Direct radiative forcing due to aerosols in Asia during March 2002

Soon-Ung Park, Jae-In Jeong*

Center for Atmospheric and Environmental Modeling
*School of Earth and Environmental Sciences, Seoul National Univ., Korea

1st International Conference : From Deserts to Monsoons
1-6 June 2008 at Crete, Greece
1. Introduction

2. Model Description
   - Aerosol dynamic model
   - Asian Dust Aerosol Model (ADAM)
   - Radiation transfer model
   - Coupled and Non-coupled MM5 model

3. Results

4. Conclusions
Roles of aerosols:
- Provide reaction sites for atmospheric chemical species
- Serve as carriers for many condensed or sorbed species
- Change the global climate system by changing atmospheric radiation balance,
  - directly by absorption, scattering and emission of solar and terrestrial radiation
  - indirectly by changing the albedo and the life time of clouds by acting as cloud condensation nuclei.
• Wind-blown mineral dust from desert and semiarid regions is an important source of tropospheric aerosols
  • contributes 1000-3000 Tg yr\(^{-1}\) to global atmospheric emission
  • a distinct feature in East Asia, West Africa, South America

• In East Asia, Asian dust (Hwangsa in Korean)
  • frequently occurs in Sand desert, Gobi desert and Loess plateau in northern China and Mongolia
  • reported to be transported to the western part of USA
  • increases the albedo over the cloudless ocean and land by up to 10-20%
  • reduces the direct solar radiation by 30-40%
Radiative effects of aerosols
Purpose:

• To estimate direct radiative forcing of Asian dust aerosols and anthropogenic aerosols for the period of March 2002, using ADAM model, Aerosol dynamic model, NCAR column radiation model (CRM) with the MM5 meteorological model.

• To estimate impacts of direct radiative forcing of Asian Dust on meteorological fields.
**Model Description**

**Aerosol Model System**

- **Emission**
  - (SO$_2$, NO$_x$, NH$_3$, VOC, CO, BC, OC, PM$_{10}$)

- **Gas Chemistry**
  - (CIT, 32 species, 53 chemical reactions)

- **Meteo. Model**
  - (MM5, 60x60 km$^2$ horizontal resolution)

- **Aerosol Dynamic Model**

- **Asian Dust Aerosol Model**

**Radiation Model CCM CRM**
Effects of radiative forcing of aerosols on meteorological Fields

Coupled model (CMM5) (with Radiative Forcing)

- MM5
- ADAM + ADM
- Optical model
- CRM

Non-Coupled model (NMM5) (without Radiative Forcing)

- MM5
- ADAM + ADM
- Optical model
- CRM

CMM5 — NMM5 — Impact
### Meteorological Model

- **MM5** version 3 nonhydrostatic model
- 60 km x 60 km horizontal resolution
- 20 Vertical layer in coordinate
- Moisture: simple ice explicit scheme
- Convection: Kain-Fritsch scheme
- PBL: Medium Range Forecasting (MRF)
- Period: March 2002

### Gas Chemistry

- **CIT** (California Institute of Technology, Russel)
- Adds (SO$_2$+OH) reaction and NH$_3$
  (52 $\rightarrow$ 53 chemical reactions, 29 $\rightarrow$ 32 species)
- 8 photolytic reaction (cloud effect)
- SO$_2$ oxidation: 3 path (O$_3$, H$_2$O$_2$, Fe$^+$, Mn$^+$)
- NH$_3$/HNO$_3$ dissolution
### Aerosol Dynamics Model

- Gas-Aerosol mass transfer (Hybrid scheme)
- Nucleation: critical value of the gas-phase sulfuric acid
- Condensation/evaporation: concentration difference between the particle surface and the bulk gas
- Dry and wet deposition
- Hygroscopic growth
- Coagulation: Brownian motion, Turbulent shear, Sedimentation

### Asian Dust Aerosol Model

- Specification of Dust source region
- 12 bins (0.02~77 μm in diameter)
- Statistically derived dust emission conditions in Sand, Gobi, Loess, mixed soil surface
- Dust emission flux \( \propto u_*^4 \)
- Dust emission modification by the land-use types
- Log-normal distributions of the suspended particles in the source region with minimally and fully dispersed particle-size distribution
Mineralogical composition in Asian Dust
[from soil samples in the source regions (Park, 2002)]

6 mineral component selected

National Center for Atmospheric Research (NCAR) column radiation model (CRM) of the community climate model (CCM)
Anthropogenic emissions over Asia

(a) SO$_2$

(b) NO$_x$

(c) NH$_3$

(d) VOC

(e) PME

(f) BC+OC

(unit: t grid$^{-1}$ month$^{-1}$) Streets et al., 2000
Results

Daily mean surface concentration over South Korea

(a) TPM$_{10}$

(b) PM$_{10}$

(c) Relative Humidity

March 2002
Location of monitoring sites of EANET

1. Guanyinqiao
2. Jinyunshan
3. Shizhan
4. Weishuliyuan
5. Hongwen
6. Xiang Zhou
7. Rishiri
8. Tappi
9. Sado-seki
10. Hoppo
11. Oki
12. Yusuhara
13. Ogasawara
14. Hedo
15. Ijira
16. Banryu
17. Petaling Jaya
18. Tanah Rata
19. Terelj
20. Metro manila
21. Los Banos
22. Kanghwa
23. Cheju
24. Imsil
25. Mondy
26. Listvyanka
27. Irkutsk
28. Primorskaya
29. Mae Hia
30. HaNoi
Comparison of observed and modeled aerosol concentration in Asia

