Development and Application of PM2.5 Interpollutant Trading Ratios to Account for PM2.5 Secondary Formation in Georgia

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Introduction

• Facilities applying for PSD air permits are required to model the impact of direct PM2.5 emissions ($\geq 10$ TPY) using AERMOD.
  – In addition, these facilities must account for the impact of secondary PM2.5 formation from precursor emissions (NOx and/or SO2 $\geq 40$ TPY).

• AERMOD does not contain chemistry or aerosol formation modules
  – The secondary formation of PM2.5 cannot be modeled directly in AERMOD.
Interpollutant Trading Ratios

- Sources applying for permits in areas designated nonattainment for PM2.5 can offset emissions increases of direct PM2.5 emissions with reductions of PM2.5 precursors in accordance with interpollutant trading ratios (also called “PM2.5 offset ratios”) contained in the approved SIP for the applicable nonattainment area.
  - For example, an existing source can increase PM2.5 emissions by $X$ tons in exchange for reducing SO2 emissions by $Y$ tons.
Equivalent Direct PM2.5 Emissions

- PM2.5 offset trading ratios can be used to account for secondary formation of PM2.5 in AERMOD.
- Convert SO2 and NOx emissions into “equivalent” direct PM2.5 emissions.
  - 100:1 $\Rightarrow$ 100 TPY SO2 = 1 TPY direct PM2.5
  - 10:1 $\Rightarrow$ 100 TPY SO2 = 10 TPY direct PM2.5
  - 1:1 $\Rightarrow$ 100 TPY SO2 = 100 TPY direct PM2.5
  - 0.5:1 $\Rightarrow$ 100 TPY SO2 = 200 TPY direct PM2.5
    - This is ~100% conversion of SO2 to $(\text{NH}_4)_2\text{SO}_4$
- **Lower** PM2.5 offset ratios will produce **more** secondary PM2.5.
Secondary Formation in AERMOD

• **Option 1:** Add SO2 and NOx “equivalent” direct PM2.5 emissions to the actual direct PM2.5 emissions and run AERMOD
  – Allows for ratios that vary temporally

• **Option 2:** Calculate a percent increase in direct PM2.5 emissions due to the addition of SO2 and NOx “equivalent” direct PM2.5 emissions and scale the AERMOD output for actual direct PM2.5 emissions
  – Allows for ratios that vary spatially
The general framework for developing PM2.5 offset ratios would include the following steps:

1) Define the geographic area(s).

2) Conduct a series of sensitivity runs with appropriate air quality models to develop a database of modeled PM2.5 concentration changes associated with reductions of direct PM2.5 emissions and PM2.5 precursor emissions.

3) Calculate the interpollutant offset ratios for PM2.5.

4) Conduct quality assurance of the resulting ratios.
Case Study: Georgia

• Plant Washington
  – 850 MW Coal Fired Power Plant located in Washington County, GA

• GA EPD used CAMx photochemical modeling to account for secondary PM2.5 impacts and ozone impacts from the proposed facility.

• Final permit issued on April 8, 2010
Model Setup

• MM5 for Meteorology
  – VISTAS 2002

• SMOKE for Emissions
  – VISTAS 2009 used in Georgia PM2.5 SIP
  – Added power plant emissions (Plant Washington)
    • 4200 TPY SO2, 1817 TPY NOx, 6 TPY EC
    • Stack height = 137.16 meters

• CAMx with Flexi-nesting
  – 12-km/4-km/1.333-km

• Three sensitivity runs to calculate baseline PM2.5 offset ratios
  – Zero-out stack emissions: (1) SO2, (2) NOx, (3) EC
CAMx Modeling Domains

- CAMx 12 km
- CAMx 4 km
- CAMx 1.3 km
- AERMOD
Modeled PM2.5 Offset Ratios

• Normalized Sensitivity (S)
  - $S_{SO2} = \frac{\Delta PM2.5_{SO2}}{\Delta TPY_{SO2}}$
  - $S_{NOx} = \frac{\Delta PM2.5_{NOx}}{\Delta TPY_{NOx}}$
  - $S_{PM2.5} = \frac{\Delta PM2.5_{PM2.5}}{\Delta TPY_{PM2.5}}$

• PM2.5 Offset Ratios (R)
  - $R_{SO2} = \frac{S_{PM2.5}}{S_{SO2}}$
  - $R_{NOx} = \frac{S_{PM2.5}}{S_{NOx}}$
Sensitivity Runs

• Sensitivity runs were performed to evaluate how PM2.5 offset ratios varied by:
  – Distance from the source
  – Season of the year
  – Stack height
  – Grid resolution
  – Location in the state
Trading Ratio vs. Distance

• **OPTION 1:** Average $S_{SO2}$, $S_{NOx}$, and $S_{PM2.5}$ for all grid cells at a given distance, then calculate the average trading ratios ($R_{SO2}$ and $R_{NOx}$)

