Sensitivity study on Ammonia Emission Impacts on Fine Particles in China

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Outline

- **Background**
  - Serious airborne particle problem in China
  - Ammonia impacts on Secondary Inorganic Aerosols (SIA)

- **Objective and Methodology**
  - Development of RSM-CMAQ model
  - Validation of the model system

- **Results and discussion**
  - Impacts of ammonia on SIA (static & dynamic sensitivity)
  - Potential AQ benefit from future NH$_3$ controls strategy

- **Conclusion**
Half of Chinese cities cannot meet the CNAAQS – II of PM$_{10}$ annual concentration (100 microgram per m$^3$).

High PM$_{2.5}$ concentration in megacities has been frequently reported during last decade.
Secondary Inorganic Aerosols (SIA) is one dominant contributor to fine particles

**Chemical compositions** *(Chan C.K and Yao X.H, 2007)*

- Inorganic species (22~54%)
  - Sulfate, Nitrate, Ammonium
- Carbonaceous species (27~42%)
  - organic carbon
  - and elemental carbon
- Crustal species (11~16%)
  - Al, Si, Ca, Mg, Fe, etc.

**Major Sources**

- Primary emissions
  - fossil / bio- fuel burning, fugitive emissions from industry plants and traffic road, dust, etc.
- Secondary sources
  - chemical reactions among precursors as NOx, SO2, NH3, VOC.
Non-linear system during SIA formation

Sensitivity studies on SIA

- **SO₂ vs NOx impacts**
  Mueller et al., ES&T, 2004; Blanchard et al., A&WMA, 2007
- **SO₂ vs NH₃ impacts**
  Tsimpidi et al., A&WMA, 2007
- **NOx vs VOC impacts**
  Tsimpidi et al., A&WMA, 2008
- **NH₃ impacts**
  Redington et al., AE, 2009
- **SO₂, NOx vs NH₃ impacts**
  Pinder et al., ES&T, 2007
- **NOx, VOC vs NH₃ impacts**
  Nguyen et al., AST, 2002
- **SO₂, NOx, NH₃, VOC, CO impacts**
  Derwent et al., AE, 2009

1. Considerable ammonia impacts
2. Highly non-linear system brings heavy computational requirements

Processes involving

- Photochemistry
- Multi-phase reactions
- Aerosol thermodynamics
- Along with precursors emissions, physical transport, wet-dry depositions, particle formation condensation, coagulation, cloud scavenging...
Anthropogenic ammonia emissions in China

Livestock and fertilizer application are the major sources (~90%). Heavy ammonia emissions condensed in Mid-East China. Strong seasonal variation, higher from May to July.

Source contribution

Seasonal variation (Streets D. G., et al, 2003)

Spatial distribution

Along with the growth of $\text{SO}_2$, NOx and VOC emissions, NH$_3$ emissions are continually increasing. (doubled in 2005 compared to 1980)
Objective: evaluate the ammonia impacts in a highly non-linear complex model system

- Response surface model experimental design
- Gridded emissions in 2005 (Base year)
- Historical emission trend starts from 1980s
- Future emission projections up to 2030
- Response model experimental design
- Training samples
- Air Quality modeling
- Predictor
- Validation
- RSM predicted system
- Sensitivity study on SIA responses
- Multi-Emission scenarios
- Multi-case Impacts
- MM5v3 / CMAQ4.7
- Target period: July 1\textsuperscript{st} ~31\textsuperscript{st} 2005
- Pollutant

- Source A
- Source B
- Source C

- NOx control factor
- SO2 control factor
- NH3 control factor

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1

- 0
- 0.5
- 1
- 1.5
- 2

- 0
- 0.5
- 1
- 1.5
- 2

- 0
- 4.000
- 6.000
- 8.000
- 10.00
- 12.00
- 14.00
- 16.00
Validation of Base year simulation (year 2005)

**NO₂ Tropospheric Column density**
OMI 0.125°×0.125°

**SO₂ Tropospheric Column density**
SCIAMACHY: 0.5°×0.5°

**Aerosol optical depth**
MODIS/Terra: 1°×1°

**2005 summer time**
Blue: North China Plain, Orange: Yangtz river delta, Green: Pearl river delta
Part 2 Methodology

Validation of model performance on SIA simulation

weekly mean.

