Application and Evaluation of CMAQ for Modeling Air Pollutants in Shanghai

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Presentation Outline

- Background
- Model configurations
- Model performance analyses
  - Simulated meteorological fields
  - Simulated concentrations of major air pollutants
  - Process analysis of major air pollutants
- Summary and future work
Background and Motivation

- Air pollution is a big problem in large cities and city clusters in China
- Coordinated observations were taken in Shanghai during 2009, which needs coordinated modeling work as well
- Ensemble air quality forecasting system has been in operation in Shanghai, and needs continuous development
Model Configurations

- **Model:** CMAQ v4.6
- **Domain (4 nested):** 81 km → 27 km → 9 km → 3 km
  - 3 km: 88×73 horizontal grid cells
  - 14 layers from surface to the tropopause
- **Meteorology:** MM5 v3.7
- **Emissions:** INTEX-B 2006 (0.5° × 0.5°)
  - Shanghai Emission 2006 (1km×1km)
- **Initial and boundary conditions (ICs/BCs):**
  - Domain 1: clean IC/BCs
  - Domain 2-4: extract from the coarser domain
- **Gas-phase mechanism:** CB05
- **Aerosol module:** AERO4
- **Simulation Period:** January 17 ~ February 17, 2009

CMAQ: the Community Multiscale Air Quality Modeling system
MM5: the fifth-generation Penn State/NCAR Mesoscale Model
CB05: the Carbon Bond Mechanism 2005
Four Nested Domains

D1: East Asia
D2: Southeastern coastal area
D3: Lower and middle reaches of Yangtze river
D4: Shanghai area
Simulated Meteorological Fields (1)

Temperature

**Hongqiao Airport**

![Temperature Graph](Hongqiao_Airport_Graph)

**Pudong Airport**

![Temperature Graph](Pudong_Airport_Graph)
Simulated Meteorological Fields (2)

Relative Humidity

**Hongqiao Airport**

- Observed (red dots)
- Simulated (blue line)

**Pudong Airport**

- Observed (red dots)
- Simulated (blue line)
Simulated Meteorological Fields (3)

Wind

Hongqiao Airport

Pudong Airport
## Statistics of Meteorological Simulations

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
<th>Relative humidity</th>
<th>Wind speed</th>
<th>Wind direction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MeanObs</strong></td>
<td>8.9</td>
<td>70.0</td>
<td>4.7</td>
<td>171.2</td>
</tr>
<tr>
<td><strong>MeanMod</strong></td>
<td>8.1</td>
<td>74.4</td>
<td>4.1</td>
<td>172.6</td>
</tr>
<tr>
<td><strong>Number</strong></td>
<td>829</td>
<td>964</td>
<td>927</td>
<td>756</td>
</tr>
<tr>
<td><strong>corr</strong></td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>MB</strong></td>
<td>-0.8</td>
<td>4.5</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>NMB (%)</strong></td>
<td>-8.4</td>
<td>6.4</td>
<td>-12.1</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>NME (%)</strong></td>
<td>23.4</td>
<td>15.5</td>
<td>30.5</td>
<td>26.0</td>
</tr>
</tbody>
</table>
Spatial Distributions of Major Air Pollutants

2009 Jan. 22\textsuperscript{nd} – Feb. 17\textsuperscript{th}, 26-day mean of hourly data

\begin{itemize}
  \item PM\textsubscript{10}
  \item PM\textsubscript{2.5}
  \item SO\textsubscript{2}
  \item NO\textsubscript{2}
\end{itemize}
Observation Sites
Hourly Variation of PM$_{10}$ and PM$_{2.5}$

Jingan, Urban site

Dianshan Lake, Rural site
Hourly Variation of $\text{SO}_2$

$\text{SO}_2$

Jingan, Urban site

Dianshan Lake, Rural site

$$C_{\mu g/m^3} = \frac{C_{\text{ppb}} \times M_a}{24.45}$$

$T = 298 \text{ K}, P = 1.01325 \times 10^5 \text{ Pa (N M}^{-2}), 1 \text{ ppb SO}_2 = 2.61 \ \mu g \text{ m}^{-3}$
Hourly Variation of NO\textsubscript{2}

**Jingan, Urban site**

**Dianshan Lake, Rural site**

\[
C_{\mu g m^{-3}} = \frac{C_{ppb} \times M_q}{24.45}
\]

T = 298 K, P = 1.01325 \times 10^5 Pa (N M^{-2}), 1 ppb NO\textsubscript{2} = 3.63 \mu g m^{-3}
Hourly Variation of $O_3$

$O_3$

Jingan, Urban site

Dianshan Lake, Rural site

$$C_{\mu g m^{-3}} = \frac{C_{ppb} \times M_q}{24.45}$$

$T = 298 \text{ K}$, $P = 1.01325 \times 10^5 \text{ Pa (N M}^{-2})$, $1 \text{ ppb SO}_2 = 3.48 \mu g m^{-3}$
### Statistics of Major Air Pollutant Simulation

<table>
<thead>
<tr>
<th></th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>SO$_2$</th>
<th>NO$_2$</th>
<th>O$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeanObs</td>
<td>82.05</td>
<td>51.78</td>
<td>39.89</td>
<td>48.20</td>
<td>53.68</td>
</tr>
<tr>
<td>MeanMod</td>
<td>80.67</td>
<td>52.51</td>
<td>47.70</td>
<td>65.33</td>
<td>60.73</td>
</tr>
<tr>
<td>Number</td>
<td>5772</td>
<td>969</td>
<td>5785</td>
<td>5838</td>
<td>4636</td>
</tr>
<tr>
<td>corr</td>
<td>0.25</td>
<td>0.18</td>
<td>0.19</td>
<td>0.41</td>
<td>0.50</td>
</tr>
<tr>
<td>MB</td>
<td>-1.38</td>
<td>0.73</td>
<td>7.82</td>
<td>17.13</td>
<td>7.05</td>
</tr>
<tr>
<td>NMB (%)</td>
<td>-1.69</td>
<td>1.4</td>
<td>19.6</td>
<td>35.53</td>
<td>13.13</td>
</tr>
<tr>
<td>NME (%)</td>
<td>77.64</td>
<td>85.78</td>
<td>81.81</td>
<td>68.61</td>
<td>65.63</td>
</tr>
</tbody>
</table>

Statistics are all based on hourly data.
Process Analysis: \( \text{SO}_2 \)

Daily-average change in \( \text{SO}_2 \) due to each process

**Jingan, Urban site**

**Dianshan Lake, Rural site**
Process Analysis: NO₂

Daily-average change in NO₂ due to each process

Jingan, Urban site

Dianshan Lake, Rural site
Summary and Future Work

- **For this study**, the MM5 model can relatively well simulate temperature, relative humidity, and wind; the CMAQ model can simulate PM\textsubscript{10}, PM\textsubscript{2.5}, SO\textsubscript{2}, NO\textsubscript{2}, and O\textsubscript{3} with relatively low biases, but has limitations in predicting hourly variations of those pollutants.

- **Emissions** are the major contributor to the increases of PM\textsubscript{10}, SO\textsubscript{2}, and NO\textsubscript{2} at urban site; transport is the major contributor to the changes of those pollutants at rural site.

- **Model biases** may due to the uncertainties in meteorological simulations (e.g., cold bias of temperature) and emissions (e.g., uncounted emission such as firecrackers and fireworks).

- **Future Work:**
  - Model comparisons with satellite data;
  - Model comparisons with observed trace gases and PM composition;
  - Column process analyses.
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