Geographic Sensitivity of PM$_{2.5}$ Mass to Large Point Source Emissions

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Policy Questions

- Which components of PM$_{2.5}$ are most sensitive to emission reductions?
- Are there any trade-offs between reductions in one species and increases in another?
- How do benefits from point source reductions compare to those from other sources?
- How do geographic regions impact each other?
- Do potential benefits of regional reductions occur where they are most needed?
One Option for Sensitivity Modeling

- Decoupled direct method (DDM) solves the set of first-order derivative equations of all relevant transport, source, sink and chemical processes.

![Graph showing emissions baseline and response of metric at baseline](image-url)
DDM Uses & Limitations

What it can provide:

- A sense of direction for responses to emission changes.
- Semi-quantitative estimates of the efficiency of responses to emission changes.
- Qualitative information on the geographic extent of responses to emission changes.

What it cannot provide:

- Quantitative estimates of air quality changes for emission changes >30%.
- Quantitative or qualitative estimates of air quality changes from changes in multiple emission species.
Basis of Analysis

- Meteorological fields: RAMS
- Emissions baseline: 2010
- Air quality model: URM-1ATM model
- Air quality model grid: Eastern ½ of U.S.
- Modeling periods: 4 of SAMI episodes
Source & Impact Regions

- Five source regions & four impact regions (impacts in region W are not reported)

Region Names:
NE: Northeast
MA: Mid-Atlantic
MW: Midwest
SE: Southeast
W: West of Miss. River
## Episode Characterization

Number of Modeled High* PM$_{2.5}$ Days per Impact Region

<table>
<thead>
<tr>
<th>Dates</th>
<th>MA</th>
<th>MW</th>
<th>NE</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 Apr - 3 May 1993</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24-29 June 1992</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>11-19 July 1995</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>3-11 August 1993</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5</td>
<td>26</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

*24-h average PM$_{2.5}$ in at least one grid cell = 35 µg/m$^3$. 
Emission Source Types

- $\text{SO}_2$, denoted “SO2”
- Point source $\text{NO}_x$, denoted “Pt\_NOx”
- Low-level $\text{NO}_x$, denoted “LL\_NOx”
Aerosol Species for which Emissions Sensitivity was Examined

- PM$_{2.5}$ mass
- Sulfate component of PM$_{2.5}$
- Organic component of PM$_{2.5}$
- Nitrate component of PM$_{2.5}$

Shorthand—
- Sulfate = “SO$_4$”
- Nitrate = “NO$_3$”
- Organic compounds = “OC”
- Fine mass = “PM2.5”
Sensitivity Response Metrics for Source-Impact Regional Pairings

- Average relative change in 24-h sulfate, OC and PM$_{2.5}$ concentrations.
- Maximum relative change in 24-h sulfate, OC and PM$_{2.5}$ concentrations.
- Average relative change for grid cells exceeding threshold values (OC=5, sulfate=10, PM$_{2.5}$=35 µg/m$^3$).
- For nitrate only, average & maximum *non-normalized* changes in concs.
Regional Interactions

Average 24-h Sulfate Responses within Impact Regions from ...

... 10% SO₂ Emission Reduction in Midwest

Bins of Percent Change in Sulfate

... 10% SO₂ Emission Reduction in Southeast

Bins of Percent Change in Sulfate
Sensitivity of 24-h SO$_4$ to 10% SO$_2$ Emission Reductions

Composite of All Episodes*

*Responses are across all regions.

Sensitivity of 24-h SO$_4$ to 10% SO$_2$ Emission Reductions

Composite of All Episodes*

*Responses are across all regions.
Sulfate Metric Sensitivities Across All Episodes

10% Reduction in SE SO₂ Emissions

10% Reduction in MA SO₂ Emissions

10% Reduction in MW SO₂ Emissions

10% Reduction in NE SO₂ Emissions

*Denotes impact region
Sensitivities of OC & PM2.5 to 10% SO$_2$ Emission Reductions

Colored bars represent different source regions. Plots are episode composites.
SO4 Sensitivities Compared for Different Source Types

Episode Composites for Selected Impact Regions (denoted with *)

SO4 Sensitivities in SO4 Threshold Cells to 10% Emission Reductions from All Source Regions

Average Changes (%) in 24-h SO4

Source Type

LL_NOx  Pt_NOx  SO2  LL_NOx  Pt_NOx  SO2  LL_NOx  Pt_NOx  SO2

MA*  MW*  NE*  SE*

SO2
OC Sensitivities Compared for Different Source Types

Episode Composites for Selected Impact Regions (denoted with *).

OC Sensitivities in OC Threshold Cells to 10% Emission Reductions from All Source Regions.
NO3 Sensitivities Compared for Different Source Types

Episode Composites for Selected Impact Regions (denoted with *)

NO3 Sensitivities in All Cells to 10% Emission Reductions from All Source Regions

Average Changes (µg/m³) in 24-h NO3

Source Type

MA*  MW*  NE*  SE*

LL_NOx  PL_NOx  SO2  LL_NOx  PL_NOx  SO2  LL_NOx  PL_NOx  SO2
Conclusions: Inter-regional Transport

- The Midwest, Mid-Atlantic and Southeast regions have the greatest impact on their own aerosol levels.
- The greatest influence on Northeast aerosols is from Midwest and Mid-Atlantic emissions.
- In general, Midwest emissions have the most influence of any region on other regions.
- The Southeast is relatively isolated: its emissions have the least affect on other regions and it is least affected by neighboring regions.
Conclusions: Species Sensitivity to Emissions

- Sulfate is the most sensitive of the fine particle species to emission changes.
- PM$_{2.5}$ is somewhat sensitive, primarily because of the influence of sulfate.
- 2010 SO$_2$ levels will be sufficiently high that small emission reductions are insufficient to produce substantial nitrate aerosol increases.
- A small decrease in low-level NO$_x$ emissions may result in small decreases in organic aerosols while point source NO$_x$ appears to have little influence on any fine particle species.
Conclusions: The Geography of Species Sensitivity

- The largest efficiency, $\Delta C/ \Delta E$, of an aerosol change relative to an emission change is for sulfate in the Southeast. There, the maximum efficiency of regional $SO_2$ emissions impacting sulfate approaches 0.8 for the four (1 spring, 3 summer) modeled episodes.

- The maximum efficiency for the $SO_2$-sulfate system approaches 0.7 in the Midwest and 0.6 in the Mid-Atlantic regions for these same episodes.

- In general, the largest modeled reductions in sulfate, organic aerosols and $PM_{2.5}$ did not occur in those areas where exceptionally high levels of their own kind were computed to occur.