Appendix A

Sensitivity of Ozone Concentrations in Atlanta to NOx and VOC Controls Inside and Outside the Nonattainment Area

Appendix A

Sensitivity of ozone concentrations in Atlanta to NO_x and VOC controls inside and outside the nonattainment area

Introduction

GA-EPD has performed an analysis of the sensitivity of ozone concentrations to reductions in emissions of both nitrogen oxides (NO_x) and volatile organic compounds (VOCs). The analysis was based on the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) modeling, using the "Base D" emissions inventory (for both 2002 and 2009), and CMAQ version 4.4 with the CB-IV chemical mechanism. A 12 km modeling grid was used, covering most of the southeastern USA. The episode modeled was May 25 – June 25, 2002, as it contained many days of elevated ozone concentrations and has been found representative of longer term trends in ozone concentrations. More details regarding the model setup and sensitivity analysis can be found in Marmur et al., 2005.

Methodology

CMAQ was utilized to model the reductions in ozone from the post 2002 operation of SCRs at major coal-fired power plants outside of the Atlanta non-attainment area (NAA). These included SCRs on units 3&4 at Plant Bowen located in Bartow County (61.1 ton-per-day NO_x controlled), SCRs on units 1&2 at Plant Wansley Heard County (51.7 TPD NO_x controlled) and the switch to Powder River Basin (PRB) coal at Plant Scherer Monroe County (24.2 TPD reduction in NO_x emissions compared bituminous coal combustion). These reductions were then compared with those from ground level VOC controls in the Atlanta 20-county NAA (10% reduction from anthropogenic ground-level VOC emissions; 49.3 TPD). Also reported are the expected reductions in ozone concentrations from potential ground-level NO_x controls in the Atlanta 20-county NAA. The purpose of this comparison is to evaluate the efficiency of NO_x controls from outside the Atlanta NAA and of VOC controls within the Atlanta NAA in terms of reductions in ozone concentrations. Such an evaluation can help determine whether existing (post 2002 ozone season) NO_x controls outside of the Atlanta NAA overweigh any potential VOC controls within the NAA.

Below is a summary of the cases modeled (also see Table 1):

Case 1: NO_x reductions from SCRs installed and operated at GA-Power Plant Bowen starting from the 2003 ozone season (units 3&4; 61.1 TPD NO_x controlled compared to the pre-installation/operation conditions).

Case 2: NO_x reductions from SCRs installed and operated at GA-Power Plant Wansley starting from the 2003 ozone season (units 1&2; 51.7 TPD NO_x controlled compared to the pre-installation/operation conditions).

Case 3: NO_x reductions from the switch to PRB coal at GA-Power Plant Scherer; 24.2 TPD reduction in NO_x emissions during the 2003 ozone season (55.7 TPD) compared to the 2002 ozone season (79.8 TPD).

Case 4: A 10% reduction in emissions of anthropogenic, non-EGU, ground level VOC emissions in the Atlanta 20 counties NAA (a potential reduction of 49.3 TPD).

Case 5: A 10% reduction in emissions of anthropogenic, non-EGU, ground level NO_x emissions in the Atlanta 20 counties NAA (a potential reduction of 38.0 TPD).

Table 1: Summary of emissions reduction scenarios modeled

Case #	Plant/Region modeled	TPD reduction
1	Bowen units 3&4 (benefits of existing SCRs)	61.1 (NO_x)
2	Wansley units 1&2 (benefits of existing SCRs)	51.7 (NO_x)
3	Scherer (use of PRB coal)	24.2 (NO_x)
4	10% anthropogenic VOC controls in the Atlanta NAA	49.3 (VOC)
5	10% anthropogenic NO_x controls in the Atlanta NAA	38.0 (NO_x)

Results

Reductions in daily maximum 8-hour ozone concentrations for each of the above cases, along with the modeled base-case concentrations (based on both 2002 and 2009 VISTAS Base D emissions), are shown in Figure 1.

