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.

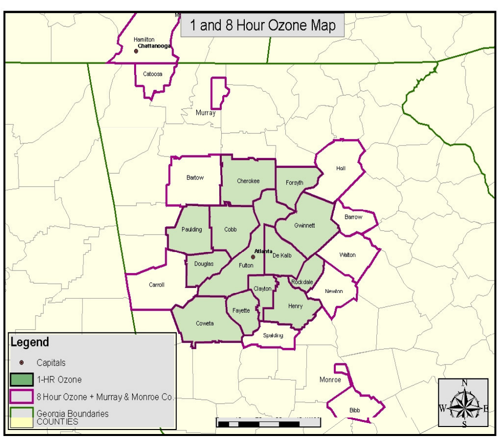

Fig. 1. Georgia 8-hour ozone non-attainment areas (Chattanooga is an EAC area).

*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

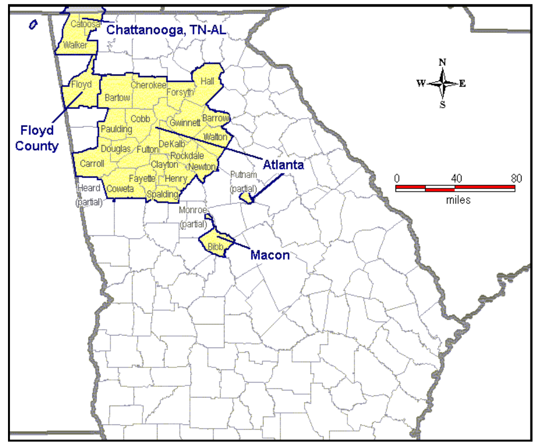

Fig. 2. Georgia annual $PM_{2.5}$ non-attainment areas.

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.

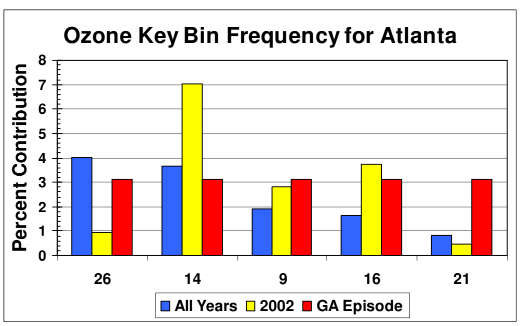

Fig. 3. Frequency of CART bins for ozone for the period 1996-2003, the year 2002, and the selected episode.

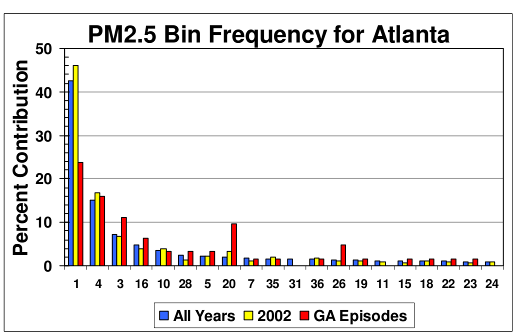

Fig. 4. Frequency of CART bins for $PM_{2.5}$ for the period 2000-2003, the year 2002, and the selected episodes.

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.

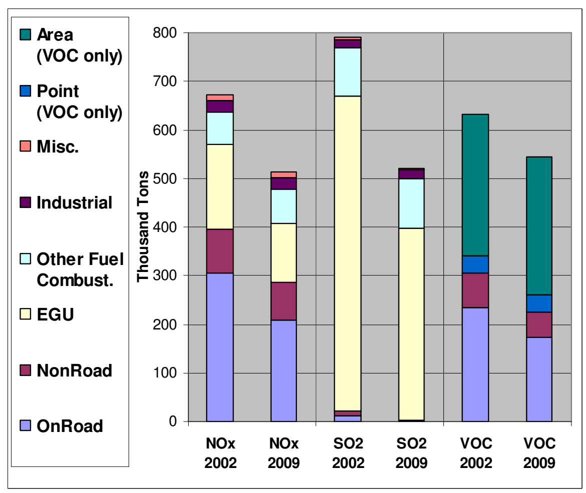

Fig. 5. Comparison between the 2002 and 2009 Georgia Emissions Inventory

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).

