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## **Estimating Future-Year Ozone Design Values with Two Regional-Scale Modeling Systems in North Carolina**

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### **ABSTRACT**

Across the United States, significantly increased numbers of counties are likely to be designated nonattainment for ozone with the proposed 8-h form of the National Ambient Air Quality Standard (NAAQS). The U.S. Environmental Protection Agency has developed a draft guidance for potential nonattainment areas to demonstrate attainment of the standard through photochemical air quality simulation models. This has led to increased emphasis on the evolution and use of regional-scale models to study longer averaging periods in addressing the complex nature of the tropospheric ozone problem. We have applied two state-of-the-art regional-scale models, the Models-3/Community Multiscale Air Quality (CMAQ) model and the Multiscale Air Quality Simulation Platform (MAQSIP), which was developed as a prototype for CMAQ, to the June 19-30, 1996, O<sub>3</sub> episode in North Carolina. Both CMAQ and MAQSIP are fully modularized, three-dimensional modeling systems, with various options for representing the physical and chemical processes for urban- and regional-scale pollution. We have previously compared and presented the relative performance of the two models for base-year modeling for this episode, a period characterized by high ozone in the Charlotte-Gastonia-Rock Hill, Greensboro-Winston Salem-High Point, and Raleigh-Durham-Chapel Hill areas. Horizontally, the two modeling systems employ a nested 36/12/4-km grid resolution, with the 4-km grid covering the entire state of North Carolina. The base case modeling was performed with harmonized sets of inputs, and we still identified day-to-day performance variability between the two modeling systems for ozone. Our objective here is to emphasize the use of these models in a “relative” sense, by applying EPA’s draft modeling guidance and determining whether the modeling systems, when using an identical set of emissions inputs, produce different Relative Reduction Factors (RRFs) at each monitored location in the 4-km grid (RRFs are ratios of ozone concentrations from future-year modeling to those from base-year modeling). Differences in RRFs are likely to cause differences in computed future-year design values at these locations. The plausible causes of these differences and their policy-relevant impacts on demonstrating attainment of the NAAQS for ozone at monitored locations are discussed.

## INTRODUCTION

The Clean Air Act Amendments of 1990 established selected comprehensive, three-dimensional (3-D) photochemical air quality simulation models (PAQSMs) as the required regulatory tools for analyzing the urban and regional problem of high ambient ozone ( $O_3$ ) levels across the United States. These models are currently applied to study and establish strategies for meeting the National Ambient Air Quality Standard (NAAQS) for ozone nonattainment areas. State Implementation Plans (SIPs) resulting from these efforts must be submitted to the U.S. Environmental Protection Agency (EPA).

EPA has developed a draft modeling guidance<sup>1</sup> for demonstrating attainment of the 8-h NAAQS for ozone. In this document, EPA recommends a methodology for applying air quality models to generate predictions that indicate whether a given set of emissions controls is likely to show attainment in the future. With this background, the use of grid-based photochemical models has expanded dramatically to include spatial scales varying from urban to regional. The Urban Airshed Model (UAM-IV) remains the only regulatory model recommended by EPA for use in demonstrating attainment<sup>2</sup> of the ozone standards. While there are many models that can be applied on a regional scale, none of these have been prescribed by EPA as the recommended regulatory model for use in developing SIPs for ozone nonattainment areas. Thus, state and local agencies intending to develop photochemical modeling applications for regulatory purposes have to make their own choice among the available models. Users trying to select a modeling system for a given application need to have a complete understanding of the structural and algorithmic differences between the models, and of their possible impacts on both operational and scientific inferences that may be drawn from the models' respective simulations. These differences could significantly affect the development of emissions control strategies for attaining the ozone NAAQS.

## MOTIVATION AND GOAL OF STUDY

The aim of our study is to systematically quantify the differences in predictions from two models, MCNC's Multiscale Air Quality Simulation Platform (MAQSIP)<sup>3</sup> and EPA's Models-3/Community Multiscale Air Quality (CMAQ) model<sup>4,5</sup>, to understand the following:

1. How differing treatment of meteorological information affects air quality predictions.
2. How differences in algorithmic and process representations affect predicted concentrations.
3. The comparative use of these systems in regulatory applications to test attainment of the 8-h NAAQS for  $O_3$ .

The first two goals were partially addressed in the first part of our study,<sup>6</sup> in which we applied MAQSIP and CMAQ to an ozone episode in North Carolina, evaluated model performance at different grid resolutions, and identified potential issues. While work is continuing to address some of these issues (earlier version of MCIP rediagnosing meteorological parameter values;  $K_z$  floor in CMAQ), this paper attempts to address the third goal listed above. In other words, we have applied the two modeling systems in a "relative" sense to projected future-year (2007) emissions control scenarios and base-year (1996) modeling scenarios; we compare the relative

reductions at individual monitoring sites in the modeling domain, and tested the reductions against ambient data for attainment of the NAAQS.

## **EPISODE DESCRIPTION**

Three episodes have been chosen to support modeling for the 8-h ozone attainment demonstration in North Carolina (NC):<sup>7</sup> July 10-15, 1995, June 19-30, 1996, and July 10-15, 1997. The period we simulated for this study was June 19-30, 1996. This period actually consists of two separate ozone episodes. They were modeled and evaluated at the same time, so the statistics and episode composite evaluation cover all days of the two episodes.

The first episode, June 21-24, had elevated ozone levels in NC; concentrations in most other areas of the eastern and southern United States were lower than those in NC. This episode is dominated by a front to the north and high pressure to the southwest of the state. The movement of the front and the observed ozone concentrations indicate possible recirculation during the episode. Light southwesterly flow was present on the 22<sup>nd</sup>, resulting in 1-h peaks of 133 and 113 ppb northeast of Charlotte and Durham, respectively. The corresponding 8-h peak ozone concentrations were 110 and 99 ppb. As the front moved into northern portions of NC on the 23<sup>rd</sup>, winds became more northerly and ozone concentrations in the Greensboro-Winston Salem-High Point and Raleigh-Durham-Chapel Hill areas decreased. Ozone was pushed back into Charlotte, causing exceedances of the 1-h and 8-h standards at all three Mecklenburg County ozone monitors. On the 24<sup>th</sup>, the front retreated northward as a warm front and southwesterly winds returned to the entire state. Ozone levels increased throughout the northern portions of NC and 8-h averaged concentrations of up to 100 ppb were recorded in all three major urban areas of NC. One exceedance (134 ppb) of the 1-h standard was measured at the Rockwell site, northeast of Charlotte.