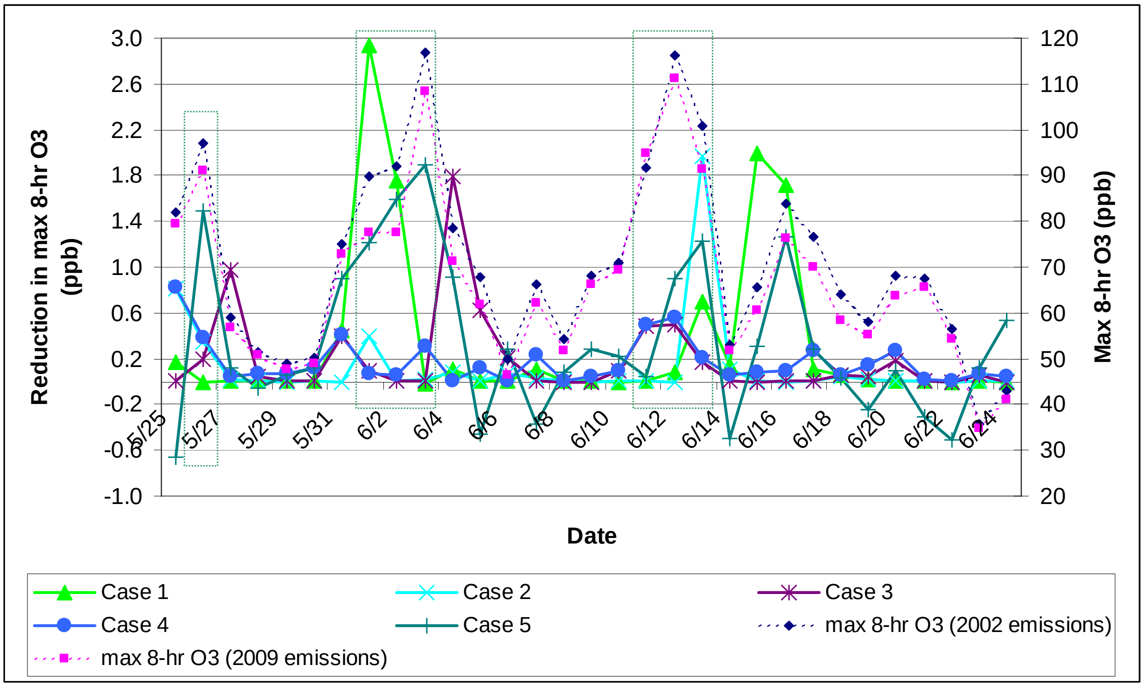

Figure 1: Daily reductions in maximum 8-hour ozone concentrations, along with base case concentrations, at the Atlanta Confederate Avenue site. Green rectangles indicate days in which the 2002 base case daily 8hr maximum ozone concentration was above 85 ppb (used for the calculations presented in Table 2)

Case 1 (modeled benefits of existing SCRs at Plants Bowen) shows the highest benefits in terms of ppb reduction in 8-hour ozone concentrations at the Atlanta Confederate Avenue site, with reductions of up to 2.9 ppb. Also evident are the impacts of NO_x controls at Georgia-Power Plants Wansley and Scherer, and the potential benefits from controlling ground level NO_x sources in the Atlanta metropolitan area (maximum reductions of 2.0, 1.8 and 1.9 ppb, respectively). VOC controls seem less effective for Atlanta, with a maximum reduction of 0.8 ppb in maximum daily 8-hr ozone concentrations.

To account for the fact that the emissions reductions scenarios modeled here differ in magnitude (TPD controlled), we also normalized the reductions in ozone to the tons of NO_x or VOC controlled. The average and normalized reductions in ozone, for days in which the 2002 base case concentration was above 85 ppb (7 days total), are given in Table 2.

Table 2: Average reductions in 8-hour ozone concentrations (ppb) and normalized reductions (ppt O3 / TPD) for days in which the 2002 base case concentration was above 85 ppb (7 days total)

Case #	Average reduction (ppb)	Normalized reduction
1	0.78	12.8 ppt O3 / TPD NO_x
2	0.39	7.6 ppt O3 / TPD NO_x
3	0.21	8.6 ppt O3 / TPD NO_x
1+2+3	1.4	10.0 ppt O3 / TPD NO_x
4	0.30	6.0 ppt O3 / TPD VOC
5	1.2	31.4 ppt O3 / TPD NO_x

These data once again demonstrate the benefits of the existing SCRs at plants Bowen and Wansley and of the use of PRB coal at Plant Scherer (12.8, 7.6 and 8.6 ppt/TPD, respectively). The sensitivity of ozone to ground level VOC controls is lower (6.0 ppt/TPD). The combined effect of controls at Bowen, Wansley and Scherer (approximate average reduction of 1.4 ppb) is substantially higher of that that could realistically be achieved by anthropogenic VOC controls (an approximate average reduction of 0.3 ppb per 10% reduction in VOC emissions). The sensitivity of ozone to ground level NO_x emissions in the Atlanta NAA (Case 5) is substantially higher than any of the other cases presented here (31.4 ppt/TPD compared to 6.0-12.8 ppt/TPD).

Also evident in Figure 1 are the impacts of NO_x emissions reductions expected by 2009, compared to the 2002 case (most of the reductions are from the mobile-source and EGU sectors; for more details see Marmur et al., 2005). This further demonstrates that ongoing reductions in NO_x emissions (such as from fleet turnover) will continue to lower concentrations of ozone in the Atlanta NAA.