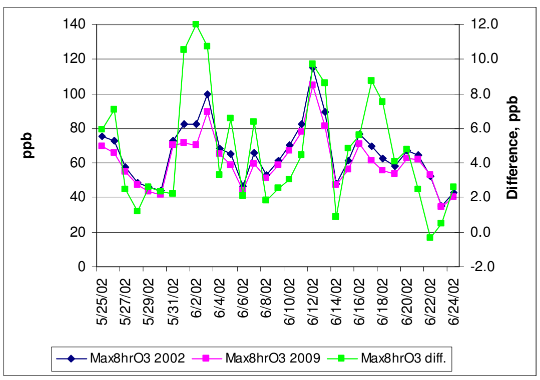

Fig. 6. Time-series of modeled daily maximum 8-hour ozone concentrations at the Confederate Avenue (Atlanta) site based on 2002 and 2009 emissions.

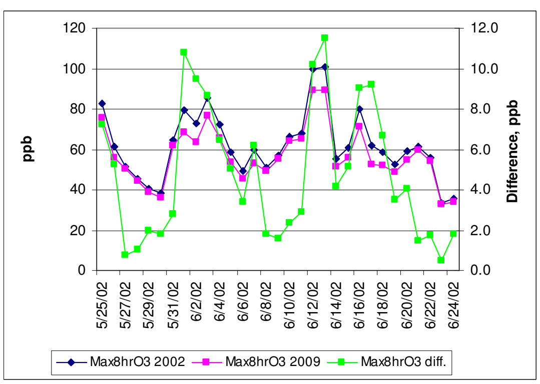

Fig. 7. Time-series of daily maximum 8-hour ozone concentrations at the Conyers site based on 2002 and 2009 emissions.

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.

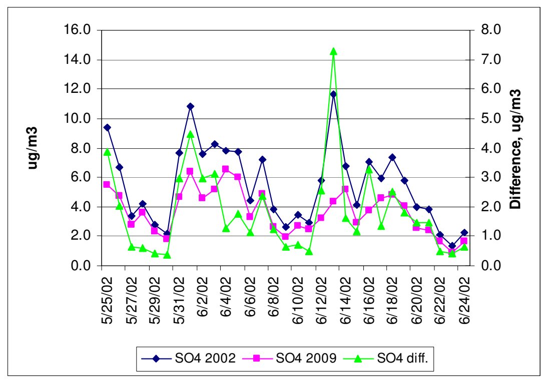

Fig. 8. Time-series of daily-modeled sulfate concentrations at the South-Dekalb site in Atlanta.

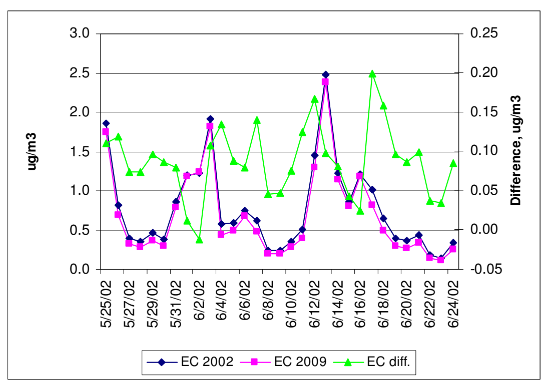

Fig. 9. Time-series of daily-modeled elemental-carbon concentrations at the South-Dekalb site in Atlanta.

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.

