

USE OF PM SOURCE APPORTIONMENT TO ASSESS THE CONTRIBUTIONS OF INDIVIDUAL POINT SOURCES TO PM_{2.5} CONCENTRATIONS IN THE EASTERN U.S.

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1. INTRODUCTION

The Association of the Southeast for Integrated Planning (ASIP) is charged with performing the technical analysis needed to support the development of 8-hour ozone and PM_{2.5} State Implementation Plans (SIPs) for the southeastern states in the United States (U.S.). ASIP has run the Community Multiscale Air Quality Modeling system (CMAQ; Byun and Ching, 1999) on a 36/12 km grid domain for the calendar year 2002 CMAQ was run for a current year 2002 base case and future year 2009 and 2012 emission scenarios. The CMAQ 2002 and 2009/2012 modeling results were used to make 8-hour ozone and PM_{2.5} projections for the southeastern states. The future year PM_{2.5} projections suggested that there were several PM_{2.5} monitors in the southeastern states and adjacent regions whose annual PM_{2.5} levels were near or above the 15.0 µg/m³ National Ambient Air Quality Standard (NAAQS). Several of the ASIP states wished to know what the contributions of specific individual point sources were to the high future year PM_{2.5} concentrations.

The ASIP CMAQ 2002 36/12 km modeling database is inappropriate for estimating the contributions of emissions from individual point sources to PM_{2.5} concentrations. The coarse 12 km grid resolution used would instantaneously dilute the point source emissions across a grid cell resulting in incorrect characterization of the chemistry and consequently ozone and secondary PM formation due to the point source emissions.

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In reality, the point source emissions would initially be within a plume a few hundred meters across where the high NO_x concentration inhibits ozone and secondary PM_{2.5} formation (e.g., sulfate and nitrate). Use of the 12km grid, on the other hand, would dilute the point source emissions thereby ignoring the NO_x inhibition effects on ozone and PM formation. Consequently a new 2002 annual PM database was developed with the following attributes:

- 12 km grid nested within the CMAQ 12 km modeling domain;
- 4 km nested-grids over regions where the individual point sources whose PM_{2.5} impacts are desired reside;
- Use of Plume-in-Grid subgrid-scale module to properly treat the near-source plume chemistry and dispersion; and
- Use of PM source apportionment to obtain the PM_{2.5} contributions of each of the individual point sources.

2. DEVELOPMENT OF THE POINT SOURCE PM SOURCE APPORTIONMENT DATABASE

A new 12/4 km modeling database was developed for several southeastern states so that PM source apportionment could be conducted to obtain the contributions of individual point sources to PM concentrations. Because of its ability to perform two-way grid nesting, PM source apportionment and a robust Plume-in-Grid (PiG) module, the Comprehensive Air Quality Model with extensions (CAMx; ENVIRON, 2008) was selected for this analysis. CAMx was configured with a 12 km modeling domain covering portions of 10 states in the Southeast/Midwest. The boundary conditions (BCs) of the 12 km domain were provided by the CMAQ 36/12 km modeling.

Embedded within the CAMx 12 km domain were four 4 km domains that covered the point sources of interest. Figure 1 displays the CAMx 12/4 km domains embedded within the CMAQ 12 km domain whose simulations results were used to provide the BCs to the CAMx 12 km domain. Figure 2 displays the CAMx 12/4 km modeling domain, with the locations of the point sources where individual PM_{2.5} concentrations were desired, which are indicated by red crosses. CAMx 12/4 domains were run using two-way grid nesting that allows concentrations to flow back and forth between the 12 km and 4 km domains.

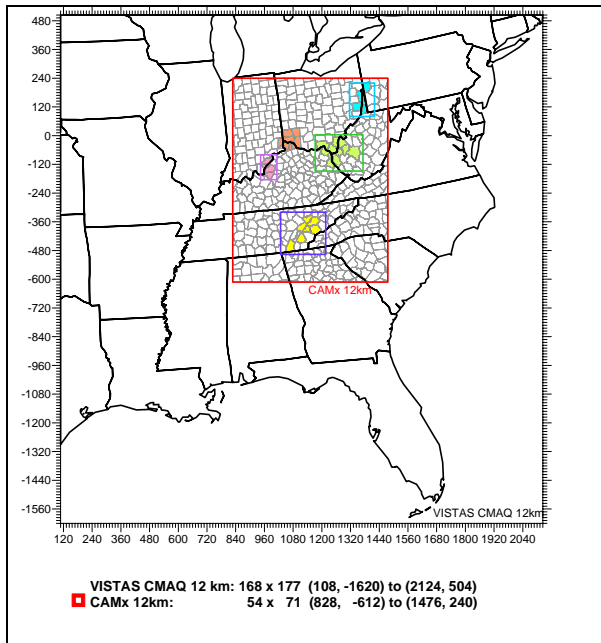


Figure 1. CAMx 12/4 km modeling domain embedded in the outer ASIP/VISTAS CMAQ 12 km domain.

