Improvement of Emission Inventories and Development of Emission Scenarios for Air Pollutants in East Asia

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# General information on REAS 2.1

## Item Description

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Areas</td>
<td>E, SE, S, and Central Asia Asian part of Russia</td>
</tr>
<tr>
<td>Target Years</td>
<td>2000-2008 ( - ???? )</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>0.25 x 0.25 degree</td>
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<tr>
<td>Temporal Resolution</td>
<td>Monthly (if possible)</td>
</tr>
<tr>
<td>Japan</td>
<td>JATOP/OPRF*</td>
</tr>
<tr>
<td>Korea and Taiwan</td>
<td>Officially estimated data</td>
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* JATOP (Japan Auto-Oil Program)  
  OPRF (Ocean Policy Research Foundation)

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## Table

<table>
<thead>
<tr>
<th>Item</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>CO</th>
<th>PM₁₀</th>
<th>PM₂.₅</th>
<th>BC</th>
<th>OC</th>
<th>NMV</th>
<th>NH₃</th>
<th>CH₄</th>
<th>N₂O</th>
<th>CO₂</th>
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<td>Others</td>
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EMs in Asia: SO$_2$, NO$_x$, BC, NMVOC

<table>
<thead>
<tr>
<th></th>
<th>CHN</th>
<th>OEA</th>
<th>SEA</th>
<th>SA</th>
<th>RCA</th>
<th>Asia</th>
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<td>88</td>
<td>113</td>
<td>148</td>
<td>102</td>
<td>134</td>
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<tr>
<td>BC</td>
<td>140</td>
<td>74</td>
<td>118</td>
<td>146</td>
<td>125</td>
<td>135</td>
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</table>

Ratio 2008 /2000 [x100]

<table>
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<tr>
<th></th>
<th>CHN</th>
<th>OEA</th>
<th>SEA</th>
<th>SA</th>
<th>RCA</th>
<th>Asia</th>
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<tbody>
<tr>
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<td>86</td>
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<td>151</td>
<td>114</td>
<td>154</td>
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<tr>
<td>VOC</td>
<td>171</td>
<td>83</td>
<td>147</td>
<td>136</td>
<td>145</td>
<td>146</td>
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</table>
Contributions (Fuel Type/Sector)

Northeast Asia

- Power Plants
- Industry
- Transport
- Domestic
- Soil

Southeast Asia

- Power Plants
- Industry
- Transport
- Domestic
- Soil

Fuel Type
- Coal
- Gas
- Oil
- Biofuel
- Others

2008

NO\textsubscript{x}

Combustion Sources
- Residential
- Solvent Use
- Paint Use
- Industrial Process
- Others

Evaporative Sources

Transport SOURCES

Combustion (PP/IND)
- Transport
- Residential
- Solvent Use
- Paint Use
- Industrial Process
- Others
Spatial distribution: SO$_2$, NO$_x$, NMVOC, and BC

- **SO$_2$**
- **NO$_x$**
- **NMV**
- **BC**

Eastern China, Sichuan province, Chongqing, the Indo-Gangetic Plain, Southern India, and Indonesia: These areas have large population and significant economic and industrial activities.
NO\textsubscript{x} emissions in China increased monotonically from 1980 to 2008 and grew rapidly after 2002 especially due to the coal combustion in power plants and industry sector.

- Emissions in China and other East Asia were almost comparable in 1980, but in 2008, majority of NO\textsubscript{x} emissions was from China due to the rapid economic growth in China and EMs regulations in other EA.
NMVOC emissions also increased monotonically and growth rate became larger especially this decade.

In 2000, majority of emissions in China was from road transport and fuel combustion in domestic sector. But recently, emissions from solvent and paint use were increasing rapidly.

Contributions from SEA and SA were relatively large because of EMs from biofuel combustion.
Fractions and trends of monthly emissions in China

Monthly fractions

Trends of monthly emissions

SO₂

NOₓ

BC

Emissions from PPs and IND sectors generally increased throughout the year. In PPs sector, small peaks during summer month probably reflects the air conditioning. Small dips in Feb. reflect the Chinese Spring Festival. → PPs and IND sectors control the monthly variations of total SO₂ and NOₓ EMs.

BC EMs are dominated by DOM sector and their emissions are estimated higher in winter. → Fuel consumption for residential heating was estimated on the basis of monthly surface temperature. → Similar tendencies were also shown in other aerosols and CO EMs.
Problems in bottom-up emission inventory

Uncertainties [%] of annual total emissions in REAS 2.1

<table>
<thead>
<tr>
<th></th>
<th>SO2</th>
<th>NOx</th>
<th>CO</th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>BC</th>
<th>OC</th>
<th>NMV</th>
<th>NH$_3$</th>
<th>CH$_4$</th>
<th>N$_2$O</th>
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<td>India</td>
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<td>49</td>
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<td>137</td>
<td>144</td>
<td>154</td>
<td>153</td>
<td>49</td>
</tr>
<tr>
<td>Rest of Asia</td>
<td>35</td>
<td>47</td>
<td>131</td>
<td>194</td>
<td>208</td>
<td>257</td>
<td>286</td>
<td>111</td>
<td>148</td>
<td>204</td>
<td>135</td>
<td>44</td>
</tr>
</tbody>
</table>

For the calculations of uncertainties in this table, emissions in Japan are not considered except for CH$_4$ and N$_2$O and those in South Korea and Taiwan were included only for CO$_2$, NH$_3$, and N$_2$O. In addition, uncertainties of emissions related to agricultural soils and livestock for NO$_x$, NH$_3$, CH$_4$, and N$_2$O were not assessed in this study.

