A new dry deposition scheme for aerosols in CAM5 and impacts on aerosols and climate

Mingxuan Wu, Xiaohong Liu, Chenglai Wu
University of Wyoming
Leiming Zhang
Environment and Climate Change Canada
Po-lun Ma, Hailong Wang
Pacific Northwest National Laboratory
Simone Tilmes
National Center for Atmospheric Research

CESM Working Group Meeting
Feb 27 – Mar 03, 2017
1. Introduction

Aerosol dry/wet removal at low latitudes can strongly influence the distribution of aerosols at high latitudes (e.g., Kinne et al., 2006; Textor et al., 2007; Shindell et al., 2008)

Dry deposition scheme by Zhang et al. (2001) tends to overestimate in a significant way the particle deposition in the fine mode, as measured by various investigators (Petroff and Zhang, 2010).
1. Introduction

BC concentration in high-latitudes remote regions is strongly influenced by dry deposition.

from Natalie Mahowald, 2016 CESM Workshops
HM: 2D bin module for aerosol microphysics by Matsui, ACP, 2014
2. Method – Dry Deposition Scheme

similar “resistance” structure

Zhang et al., 2001 (Z01)

\[ V_{drift} = W_S \]  
gravitational settling velocity

\[ R_s = 1/\varepsilon u_*(E_B + E_{IM} + E_{IN})R_1 \]

\[ E_B = Sc^{-\gamma} \]  
collection efficiency from Brownian diffusion

\[ E_{IM} = \left( \frac{St}{\alpha + St} \right)^2 \]  
collection efficiency from impaction

\[ E_{IN} = \left( \frac{d_p}{A} \right)^2/2 \]  
collection efficiency from interception

St Stokes number

BAM

\[ V_{drift} = W_S \]

\[ R_s = 1/\varepsilon u_*(E_B + E_{IM}) \]

\[ E_B = \begin{cases} Sc^{-1/2} & \text{wet} \\ Sc^{-2/3} & \text{non-wet} \end{cases} \]

\[ E_{IM} = 10^{-3/St} \]

Petroff and Zhang, 2010 (PZ10)

phoretic effects on water/ice/snow

Rs derived by a 1D aerosol transport model

Rs more sensitive to LUCs

\[ R_s = 1/V_{ds} \]

non-vegetated surface

\[ V_{ds} = u_*(E_{gb} + E_{IT}) \]  
\[ E_{gb} \propto Sc^{-\gamma} \]  
\[ (1/2 \leq \gamma \leq 2/3) \]

Egb Brownian diffusion efficiency on the ground below veg

Sc Schmidt number \( \nu/\mu \)

\[ E_{IT} \]  
collection efficiency due to turbulent impaction

vegetated surface

\[ V_{ds} = u_* \left( E_{gb} + E_{gt} \right) \frac{1 + \left[ Q/Q_g - \alpha/2 \right] \cdot \tanh(\eta)/\eta}{1 + \left[ Q_g + \alpha/2 \right] \cdot \tanh(\eta)/\eta} \]

Q time scale ratio turbulent transport/vegetation collection

\[ \eta = \sqrt{\alpha^2/4 + Q} \]
2. Method – Model Configuration and Experiments

CAM5 setup

**Configuration:** CAM5.4, MG microphysics, MAM4, CLM4.0, data ocean,

**Runtime period:** 2002 to 2012, last 10 years for analysis

**Resolution:** 1.9° × 2.5°

**Meteorology:** U, V nudged to ERA-interim Reanalysis

Each experiment run for PD and PI aerosol emissions

Radiative forcing calculation follows Ghan, ACP, 2013

Experiments

Z01: Zhang et al. (2001).

BAM: BAM (Slinn and Slinn, 1980)

PZ10: Petroff and Zhang (2010)

PZ10_Egb01: same as PZ10, Sc^{-2/3} to Sc^{-1/2} in Egb.

PZ10_Egb02: same as PZ10_Egb01, Egb*5

PZ10_Egb03: same as PZ10_Egb01, Egb*10
3. Results - Dry Deposition Velocity

Validation of dry deposition velocities over water and ice surface

PZ10 predicts much smaller deposition velocity for fine particles in accumulation, Aitken, and primary carbon mode, which is closer to observations.