• **OPTION 2:** Calculate trading ratios ($R_{SO2}$ and $R_{NOx}$) for each individual grid cell, then average for all grid cells at a given distance
  – A single cell with small $\Delta PM2.5_{SO2}$ or small $\Delta PM2.5_{NOx}$ can bias the results

• GA EPD picked **OPTION 1**
Binned Offset Ratios

• For each precursor (SO2 and NOx) and each season (spring, summer, fall, winter), average $S_{SO2}$, $S_{NOx}$, and $S_{PM2.5}$ for all grid cells at a given distance, then calculate the average trading ratios ($R_{SO2}$ and $R_{NOx}$) for that distance
• Place trading ratios into bins and use the lowest ratio in the bin
  • <1 km, 1-4 km, 4-10 km, >10 km
Δ PM2.5 – Annual EC and SO2

Option 2 - SO2 Trading Ratio

PEC Contribution
Annual Average, 1.332 km Domain

SO2 Contribution
Annual Average, 1.333 km Domain
△ PM2.5 – Annual EC and NOx

Option 2 - NOx Trading Ratio
Spring SO$_2$ Offset Ratios

[Graph showing the offset ratios for Plant Washington as a function of distance (meters).]
Summer SO$_2$ Offset Ratios

[Graph showing the offset ratios for Plant Washington over distance in meters.]

- Offset Ratio on the y-axis ranges from 0 to 35.
- Distance on the x-axis ranges from 0 to 40,000 meters.
- The graph illustrates the decrease in offset ratios with increasing distance from Plant Washington.
Fall SO₂ Offset Ratios

Plant Washington

Offset Ratio

Distance (meters)
Winter SO$_2$ Offset Ratios

Plant Washington

Offset Ratio vs. Distance (meters)
### Binned SO2 Offset Ratios

<table>
<thead>
<tr>
<th>Distance</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 km</td>
<td>51:1</td>
<td>22:1</td>
<td>25:1</td>
<td>154:1</td>
</tr>
<tr>
<td>1 – 4 km</td>
<td>25:1</td>
<td>11:1</td>
<td>15:1</td>
<td>91:1</td>
</tr>
<tr>
<td>4 – 10 km</td>
<td>13:1</td>
<td>7:1</td>
<td>9:1</td>
<td>45:1</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>5:1</td>
<td>4:1</td>
<td>7:1</td>
<td>25:1</td>
</tr>
</tbody>
</table>

“Donut” plots are binned by distance and offset ratio.
Spring NOx Offset Ratios
Fall NOx Offset Ratios

\[ R_{NOx} = \frac{(\Delta PM2.5_{PM2.5}/\Delta TPY_{PM2.5})}{(\Delta PM2.5_{NOx}/\Delta TPY_{NOx})} \]
Winter NOx Offset Ratios

\[ R_{NOx} = \frac{\Delta PM_{2.5} / \Delta TPY_{PM2.5}}{\Delta PM_{2.5} / \Delta TPY_{NOx}} \]
## Binned NOx Offset Ratios

<table>
<thead>
<tr>
<th>Distance</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 km</td>
<td>58:1</td>
<td>47:1</td>
<td>67:1</td>
<td>N/A</td>
</tr>
<tr>
<td>1 – 4 km</td>
<td>38:1</td>
<td>29:1</td>
<td>45:1</td>
<td>N/A</td>
</tr>
<tr>
<td>4 – 10 km</td>
<td>26:1</td>
<td>23:1</td>
<td>41:1</td>
<td>N/A</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>15:1</td>
<td>20:1</td>
<td>37:1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### NOx, Annual Trading Ratio
- 1 - 5
- 6 - 10
- 11 - 20
- 21 - 35
- 36 - 50
- 51 - 100
- > 100
- N/A
Impact of Stack Height

• Stack height has a small impact on the SO2 offset ratios.
• Stack height has a bigger impact on NOx offset ratios.
• Shorter stacks have higher offset ratios (less PM2.5 formation), so using the lower offset ratios is conservative.
• Taller stacks will be limited by GEP Stack Height Regulations, so we will not need to adjust the ratios.
Impacts of Grid Resolution

• Larger grid resolutions (e.g., 12 km) produce more conservative SO2 and NOx offset ratios (lower ratios) compared to smaller grid resolutions (e.g., 1.3 km) near the source.

• Larger grid resolutions produce similar SO2 and NOx offset ratios compared to smaller grid resolutions far from the source.

