Progress of S-7-1: Quantification of Ozone and Aerosol Pollution in East Asia and the Hemisphere Synthesizing Numerical Modeling and Observation

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in collaboration with
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and participants in S-7 project
To better understand the structure of air pollution in East Asia

- **Source-receptor (S-R) relationship** which is defined as the response of concentration of an air pollutant at a given receptor location to a perturbation of emissions in a source region is a key concept.

- S-R relationship of $O_3$ (and $PM_{2.5}$) has been evaluated by using chemical transport models (CTMs), and the structure of air pollution in East Asia has gradually become clear recently.

Structure of air pollution

= Quantitative understanding on the contributions of the sources of air pollutants
Our Tools to estimate the S-R relationship

**Global CTM**

- Tropospheric gas chemistry: $O_x$-HO$_x$-NO$_x$-CO-CH$_4$, NMHCs, SOx
- Main target is tropospheric $O_3$
- Aerosols (S, N, OC/BC, SS, Dust) and stratospheric chemistry are now introducing.

**Regional CTM**

- Tropospheric gas and aerosol chemistry
- Main target is tropospheric $O_3$ and PMs (S, N, OC, BC, SOA)
- CHASER (↔) has been used as boundary conditions of this system

**CHASER**

(Sudo et al., 2002)

**Regional weather model**

- WRF

**Regional CTM**

- CMAQ

**Resolution**

- Global CTM: $\approx 180,300$ km
- Regional CTM: $< 80$ km
**S-R relationship of surface $O_3$ in East Asia**

**Contributions of source regions to surface $O_3$ in Japan (Spring/Summer)**

- **Regions where the $O_3$ was chemically created**
  - Remote region (NA, EUR, CAS etc.)
    - 6.5 ppbv (12.7%)
  - East Siberia
    - 1.2 ppbv (2.3%)
  - Free Troposphere
    - 6.5 ppbv (12.6%)
  - Stratosphere
    - 0.3 ppbv (0.8%)
  - Remote region (NA, EUR, CAS etc.)
    - 10.9 ppbv (21.2%)
  - East Siberia
    - 0.3 ppbv (0.8%)
  - Free Troposphere
    - 7.2 ppbv (17.9%)
  - Stratosphere
    - 2.3 ppbv (5.9%)

**Diverse origins of $O_3$ over Japan in Spring**
- Domestic contribution: 22%
- Chinese contribution: 12%
- N. America and Europe: 7%
- Stratosphere and FT have large contribution

**Spring → Summer**
- Domestic contribution gets larger
- At least 70% of $O_3$ over Japan is Asia origin.

*Nagashima et al., ACP 2010*
Long-term (1980-2005) trend in surface O₃ in Japan

Long-term increasing trend of surface O₃ in Japan was well represented by the model.

Anomaly of annual mean surface O₃ averaged over Japan (ppbv)

Anomaly of seasonal mean surface O₃ averaged over Japan (ppbv)

Horizontal distribution of the trend in surface O₃

Nagashima et al., in prep.

Observed features in the long-term trend of O₃ were well captured by the model:
- seasonal difference
- longitudinal difference
Long-term (1980-2005) trend in $O_3$ S-R relationship in Japan

Inter-annual variation of the contributions of source regions to surface $O_3$ in Japan

Nagashima et al., in prep.

Relative contribution (%) of the regions where the $O_3$ was created to the total increasing trend (not the regions of $O_3$ precursor emission)

$O_3$ created in China has the largest contribution to the recent $O_3$ increase in Japan, however, contributions of $O_3$ created in the other regions also has a certain impact.

<table>
<thead>
<tr>
<th>Total</th>
<th>2.4 [ppbv/decade]</th>
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<tbody>
<tr>
<td>China</td>
<td>36 %</td>
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<tr>
<td>Korean Pen.</td>
<td>14 %</td>
</tr>
<tr>
<td>Japan</td>
<td>11 %</td>
</tr>
<tr>
<td>Asian Seas</td>
<td>13 %</td>
</tr>
<tr>
<td>S+SE Asia</td>
<td>7 %</td>
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<tr>
<td>Free Troposphere</td>
<td>16 %</td>
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</tbody>
</table>
The interests of countries for transboundary air pollution is complicated in NE and SE Asia.