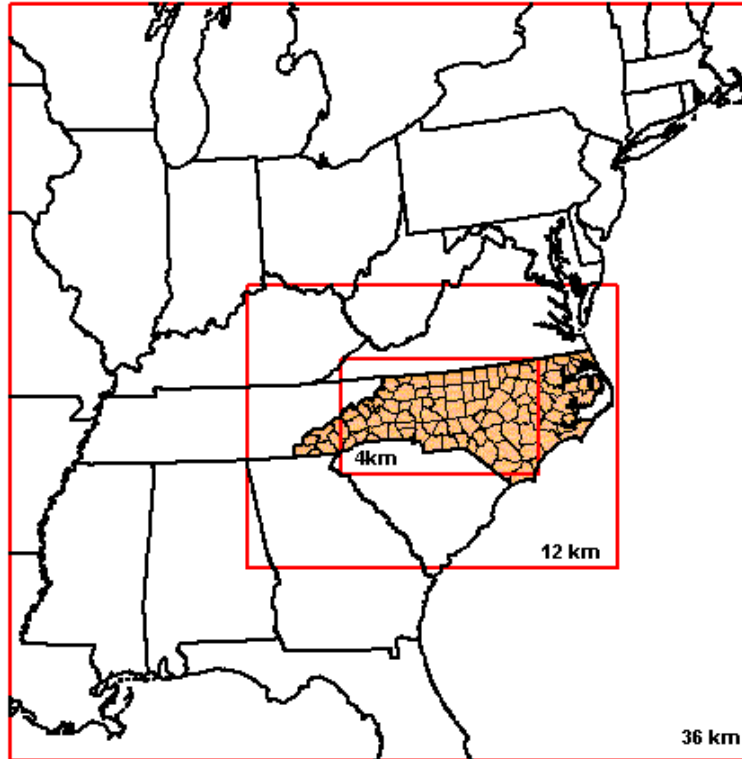
A stronger front moved toward NC on the 25<sup>th</sup>, touching off storms and dropping ozone readings. The front passed through the state by the 26<sup>th</sup>, and concentrations remained low. During the second episode (June 27-29), an upper-level ridge began to build to the west of NC and surface high pressure over Canada moved southward throughout the episode and settled into western NC by the 29<sup>th</sup>. Northerly winds predominated at the surface and upper levels. High temperatures of up to 90°F remained in NC and much of the eastern half of the United States during this period. Dew point temperatures were relatively low and winds were light enough to produce 8-h exceedances in many areas of NC on the 28<sup>th</sup> and 29<sup>th</sup>. As high pressure remained over western NC, ozone concentrations continued to rise throughout the episode. Exceedances of the 1-h standard were measured at two monitors in Charlotte on June 29.

## **MODELING SYSTEMS**

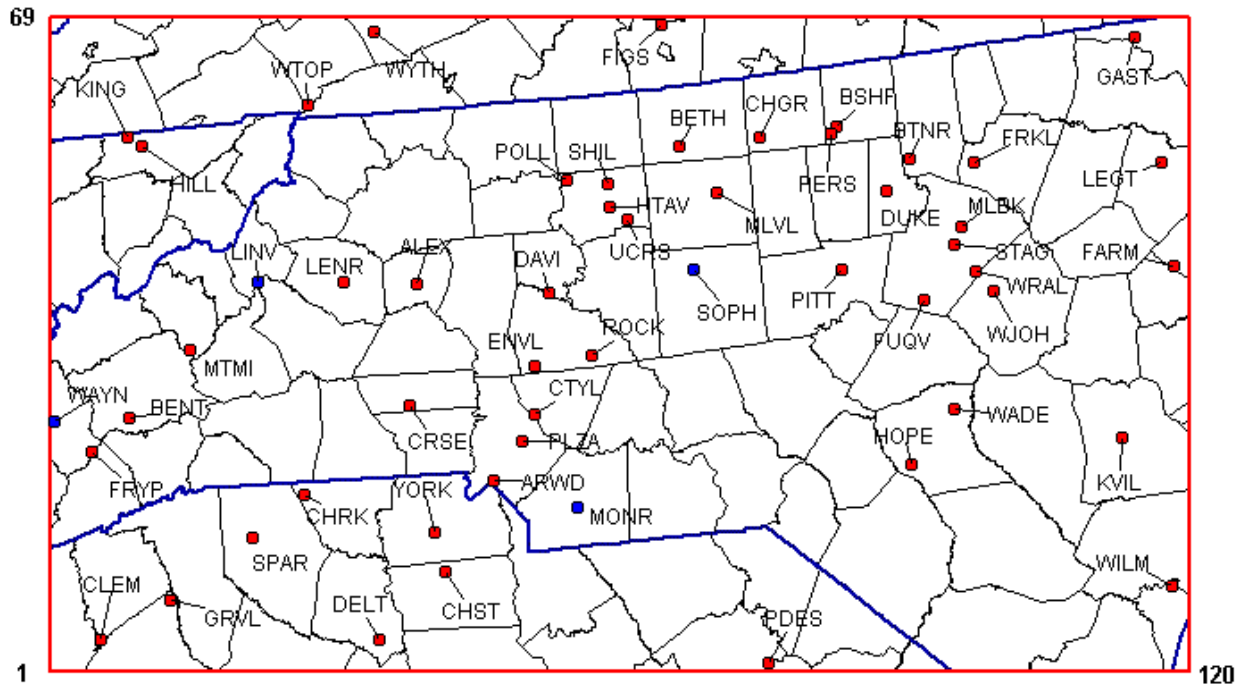
The modeling domain used for this study has a nested system of 36-, 12-, and 4-km grids centered over NC (Figure 1); this paper focuses on analyses in just the 4-km grid. Figure 2 shows the location of the air quality monitors within the 4-km domain.

We used the MM5-SMOKE-MAQSIP/CMAQ combination of modeling systems in this study; brief descriptions of the various models are given below. Complete details were discussed in our first paper.<sup>6</sup>

**Figure 1:** Air quality modeling domain showing the 36-, 12-, and 4-km grids.



**Figure 2:** O<sub>3</sub> monitors in the 4-km domain.



## Mesoscale Model (MM5)

The meteorological inputs for this study were derived from the Fifth-Generation Penn State/NCAR Mesoscale Model Version 2 (MM5 V2.12).<sup>8</sup> An iterative procedure was used to generate the best meteorological inputs possible. The meteorological model performance was evaluated each time to measure improvements.

MM5 was vertically resolved into 26 layers, and the top of the domain extended up to 16 km. While the first layer had a height of 38 m, there were 9 layers within the lowest 1 km. To generate MAQSIP-ready inputs, MM5 was executed in the coupled mode along with MCPL;<sup>9</sup> CMAQ, on the other hand, uses outputs from the Meteorology-Chemistry Interface Processor (MCIP).<sup>6</sup>

## Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System

Emissions inputs to the models were developed using the SMOKE<sup>10</sup> processing system. Biogenic emissions were processed using an implementation of BEIS-2<sup>11</sup> within SMOKE. For the future-year scenario, the emissions were projected to the year 2007 with the following emissions controls:<sup>12</sup>

- Title IV acid rain controls on power plants
- Tier II automobile standards
- Low-sulfur gasoline
- Maximum Available Control Technology (MACT) standards
- Nonroad spark engine standards
- Mobile-source NO<sub>x</sub> reductions from the inspection and maintenance (I/M) program in North Carolina counties
- U.S. EPA's NO<sub>x</sub> SIP-Call controls in 22 states in the eastern United States, which includes
  - 0.15 lb of NO<sub>x</sub> / mBTU on all large utility and industrial boilers
  - 90% reduction in NO<sub>x</sub> emissions from internal combustion engines
  - 60% reduction on other industrial sources of NO<sub>x</sub>

## Air Quality Simulation Models

### *Multiscale Air Quality Simulation Platform (MAQSIP)*

MAQSIP is a comprehensive urban- to intercontinental-scale atmospheric chemistry-transport model, developed at the MCNC Environmental Modeling Center in collaboration with EPA; the model also served as a prototype for EPA's CMAQ modeling system. In its current form, MAQSIP has been used at various scales to study problems related to tropospheric O<sub>3</sub>, acidic substances, and aerosol formation and pollutant distribution for a variety of geographic areas of the world.<sup>13-22</sup> Over the past three summers, MCNC has adapted the MM5-SMOKE-MAQSIP system to produce operational real-time forecasts for ozone over the eastern United States.<sup>23</sup>

Since the Carbon Bond-4 mechanism (CBM-IV)<sup>24</sup> has been the most widely used chemical mechanism for most regulatory applications, we used the CBM-IV mechanism in both MAQSIP and CMAQ.