References

Marmur, A., Boylan, J., Khan, M., and Cohan, D. (2005), 8-Hour Ozone and $PM_{2.5}$ Modeling to Support the Georgia SIP, 4th Annual CMAS Models-3 Users' Conference, Chapel Hill, NC (http://www.cmascenter.org/conference/2005/abstracts/7_6.pdf), included as Appendix A Exhibit 1, below.

Appendix A Exhibit 1

8-Hour Ozone and PM2.5 Modeling to Support the Georgia SIP

8-HOUR OZONE AND $PM_{2.5}$ MODELING TO SUPPORT THE GEORGIA SIP

Amit Marmur*, James Boylan, Maudood Khan, and Daniel Cohan
Environmental Protection Division, Georgia Department of Natural Resources, Atlanta, GA, USA

1. INTRODUCTION

With the onset of the new National Ambient Air Quality Standards (NAAQS) for ozone and fine particulate matter ($PM_{2.5}$), Georgia now confronts nonattainment for multiple pollutants and regions. While 13 Atlanta counties had historically violated the now-revoked 1-hour standard for ozone of 0.12 ppm (below 125 ppb), a larger Atlanta region (Figure 1), along with Macon, violate the new 8-hour standard of 0.08 ppm (below 85 ppb). Also, an early action compact (EAC) has been developed to reduce ozone in Chattanooga and Augusta. Atlanta, Macon, Floyd County, and Chattanooga (Figure 2) violate the annual $PM_{2.5}$ standard (15 $\mu g/m^3$), marking the first time that Georgia must develop state implementation plans (SIPs) to control particulate matter. SIPs demonstrating plans of action for future attainment are due in 2007 for ozone and in 2008 for $PM_{2.5}$. These plans will detail local control measures to complement expected emissions reductions from federal actions, including the Clean Air Interstate Rule for power plants and more stringent federal standards for vehicles, fuels, and non-road equipment.

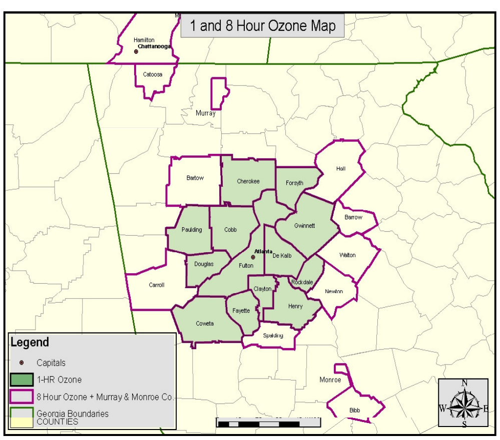

Fig. 1. Georgia 8-hour ozone non-attainment areas (Chattanooga is an EAC area).

*Corresponding author: Amit Marmur, Environmental Protection Division, Georgia Department of Natural Resources, 4244 International Parkway, Suite 120, Atlanta, GA 30354; e-mail: amit_marmur@dnr.state.ga.us

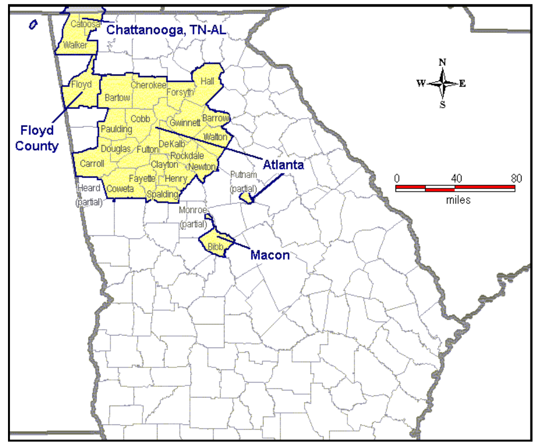

Fig. 2. Georgia annual $PM_{2.5}$ non-attainment areas.

2. MODELING SYSTEM AND GRID CONFIGURATION

In order to evaluate and develop efficient emission control strategies and demonstrate future attainment with the NAAQS, the Georgia Environmental Protection Division (GA EPD) is using the MM5/SMOKE/CMAQ modeling system. The modeling used in these SIP attainment demonstrations is based on the VISTAS regional haze modeling which includes annual simulations of 2002, 2009, and 2018 at 36 km (continental U.S.) and 12 km (Eastern U.S.) grid resolutions. In addition, GA EPD has developed a smaller 12 km grid (referred to as ALGA12) that covers Georgia and Alabama (and their adjacent states) and a 4-km grid over Georgia (referred to as GA4). While annual $PM_{2.5}$ modeling simulations will be conducted on the ALGA12 grid, only 4 months of the 2002 ozone season (05/20/02-09/20/02) will be simulated on the more refined GA4 grid