- Bottom-up EI has inevitable uncertainties associated with the statistics, emission factors, temporal and spatial allocation factors.
- Uncertainties of gridded monthly emissions must be much larger than those of annual total emissions. → How to evaluate bottom-up emission inventories?
- Estimating “current” emissions by the bottom-up approach is fundamentally impossible because the publication of statistics is generally a couple of years behind. → How to provide quasi-real time emissions?

Emission data sets derived from observation data and inverse modeling are essential.
Comparison of annual NO$_x$ emissions maps

By GOME2 in 2007  By OMI in 2007  REAS 2.1 in 2007

GOME2/OMI: GlobEmission projects
http://www.globemission.eu/data.php
[Mijiling,B. and R.van der A (2012); Mijiling et al. (2009)]
Monthly mean NO$_x$ emission estimates derived from GOME2/OMI observations of NO$_2$ VCDs by the EDCSO algorithm

- Spatial distributions of NO$_x$ emissions in China by GOME2, OMI, and REAS 2.1 generally show the similar results.
- Emission amounts of REAS 2.1 look larger than satellite derived data.
Comparison of annual NO$_x$ emissions in each region

**Absolute NO$_x$ Emissions in each region**

- CHN: 24.1 Tg/year
- CEC: 12.1 Tg/year
- BEI: 10.2 Tg/year
- NCP: 2.9 Tg/year
- YTD: 2.4 Tg/year
- PRD: 1.3 Tg/year
- SCH: 1.9 Tg/year

**Relative ratios for each region to CHN**

- CEC: 50%
- BEI: 40%
- NCP: 20%
- YTD: 20%
- PRD: 20%
- SCH: 20%

**Definition of regions**

- CHN: China
- CEC: Central Eastern China
- BEI: Around Beijing
- NCP: The North China Plain
- YTD: The Yangtze Delta
- PRD: The Pearl River Delta
- SCH: Around Sichuan Province

- NO$_x$ emissions of REAS 2.1 are generally larger than those by GOME2 and OMI.
- NO$_x$ EMs of China in REAS 2.1 are about 20% larger than satellite derived results.
- Relative ratio of emissions for each region to CHN are generally agreed with each other.
Comparison of annual NO\textsubscript{x} emissions for each province

- In most provinces, emissions in REAS 2.1 are larger than those by OMI and GOME2.
- The differences of emissions between REAS 2.1 and satellite derived data vary from province to province.
- If we can find common contributing emission sources in the provinces whose differences between REAS 2.1 and satellite derived data are large, it might give clues to improve REAS 2.1.

→ Activity data and EFs for such sources can be revisited.
Comparison of monthly fractions of NO\textsubscript{x} emissions (CEC/BEI/SCH)

- MVs in REAS 2.1 agree well with those by OMI for CEC and SCH. 
  → In REAS 2.1, large summer peaks in these region were mainly due to soil emissions.

- As for BEI, MVs in 2007 are relatively small for all results, but in 2008, satellite derived emissions decreased rapidly after July. 
  → EMs mitigation measures for Beijing Olympic such as for industrial and road transport sectors were not explicitly included in REAS 2.1.
## Future projected emissions

<table>
<thead>
<tr>
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</tr>
</thead>
</table>
| Scenario for activity data from AIM/CGE model                       | 1. Business as usual (BAU)  
2. 50% CO₂ cut scenario by 2050 (C50%)  
3. 50% CO₂ cut scenario by 2050 considering mitigation of air pollution in AIM/CGE model (C50%+A)                                                                                                                                                                                                                         |
| Scenario for emission factors for 2030                             | 1. EFs for 2005 (used in each country and region)  
2. EFs of Japan for 2005 for developing countries; EMs reduction is assumed for developed countries.                                                                                                                                                                                                                                     |
| Base Year                                                           | 2005                                                                                                                                                                                                                                                                                                                                      |
| Target Years                                                       | 2030                                                                                                                                                                                                                                                                                                                                      |

Activity data for REAS in 2005, such as fuel consumption and production of industrial commodity, are extrapolated based on the trends for future activity data provided by AIM/CGE model.

![Energy Consumption in China [PJ]](chart.png)
Preliminary results for China

- Without improvement of emission factors (EFs), reduction of emissions for scenarios of 50% CO$_2$ cut by 2050 is limited in 2030.
- By using EFs for Japan in 2005, emissions of SO$_2$ and BC in 2030 will be smaller than those in 2005.
- Reduction of emissions of NO$_x$ and NMVOC seem to be more difficult compared to SO$_2$ and BC.
Key messages

- Both spatial and temporal variation of emissions of air pollutants and greenhouse gases in Asian region is expected to be complicated and continuous effort for developing and improving Asian emission inventory is needed and never-ending.

- Detailed information from each country is required to develop emission inventory which can be used for considering effective measures to mitigate emissions and thus, collaboration with researchers in each country is essential.

- For understanding status of air quality and climate and creating effective scenarios to mitigate air pollution and climate change, combination of wide range of research fields such as observation, bottom-up emission inventory, regional and global modeling for atmosphere, inverse modeling, social modeling, policy science studies, etc. is important.
Thank you for your attention!