## ***Community Multiscale Air Quality (CMAQ) Model***

Since the MM5-MAQSIP system served as a prototype for CMAQ, several of the features described above also apply to CMAQ. While the overall representations of various chemistry and transport processes in the two models are similar, there are some differences in the implementation or parameterizations of individual processes. There are many ongoing efforts to formally evaluate CMAQ. CMAQ can be configured for a wide range of applications, from scientific studies to regulatory applications. While the scientific community can take advantage of CMAQ's ability to create alternative applications for research and development purposes, regulatory applications depend upon a standardized, evaluated form of CMAQ. Various qualitative approaches<sup>25</sup> have been proposed in the past for evaluating the reliability of a PAQSM for regulatory applications. We hope that our study will help support the scientific benchmark needed for the evaluation program.

CMAQ utilizes a meteorology-chemistry interface processor (MCIP) that rediagnoses certain boundary layer parameters like mean wind, temperature, and humidity profiles, surface data, and detailed land use information. Consequently, some differences in model predictions between CMAQ and MAQSIP are likely due to the differences in the individual treatments of the input meteorological conditions.

### ***Model Configurations***

We configured the two models to be as similar as possible for our comparison study. We made one improvement to the modeling configuration in this phase, by adding cloud treatment in both MAQSIP and CMAQ. While MAQSIP uses the Kain-Fritsch<sup>26</sup> cloud treatment, CMAQ uses the cloud treatment based upon the Regional Acid Deposition Model (RADM)<sup>5,27</sup>.

In addition to maintaining similar model configurations, we harmonized the inputs to ensure that potential discrepancies in model outputs would be due to differences in the model formulations. The emissions, initial and boundary conditions, clear-sky photolysis rates, and raw meteorology data were identical for both the MAQSIP and CMAQ modeling systems.

## **ATTAINMENT DEMONSTRATION**

In its draft guidance for demonstrating attainment of the 8-h NAAQS for ozone, EPA defines a modeled attainment demonstration to consist of two parts:

- a) Analyses that estimate whether selected emissions reductions will result in ambient concentrations that meet the NAAQS, and
- b) An identified set of control measures that will result in the required emissions reductions.

Part (a) above necessitates use of a *modeled attainment test*, plus a *screening test* at selected locations without ozone monitors. (In addition, "weight of evidence" corroboratory analyses might also be required to demonstrate attainment of the NAAQS.) This paper focuses on an illustration

of a modeled attainment test in the North Carolina modeling domain using the two different air quality modeling systems.

## **Modeled Attainment Test**

The various steps prescribed by the draft guidance, and our implementation of the guidance for this project, are described below.

### ***1. Calculate the site-specific current design values (DVCs) from monitored data***

To be consistent with the form of the NAAQS, we calculated the DVC at each site by using the fourth-highest daily maximum 8-h ozone concentration in each of three consecutive years (chosen as discussed below), and then finding their arithmetic mean. Because there is likely to be some variability in observed design values due to meteorological variations, EPA in its guidance recommends using the higher of the following two values:

- Average design value from the three-year period “straddling” the year represented by the most recent available emissions inventory. NC’s current emissions inventory is for the year 1997, so the corresponding period to use is 1996-1998.
- Average design value from the three-year period used to designate an area “nonattainment.” Initially this was 1997-1999, but since 2000 data became available, we chose the higher of the DVCs from the 1997-1999 and 1998-2000 periods.

Based upon the above, the DVCs we used were the highest of the values from 1996-1998, 1997-1999, and 1998-2000.

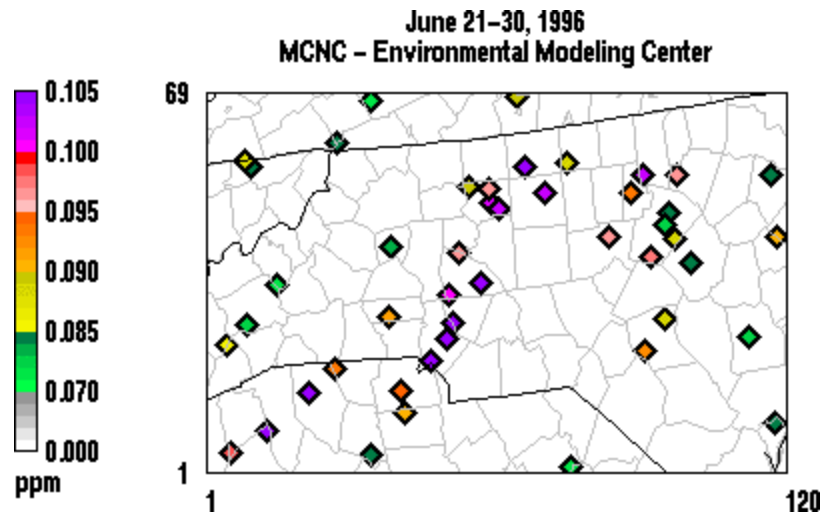
Figure 2 shows the location of the O<sub>3</sub> monitors in the 4-km grid, and Table 1 lists the monitors in NC grouped by urban area, along with various site characteristics, including the DVC for each site. It can be seen that there is a very extensive monitoring network in the three urban areas of North Carolina (i.e., Charlotte, Triangle, and Triad), and the monitors within each urban area are located very close to each other. Figure 3 shows the episodic-maximum observed 8-h ozone concentrations, and Figure 4 shows the DVCs for the NC sites.