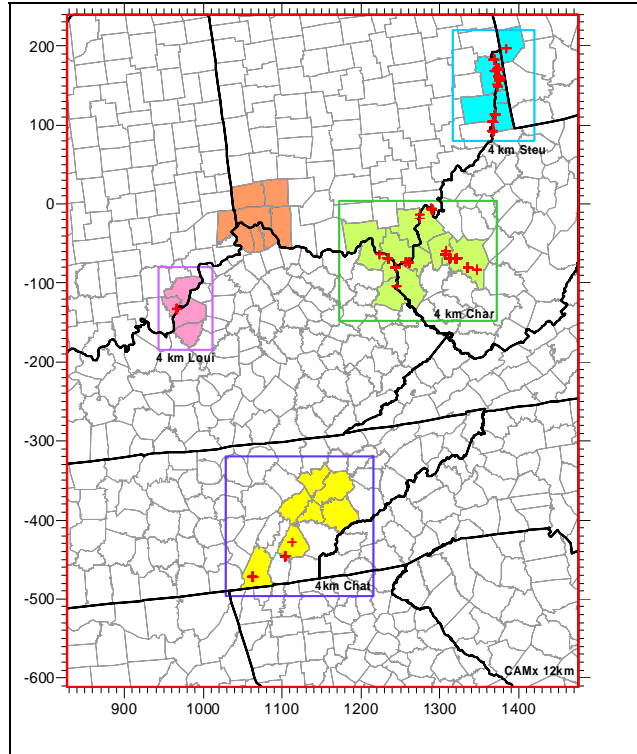


Figure 2. CAMx 12/4 km two-way grid nesting modeling domain and locations of sources (red crosses) whose individual contribution to PM_{2.5} will be calculated.

3. PM SOURCE APPORTIONMENT TECHNOLOGY (PSAT)

CAMx includes several “probing tools” that extract information from the model. These probing tools include the ozone and PM source apportionment technology (OSAT and PSAT). These source apportionment techniques use reactive tracers that operate in parallel to the CAMx host model extracting information on source-receptor relationships for reactive and inert pollutants. To use OSAT or PSAT, the user must first define the emission source groups that will be used in the source apportionment calculations. Usually source groups are defined as the intersection between a geographic region map (e.g., states) with the inventory stratified by source categories (e.g., mobile, point, biogenic). However, in this case we defined the source groups as the individual point sources.

PSAT includes separate families of reactive tracers for sulfate (SO₄), nitrate (NO₃) and ammonium (NH₄), primary PM (EC, OC, PM_{2.5} and PMC), secondary organic aerosol (SOA) and mercury. For example, for the SO₄ families of

tracers each source group is represented by two reactive tracers representing SO₂ and SO₄ from that source group. When SO₄ is formed in a grid cell, it is allocated to the source groups based on the relative contributions of each source group's SO₂ concentrations to the total SO₂ concentration. When SO₂ and SO₄ are lost in a grid cell, the SO₂ and SO₄ reactive tracers are reduced the same percentage across source groups. The NO₃/NH₄ family of reactive tracers is much more complicated using 7 reactive tracers for each source group as they have to account for the conversion of NO_x to various species and back again. The SOA family of tracers is most complicated with numerous reactive tracers needed to represent the different types of VOCs, condensable gases (CG) and SOA species.

4. PLUME-IN-GRID MODULE

The CAMx Plume-in-Grid (PiG) module uses full chemistry to simulate the chemical conversion within point source plumes. Point sources can be flagged for treatment of the PiG module, in which case the early plume chemistry and dispersion is treated by the PiG module. When the size of the PiG plume is commensurate with the size of a grid cell, the processed emissions in the plume are released to the grid model for further modeling. The PiG plume dispersion is defined using a second order closure dispersion approach. Chemical transformation in the PiG module uses the full gas-phase, aqueous-phase and aerosol-phase chemistry approach in CAMx using the incremental chemistry approach that accounts for the increment concentrations within the PiG puffs and the background concentrations within the grid cell where the puffs reside.