• Creating SO2 and NOx offset ratios using larger grid cells is a conservative approach.
Impact of Location

- Developed PM2.5 offset ratios for eight different locations in Georgia
- Need to assign specific PM2.5 offset ratios to each county in Georgia based on distance from the eight locations.
Modeling Domains

N. Atlanta

E. Atlanta

Plant Washington

Downtown

W. Atlanta

S. Atlanta

South East

South West
Spring SO$_2$ Offset Ratios

- Distance (meters)
- Offset Ratio

Legend:
- Downtown Atlanta
- North Atlanta
- East Atlanta
- South West GA
- South Atlanta
- Plant Washington
- West Atlanta
- South East GA

Graph shows the offset ratios for different regions as a function of distance (meters). The ratios decrease rapidly with increasing distance.
Spring SO$_2$ Ratios

The map above shows the distribution of Spring SO$_2$ Ratios across a region. The color legend indicates different trading ratio ranges:

- Red: 1 - 5
- Orange: 6 - 10
- Yellow: 11 - 20
- Light Blue: 21 - 35
- Blue: 36 - 50
- Dark Blue: 51 - 100
- Gray: > 100
- White: N/A
Summer SO$_2$ Offset Ratios

Distance (meters) vs. Offset Ratio graph showing various locations in Atlanta.
Summer SO$_2$ Ratios
Fall SO$_2$ Offset Ratios

Graph showing offset ratios as a function of distance in meters for different locations. The x-axis represents distance in meters, ranging from 0 to 40,000. The y-axis represents offset ratio, ranging from 120 to 0. The graph includes lines for different locations such as Downtown Atlanta, North Atlanta, East Atlanta, South West GA, South Atlanta, Plant Washington, West Atlanta, and South East GA.
Fall SO$_2$ Ratios
Winter $\text{SO}_2$ Offset Ratios

Offset Ratios vs. Distance (meters)
Winter $\text{SO}_2$ Ratios

SO$_2$, Spring Trading Ratio
- 1 - 5
- 6 - 10
- 11 - 20
- 21 - 35
- 36 - 50
- 51 - 100
- > 100
- N/A
Spring NOx Offset Ratios

Offset Ratio vs. Distance (meters)

Legend:
- Downtown Atlanta (Red)
- North Atlanta (Black)
- East Atlanta (Purple)
- West Atlanta (Green)
- South West GA (Teal)
- South Atlanta (Blue)
- Plant Washington (Light Green)
- South East GA (Orange)
Spring NOx Ratios
Summer NOx Ratios
Fall NOx Offset Ratios
Fall NOx Ratios

[Map showing distribution of NOx ratios across regions, with a legend for trading ratios: 1 - 5, 6 - 10, 11 - 20, 21 - 35, 36 - 50, 51 - 100, > 100, N/A]
Winter NOx Offset Ratios

Offset Ratio vs Distance (meters)

- Downtown Atlanta
- North Atlanta
- East Atlanta
- East Atlanta
- South West GA
- South Atlanta
- Plant Washington
- West Atlanta
- South East GA

Graph showing the offset ratios for different areas as a function of distance.
Winter NOx Ratios

[Map showing various locations marked with different colors representing NOx trading ratios.]
SO$_2$ and NOx Offset Ratios

- SO$_2$ – Spring
- SO$_2$ – Summer
- SO$_2$ – Fall
- SO$_2$ – Winter

- NOx – Spring
- NOx – Summer
- NOx – Fall
- NOx – Winter
Example Tiered Approach

- Use tiered approach starting with the most conservative offset ratios and easiest to apply:
  - Tier 1
    - SO2 and NOx ratios from Q3 at d > 10 km
  - Tier 2a
    - SO2 and NOx ratios from Q3, vary with distance
  - Tier 2b
    - SO2 and NOx ratios by quarter at d > 10 km
  - Tier 3
    - SO2 and NOx ratios by quarter, vary with distance
<table>
<thead>
<tr>
<th>Distance</th>
<th>Tier 1 Ratios (SO2)</th>
<th>Tier 1 Ratios (NOx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 km</td>
<td>Q1: 80:1</td>
<td>Q1: 250:1</td>
</tr>
<tr>
<td></td>
<td>Q2: 35:1</td>
<td>Q2: 50:1</td>
</tr>
<tr>
<td></td>
<td>Q3: 20:1</td>
<td>Q3: 50:1</td>
</tr>
<tr>
<td></td>
<td>Q4: 40:1</td>
<td>Q4: 120:1</td>
</tr>
<tr>
<td>1 – 4 km</td>
<td>Q1: 40:1</td>
<td>Q1: 160:1</td>
</tr>
<tr>
<td></td>
<td>Q2: 20:1</td>
<td>Q2: 35:1</td>
</tr>
<tr>
<td></td>
<td>Q3: 10:1</td>
<td>Q3: 35:1</td>
</tr>
<tr>
<td></td>
<td>Q4: 25:1</td>
<td>Q4: 120:1</td>
</tr>
<tr>
<td>4 – 10 km</td>
<td>Q1: 25:1</td>
<td>Q1: 80:1</td>
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<tr>
<td></td>
<td>Q2: 10:1</td>
<td>Q2: 20:1</td>
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<tr>
<td></td>
<td>Q3: 7:1</td>
<td>Q3: 20:1</td>
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<tr>
<td></td>
<td>Q4: 18:1</td>
<td>Q4: 120:1</td>
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<tr>
<td>&gt; 10 km</td>
<td>Q1: 15:1</td>
<td>Q1: 40:1</td>
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<tr>
<td></td>
<td>Q2: 7:1</td>
<td>Q2: 20:1</td>
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<tr>
<td></td>
<td>Q3: 5:1</td>
<td>Q3: 20:1</td>
</tr>
<tr>
<td></td>
<td>Q4: N/A</td>
<td>Q4: N/A</td>
</tr>
</tbody>
</table>