**Table 1:** Description of NC O<sub>3</sub> monitoring sites in the 4-km domain.

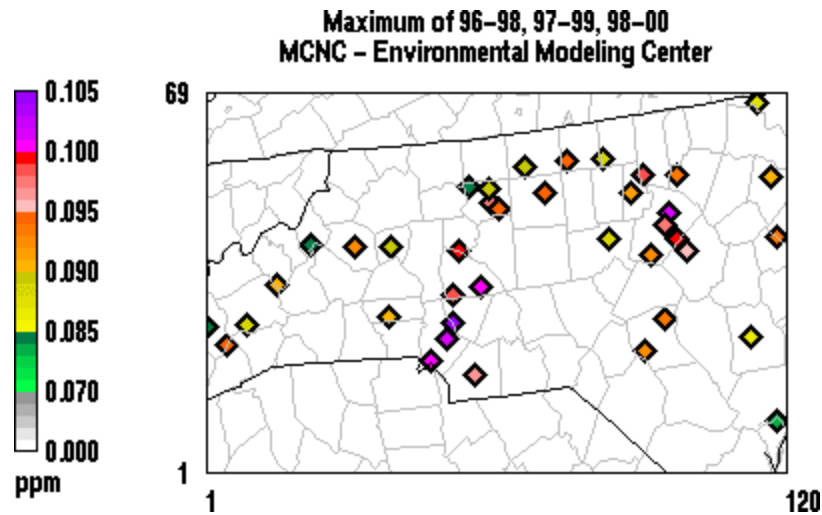
Region	AIRS-ID	ID	City	Setting	Elevation <sup>1</sup>	DVC
Charlotte	371191009	CTYL	County Line	Rural	216	0.104
	371190034	PLZA	Garinger (Plaza)	Suburban	4	0.101
	371191005	ARWD	Arrowood	Rural	195	0.100
	371590021	ROCK	Rockwell	Rural	240	0.100
	371590022	ENVL	Enochville	Suburban	270	0.098
	371790003	MONR	Monroe	Suburban	200	0.096
	371090004	CRSE	Crouse	Rural	270	0.090
	Triangle	371830014	MLBK	Millbrook	Suburban	100
371830015		STAG	St. Augustine	Urban	127	0.097
371830017		WRAL	Tower	Suburban	320	0.099
370770001		BTNR	Butner	Suburban	91	0.098
371450003		BSHF	Bushy Fork	Rural	198	0.095
371010002		WJOH	W. Johnston	Rural	127	0.095
370690001		FRKL	Franklinton	Urban	135	0.093
371830016		FUQV	Fuquay-Varina	Urban	117	0.092
370630013		DUKE	Duke St.	Suburban	390	0.091
370370004		PITT	Pittsboro	Rural	400	0.088
Triad	370590002	DAVI	Cooleemee	Suburban	219	0.099
	370670022	HTAV	Hattie Ave.	Urban	287	0.097
	370330001	UCRS	Union Cross	Rural	241	0.094
	370671008	CHGR	Cherry Grove	Rural	285	0.094
	370810011	MLVL	McLeansville	Rural	229	0.094
	371570099	BETH	Bethany	Rural	277	0.089
	370670028	SHIL	Shiloh Church	Rural	294	0.089
	370670027	POLL	Pollitosa	Rural	271	0.084
Asheville	370870035	FRYP	Fry Pan	Rural	1585	0.094
	370870036	PKNO	Purchase Knob	Rural	1494	0.090
	371990003	MTMI	Mt. Mitchell	Rural	1982	0.090
	370210030	BENT	Bent Creek	Suburban	675	0.088
	370990005	BKNO	Barnet Knob	Rural	1433	0.087
	370870004	WAYN	Waynesville	Suburban	802	0.082
	371730002	BRYN	Bryson	Suburban	560	0.076
Greenville,	371470099	FARM	Farmville	Rural	26	0.093
Rocky Mount,	371070004	KINS	L. College / Lenoir Co.	Suburban	29	0.090
& Wilson	370650099	LEGT	Leggett	Rural	18	0.090
(Down East)	370610002	KVIL	Kenansville	Urban	34	0.086
	371170001	JVIL	Jamesville	Rural	6	0.083
Fayetteville	370510008	WADE	Wade	Rural	43	0.093
	370511002	HOPE	Golfview (Hope Mills)	Suburban	68	0.092
NW Piedmont	370270003	LENR	Lenoir / Caldwell Co.	Urban	366	0.092
(Hickory)	370030003	ALEX	Taylorsville	Suburban	339	0.089
Various Areas	371310002	GAST	Gaston	Rural	40	0.087
	370290099	CAMD	Camden	Rural	3	0.084
	370110002	LINV	Linville	Rural	987	0.082
	371290002	WILM	Castle Hayne	Rural	12	0.081

<sup>1</sup> Units in meters above mean sea level.

**Figure 3.** Episodic-maximum observed 8-h ozone concentrations at  $O_3$  monitors in the NC 4-km modeling domain.



**Figure 4:** Current-year design values (DVCs) for  $O_3$  monitors in the NC 4-km modeling domain.



## **2. Use air quality modeling results to estimate site-specific relative reduction factors (RRFs)**

Using the set of DVCs from step 1, we first discarded all sites with DVCs <75 ppb. Next, we identified surface grid cells that were considered to be “near” a monitoring site, rather than just the cell containing the monitor. Since it is hypothesized that RRFs can be underestimated due to potential migration of the predicted ozone peak that results from a chosen control strategy, EPA has identified a 15-km radius as being “near” a site, i.e., as an area consistent with the intended representativeness for urban-scale ozone monitors.

For the purposes of this project, we applied the modeled attainment test only to NC sites in the 4-km grid; the size of the array of “nearby” cells for this grid resolution thus becomes “7×7”. In other words, it can be hypothesized that the monitor is at the center of the cell in which it is located, and that this cell is at the center of a 7×7 array of “nearby” cells.

The site-specific RRFs were computed as follows:

- a) Compute daily maximum 8-h ozone concentration in every grid cell for each modeled episode day in the base case (June 21-24 and 27-30, 1996). (After establishing model performance for the base case with episodic emissions inputs, both MAQSIP and CMAQ were run using the “current-year” emissions (i.e. 1997 for NC) for use in the base-year calculations.)
- b) Find the highest value of the predicted daily maximum 8-h ozone concentrations in the “nearby” cells (7×7) for each day.
- c) Find the average of the highest values for all modeled episode days, using only those days when the highest was =70 ppb, to get a site-specific mean base-year value (Mean\_BY). The threshold of 70 ppb is applied to exclude low-value days that would cause overestimation of future-year design values (calculated in step 3 below).
- d) Repeat steps (a) through (c) for the future-year projected case, using the same days to average in the future year calculation as were used in the base-year calculation, to get a site-specific mean future-year value (Mean\_FY)
- e) Calculate the RRF:

$$\text{RRF} = \text{Mean\_FY} / \text{Mean\_BY}$$

## **3. Compute site-specific future-year design values (DVF's)**

$$\text{DVF} = \text{DVC} \times \text{RRF}$$

## **4. Compare all DVFs to NAAQS for 8-h O<sub>3</sub>**

If all the calculated DVFs (for sites with DVCs =75 ppb, as stated at the beginning of step 2) are = 84 ppb, the modeled attainment test has been passed, and the modeling domain is set to be in attainment of the 8-h NAAQS for O<sub>3</sub> in the future year.

## ANALYSES

We applied the entire procedure described above for model predictions from MAQSIP and CMAQ. Furthermore, as a sensitivity test of the definition of “nearby” cells for the 4-km grid (i.e.,  $7\times 7$ ), we also computed RRFs and DVFs for  $9\times 9$  arrays surrounding each monitor. Figures 5a and 5b illustrate the  $7\times 7$  and  $9\times 9$  arrays around each monitor in the 4-km grid. This could help us evaluate whether a potential shift in the plume might affect the DVFs that are calculated.

Figure 6a (based on  $7\times 7$  arrays) and Figure 7a (based on  $9\times 9$  arrays) show the daily maximum concentrations predicted by MAQSIP and CMAQ for each episode day, plus their average over the time period (a 1:1 line is included for reference). Figures 6b and 7b give the site-specific RRFs plotted against the average base-year ozone concentrations. These plots were created to study how the two models respond in the future year for a given base year value at each site. While Figures 6a and 7a show that the average base-year ozone values are somewhat comparable for the two models, the responses of the two modeling systems are distinctly different, as shown in Figures 6b and 7b. MAQSIP-computed RRFs are lower than those of CMAQ for almost all the sites included in this study, indicating that MAQSIP seems to respond more to controls for the episode studied. Table 2 (for the  $7\times 7$  array) and Table 3 (for the  $9\times 9$  array) list the RRFs and DVFs computed for the different cases. DVC and DVF values that are more than 84 ppb are shown in bold and underlined in these tables to quickly distinguish them from those sites that are in attainment.