More recently the CAMx PiG module has been updated to be compatible with PSAT. The PSAT source apportionment has been linked with the full-chemistry PiG module so that it can track the PM contributions of emissions from point sources that are treated by the PiG module. Another feature that has been added to the PiG module is the subgrid-scale sampling of the PiG plumes. Previously the user had the choice of either obtaining the gridded output from the model without the concentrations in the PiG plumes accounted for, or with the mass contained in the PiG plumes accounted for in the output concentrations. The subgrid-scale PiG sampling obtains the concentrations of the PiG plumes using a Gaussian distribution accounting for plume rise, dispersion and chemistry.

5. PM SOURCE APPORTIONMENT MODELING RESULTS

5.1 Modeling Approach

The CAMx model was applied in its standard mode (i.e., with PiG but no PSAT) for the 2002 annual period and the VISTAS/ASIP 2002 Base G2a base case emissions scenario using the 12/4 km modeling domain (Figure 2). CAMx was then applied for the 2002 calendar year on the 12/4 km domain for the ASIP 2009 G4 base case emissions using both PiG module and with PSAT to separately track the PM_{2.5} contributions of the 31 point sources under study. The PSAT SO₄ and primary PM families of tracers were involved for the ASIP PSAT run. The PSAT NO₃/NH₄ family of tracers were not used because NO₃ is an extremely small contributor to PM_{2.5} in the ASIP states. The PSAT SOA family of tracers was also not used because most of the SOA is due to biogenic VOC emissions and the 31 point source under study did not emit any SOA precursors. The CAMx standard model output was used to project 2009 PM_{2.5} Design Values using EPA's Model Attainment Test Software (MATS) whose results were compared with the PM_{2.5} projections obtained using the CMAQ model. The 2009 CAMx/PSAT results were then analyzed to determine the contributions of individual point sources to 2009 PM_{2.5} projections at the monitoring sites for the four 4 km modeling domains:

- Louisville;
- Knoxville;
- Charleston-Huntington-Ashland; and
- Wheeling-Steubenville-Weirton.

The 2009 PM_{2.5} projections and point source PM_{2.5} contributions for the last two 4 km domains listed above are discussed next.

5.2 2009 PM_{2.5} Projections

Figure 3 compared the projected 2009 PM_{2.5} Design Values at monitoring sites in West Virginia using the EPA MATS projection tool and the CAMx 12/4 km and CMAQ 12 km modeling results. Both models estimate large reductions in PM_{2.5} concentrations between 2002 and 2009, which are primarily due to reductions in sulfate and the particle bound water (PBW) associated with the sulfate reductions. CAMx estimates slightly higher PM_{2.5} Design Values in 2009 due in part to emission updates that removed SO₂

controls from a major coal-fired power plant that is estimated to be installed between 2009 and 2010. These SO₂ controls were assumed to be in place by the 2010 Integrated Planning Model (IPM) estimated of EGU emissions used in the CMAQ 2009 simulation.

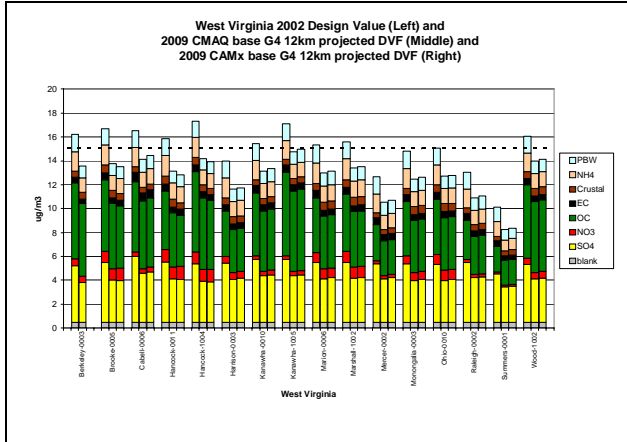


Figure 3. Projected 2009 PM Design Values estimated by the CMAQ 12 km and CAMx 12/4 modeling results.

