Comparison of AERMOD and CALPUFF Modeling of an SO$_2$ Nonattainment Area in Northeast Ohio

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Comparison of AERMOD and CALPUFF Modeling of an SO$_2$ Nonattainment Area in Northeast Ohio

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ABSTRACT

Dispersion models have been used historically for studies to demonstrate compliance in support of State Implementation Plans (SIPs) for SO$_2$. Since the promulgation of the SO$_2$ 1-hour National Ambient Air Quality Standard (NAAQS) in 2010, models have been recommended by USEPA for use not only in attainment studies and demonstration but also to facilitate the designation of areas where ambient monitoring does not exist. To this end, states have attempted to use EPA guidance to formulate their strategies and analyses to complete designations and nonattainment studies. Complex terrain in an area can make the selection of the appropriate model difficult. This paper recognizes the guidance proposed by EPA and uses it in the context of both the AERMOD and CALPUFF models in an area of northeastern Ohio. The area is characterized by several coal-fired utility stations in addition to a coke plant, steel mill, and other neighboring facilities. All of the facilities as well as the nonattainment monitor are located in the basin of the Ohio River Valley where valley winds dominate sources located beneath the ridge top of the valley while taller stacks are influenced by the winds above the valley. Three meteorological stations have been run at two valley and one ridge location for 2011-2013 as well as four SO$_2$ monitor locations. This case study compares the use of AERMOD with a standard set of NWS meteorological data (Pittsburgh) to the use of these onsite data sets. Concentrations have been calculated following EPA guidance using AERMOD with all meteorological data sets. WRF to CALMET data sets have been derived for the area with CAPUFF modeling underway. This early assessment of the comparison between AERMOD and CALPUFF focuses on the AERMOD results, meteorological characterization, and expected future comparisons of estimated air concentrations to monitored results.

INTRODUCTION

The AERMOD Model$^{1,2}$ was introduced to the regulatory dispersion modeling community in 1995 as part of EPA’s proposed updates and later introduced as a regulatory preferred model in
2005 in Section 4.2.2.b of the *Guideline on Air Quality Models (GAQM)*³ where it states that AERMOD is the recommended model for “a wide range of regulatory applications in all types of terrain”. Along with AERMOD are preprocessors also recommended for preparing data sets applicable to running the AERMOD algorithms for transport, dispersion, convective boundary layer turbulence, stable boundary layer, terrain influences, building downwash, and land use. These are AERMAP, AERSURFACE, and AERMET. Draft versions of the EPA’s guidance for modeling in nonattainment areas⁴ where modeling is used as part of the nonattainment demonstration process recommended the use of AERMOD in most situations:

“…AERMOD is identified as the preferred model under Appendix W for a wide range of applications and would be appropriate for most modeling applications to support the 1-hour SO2 NAAQS…”

This draft guidance as well as that more recently available from EPA in the form of an updated draft of the guidance in 2013⁵, goes on to say:

“…Appendix W allows flexibility to consider the use of alternative models on a case-by-case basis when an adequate demonstration can be made that the alternative model performs better than, or is more appropriate than, the preferred model for a particular application.”

In the northeast portion of Ohio where this study is taking place, the demonstration hinges on the latter part of the EPA guidance statement regarding a “more appropriate” model. The basis for this appropriateness is based on a section of Appendix W³, namely, Section 7.2.8 Complex Winds, which describes geographical variations that can generate local winds, valley flows, and modified prevailing winds. In some of these special cases the assumption of steady-state straight-line transport such as in the time steps of the AERMOD Model are inappropriate and the CALPUFF Model may be applied.

This study considered all aspects of the sources, monitors, Ohio River Valley air shed, river bottom versus neighboring hilltop air flow, and measured data sets in determining that the AERMOD Model may not be the best representation of this northeast Ohio nonattainment area for SO2.

**METHODOLOGY**

In the EPA, Region 5 letter to Governor Kasich⁶, EPA stated that in response to the State of Ohio’s air quality designation recommendations for the 1-hour NAAQS, that the Steubenville-Weirton, OH-WV area would be designated nonattainment on the basis of the 2009-2011 1-hour SO2 monitoring data. The Ohio EPA initiated plans to facilitate their activities in preparing a State Implementation Plan (SIP) which included dispersion modeling for assessing contributing sources, for assessing the magnitude of such contributions, and for determining compliance after control strategies were implemented. In a parallel and complimentary course of activity, the Ohio Utilities Group (OUG, a consortium of public and private utility companies in and providing power to Ohio) proceeded with dispersion modeling activities. The area selected as a test nonattainment area was the Steubenville-Weirton nonattainment area due to the limited
number of sources in the area, the presence of a river valley with surrounding hills which could lead to complex wind flow, and the fact that one of the utilities had collected over a year of PSD-quality meteorological data at three sites in and around the river valley.