To obtain an estimate of the differences between the two modeling systems when applied in a “relative” sense, the differences between the DVFs from MAQSIP and CMAQ at each site are computed and plotted in Figures 8a ( $7\times 7$  array) and 8b ( $9\times 9$  array). Figures 8a and 8b both show that at all sites the CMAQ-predicted DVFs are always higher than the MAQSIP-predicted DVFs. The largest differences are 8 ppb at Farmville in the  $7\times 7$  approach, and 9 ppb at Leggett in the  $9\times 9$  approach; both are at the eastern edge of the modeling domain. With  $7\times 7$  arrays, 14 sites transition from being in attainment when using MAQSIP to being in nonattainment when using CMAQ. With  $9\times 9$  arrays, the corresponding number of sites is 11.

These figures indicate that there are no differences between DVFs computed from MAQSIP and CMAQ in the Charlotte metropolitan area. Most of the large differences are seen in rural locations (to confirm this, the reader can obtain the relevant monitor IDs from Figure 2 and then check the “Setting” column in Table 1 for each monitor).

Figure 5a: 7x7 array of “nearby” cells around monitors for base case.

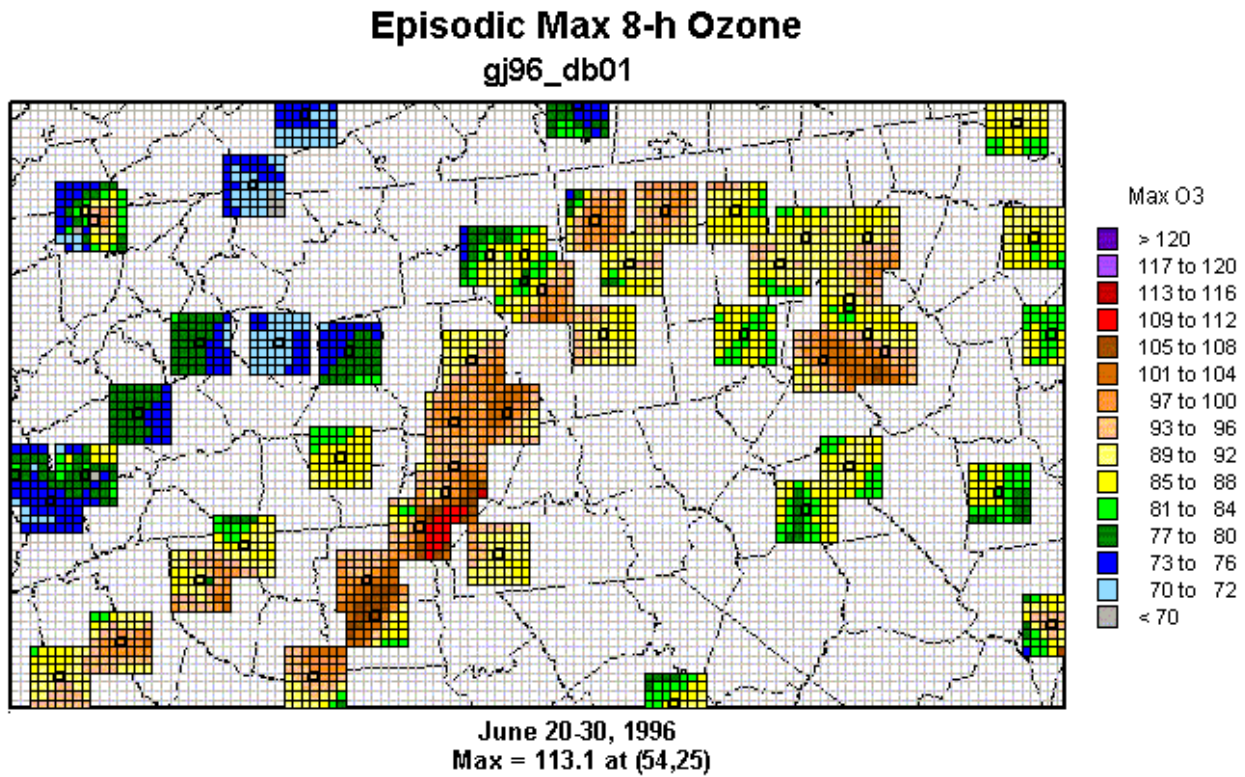
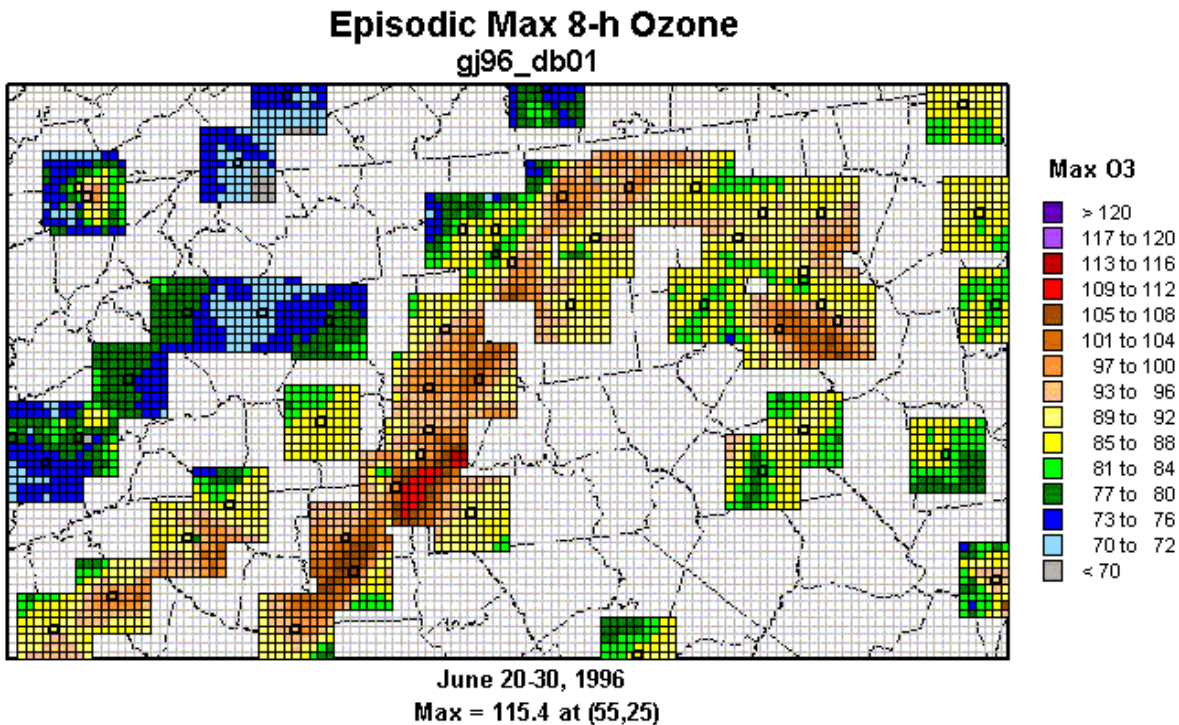
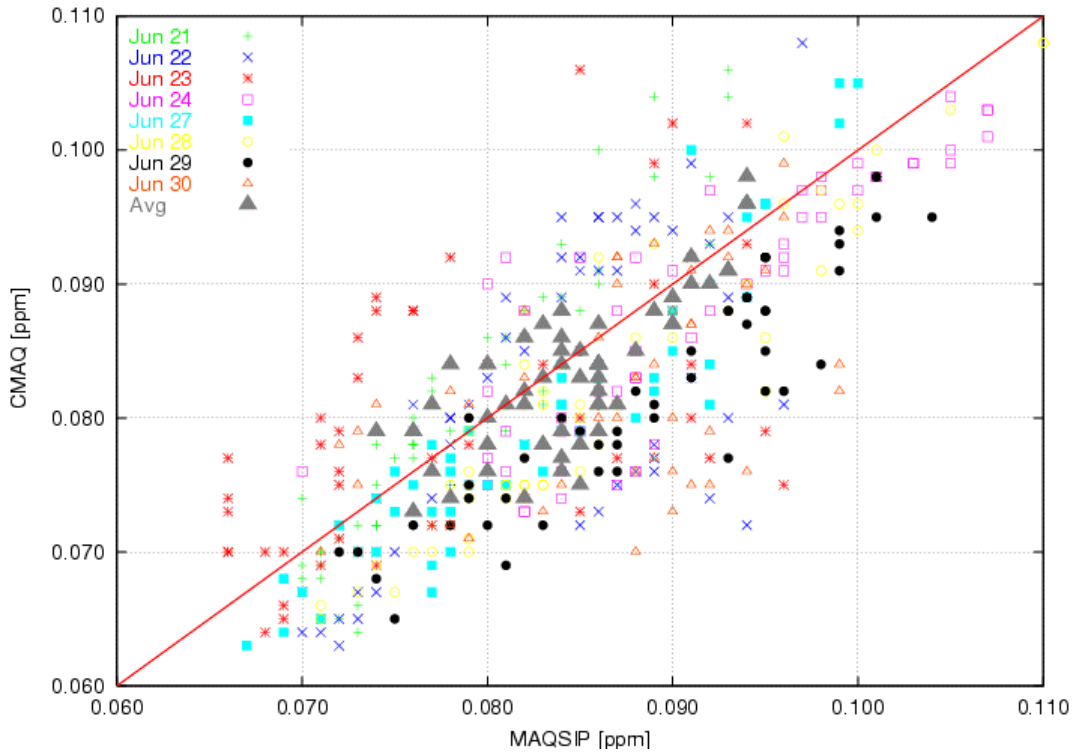