5.3 PSAT Results for Charleston-Huntington-Ashland

Figure 4 displays the Charleston-Huntington-Ashland 4 km domain and the locations of the monitoring sites and point sources modeled with CAMx/PIG/PSAT to obtain individual PM_{2.5} contributions. The PSAT results were processed at each monitoring site to obtain the contributions of each of the 31 point sources, remainder emissions in the CAMx 12/4 km modeling domain (Figure 2) and the contributions due to transport from outside of the CAMx modeling domain (i.e., the BCs provided by the 12 km CMAQ run, see Figure 1). These results are seen in Figure 5 where the largest contributions at most monitors are due to the remainder of the emissions in the CAMx 12/4 km domain and regional transport (BCs) from outside of the 12 km domain. Figure 6 just examines at the contributions of the 31 point sources to PM_{2.5} concentrations in the Charleston 4 km domain. The 31 point sources contribute from 0.5 to 2.5 µg/m³ to the annual average PM_{2.5} levels at the 7 monitoring sites in the Charleston domain. The largest single contributions by any point source is 2.1 µg/m³ at the Lawrence County, Ohio monitor, with single point source contributions as high as 0.6 µg/m³ occurring at Cabell County, West Virginia and as high as 0.2

µg/m³ at Kanawha County, West Virginia and Boyd County, Kentucky.

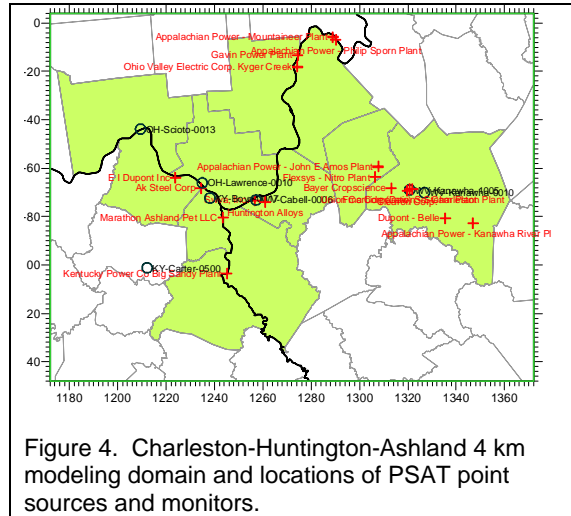


Figure 4. Charleston-Huntington-Ashland 4 km modeling domain and locations of PSAT point sources and monitors.

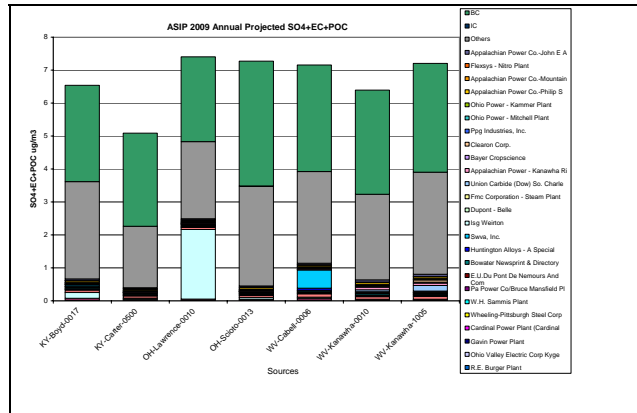


Figure 5. Contributions of point sources, remainder emissions and BCs to PM 2.5 for monitors in the Charleston-Huntington-Ashland 4 km domain.

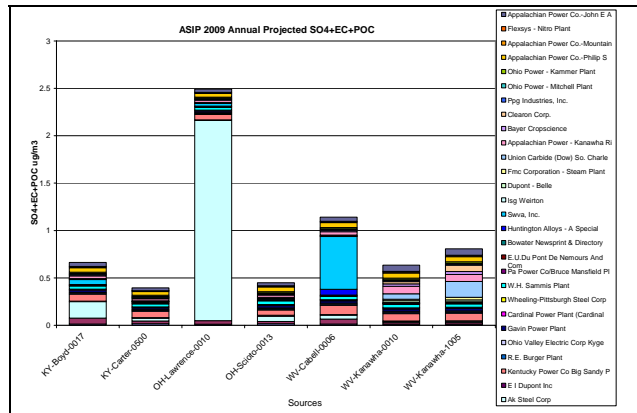


Figure 6. Contributions of the 31 point sources to PM_{2.5} for monitors in the Charleston-Huntington-Ashland 4 km domain.