3. EPISODE SELECTION

In order to most efficiently design emission control strategies to reduce $PM_{2.5}$ and ozone, GA EPD is performing episodic emission sensitivities on a winter (11/19/02-12/19/02) and a summer episode (05/25/02-06/25/02). To objectively select representative time periods for sensitivity simulations, GA EPD selected the above episodes based on a classification and regression tree (CART) analysis. CART analysis examines historical records of meteorology and pollutant concentrations to identify "bins" of days with similar conditions. Episodes are then selected to capture a spectrum of representative conditions. For ozone, which is subject to a standard based on peak days, a one-month summertime episode was selected that included all "key bins" of most typical polluted conditions. For $PM_{2.5}$, which is subject to an annual average standard, the summer episode was paired with a one-month winter episode to capture a broad range of both polluted and relatively clean conditions. These episodes were selected based on a CART analysis to ensure that a variety of meteorological conditions important to $PM_{2.5}$ and ozone formation were simulated. A histogram comparing frequency of occurrence of key high ozone bins during the entire eight-year period (1996-2003), the year 2002, and the chosen summer episode (05/25/02-06/25/02) (Figure 3) shows that this episode represents all key ozone conducive meteorological conditions in Atlanta. Under/over representation of specific bins (e.g., bin 21) can be corrected by assigning weights to the different bins. A similar histogram for $PM_{2.5}$ (Figure 4), covering both summer and winter episodes, shows that most key $PM_{2.5}$ bins are captured as well.

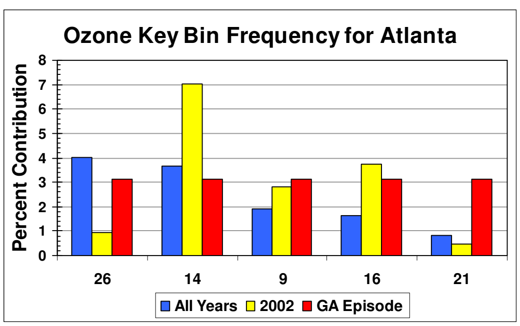

Fig. 3. Frequency of CART bins for ozone for the period 1996-2003, the year 2002, and the selected episode.

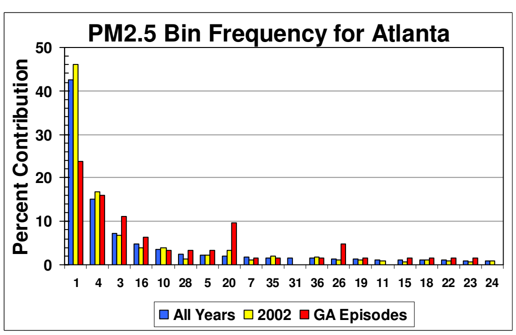

Fig. 4. Frequency of CART bins for $PM_{2.5}$ for the period 2000-2003, the year 2002, and the selected episodes.

4. PROJECTED EMISSIONS REDUCTIONS BY 2009 AND THEIR EFFECT ON OZONE AND $PM_{2.5}$ LEVELS

Since Georgia's attainment status will be evaluated in 2010, sensitivity runs are conducted using the VISTAS 2009 emissions inventory. The following is a preliminary analysis of the impact of projected regional reductions in emissions (2009 inventory compared to 2002) on ozone and $PM_{2.5}$ concentrations.

4.1 Projected Emissions Reductions by 2009 compared to 2002

Comparing the Georgia 2002 and 2009 inventories (Figure 5), reductions of 24%, 34% and 14% are observed for NO_x, SO_2 and VOCs, respectively.

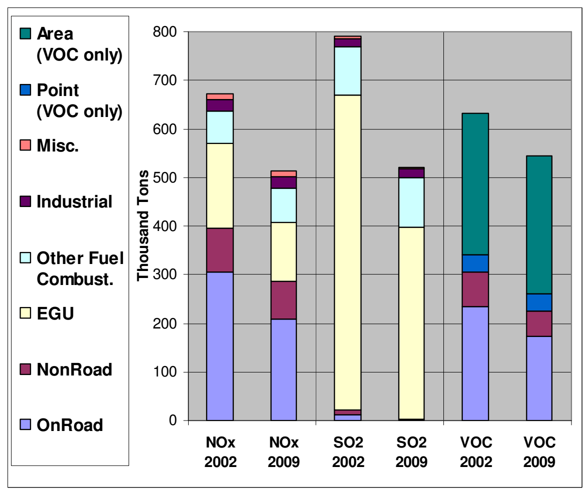

Fig. 5. Comparison between the 2002 and 2009 Georgia Emissions Inventory

4.2 Reductions in ozone and $PM_{2.5}$ based on the 2009 inventory

The following is a preliminary analysis of reductions in ozone and $PM_{2.5}$ from controls already in the process of being implemented (as shown in Figure 5).