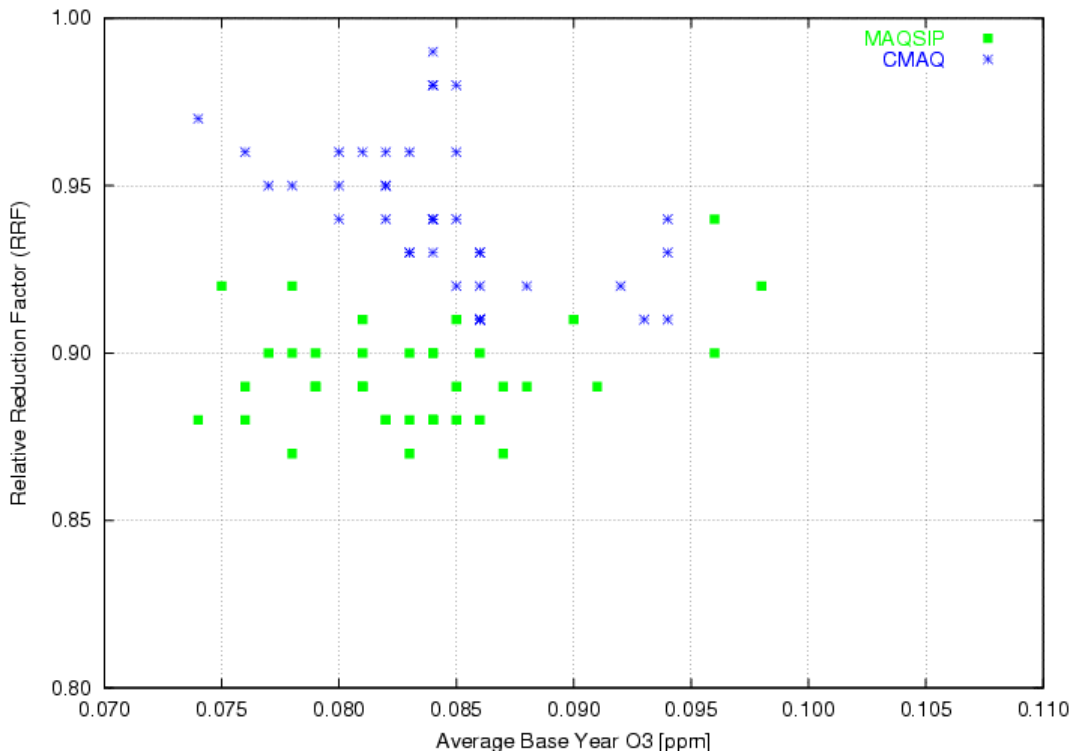
Figure 5b: 9x9 array of “nearby” cells around monitors for base case.



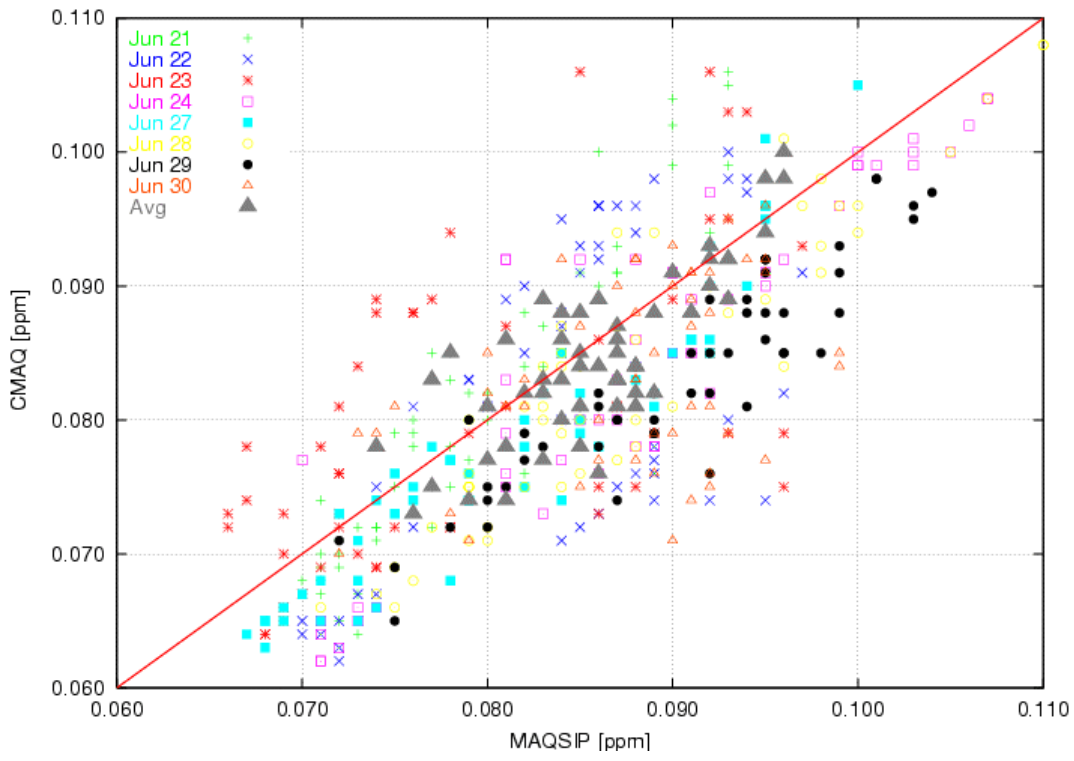
**Figure 6a:** Comparison of CMAQ and MAQSIP base-year daily maximum 8-h O<sub>3</sub> concentrations, using 7×7 “nearby” cells from each site.