**Beijing Urban**

- **PM$_{2.5}$**
- **NO$_3^-$**
- **SO$_4^{2-}$**
- **NH$_4^+$**

**Beijing Rural**
Validation Methods:
- Cross validation $R > 0.99$
- Out of sample validation NME <10%
- Isopleths validation $R > 0.99$

Out of sample validation (12 cases)

<table>
<thead>
<tr>
<th>City</th>
<th>PM2.5</th>
<th>Sulfate</th>
<th>Nitrate</th>
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<tbody>
<tr>
<td>Beijing</td>
<td>1%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>Miyun</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Tianjin</td>
<td>1%</td>
<td>5%</td>
<td>3%</td>
</tr>
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<td>Shanghai</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
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<tr>
<td>Guangzhou</td>
<td>2%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Nanning</td>
<td>3%</td>
<td>2%</td>
<td>8%</td>
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<td>Jining</td>
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<td>Shijiazhuang</td>
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<td>5%</td>
<td>6%</td>
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<td>Zhengzhou</td>
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<td>4%</td>
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<tr>
<td>Xi'an</td>
<td>1%</td>
<td>3%</td>
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<td>2%</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>Shenyang</td>
<td>2%</td>
<td>2%</td>
<td>8%</td>
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<tr>
<td>Hangzhou</td>
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<td>4%</td>
<td>7%</td>
</tr>
</tbody>
</table>

NME for Reduction ratio of concentration

R1: Two variables RSM (30); R2: Five variables RSM(100)
List of cases conducted in this study

- **Base case:**
  - July, 2005 (monthly mean)
- **Pollutants:**
  - PM$_{2.5}$, Sulfate, Nitrate
- **Target Sites:**
  - 18 cities

- Change NH$_3$ emissions alone
  - Reduce by 50% (= 1980 level) and Increase by 30% (= 2030 level)

- Change all emission including NH$_3$, SO$_2$, NOx, VOC and PM
  - Static sensitivity: keep the same emission level of other species
  - Dynamic sensitivity: when other species emission changes

- Potential benefit from future NH$_3$ control strategy
  - Extra NH$_3$ control effects base on current SO$_2$/NOx control strategy
  - Possible risk from acid deposition effects
Static sensitivity analysis

---NH₃ impacts

Ammonia reduction is benefit for the particle control

Nitrate is more sensitive to ammonia emissions

**NH₃ reduced by 50%**

- PM₂.₅ reduced by 4~20%
- Sulfate reduced by 4~20%
- Nitrate reduced by 20~80%

**NH₃ increased by 30%**

- PM₂.₅ increased by 0~8%
- Sulfate increased by 0~10%
- Nitrate increased by 0~50%
Static sensitivity analysis
—Impacts of SO$_2$/NOx/NH$_3$ on PM

The relative contribution of NH$_3$ to fine particle is comparable with SO$_2$ and NOx.

Effects on NO$_3^-$ become larger under strengthened NH$_3$ control level.

SO$_4^{2-}$

5~33%

PM$_{2.5}$

6~21%

NO$_3^-$

37~46%
Dynamic sensitivity analysis

---Historical impacts

The growth of ammonia emissions enhance ~40% increase of sulfate and nitrate.

39(11~73)%

39(24~58)%
Dynamic sensitivity analysis

Future SIA concentration from 2005-2030

The future ammonia emissions will continually enhance 4~8% increase of sulfate and nitrate.

Emission projection from 2005-2030

Potential NH₃ control benefit

---Extra benefit

Extra NH₃ reduction is effective under current / future SO₂/NOx control strategy.

---potential solution when extra PM reduction needed while SO₂/NOx become hardly controlled (with larger marginal cost).

SO₄²⁻

Robustness of NH₃ reduction benefit

Emission ratios of SO₂ and NOx change between 0.5~2.0

PM₂.₅

NO₃⁻
Ammonia reduction is benefit for the particle control, specially for nitrate which is more sensitive to ammonia emissions.

The importance of NH$_3$ emission to fine particle is comparable with SO$_2$ and NOx, with 6~21% relative contribution.

The growth of ammonia emissions enhance ~40% increase of sulfate and nitrate, starting from 1990.

The future ammonia emissions will continually enhance 4~8% increase of sulfate and nitrate, till 2030.

NH$_3$ emission reduction is effective under current / future SO$_2$/NOx control strategy.
Uncertainty and Future plan

- Impacts from Seasonal variations
- Risk evaluation, such as enhancing acid deposition
Potential NH₃ control benefit
——Risk evaluation

The Reduction of NH₃ emission within 50% control won’t have negative effects on acid deposition.
Thank you!
And waiting for your comments!