sulfur emission [Hoesly et al., 2018]
Nitrate in CESM2

- In order to treat NO3 aerosols, Model for Simulating Aerosol Interactions and Chemistry (MOSAIC) module [Zaveri et al., 2008] is coupled with MAM4 in CESM2.

- In the version of MAM coupled with MOSAIC, gas-aerosol exchange is treated by MOSAIC. The other processes are handled by MAM.

- Coupled with TS1 full chemistry

<table>
<thead>
<tr>
<th></th>
<th>BC</th>
<th>PO</th>
<th>OM</th>
<th>SOA</th>
<th>SO4</th>
<th>NH4</th>
<th>NO3</th>
<th>Cl</th>
<th>Na</th>
<th>Ds</th>
<th>Ca</th>
<th>CO3</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acc.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>11</td>
</tr>
<tr>
<td>Aitken</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Coarse</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>P-Carb.</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

Red crosses: new aerosol tracers in MAM4-MOSAIC
Modeled surface mass concentration of NO3 in good agreement in E. Asia, including China, U.S. and E.U.
Aitken mode is negligible.

More than 80% of total nitrate masses are formed on the coarse mode. This fraction decreases in winter.

The total mass burden of coarse mode nitrate peaks in summer (JJA), while the maximum total mass burden of accumulation mode nitrate happened in Winter (DJF).
Brown Carbon (BrC) in CESM2

Based on Brown et al. ACP, 2018

**BrC parameterization**

From Saleh et al. (2014):

\[
1.7 (\pm 0.2) + k_{\text{OA}i} = 1.7 (\pm 0.2) + k_{\text{OA,550}}(550/\lambda)^w i
\]

\[
k_{\text{OA,550}} = 0.016*\log_{10}(\text{BC-to-OA}) + 0.04
\]

\[
w = 0.21 / (\text{BC-to-OA} + 0.07)
\]

**modal_aer_opt.F90**

Call the different species optical properties at each mode, level, wavelength, lat/lon

Calculate bulk refractive index for each mode

Modify refractive index for biomass burning and biofuel POM based on BC-to-OA ratio calculated at each timestep, grid cell.

**Saleh et al. (2014).** “Brownness of Organics in Aerosols from Biomass Burning Linked to Their Black Carbon Content.” *Nature Geoscience* 7, 647–650.
Significant brown carbon absorption of incoming solar radiation is focused over wildfire regions and populated areas where use of wood and other biofuels is prevalent.

Comparison of brown carbon absorption Angstrom exponent (AAE) to AERONET observations show the new model (BRC) improves compared to the default model (NOBRC).
Brown Carbon Direct Radiative Effect (DRE)

Brown carbon DRE from chemical transport models:

**DRE (w/o bleaching)**
- Feng et al., 2013: **0.04–0.11 W m\(^{-2}\)**
- Wang et al., 2014: **0.11 W m\(^{-2}\)**
- Saleh et al., 2015: **0.13 W m\(^{-2}\)**
- Jo et al., 2016: **0.11 W m\(^{-2}\)**

**DRE (w/ bleaching)**
- Wang et al., 2018: **0.05 W m\(^{-2}\)**

Based on Brown et al. ACP, 2018
BC compared with SP2 (tropics and midlat.)

Major differences and overestimations in free troposphere

Koch et al. (2009)
Aerosol activation at a prescribed rate

Precipitation removal rate neglects microphysics

\[ Wet = \frac{Pr \text{ec}}{Pr \text{ec} + cldm} \]

Remaining cloud-borne aerosols are released locally, rather than detrained

\[
\left( \frac{\partial q_{ec}}{\partial t} \right)_{up} = \frac{\partial (M_u q_{uc})}{\partial p} - \frac{\partial (M_u q_{ec})}{\partial p} + Act \cdot q_{ul} - Wet \cdot q_{uc} - Res \cdot q_{uc}
\]
Aerosol Wet Scavenging Improvement – Shan et al. (2019)

Rain Evaporation

Prescribed SS

Predicted SS

\[
\left( \frac{\partial q_{ec}}{\partial t} \right)_{up} = \frac{\partial (M_u q_{uc})}{\partial p} - \frac{\partial (M_u q_{ec})}{\partial p} + Act \cdot q_{ul} - Wet \cdot q_{uc} - Res \cdot q_{uc}
\]

Aerosol Releasing by Rain droplet Entire Evaporation

Cloud-borne Aerosol Detrainment

\[
Wet = \frac{Pr_{ec} - R_{eva}}{Pr_{ec} + cldm}
\]
Improvements of Aerosol Profile Simulation – Sea Salt

Pacific

Atlantic

- ToMod_SYP
- YPF+MAM4_NoBCa4Removal
- YPF+MAM4_BCa4Removal
- YPF+MAM3
- CTL
- ATom1