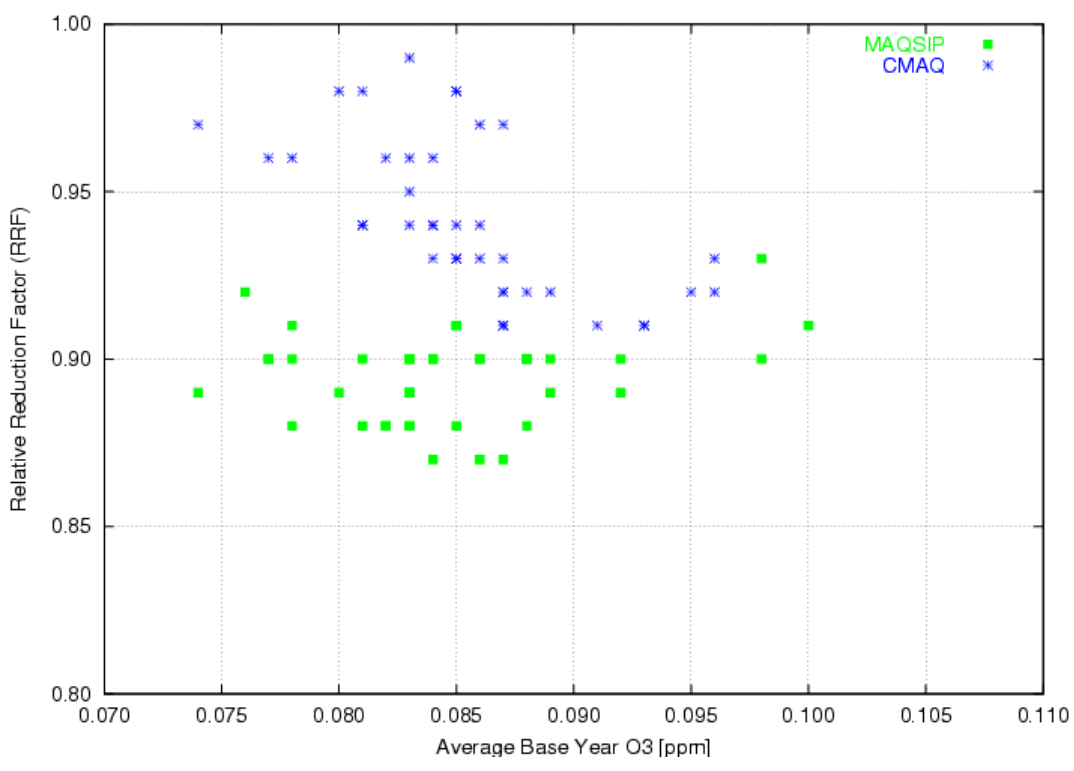
**Figure 6b:** Comparison of RRFs and average base-year O<sub>3</sub>, using 7×7 “nearby” cells.



**Figure 7a:** Comparison of CMAQ and MAQSIP base-year daily maximum 8-h O<sub>3</sub> concentrations, using 9×9 “nearby” cells from each site.



**Figure 7b:** Comparison of RRFs and average base-year O<sub>3</sub>, using 9×9 “nearby” cells.



**Table 2:** Current- and future-year design values (with 7×7 “nearby” cells) for NC O<sub>3</sub> monitoring sites.

ID	DVC	BY_M	FY_M	RRF_M	DVF_M	BY_C	FY_C	RRF_C	DVF_C
CTYL	<u>0.104</u>	0.096	0.086	0.90	<u>0.094</u>	0.094	0.086	0.91	<u>0.095</u>
PLZA	<u>0.101</u>	0.098	0.090	0.92	<u>0.093</u>	0.094	0.087	0.93	<u>0.094</u>
ARWD	<u>0.100</u>	0.096	0.090	0.94	<u>0.094</u>	0.094	0.088	0.94	<u>0.094</u>
ROCK	<u>0.100</u>	0.091	0.081	0.89	<u>0.089</u>	0.093	0.085	0.91	<u>0.091</u>
ENVL	<u>0.098</u>	0.090	0.082	0.91	<u>0.089</u>	0.092	0.085	0.92	<u>0.090</u>
MONR	<u>0.096</u>	0.087	0.077	0.89	<u>0.085</u>	0.086	0.079	0.92	<u>0.088</u>
CRSE	<u>0.090</u>	0.081	0.073	0.90	0.081	0.086	0.080	0.93	0.084
MLBK	<u>0.101</u>	0.086	0.077	0.90	<u>0.091</u>	0.084	0.079	0.94	<u>0.095</u>
STAG	<u>0.097</u>	0.088	0.078	0.89	<u>0.086</u>	0.084	0.079	0.94	<u>0.091</u>
WRAL	<u>0.099</u>	0.086	0.076	0.88	<u>0.087</u>	0.082	0.077	0.94	<u>0.093</u>
BTNR	<u>0.098</u>	0.083	0.072	0.87	<u>0.085</u>	0.083	0.077	0.93	<u>0.091</u>
BSHF	<u>0.095</u>	0.084	0.074	0.88	0.084	0.086	0.078	0.91	<u>0.086</u>
WJOH	<u>0.095</u>	0.084	0.074	0.88	0.084	0.080	0.075	0.94	<u>0.089</u>
FRKL	<u>0.093</u>	0.082	0.072	0.88	0.082	0.082	0.078	0.95	<u>0.088</u>
FUQV	<u>0.092</u>	0.087	0.076	0.87	0.080	0.083	0.077	0.93	<u>0.086</u>
DUKE	<u>0.091</u>	0.085	0.075	0.88	0.080	0.085	0.078	0.92	0.084
PITT	<u>0.088</u>	0.084	0.074	0.88	0.077	0.084	0.078	0.93	0.082
DAVI	<u>0.099</u>	0.085	0.076	0.89	<u>0.088</u>	0.088	0.081	0.92	<u>0.091</u>
HTAV	<u>0.097</u>	0.083	0.075	0.90	<u>0.087</u>	0.085	0.080	0.94	<u>0.091</u>
UCRS	<u>0.094</u>	0.082	0.072	0.88	0.083	0.086	0.078	0.91	<u>0.086</u>
CHGR	<u>0.094</u>	0.084	0.076	0.90	<u>0.085</u>	0.086	0.080	0.93	<u>0.087</u>
MLVL	<u>0.094</u>	0.084	0.074	0.88	0.083	0.086	0.078	0.91	<u>0.086</u>
BETH	<u>0.089</u>	0.083	0.073	0.88	0.078	0.086	0.078	0.91	0.081
SHIL	<u>0.089</u>	0.081	0.072	0.89	0.079	0.081	0.078	0.96	<u>0.085</u>
POLL	0.084	0.078	0.068	0.87	0.073	0.080	0.077	0.96	0.081
FRYP	<u>0.094</u>	0.075	0.069	0.92	<u>0.086</u>	0.085	0.082	0.96	<u>0.090</u>
MTMI	<u>0.090</u>	0.078	0.070	0.90	0.081	0.083	0.080	0.96	<u>0.086</u>
BENT	<u>0.088</u>	0.078	0.072	0.92	0.081	0.085	0.083	0.98	<u>0.086</u>
WAYN	0.082	0.077	0.069	0.90	0.074	0.084	0.083	0.99	0.081
FARM	<u>0.093</u>	0.079	0.070	0.89	0.083	0.084	0.082	0.98	<u>0.091</u>
LEGT	<u>0.090</u>	0.079	0.070	0.89	0.080	0.076	0.073	0.96	<u>0.086</u>
KVIL	<u>0.086</u>	0.079	0.071	0.90	0.077	0.074	0.072	0.97	0.083
WADE	<u>0.093</u>	0.081	0.074	0.91	<u>0.085</u>	0.077	0.073	0.95	<u>0.088</u>
HOPE	<u>0.092</u>	0.084	0.076	0.90	0.083	0.078	0.074	0.95	<u>0.087</u>
LENR	<u>0.092</u>	0.074	0.065	0.88	0.081	0.082	0.079	0.96	<u>0.088</u>
ALEX	<u>0.089</u>	0.076	0.067	0.88	0.078	0.080	0.076	0.95	<u>0.085</u>
GAST	<u>0.087</u>	0.081	0.072	0.89	0.077	0.082	0.078	0.95	0.083
LINV	0.082	0.076	0.068	0.89	0.073	0.084	0.082	0.98	0.080
WILM	0.081	0.085	0.077	0.91	0.074	0.084	0.079	0.94	0.076

