AIM/Air: Approach to local air quality modeling
~ Emission from outside ~

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Content

1. Background and research purpose

2. Approach
   - Outline
   - Meteorology model and chemical transport model
   - Emission inventory

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Recent years, according to increase of energy consumption in developing countries, emission and deposition of air pollutants ($SO_2$, $NO_x$, PM) become serious problem of heath risk.

Air pollution problem comes out mainly in the city with high population density.

However, it was found not only emission from the city but also emission from surrounding area and outside of the country are high level.

In order to figure out movement and chemical transform of air pollutants, several chemical transport models have been developed.
In the AIM workshop in the last year, we presented application of multi-scale air quality model, MM5 and CMAQ to estimate background concentration of SO$_2$ and NOx in Beijing and Tianjin.

In this research, more detailed study on background analysis and source-receptor relationship by using MM5 and CMAQ.

Source-receptor relationship means affection by emission among (neighboring) regions.

In this presentation, the affection is evaluated as ratio of emission contribution by source region.

Source-receptor relationship among local regions in China and Japan were evaluated in this study.
Another purpose is to project future air quality by using econometric model and AIM/Enduse model.

Econometric model estimates the energy demanded by the future world from socio-economic condition, such as population growth, economic growth, industrial structure, unemployment ratio, and so on.

SO₂ and NOx concentration in 2020 were estimated by using output of AIM/Enduse model with BAU condition.
Regions and targets (1)

- **Target area**
  1. Whole Asia
  2. China
  3. Beijing, Chongqing
  4. Kansai area

- **Target period**
  - 2001

- **Target pollutants**
  - Sulfur oxides ($\text{SO}_2$, $\text{SO}_4^{2-}$)
  - Nitrogen oxides ($\text{NO}_2$, NO, $\text{NO}_3^-$)
  - NH$_3$
  - O$_3$
  - CO
  - PM
  - NMVOC
**Regions and Targets (2)**

Grid size:
- **D1**: 80km
- **D2**: 20km
- **D3, D4**: 5km
- **D5**: 20km
- **D6**: 5km

Major city or area in regions:
- **D3**: Beijing
- **D4**: Chongqing
- **D6**: Kansai
**Integrated Computational System**

- Outline of process flow

![Diagram of process flow](image)
Annual emission data of anthropogenic source

- **China**
  Estimated result by AIM/Enduse model

- **Japan, Korea, South and North Korea, Mongolia**
  EAGrid2000 (Kaminari et al, 2005)

- **South ~ East Asia**

- **Other countries**
  EDGAR3.2FT2000 (Olivier *et al*, 2005)
Emission data (2)

- AIM/Enduse
- EAGrid2000
- Streets et al. (2003)
- EDGAR3.2FT2000
$SO_2$ emission data

$SO_2$ emission

$271.3$
NO₂ emission data

NO₂ emission (Gg/year/grid)

NO₂ Emission
Generation of emission inventory

- Monthly, daily, and hourly change in emission by each of industrial, commercial, public, and transport sectors was considered.
- For countries except China, monthly and hourly change by each sector was considered.
- Time lag between local time and world standard time was considered.
Emission data from natural source

- Volcano source $O_2$
  - Central Research Institute of Electric Power Industry /GEIA,
  - Japan Meteorological Agency (Miyake island)
- Soil source $NO_x$
  - Yienger et al. (1995)
- Biological source NMVOC
  - Guenther et al. (1995)
Air Quality Model

**MM5**: 5th Generation Meso-scale Model
- Meso-scale meteorological model developed by Pennsylvania State University (PSU) and National Center for Atmospheric Research (NCAR)

**CMAQ**: Community Multi-scale Air Quality Model
- Three dimensional Euler-type chemical reaction & transportation model developed by US EPA
- As chemical reaction in gas phase, B4(Gery et al., 1989) or SAPRC99(Carter, 2000) is available.
CMAQ: Community Multiscale Air Quality Model
Result of calculation

- Dry deposition of NO$_2$ in September, 2001

![Map of dry deposition of NO$_2$ in September, 2001](image_url)
Comparison to EANET observations (1)

EANET observation sites (automatic measurement facility)
Comparison to EANET observations (2)

Remarks:

◆ Tendency of concentration is represented.
◆ Estimated values tend to be higher than observed values.
◆ There exist peaks around 200 days which can not be expressed.
Comparison to EANET observations (3)