As Egb becomes larger (PZ10-PZ10_Egb03), dry deposition velocity increases.
3. Results - Aerosol Distribution and Budgets

BC Budgets

<table>
<thead>
<tr>
<th>BC</th>
<th>Dry Deposition (Tg yr⁻¹)</th>
<th>Wet Deposition (Tg yr⁻¹)</th>
<th>Lifetime (day)</th>
<th>Burden (Tg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z01</td>
<td>1.6622</td>
<td>6.0870</td>
<td>5.4434</td>
<td>0.1156</td>
</tr>
<tr>
<td>BAM</td>
<td>0.8386</td>
<td>6.9095</td>
<td>6.2392</td>
<td>0.1324</td>
</tr>
<tr>
<td>PZ10</td>
<td>0.4262</td>
<td>7.3219</td>
<td>6.7318</td>
<td>0.1429</td>
</tr>
<tr>
<td>PZ10_Egb01</td>
<td>0.4490</td>
<td>7.2990</td>
<td>6.7073</td>
<td>0.1424</td>
</tr>
<tr>
<td>PZ10_Egb02</td>
<td>0.5486</td>
<td>7.1996</td>
<td>6.6014</td>
<td>0.1401</td>
</tr>
<tr>
<td>PZ10_Egb03</td>
<td>0.6612</td>
<td>7.0870</td>
<td>6.4824</td>
<td>0.1376</td>
</tr>
</tbody>
</table>

PZ10 reduces BC dry deposition by 74%, BC lifetime increases by 24%.

Similar changes for POM, sulfate, SOA.

As Egb becomes larger (PZ10-PZ10_Egb03), BC dry deposition increases, lifetime and burden decreases.
3. Results - Aerosol Distribution and Budgets

Column burden of BC

BC burden increases globally, especially over high-latitude regions.
3. Results - Aerosol Distribution and Budgets

BC vertical distribution compared with HIPPO aircraft campaigns

PZ10 and BAM increase BC concentration. In some places, the new scheme improves the BC concentration.

Courtesy Simone Tilmes
3. Results - Aerosol in High-latitude Remote Regions

BC surface concentration in four polar sites

(a) Barrow (156.60°W, 71.30°N)
(b) Alert (62.33°W, 82.50°N)
(c) Zepelin (11.88°E, 78.90°N)
(d) Halley (26.20°W, 75.60°S)

- Improved seasonality of BC surface concentration
- Increased BC surface concentration
- BC transport and total deposition increase

Month
### 3. Results - Radiative Forcing

**Aerosol radiative forcing (PD-PI)**

<table>
<thead>
<tr>
<th>Radiative forcing (W m$^{-2}$)</th>
<th>Direct forcing</th>
<th>Indirect forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z01</td>
<td>0.1001</td>
<td>-1.6696</td>
</tr>
<tr>
<td>BAM</td>
<td>0.1046</td>
<td>-1.5827</td>
</tr>
<tr>
<td>PZ10</td>
<td>0.1122</td>
<td>-1.5585</td>
</tr>
<tr>
<td>PZ10_Egb01</td>
<td>0.1129</td>
<td>-1.5575</td>
</tr>
<tr>
<td>PZ10_Egb02</td>
<td>0.1151</td>
<td>-1.5786</td>
</tr>
<tr>
<td>PZ10_Egb03</td>
<td>0.1169</td>
<td>-1.5961</td>
</tr>
</tbody>
</table>

*Increased direct forcing, reduced indirect forcing*
4. Summary

1. The new PZ10 dry deposition scheme predicts much lower **dry deposition velocity** for fine particles in accumulation, Aitken, and primary carbon mode compared with Z01.

2. The new PZ10 dry deposition scheme greatly changes the **aerosol lifecycle**. Dry deposition fluxes for BC, POM, sulfate, and SOA decreases while dry deposition fluxes for dust and sea salt increases. Column burden of BC, POM, sulfate, sea salt, and SOA all increases.

3. The new PZ10 dry deposition scheme improves the **BC representation in remote regions**. BC profiles in high-latitudes regions are improved. BC surface concentration in the Polar regions increases significantly, Seasonality of BC concentration is also improved.

4. The new PZ10 scheme results in larger aerosol direct forcing and smaller indirect forcing, and the total aerosol radiative forcing decreases.