Figure 1 shows the location of the Steubenville-Weirton nonattainment (SW-NA, hereafter) area in northeast Ohio and Figure 2 shows a close up of the nonattaining monitors as well as a graphical portrayal of the terrain. The four monitors shown in the northern portion of Figure 2 are those that are in in the Ohio and West Virginia state monitoring system as indicated by the
Identification numbers. The three locations indicated by “blue stars” that are in the south portion of Figure 2 are locations where meteorological data were collected. Two of the locations (as well as a third, not shown) also collect SO₂ ambient monitoring data.

According to EPA guidance for modeling SO₂ nonattainment areas the responsible agency must gather information specific to sources identified in the designation process including all stack characterization, source configurations, actual emissions, permit allowable emissions, and other required information to characterize the facilities. This data generally comes from state inventories. The State then identifies the sources to explicitly model and separates them from those that will be represented in the background concentrations. Emissions in tons per year above certain levels were recommended by EPA guidance as a starting point with the states allowed to further refine those limits if knowledgeable selection can be made. Modeling of all sources either directly or as background is performed in this case at the monitors to discern contributing sources and allow selection of appropriate levels of control to bring the monitor into compliance. Additional modeling will next be applied across the nonattainment area to assure area wide compliance.

The OUG first followed a procedure thought to be that which the OEPA would follow, namely, using the nearest meteorological data sets from the Pittsburgh International Airport (KPIT) for both surface and upper air data. KPIT is located approximately 35km to the east northeast of Steubenville in rolling hilly terrain. All major sources were included in the modeling including a major coal-fired utility 18km to the south, a major coal-fired utility 18km to the north, a coke plant just across from Steubenville in West Virginia, and a small power supplier (dependent in part on excess coke oven gas) nearby the coke plant. Another facility in Ohio which has not operated for a few years and was in question as to future operations, was not included in the current study because it would not have contributed to the current air quality at the monitor.

AERMOD (Version 12345) and its attendant preprocessor programs was applied in the modeling. No updates have been made to consider AERMOD (Version 13350) or its subsequent updates at the time of this writing. Buildings were included for each facility to incorporate building downwash into the modeling. All stacks were modeled at actual heights. The area was considered rural and no urban options were used.

Following these analyses using the Pittsburgh meteorology, three additional meteorological data sets were prepared using data from local measurements. These sites are indicated in Figure 2. The southernmost, located in West Virginia, across from Station 1, is in the valley floor at just above the river and represents the wind flow in the base of the valley. The first location just above Station 1 is located slightly above the valley floor and located further up the valley. Finally, the third meteorological site is located second to the north of Station 1 and is located on a hilltop. This site would be considered a localized version of the Pittsburgh airport data in terms of its more likely connection to mesoscale winds and less likely connection to and influence by valley wind flow. As a reference, the difference between the valley floor and nearby hilltops is in the 300 to 400 foot range.

Dispersion modeling considering the use of AERMOD and its various findings depending on the meteorology selected, source contributions, and source impact areas are presented in the
following sections. Limitations on the applicability of AERMOD and its use in this Ohio region are described.

Following this application, the next steps in the modeling analysis were a consideration of the CALPUFF Model to better consider the differences in wind flow regimes between the valley floor and the upper portions of the surrounding hills. CALMET data sets were prepared but the next step in CALPUFF application has not proceeded at this point nor has the comparison of AERMOD and CALPUFF results. These will be described in a subsequent paper.

Sources

EPA has recognized the need to consider the impacts of all major contributors to exceedances in nonattainment areas. In the SWNA area are located two major power plants both of which burn coal, a coke making operation using coke ovens, multiple shut down and moth-balled steel mills, a small gas and coke gas fed power plant, and other smaller regional sources of SO$_2$ emissions. In keeping with the EPA draft SIP modeling guidance, only the larger of these facilities were chosen for the modeling. All stacks were modeled as point sources and fugitive emissions associated with the coke ovens were modeled as volume sources. No consideration of the buoyancy of the coke oven gases was considered in these initial runs. All other smaller background sources generally will be considered to be included in any background concentrations added later.

Monitors

Four ambient monitors installed and operated by the States of Ohio and West Virginia were the focus of the initial modeling as would be conducted by the Ohio EPA and West Virginia DEP. These sites are identified as:

- 39-081-0017 in Steubenville, Ohio
- 54-009-0005 in Follansbee, WV
- 54-009-0007 located 10m west of McKims Ridge Road, WV
- 54-009-0011 in Weirton, WV

Design values of the monitors were all greater than the 75 ppb 1-hour NAAQS for SO$_2$. Coordinates for the sites as well as the elevations above sea level were derived from EPA’s AIRData website.$^7$

Three additional monitors run by the southernmost power station have data over the same time frame but have yet to be considered in the modeling and SIP nonattainment analysis.