Plot of month average SO$_2$ concentration (observation vs. estimation)
Comparison to EANET observations (4)

Plot of month average NO$_2$ concentration (observation vs. estimation)
Comparison to Kansai observations

![NO2 Observation (ppbV)](image1)

- **SO2**
  - 大津
  - 草津
  - 彦根
  - 八幡
  - 長浜
  - 守山
  - 東近江
  - 東成

- **NO2**
  - 東成
  - 八幡B
  - 四条畷

![NO2 Observation (ppbV)](image2)
Approach to estimation of emission contribution

Region: D1 (Asian countries)

The difference between emissions of case 1 and 2 is regarded as emission contribution from China:

Case 1. Asian countries have SO$_2$ emission.

Case 2. Only emission from China is set to be zero.
**Emission contribution from China (1)**

**Contribution =**

\[
\text{difference of } sulphur \text{ deposition} \times \frac{\text{between Case 1 and 2}}{\text{total } sulphur \text{ deposition in Case 1}} \times 100
\]

*_sulfur deposition_* : amount of sulfur deposition in a year

<table>
<thead>
<tr>
<th>Country</th>
<th>Contribution(%) Sulfur oxide</th>
<th>Nitrogen oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>80</td>
<td>68</td>
</tr>
<tr>
<td>South Korea</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>Japan</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Mongolia</td>
<td>81</td>
<td>66</td>
</tr>
<tr>
<td>Indian</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Indonesian</td>
<td>36</td>
<td>40</td>
</tr>
<tr>
<td>Cambodian</td>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>30</td>
<td>64</td>
</tr>
<tr>
<td>Laos</td>
<td>42</td>
<td>39</td>
</tr>
<tr>
<td>Macao</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>Malaysian</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>Thai</td>
<td>15</td>
<td>26</td>
</tr>
<tr>
<td>Vietnam</td>
<td>64</td>
<td>58</td>
</tr>
<tr>
<td>Myanmar</td>
<td>25</td>
<td>31</td>
</tr>
</tbody>
</table>
## Emission contribution from China (2)

<table>
<thead>
<tr>
<th>Country</th>
<th>Contribution(%)</th>
<th>Sulfur oxide</th>
<th>Nitrogen oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>80</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>South Korea</td>
<td>23</td>
<td>14</td>
<td></td>
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<tr>
<td>Japan</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Mongolia</td>
<td>81</td>
<td>66</td>
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</tr>
<tr>
<td>Indian</td>
<td>6</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Indonesian</td>
<td>36</td>
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<td>17</td>
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</tr>
<tr>
<td>Vietnam</td>
<td>64</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Myanmar</td>
<td>25</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>
Contribution from City to City (1)

Region : D2
(China)

The difference between emissions of case 1 and 2 is regarded as emission contribution from Chongqing area:

Case 1. D2 area have SO₂ emission.

Case 2. Only emission from Chongqing is set to be zero.
Contribution from City to City (2)

Contribution = \frac{\text{difference of } \text{sulfur deposition} \text{ between Case 1 and 2}}{\text{total } \text{sulfur deposition in Case 1}} \times 100

\text{sulfur deposition}: \text{amount of sulfur deposition in a year}

<table>
<thead>
<tr>
<th>City</th>
<th>Province</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>Beijing</td>
<td>3.6</td>
</tr>
<tr>
<td>Amoy</td>
<td>Fujian</td>
<td>6.7</td>
</tr>
<tr>
<td>Jinan</td>
<td>Shandong</td>
<td>6.3</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>Henan</td>
<td>5.1</td>
</tr>
<tr>
<td>Luoyang</td>
<td>Henan</td>
<td>5.1</td>
</tr>
<tr>
<td>Shanghai</td>
<td>Shanghai</td>
<td>2.7</td>
</tr>
<tr>
<td>Xi'an</td>
<td>Shanxi</td>
<td>7.2</td>
</tr>
<tr>
<td>Chengdu</td>
<td>Sichuan</td>
<td>7.5</td>
</tr>
<tr>
<td>Nanjing</td>
<td>Jiangsu</td>
<td>6.3</td>
</tr>
<tr>
<td>Nanchang</td>
<td>Jiangxi</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Remarks:
Deposition amount in cities near Chongqing is larger than others.
Deposition contribution among neighboring regions (1)

Region : D5
(Kansai district in Japan)

Source-receptor relationship among regions is analyzed

The difference between emissions of case 1 and 2 is regarded as emission contribution from target prefecture:

Case 1. Asian countries have SO$_2$ emission.