Time-series plots for ozone using the 2002 and 2009 inventories for a central Atlanta site (Confederate Avenue, Figure 6) and a suburban downwind site (Conyers, Figure 7) show reductions of up to 12 ppb in the daily maximum 8-hour ozone concentration. Using these simulated values for the sensitivity episode of 5/25/02-6/25/02 and a cutoff value of 75 ppb, Relative Reduction Factors (RRF, the ratio between controlled and uncontrolled case concentrations) were calculated for these sites, and resulted in a RRF of 0.9. When these ratios are applied to the Design Values (DV, weighted average of the forth-highest 8-hour ozone concentration over a five year period centered around the modeling year) at each site, a future (2009) DV is obtained. In the preliminary analysis conducted here (accounting for only one month of modeling and only two specific sites/gird-cells), the future DVs obtained are 86 ppb (0.9 x 95 ppb, the DV for 2002) for the Confederate Avenue site and 82 (0.9 x 91 ppb, the DV for 2002) for the Conyers site. Based on this preliminary and "informal" analysis, it would seem that the Confederate Avenue site would not attain the standard (>85 ppb), while the Conyers site would attain (<85 ppb).

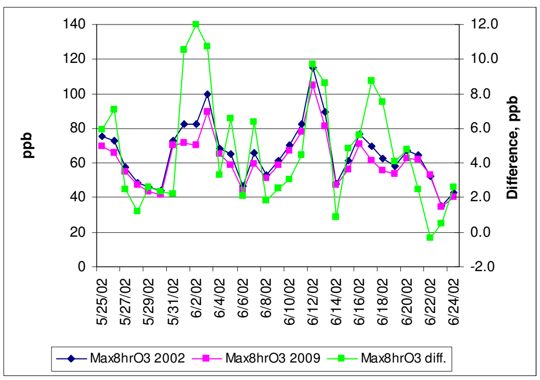

Fig. 6. Time-series of modeled daily maximum 8-hour ozone concentrations at the Confederate Avenue (Atlanta) site based on 2002 and 2009 emissions.

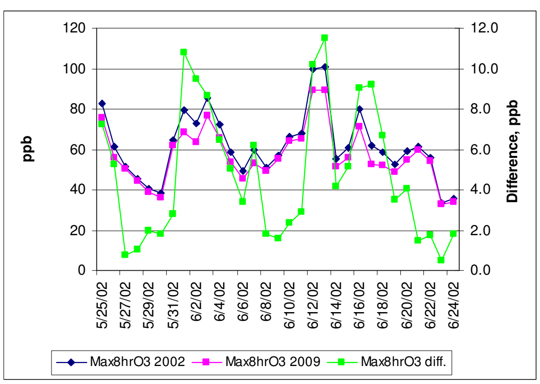

Fig. 7. Time-series of daily maximum 8-hour ozone concentrations at the Conyers site based on 2002 and 2009 emissions.

The sensitivity analysis process was initiated based on two assumptions: 1) projected 2009 controls alone would not be sufficient for demonstrating attainment, as informally demonstrated here; 2) barely attaining the standard (i.e., a future DV of 84 ppb) might not ensure long-term attainment (under more extreme meteorological conditions), hence a "safety buffer" should be considered, i.e. a future DV lower than 84 ppb would be preferable. A preliminary analysis of the "safety buffer" for ensuring long-term attainment suggests a buffer of 3-4 ppb at most sites.

Testing attainment for $PM_{2.5}$, even "informally", is not possible at present, as results for the winter episode are not yet available (the $PM_{2.5}$ standard in an annual one, and all seasons need to be represented). However, based on the results for the summer episode, significant reductions in sulfate levels (Figure 8, the average RRF for this period is 0.7), and smaller reductions in elemental carbon levels (Figure 9, the average RRF for this period is 0.85) are observed.

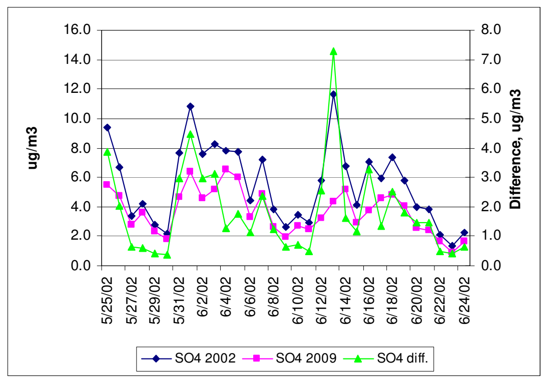

Fig. 8. Time-series of daily-modeled sulfate concentrations at the South-Dekalb site in Atlanta.

