Direct Radiative Effect of Dust in China on Precipitation in the UCLA AGCM

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Model Description

UCLA AGCM

- Physical Parameterizations
  - Planetary boundary layer processes: Suarez et al. (1983), Li et al. (1999, 2001)
  - Cumulus Convection: Prognostic Arakawa-Schubert (Pan and Randall 1998), with downdrafts (Cheng and Arakawa 1997)
  - Aerosol Observations in China
    - Prognostic Cloud Water/Ice: Kohler (1999) \rightarrow Fractional clouds/Cloud overlap (Gu et al. 2003)

- Dynamics
  - Horizontal Finite Difference Scheme: Arakawa and Lamb (1981)
  - Resolution: 5° longitude \times 4° latitude
  - Vertical Finite Difference Scheme: Suarez and Arakawa (1983)
  - Resolution (top at 1 hPa): 15 layers
  - Time integration: Leapfrog, Matsuno

- Surface Conditions
  - Prescribed sea surface temperatures (Rayar et al. 1995), albedo, ground wetness, and surface roughness (Dorman and Sellers 1989)

- Parameterization of Aerosol Effect
  - 18 aerosol types: maritime, continental, urban, five different sizes of mineral dust, insoluble, water soluble, soot (black carbon), sea salt in two modes (accumulation mode and coarse mode), mineral dust in four different modes (nucleation mode, accumulation mode, coarse mode, and transported mode), and sulfate droplets.
  - Parameterized by using the recent addition of the Optical Properties of Aerosols and Clouds (OPAC) database (d’Almeida et al. 1991; Tegen and Lacis 1996; Hess et al. 1998), which provides the single-scattering properties for spherical aerosols computed from the Lorenz-Mie theory in which humidity effects are accounted for.
  - The single-scattering properties of 18 aerosol types for 60 wavelengths in the spectral region between 0.3 \( \mu \text{m} \) and 40 \( \mu \text{m} \) were interpolated into the Fu-Liou spectral bands. These properties are vertically distributed and dependent on the aerosol type and relative humidity.

- Design of Experiment

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Aerosol Optical Depth</th>
<th>Aerosol Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL</td>
<td>0.0 (Aerosol direct radiative effect not included)</td>
<td>None</td>
</tr>
<tr>
<td>DUST</td>
<td>Observed aerosol optical depths at the wavelength of 0.75 ( \mu \text{m} ) over China; background aerosol optical depth of 0.2 for areas other than China</td>
<td>100% Dust (8 ( \mu \text{m} ))</td>
</tr>
</tbody>
</table>

| Black carbon contributed about 11% to the visible optical depth of the Indo-Asian aerosols with a single-scattering albedo of \(-0.9\) both inland and over open ocean (Ramanathan et al. 2001). |

Aerosol Observations in China

- Mineral dust aerosols, an amount up to 30 to 50% originated from anthropogenic activities (Tegen and Fung 1995).
- Yearly and monthly mean aerosol optical depths at the wavelength of 0.75 \( \mu \text{m} \) over China have been determined from the data involving the daily direct solar radiation, sunshine duration, surface pressure, and vapor pressure from 1961 to 1990 (Luo et al. 2001). Larger aerosol optical depths are found in southern China.

Simulation Results

<table>
<thead>
<tr>
<th>Simulation Yearly</th>
<th>Precipitation (mm/day)</th>
<th>DUST – CTRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>-0.84</td>
<td>-0.84</td>
</tr>
<tr>
<td>July</td>
<td>-7.30</td>
<td>-7.13</td>
</tr>
</tbody>
</table>

Positive solar radiative forcing is found at TOA due to the absorption of solar radiation by dust aerosols, leading to a significant decrease in planetary albedo, and increase in global surface air temperature, revealing that dust has a significant warming effect.

Observed aerosol optical depths at the wavelength of 0.75 \( \mu \text{m} \) over China since 1975 (Zeng et al. 2006). The present simulation results for precipitation and its impact on dust storm occurrence match the observed patterns in northwestern China.

Summary

Dust particles absorb substantial solar radiation and have a positive solar forcing at the top of the atmosphere, but a negative solar forcing at the surface.

Increasing dust in China would produce additional heating in the air column of mid- to high latitudes and tend to move the simulated precipitation inland, i.e., toward the Himalayas.

Incorporating a large loading of dust particles in China increases simulated precipitation in northwestern China where it is normally dry, and hence tends to reduce the occurrence of dust storms. The total number of dust storm occurrence days observed between 1961 to 2003 in China has been decreasing since 1975 (Zeng et al. 2006). The present simulation results for precipitation and its impact on dust storm occurrence match the observed patterns in northwestern China.