China is not always the exporter of air pollution but also suffers air pollutants from neighboring countries.
Estimating the impact of reduction in the emission of air pollutants

- **Reg. Weather Model**: WRF\textsuperscript{(v3.3)}
- **Downscaled Meteorology**: Reg. CTM CMAQ\textsuperscript{(v4.7.1)}

- **Year**: 2005
- **Emission data**: REAS v1.2

  - (i) Standard Run (w/o emission reduction)
  - (ii) Sensitivity Runs (4 × 4 × 2 = 32 cases)

- **Regions of emission reduction**: NCHN, SCHN, KRNP, JPN
- **Sectors**: Power generation (POW), Industry (IND), Transport (TRA), Domestic (DOM)
- **Reduction rate**: 50%
Impact of 50% reduction in emission from each region and sector on high $O_3$ and high PM$_{2.5}$ events

The days that daily max 8h $O_3$ exceeds 75 ppb for the present (2005)

- High $O_3$ events

The days that daily mean PM$_{2.5}$ exceeds 35 μg/m$^3$ for the present (2005)

- High PM$_{2.5}$ events

• For high $O_3$ event, **domestic emission control** (TRA and IND sectors) has the largest effect in Japan.
• Impact of emission control in China is also large

The days of high $O_3$ event (←) reduced by 50% reduction in emission from each region and sector over **Central Japan**

The days of high PM$_{2.5}$ event (←) reduced by 50% reduction in emission from each region and sector over **Central Japan**

• For high PM$_{2.5}$ event, **emission control in China** (POW and IND sectors) has the largest effect in Japan.
Estimating the effectiveness of the future emission scenarios of air pollutants

- Present-day (2005) emission scenario (year 2005 of CLE)
- Three near future (2030) emission scenarios

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>content/remarks</th>
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<tbody>
<tr>
<td>CLE</td>
<td>Only consider the current (as of 2002) policy to reduce emissions of air pollutants</td>
</tr>
<tr>
<td></td>
<td>• practical and needs minimum efforts</td>
</tr>
<tr>
<td>450ppm</td>
<td>Stabilize CO₂-equivalent GHG mixing ratio at 450 ppm <strong>for global mean temperature not to exceed 2°C</strong> by peaking out GHG emissions until 2020.</td>
</tr>
<tr>
<td></td>
<td>• developed by IEA(Intl. Energy Agency)</td>
</tr>
<tr>
<td></td>
<td>• considered as the standard scenario to elude fatal climate change</td>
</tr>
<tr>
<td>MFR</td>
<td>Adopt all technically feasible measures to reduce emissions of air pollutants regardless of their cost.</td>
</tr>
<tr>
<td></td>
<td>• hard to attain</td>
</tr>
</tbody>
</table>

Relative change in annual emission of NOₓ and SO₂ at 2030 from 2005 for each scenario
Japanese AAQS for PM2.5: (1) Daily mean < 35μg/m³ and (2) Annual mean < 15μg/m³

• If we adopt the Japanese AAQS for CEC and KOR, 450 ppm scenario is insufficient to attain it (annual mean < 15μg/m³).
Summary

Analysis on the S-R relationship of O$_3$ in Asia
► The surface O$_3$ in Japan has diverse origins.
► Recent increasing trend of O$_3$ in Japan can be partially (at least 36%) attributed to the increase in O$_3$ created in China.
► NE and SE Asia have strong relationship about O$_3$ pollution issue.

Estimating the effect of emission reduction and future emission scenarios in East Asia
► Emission control of air pollutants in China has large impact on Japanese air quality (AQ), but the impact is different for different pollutants (O$_3$ < PM$_{2.5}$)
► The 450ppm scenario can improve AQ in East Asia in a certain degree, but its not sufficient especially for China and Korea.