Case 2. Only emission from the prefecture is set to be zero.
Deposition contribution from source to receptor
(Sulfur oxides)

- Source to receptor matrix of sulfur oxides deposition (%)

<table>
<thead>
<tr>
<th>Source</th>
<th>Osaka</th>
<th>Kyoto</th>
<th>Shiga</th>
<th>Hyogo</th>
<th>Nara</th>
<th>Wakayama</th>
<th>Mie</th>
<th>Other places in D5</th>
<th>Other places in Kansai region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osaka</td>
<td>25.3</td>
<td>4.6</td>
<td>1.8</td>
<td>2.4</td>
<td>4.5</td>
<td>2.9</td>
<td>1.6</td>
<td>0.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Kyoto</td>
<td>5.3</td>
<td>11.6</td>
<td>2.6</td>
<td>1.6</td>
<td>2.0</td>
<td>0.8</td>
<td>1.6</td>
<td>0.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Shiga</td>
<td>0.6</td>
<td>1.1</td>
<td>4.9</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Hyogo</td>
<td>2.3</td>
<td>3.1</td>
<td>0.6</td>
<td>10.5</td>
<td>0.7</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Nara</td>
<td>1.7</td>
<td>0.8</td>
<td>0.4</td>
<td>0.3</td>
<td>5.1</td>
<td>0.6</td>
<td>1.4</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Wakayama</td>
<td>1.6</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>1.0</td>
<td>3.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Mie</td>
<td>0.3</td>
<td>0.4</td>
<td>2.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>3.8</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Other places in D5</td>
<td>7.1</td>
<td>6.1</td>
<td>8.8</td>
<td>8.9</td>
<td>3.0</td>
<td>3.5</td>
<td>4.5</td>
<td>13.2</td>
<td>10.6</td>
</tr>
<tr>
<td>China</td>
<td>13.2</td>
<td>11.8</td>
<td>11.8</td>
<td>11.8</td>
<td>11.8</td>
<td>17.7</td>
<td>11.8</td>
<td>11.8</td>
<td>12.1</td>
</tr>
<tr>
<td>Others</td>
<td>42.6</td>
<td>60.4</td>
<td>66.9</td>
<td>64.0</td>
<td>71.2</td>
<td>70.2</td>
<td>74.1</td>
<td>72.6</td>
<td>70.3</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Remarks:

◆ For Osaka prefecture, which is the largest industrial city in Kansai region, deposition to itself is largest.
◆ Deposition from outside Kansai region is relatively significant.
◆ Contribution to Osaka from others is smaller than contribution to other prefectures.
### Deposition contribution from source to receptor (Nitrogen oxides)

- **Source** to receptor matrix of nitrogen oxides deposition (%)

<table>
<thead>
<tr>
<th>Source</th>
<th>Osaka</th>
<th>Kyoto</th>
<th>Shiga</th>
<th>Hyogo</th>
<th>Nara</th>
<th>Wakayama</th>
<th>Mie</th>
<th>Other places in D5</th>
<th>Kansai region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osaka</td>
<td>26.9</td>
<td>6.9</td>
<td>4.1</td>
<td>4.4</td>
<td>7.2</td>
<td>6.2</td>
<td>4.2</td>
<td>2.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Kyoto</td>
<td>7.3</td>
<td>20.8</td>
<td>5.8</td>
<td>4.5</td>
<td>3.8</td>
<td>2.0</td>
<td>4.2</td>
<td>1.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Shiga</td>
<td>2.0</td>
<td>2.9</td>
<td>15.6</td>
<td>0.8</td>
<td>1.4</td>
<td>0.7</td>
<td>3.8</td>
<td>1.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Hyogo</td>
<td>3.1</td>
<td>6.4</td>
<td>1.9</td>
<td>21.1</td>
<td>1.9</td>
<td>1.5</td>
<td>1.1</td>
<td>1.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Nara</td>
<td>3.7</td>
<td>1.7</td>
<td>1.2</td>
<td>1.1</td>
<td>13.7</td>
<td>3.8</td>
<td>4.6</td>
<td>0.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Wakayama</td>
<td>4.0</td>
<td>0.7</td>
<td>0.5</td>
<td>0.8</td>
<td>3.3</td>
<td>13.8</td>
<td>1.0</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Mie</td>
<td>1.5</td>
<td>1.7</td>
<td>4.5</td>
<td>0.8</td>
<td>2.0</td>
<td>1.2</td>
<td>14.4</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Other places in D5</td>
<td>11.1</td>
<td>12.6</td>
<td>20.4</td>
<td>15.3</td>
<td>7.6</td>
<td>9.2</td>
<td>14.8</td>
<td>26.5</td>
<td>21.6</td>
</tr>
<tr>
<td>China</td>
<td>10.4</td>
<td>9.7</td>
<td>9.3</td>
<td>10.8</td>
<td>9.4</td>
<td>18.0</td>
<td>12.8</td>
<td>11.8</td>
<td>11.6</td>
</tr>
<tr>
<td>Others</td>
<td>30.0</td>
<td>36.7</td>
<td>36.7</td>
<td>40.4</td>
<td>49.7</td>
<td>43.6</td>
<td>39.2</td>
<td>52.4</td>
<td>47.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Remarks:**