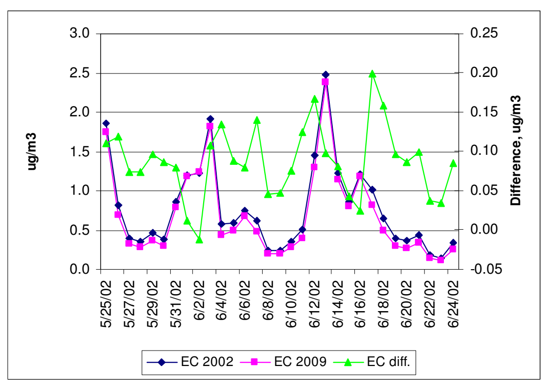

Fig. 9. Time-series of daily-modeled elemental-carbon concentrations at the South-Dekalb site in Atlanta.

5. SENSITIVITY ANALYSIS

Regional sensitivities of ozone (ppb/ton per day, TPD) and $PM_{2.5}$ ($\mu g/m^3$/TPD) include responsiveness to 10% emission reductions in anthropogenic, non-power plant NO_x, VOCs, SO_2,

NH_3, and primary carbon $PM_{2.5}$ in Atlanta, Macon, Chattanooga, and Floyd County. Point source sensitivities simulate the installation of SCRs (NO_x) and scrubbers (SO_2) at the seven largest coal-fired power plants in the state (Bowen, Branch, Hammond, McDonough, Scherer, Wansley, Yates).

5.1 Regional sensitivities

Here we present results for the sensitivities of ozone and $PM_{2.5}$ to regional reductions of precursors (NO_x, VOCs, SO_2, primary carbon) in both Atlanta (defined as the 20 non-attainment counties) and Macon (Bibb, Crawford, Houston, Jones, Monroe, Peach, and Twiggs counties). Results from these sensitivities demonstrate that the ozone chemistry in Atlanta is mainly NO_x limited (Figures 10-11). Very limited local sensitivity to anthropogenic VOC emissions is observed in the Atlanta urban core. This sensitivity is higher on relatively low ozone days (such as 5/25/02, sensitivity of up to 0.8 ppb), likely due to the lower biogenic VOC emissions on relatively cooler days. However, such days are of low importance in RRF calculations, as the ozone level is below the threshold used for RRF calculations. Sensitivities for emissions reductions in Macon show similar patterns, with ozone being completely NO_x limited.

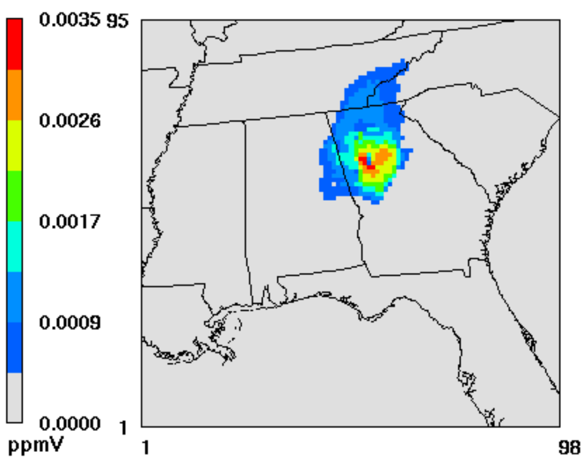

Fig. 10. Sensitivity of ozone (maximum 8-hour ozone concentration, ppm) on 6/12/02 to a 10% reduction in non-power plant NO_x in the Atlanta area.

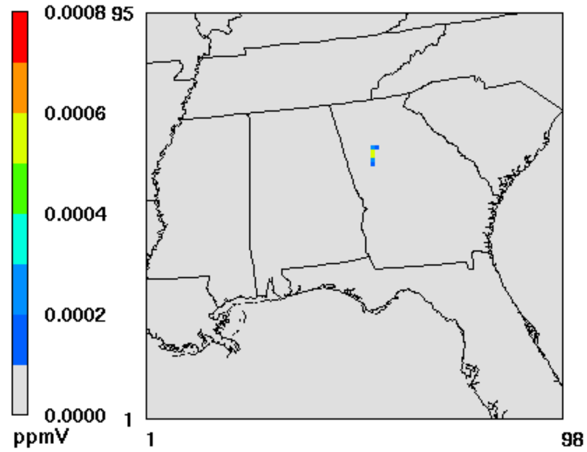

Fig. 11. Sensitivity of ozone (maximum 8-hour ozone concentration, ppm) on 6/12/02 to a 10% reduction in anthropogenic VOCs in the Atlanta area.

Sensitivity of $PM_{2.5}$ to regional emissions reductions is described here in terms of the episode average change (future work will include assigning specific weights to various modeled days based on the CART analysis). Considering a 10% reduction in non-power plant emissions of NO_x, SO_2, VOCs, NH_3, and primary carbon (PC), the reduction in PC had the greatest impact (Figure 12). The impact due to PC emission reductions is very local and corresponds to high emissions in the core urban area (as opposed to the more "regional" effect of SO_2 reductions, shown in Figure 13).