Meteorology Data

As described above, four sets of meteorological data were derived for the AERMOD Model, all using the upper air data from the Pittsburgh International Airport. Each of the sites used the cloud cover data from the surface observations at Pittsburgh to supplement the wind speed, wind direction, and air temperature data at each site and make the data AERMOD-ready.
Figure 3 shows a wind rose generated for each surface observation site for each of the four sites considered in the modeling analysis using the AERMOD Model. The data are indicated in the figure with the first set of letters representing the surface station and the second set being the upper air. Thus the sites are identified as:

PIT-PIT – Pittsburgh-Pittsburgh
LF-PIT - Hill top area – Pittsburgh
ST-PIT – Area in valley just north of power station
WV-PIT – Area across and near the Ohio River in West Virginia – Pittsburgh

As can be seen in Figure 3, the PIT-PIT and LF-PIT sites which are located in the upper parts of the hill country are subject to the mesoscale wind and thus, applicable to the tall power station stacks. Conversely, as can also be seen in Figure 3, the ST-PIT and WV-PIT show the effects of the wind flows in the river. Thus, this was confirming of the complex flows in the area.

Additional meteorological generation has been completed for the CALPUFF Model. A 500m grid spacing was used within a 100km by 100km modeling domain. The Weather Research and Forecasting Model (WRF) is a mesoscale numerical weather prediction system used to generate
real data observations that was used as the first-guess fields for CALMET. The four sets of meteorological data listed above for the Pittsburgh and other measurement sites were all used in the nudging process in this meteorological data generation. These data are currently being reviewed and set up to use in the CALPUFF modeling.

**Receptors**

In the modeling, receptors were placed at the monitor locations to determine the contributions from the major sources at actual emissions. This gave the first contribution analysis to allow the first determination of required control levels for specific sources and facilities. A second set of receptors was located over all of Jefferson County, Ohio at an even 500m spacing. This allowed an area wide distribution of air concentrations to be determined as well as the hot spot areas of the county. Further work on the WV side of the river will be determined in a future study.

**RESULTS**

Currently, only the AERMOD model simulations are completed for the Jefferson County, Ohio portion of the modeling. West Virginia AERMOD modeling and CALPUFF analysis will be completed over the next several months and presented as part of the final presentation. For AERMOD modeling, all sources were run with the PIT-PIT data set and also with the other local data sets.

Figure 4 shows the 1-hour SO2 99th percentile concentrations (highest 4th high maximum daily 1-hour concentrations) for all sources considered in the modeling for Jefferson Co. In 2009 the emissions of the north power station were not controlled and the air impacts due to these sources are obvious with the highest concentrations occurring to the north in Jefferson Co. Controls were installed at the end of 2009 and these reduced emissions are noted in the reduced concentrations on the figure as well as the area of coverage of the impacts. The concentration isopleths for 2011 look much the same as 2010 and are not presented here. Review of the remaining hot spots in the county are evident along the river valley.

Review of the contributions to the Steubenville monitor (39-081-0017) indicate that the power plants contributed less than 1% total to the monitored exceedances whereas the coke plant in the valley located less than 1km southeast in the river valley contributed most of the impacts. An additional impact analysis was conducted using the WV-PIT meteorological data set for the small power station and the coke (carbon) plant. In both cases the winds tended to be more aligned with the valley with the majority of impacts in and along the valley including the Steubenville monitor. Figure 5 shows the individual source impacts for the small power station and the coke ovens.

**CONCLUSIONS**

To facilitate the determination of the contributing sources and prepare the best control strategy for the area, some recommendations which will be tested in the completion of this study are:
Figure 4. All sources 1-hour SO$_2$ Modeling in AERMOD

Figure 5. Valley Sources 1-hour SO$_2$ Modeling in AERMOD
1) Apply the CALPUFF Model to determine if the consideration of complex wind flows is important to this analysis. The basis for the determination will be comparison of the AERMOD and CALPUFF estimates.

2) Use the CALPUFF option for considering buoyant plumes from fugitive sources.

3) Decide if the use of Pittsburgh meteorology data is better or the onsite data.

4) Possible need to re-characterize the coke oven batteries.

5) Possibility of considering hourly emissions for each source?

6) Is the nearby steel company that is currently not operating going to start up again?

These issues as well as the application of CALPUFF are ongoing and being considered in the late winter and spring of 2014.

REFERENCES


7. AIRData Website, http://www.epa.gov/airdata/ad_maps.html

KEYWORDS
AERMOD, NAAQS, CALPUFF, dispersion, modeling, control strategy