Tier 1 “equivalent” direct PM2.5 emissions from SO2 and NOx can be accounted for by scaling the standard AERMOD output files.
Tier 2a “equivalent” direct PM2.5 emissions from SO2 and NOx can be accounted for by scaling the standard AERMOD output files.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 km</td>
<td>80:1</td>
<td>35:1</td>
<td>20:1</td>
<td>40:1</td>
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<tr>
<td>1 – 4 km</td>
<td>40:1</td>
<td>20:1</td>
<td>10:1</td>
<td>25:1</td>
</tr>
<tr>
<td>4 – 10 km</td>
<td>25:1</td>
<td>10:1</td>
<td>7:1</td>
<td>18:1</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>15:1</td>
<td>7:1</td>
<td>5:1</td>
<td>10:1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distance</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 km</td>
<td>250:1</td>
<td>50:1</td>
<td>50:1</td>
<td>120:1</td>
</tr>
<tr>
<td>1 – 4 km</td>
<td>160:1</td>
<td>35:1</td>
<td>35:1</td>
<td>120:1</td>
</tr>
<tr>
<td>4 – 10 km</td>
<td>80:1</td>
<td>20:1</td>
<td>20:1</td>
<td>120:1</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>40:1</td>
<td>20:1</td>
<td>20:1</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Tier 2b “equivalent” direct PM2.5 emissions from SO2 and NOx should be added to the actual direct PM2.5 emissions prior to running AERMOD.
Tier 3 “equivalent” direct PM2.5 emissions from SO2 and NOx will require scaling quarterly AERMOD outputs followed by recalculation of annual and daily PM2.5 impacts.
Summer SO$_2$ Offset Ratios

Plant Washington

Offset Ratio vs. Distance (meters)
Summer $SO_2$ Offset Ratios

Offset Ratio

Distance (meters)
Example PSD Application

- Direct PM2.5 emissions = 118.30 TYP
- SO2 emissions = 190.93 TPY
- NOx emissions = 340.65 TPY

- PM2.5 Scaling Factor =
  \[(\text{SO2 TPY/SO2 Ratio}) + (\text{NOx TPY/NOx Ratio}) + \text{PM2.5 TPY}] / \text{PM2.5 TPY}\]

<table>
<thead>
<tr>
<th>Distance</th>
<th>Q3 SO2 Ratio</th>
<th>Q3 NOx Ratio</th>
<th>Scaling Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 km</td>
<td>20</td>
<td>50</td>
<td>1.138</td>
</tr>
<tr>
<td>1 - 4 km</td>
<td>10</td>
<td>35</td>
<td>1.244</td>
</tr>
<tr>
<td>4 - 10 km</td>
<td>7</td>
<td>20</td>
<td>1.375</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>5</td>
<td>20</td>
<td>1.467</td>
</tr>
</tbody>
</table>

(Tier 1) (Tier 2)
Annual PM2.5 – No Secondary
Annual PM2.5 vs. SIL

Annual PM2.5

Distance from Source

PM2.5 Concentration (µg/m3)

- Annual_No_Secondary
- Annual_Tier_1
Daily PM2.5 – No Secondary

Daily w/o secondary [ug/m3]
- > 1.2
- 1.1 - 1.2
- 1.0 - 1.1
- 0.9 - 1.0
- < 0.9
Daily PM2.5 – Tier 1
Daily PM2.5 – Tier 2
Daily PM2.5 vs. SIL

![Graph showing Daily PM2.5 concentrations against distance from source (meters). The graph includes data points for Daily_No_Secendary, Daily_Tier_1, and Daily_Tier_2.](image-url)
Next Steps

- Perform Tier 2b and Tier 3 calculations for example PSD application.
- Assign binned SO2 and NOx offset ratios to each county in Georgia so applicants can use them in PSD applications.
- Document approach and final results.
- Repeat the analysis with new 2011/2018 modeling platform.
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