- For Osaka prefecture, which is the largest industrial city in Kansai region, deposition to itself is largest.
- Deposition from outside Kansai region is significant.
- Contribution from other place in region D5 is larger than sulfur oxides deposition.
Ratio of nitrogen oxides deposition (Osaka)

- Ratio by emission source of sulfur oxides deposition fallen into Osaka.

**Remarks:**

- Year average ratio of background deposition is about 50%.
- Deposition to emission source itself (Osaka) is 20 ~ 30% in the year.
- In summer, self-deposition is weak in March and August.
Ratio of nitrogen oxides deposition (Osaka)

- Ratio by emission source of nitrogen oxides deposition fallen into Osaka.

Remarks:
- Year average ratio of background deposition is about 40%
- Deposition to emission source itself (Osaka) is larger in summer.
- In summer, self-deposition is a little weak in August.
**Emission contribution from sector**
(Sulfur oxides and Nitrogen oxides)

The difference in amount of deposition between emission and zero emission from target sector is regarded as emission contribution from the sector.

![Bar chart showing emission contribution from sector for Sulfur oxides and Nitrogen oxides](chart)

**Remarks:**

◆ Emission from automobiles strongly affects on deposition of nitrogen oxides.
Comparison of SO₂ and NO₂ concentration in Beijing and Tenjing, between year 2001 and 2020, under BaU condition without any countermeasure for air pollution.
Future projection of SO$_2$ concentration (Beijing)

Year average
SO$_2$ concentration of Beijing

Year average SO$_2$ concentration 7ppb → 56ppb

Chinese 2$^{nd}$ level environmental standard:
Day average SO$_2$: 150 $\mu$ g/m$^3$ ~56ppb

Remarks:
Year average SO$_2$ concentration in 2020 is 8 times larger than 2001’s. Concentration level excesses so often the 2$^{nd}$ standard level in the year.
Future projection of NO$_2$ concentration (Beijing)

Year average NO$_2$ concentration of Beijing

- Year average NO$_2$ concentration in 2020 is 4.5 times larger than 2001’s.
- Concentration level sometimes exceeds the 2$^{nd}$ standard level.

Remarks:

Year average NO$_2$ concentration in 2020 is 4.5 times larger than 2001’s.
Concentration level sometimes exceeds the 2$^{nd}$ standard level.
Future projection of SO$_2$ concentration (Tenjing)

Year average SO$_2$ concentration of Tenjing

- Year average SO$_2$ concentration: 9ppb → 35ppb

Chinese 2nd level environmental standard:
- Day average SO$_2$: 150 $\mu$g/m$^3$ ~56ppb

Remarks:
- High concentration exists during summer to winter season in 2020.
- Concentration level often excesses the 2nd standard level.
Future projection of NO₂ concentration (Tenjing)

<table>
<thead>
<tr>
<th>Year average NO₂ concentration of Tenjing</th>
<th>Year 2001</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11 ppb</td>
<td>36 ppb</td>
</tr>
</tbody>
</table>

Chinese 2nd level environmental standard:

Day average NO₂:
120 μg/m³ ~46 ppb

Remarks: High concentration exists in summer season in 2020. Concentration level often exceeds the 2nd standard level.
Conclusion

- Estimation of background concentration was estimated.
- Source and receptor relationship was estimated.
- Future air quality was projected.