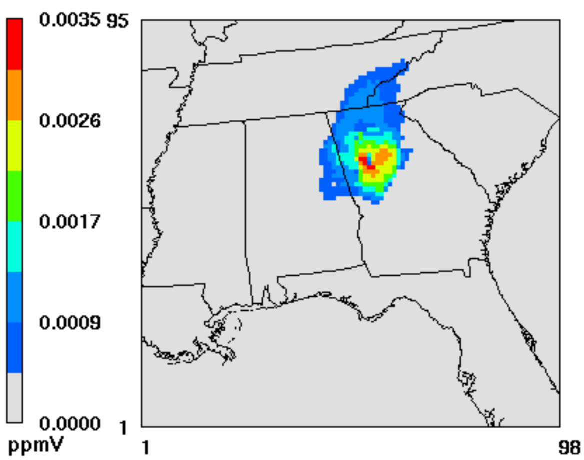

Fig. 10. Sensitivity of ozone (maximum 8-hour ozone concentration, ppm) on 6/12/02 to a 10% reduction in non-power plant NO_x in the Atlanta area.

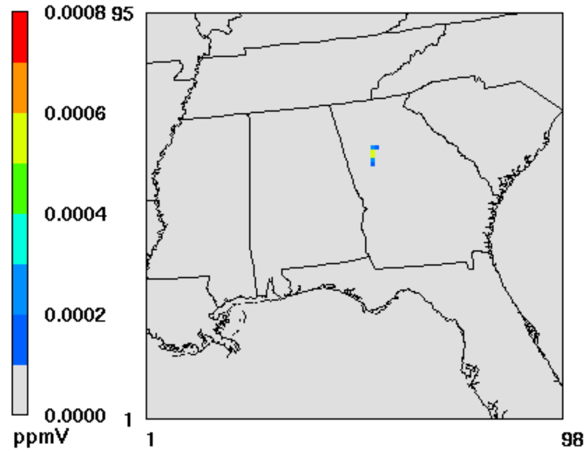

Fig. 11. Sensitivity of ozone (maximum 8-hour ozone concentration, ppm) on 6/12/02 to a 10% reduction in anthropogenic VOCs in the Atlanta area.

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).

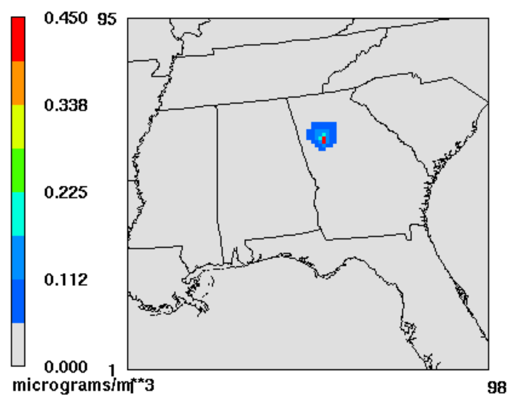

Fig. 12. Sensitivity of $PM_{2.5}$ (average over entire sensitivity episode) to a 10% reduction in non-power plant primary carbon emissions in the Atlanta area.

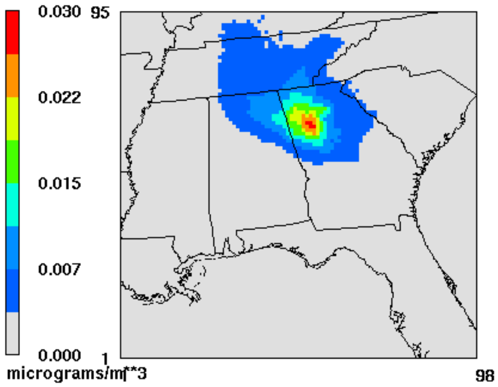

Fig. 13. Sensitivity of $PM_{2.5}$ (average over entire sensitivity episode) to a 10% reduction in non-power plant SO_2 emissions in the Atlanta area.

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).