5.4 PSAT Results for Wheeling-Steubenville-Weirton

Figure 7 displays the Wheeling 4 km domain and locations of the monitoring sites and point sources modeled with PSAT, with the PSAT point source results shown in Figure 8. Like seen for the Charleston 4 km domain, the largest contributor to PM_{2.5} at three monitoring sites are the remainder emissions in the CAMx 12/4 km domain and regional transport (BCs). The 31 individual point sources contribute from 0.5 to 2.0 µg/m³ to the annual PM_{2.5} concentrations at these monitoring sites. The largest single point sources PM_{2.5} contribution is 1.4 µg/m³, followed by 1.1 and 0.7 µg/m³.

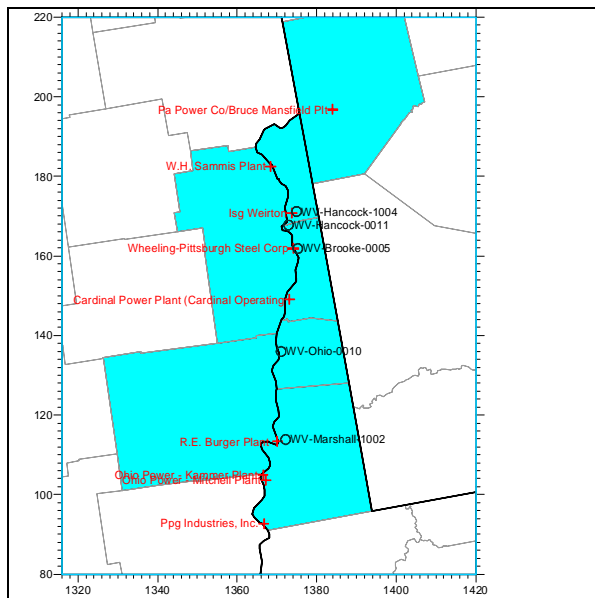


Figure 7. Wheeling-Steubenville-Weirton 4 km modeling domain and locations of PSAT point sources and monitors.

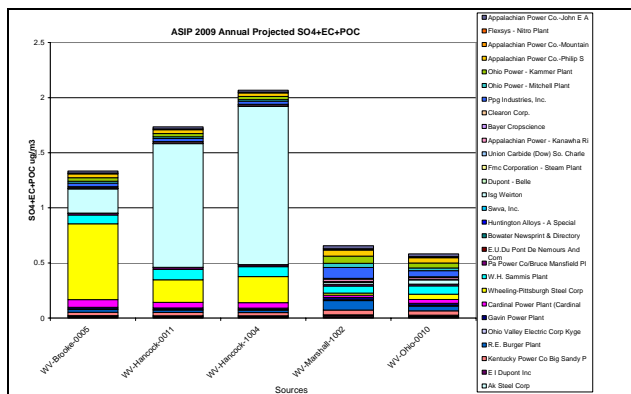


Figure 8. Contributions of the 31 point sources to PM_{2.5} for monitors in the Wheeling-Steubenville-Weirton 4 km domain.

6. CONCLUSIONS

The CAMx model using high resolution grids (4 km), Plume-in-Grid (PiG) and PM Source Apportionment Technology (PSAT) has been demonstrated to be a useful tool for assessing the contributions of a single point source to PM_{2.5} concentrations. The use of the subgrid-scale PiG module allows the correct depiction of the near-source chemistry and plume dynamics of the point source plumes that is not possible in a photochemical grid model without using very fine grid cell sizes. And PSAT allows for the assessment of the contributions of multiple point sources to PM_{2.5} concentrations within a single simulation. CAMx incorporates current state-of-science chemistry so is able to assess the contributions of both primary and secondary PM_{2.5} from point sources, which is a big advantage over Gaussian plume and puff models that incorporate no or very simplified representation of chemistry.

Although not used in this application for ASIP, the use of the Ozone Source Apportionment Technology (OSAT) would allow the assessment of individual point source ozone contributions. Another feature of the PiG module not used in the ASIP application is the ability to sample the subgrid-scale PiG puffs before they are released to the grid model. This feature is proving useful for modeling point source near-source impacts (e.g., fence line) for PM_{2.5} and air toxics.

7. REFERENCES

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