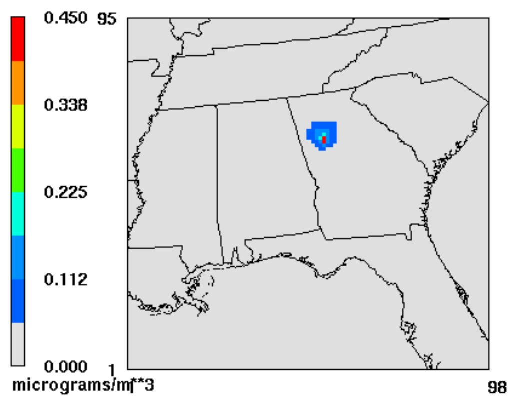

Fig. 12. Sensitivity of $PM_{2.5}$ (average over entire sensitivity episode) to a 10% reduction in non-power plant primary carbon emissions in the Atlanta area.

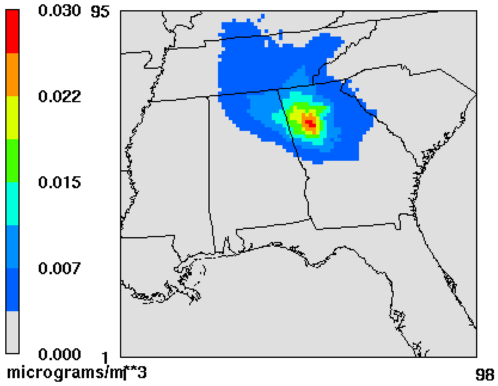

Fig. 13. Sensitivity of $PM_{2.5}$ (average over entire sensitivity episode) to a 10% reduction in non-power plant SO_2 emissions in the Atlanta area.

To best summarize the impact of various emissions reductions on ozone and $PM_{2.5}$ levels we scaled the maximum ozone reductions and episode-average $PM_{2.5}$ reductions based on the actual tonnage reduction in emissions (Table 1). These results further demonstrate the higher efficiency of NO_x controls compared to VOC for ozone abatement in Atlanta and emphasize the conceptual difference between controlling primary and secondary $PM_{2.5}$ components.

	Ozone		$PM_{2.5}$	
10% change in	maximum reduction (ppb)	reduction per ton (ppb/TPD)	episode average reduction ($\mu g/m^3$)	reduction per ton ($\mu g/m^3$/TPD)
NO_x	3.5	**0.092**	0.09	0.002
VOC	0.8	0.016	0.004	8E-05
SO_2	-	-	0.03	0.004
NH_3	-	-	0.08	0.01
carbon	-	-	0.45	**0.22**

Table 1. Per ton sensitivity (concentration/TPD) of ozone and $PM_{2.5}$ from a 10% reduction of non-power plant emissions in the Atlanta area.

5.2 Point-source sensitivities

Point-source sensitivities simulated the installation of scrubbers (for SO_2 reductions) and SCRs (for NO_x reductions) in seven major power plants in Georgia. Results were analyzed in terms of reductions in both ozone and $PM_{2.5}$. Simulating the installation of a SCR to reduce NO_x emissions from plant McDonough, located in an Atlanta suburb, shows reductions of up to 2 ppb in the maximum 8-hour ozone concentration in Atlanta, on a high ozone day (6/12/02, Figure 14). A similar simulation for from plant Scherer, located approximately 40 miles northwest of Macon, resulted in reduction of approximately 4 ppb in the maximum 8-hour ozone concentration in Macon, on a high ozone day (6/3/02, Figure 15).

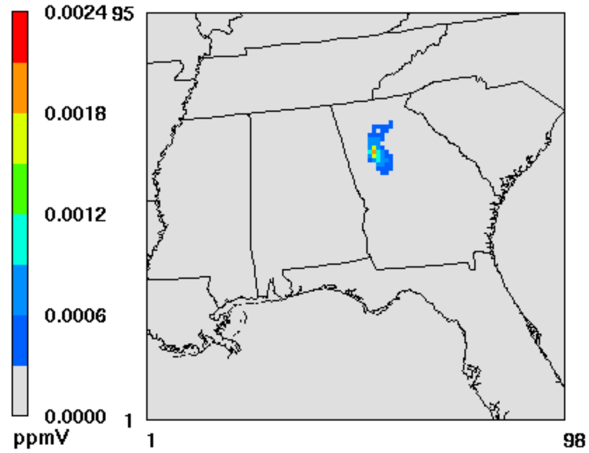

Fig. 14. Sensitivity of maximum 8-hour ozone concentration on 6/12/02 to the installation of a SCR at Plant McDonough.