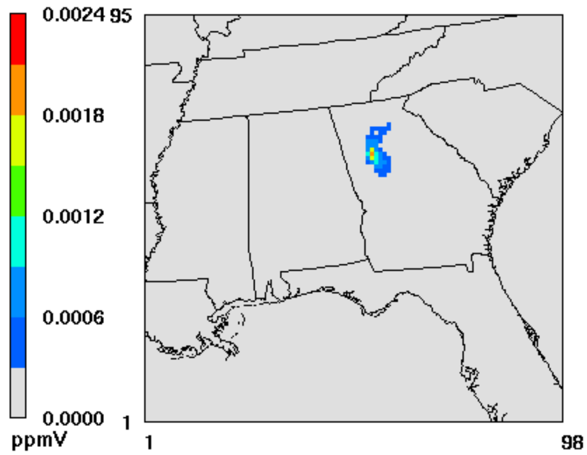

Fig. 14. Sensitivity of maximum 8-hour ozone concentration on 6/12/02 to the installation of a SCR at Plant McDonough.

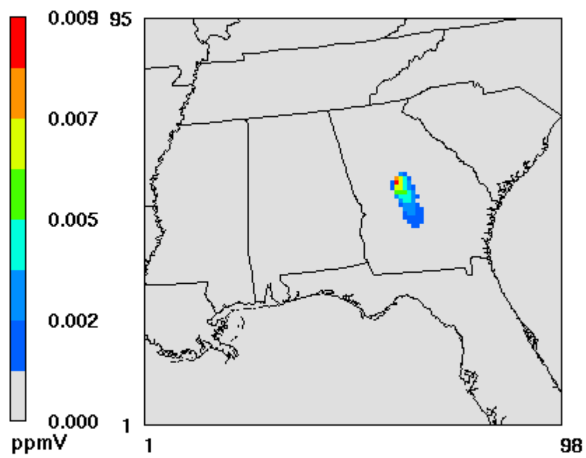

Fig. 15. Sensitivity of maximum 8-hour ozone concentration on 6/3/02 to the installation of a SCR at Plant Scherer.

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).

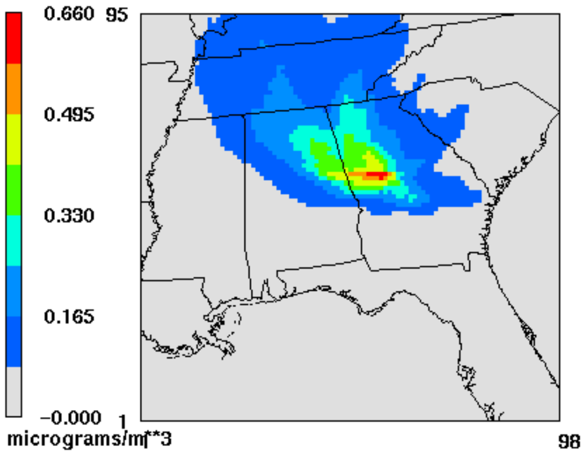

Fig. 16. Sensitivity of episode-average $PM_{2.5}$ concentrations to the installation of a scrubber and SCR at Plant Scherer.

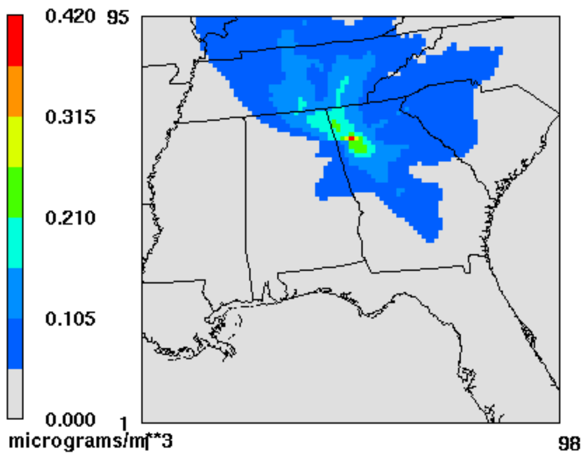

Fig. 17. Sensitivity of episode-average $PM_{2.5}$ concentrations to the installation of a scrubber at Plant Bowen.

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.