(a) Sulfate
\[ y = 0.89x - 0.19 \]
\[ R^2 = 0.86 \]

(b) Nitrate
\[ y = 0.97x - 0.12 \]
\[ R^2 = 0.82 \]

(c) Ammonium
\[ y = 0.59x + 0.58 \]
\[ R^2 = 0.36 \]

(d) PM$_{10}$
\[ y = 1.05x + 11.31 \]
\[ R^2 = 0.71 \]
Asian dust concentration ($\mu g \ m^{-2}$) expressed in common logarithm scale

SIA concentration ($\mu g \ m^{-2}$) expressed in common logarithm scale

Column integrated Asian dust and Secondary inorganic aerosol
Spatial distribution of aerosol concentrations

Column integrated monthly mean concentration (μg m⁻²) expressed in common logarithm scale
Direct radiative forcing ($W \, m^{-2}$) at the surface

**Dust + PM**

**BC**

**OC**

**SIA**

**MIX**

**TOTAL**

($W \, m^{-2}$)
Direct radiative forcing (W m$^{-2}$) at the top of Atmosphere (TOA)
Direct radiative forcing (W m⁻²) in the Atmosphere

**Dust + PM**

**BC**

**OC**

**SIA**

**MIX**

**TOTAL**

(W m⁻²)
Fractional contributions of each type of aerosols

(a) Total Mass
- Dust: 66%
- OC: 2%
- BC: 0.2%
- SIA: 11%
- MIX: 14%

Total Mass: 78 mg m⁻²

(b) ADRF at SFC
- Dust: 22%
- BC: 13%
- OC: 7%
- SIA: 3%
- SEA: 6%

ADRF: -6.8 W m⁻²

(c) ADRF at TOA
- Dust: 31%
- BC: 55%
- OC: 6%
- SIA: 43%
- SEA: 6%

ADRF: -2.9 W m⁻²

(d) ADRF at ATM
- Dust: 13%
- BC: 26%
- OC: 3%
- SIA: 0.03%
- SEA: 3%

ADRF: 3.8 W m⁻²
Impacts of Aerosol Radiative Forcing on Meteorological Fields

vertically integrated DUST concentration and WIND VECTOR (coupled)
Difference of SLP (Coupled – Non-Coupled)
Wind affected by Radiative Forcing

Difference of SLP and WIND VECTOR (Coupled – Non-Coupled)

(a) 18 March

(b) 19 March

(c) 20 March

(d) 21 March

(e) 22 March

(f) 23 March
Radiative Forcing

(a) Daily Total Emission

(b) Column Concentration

(c) D SRF (W m⁻²)

(d) D T (°C)

(e) D SLP (Pa) & D WV

(f) Daily Total Emission Diff.
Diurnal variation of affected meteorological fields
## Radiative Intensity

<table>
<thead>
<tr>
<th>Aerosol</th>
<th>Surface (W mg(^{-1}))</th>
<th>TOA (W mg(^{-1}))</th>
<th>Atmosphere (W mg(^{-1}))</th>
<th>Total mass con. (mg m(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian dust</td>
<td>-0.03</td>
<td>-0.02</td>
<td>0.01</td>
<td>51.48</td>
</tr>
<tr>
<td>SIA</td>
<td>-0.20</td>
<td>-0.18</td>
<td>0.01</td>
<td>8.58</td>
</tr>
<tr>
<td>Mixed type</td>
<td>-0.19</td>
<td>+0.01</td>
<td>0.19</td>
<td>10.92</td>
</tr>
<tr>
<td>BC</td>
<td>-5.67</td>
<td>+1.35</td>
<td>6.21</td>
<td>0.16</td>
</tr>
<tr>
<td>OC</td>
<td>-0.31</td>
<td>-0.25</td>
<td>0.07</td>
<td>1.56</td>
</tr>
<tr>
<td>Sea salt</td>
<td>-0.04</td>
<td>-0.04</td>
<td>0.00</td>
<td>5.46</td>
</tr>
</tbody>
</table>
Effects of radiative forcing of Asian dust on meteorological fields

- With vertically integrated Asian dust aerosol concentration of 15 g m\(^{-2}\) produces -200 W m\(^{-2}\) surface radiative forcing, which in turn reduces the surface temperature of -2 °C.

- In the meanwhile it produces a positive pressure anomaly (about 0.8 hPa) with the negative pressure anomaly toward the synoptic low pressure center forming a dipole shape of pressure anomaly.

- The associated secondary circulation reduces the mean wind speed (about 3 m s\(^{-1}\)) in the upstream part of the high dust concentration region, resulting in the reduction of dust emission.

- Lower level cooling due to Asian dust aerosol enhances stable stratification in the lower layer.
Thank You!