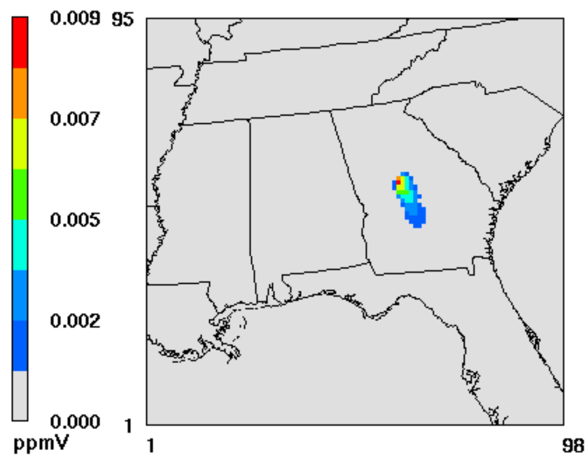

Fig. 15. Sensitivity of maximum 8-hour ozone concentration on 6/3/02 to the installation of a SCR at Plant Scherer.

Sensitivities of $PM_{2.5}$ concentrations to installation of scrubbers and SCRs are presented here in the form of the change in episode-average concentrations. The impacts of an installation of a scrubber and SCR in plant Scherer and a scrubber in Plant Bowen (SCRs already installed) (Figures 16, 17) are relatively large on an average basis, considering that on many of the simulated days a single monitor/cell may not be affected at all by reductions in a specific plant (reflecting different plume trajectories).

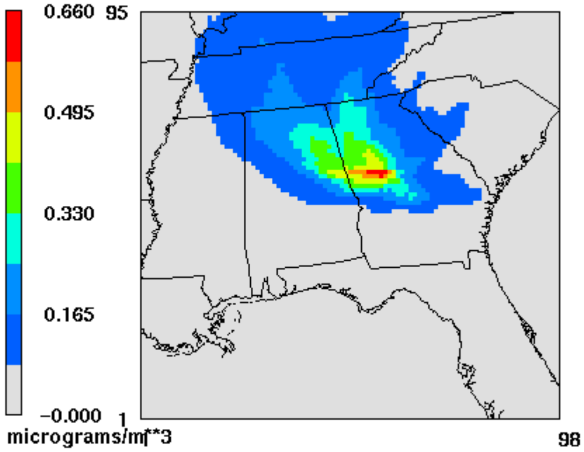

Fig. 16. Sensitivity of episode-average $PM_{2.5}$ concentrations to the installation of a scrubber and SCR at Plant Scherer.

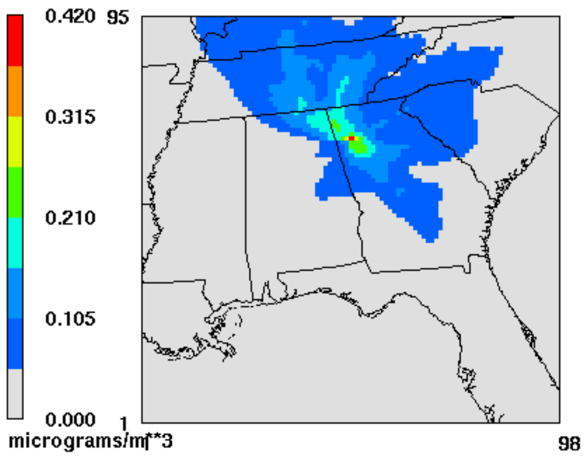

Fig. 17. Sensitivity of episode-average $PM_{2.5}$ concentrations to the installation of a scrubber at Plant Bowen.

Scaling these modeled reductions in both ozone and $PM_{2.5}$ based on actual tonnage reduction in precursor emissions (Table 2) can serve to evaluate the effectiveness of such reductions (especially when also combined with population exposure).

6. DISCUSSION

Results presented here, along with a winter episode sensitivity analysis which is in process, and after further analysis to account for meteorological bin frequencies and spatial variability, will serve as the basis for evaluating various control strategies for SIP development. Results from this sensitivity analysis, in the form of ppb/TPD or μg/m^3/TPD will be linked with economical considerations ($/ton) and with a health/exposure analysis to develop the most cost-effective and health-beneficial strategy for attaining both the 8-hour ozone and annual $PM_{2.5}$ standards .

	Ozone		$PM_{2.5}$	
Scrubber and/or SCR at	maximum reduction (ppb)	reduction per ton (ppb/TPD)	episode average reduction (μg/m^3)	reduction per ton (μg/m^3/TPD)
Branch	5	0.33	0.36	0.0023
Bowen	-	-	0.42	0.0024
Hammond	5	0.45	0.30	0.0034
McDonough	1.5	0.21	0.18	0.0033
Scherer	6	0.20	0.66	0.0020
Wansley	-	-	0.31	0.0034
Yates	5	0.45	0.26	0.0028

Table 2. Per ton sensitivity (concentration/TPD) of ozone and $PM_{2.5}$ to reductions of SO_2 and NO_x from major power plants in Georgia.