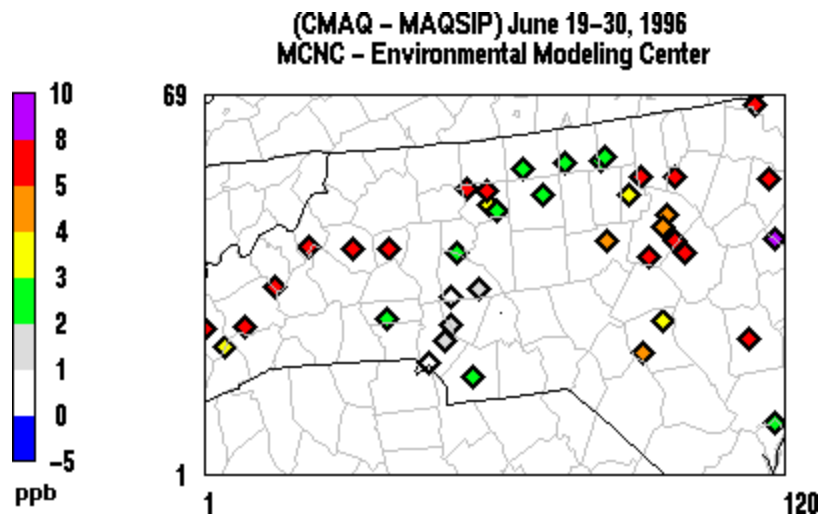
**Legend:** DVC = current year design value; BY\_M = average MAQSIP base-year O<sub>3</sub>; FY\_M = average MAQSIP future-year O<sub>3</sub>; RRF\_M = MAQSIP relative reduction factor; DVF\_M = MAQSIP future-year design value; BY\_C, FY\_C, RRF\_C and DVF\_C = similar measures for CMAQ.

**Table 3:** Current- and future-year design values (with 9×9 “nearby” cells) for NC O<sub>3</sub> monitoring sites.

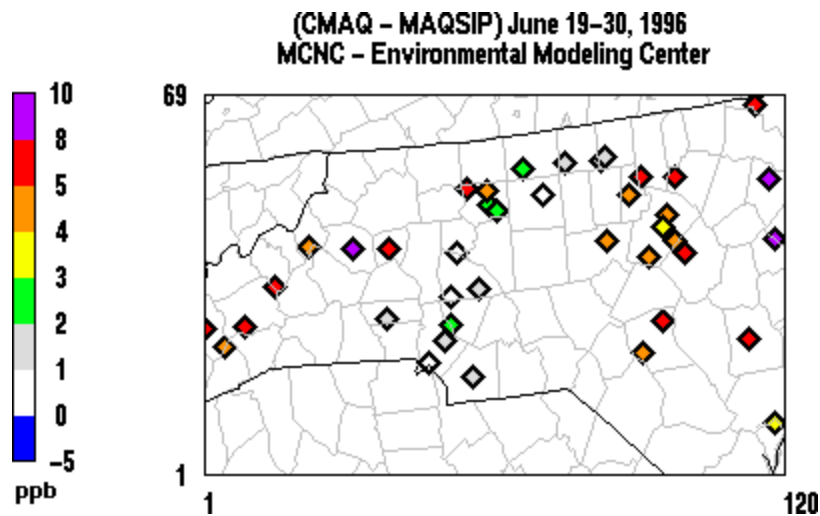
ID	DVC	BY_M	FY_M	RRF_M	DVF_M	BY_C	FY_C	RRF_C	DVF_C
CTYL	<u>0.104</u>	0.098	0.088	0.90	<u>0.094</u>	0.095	0.087	0.92	<u>0.096</u>
PLZA	<u>0.101</u>	0.100	0.091	0.91	<u>0.092</u>	0.096	0.088	0.92	<u>0.093</u>
ARWD	<u>0.100</u>	0.098	0.091	0.93	<u>0.093</u>	0.096	0.089	0.93	<u>0.093</u>
ROCK	<u>0.100</u>	0.092	0.082	0.89	<u>0.089</u>	0.093	0.085	0.91	<u>0.091</u>
ENVL	<u>0.098</u>	0.092	0.083	0.90	<u>0.088</u>	0.093	0.085	0.91	<u>0.089</u>
MONR	<u>0.096</u>	0.088	0.079	0.90	<u>0.086</u>	0.089	0.082	0.92	<u>0.088</u>
CRSE	<u>0.090</u>	0.084	0.076	0.90	0.081	0.088	0.081	0.92	0.083
MLBK	<u>0.101</u>	0.088	0.079	0.90	<u>0.091</u>	0.085	0.080	0.94	<u>0.095</u>
STAG	<u>0.097</u>	0.089	0.080	0.90	<u>0.087</u>	0.086	0.081	0.94	<u>0.091</u>
WRAL	<u>0.099</u>	0.089	0.079	0.89	<u>0.088</u>	0.083	0.078	0.94	<u>0.093</u>
BTNR	<u>0.098</u>	0.084	0.073	0.87	<u>0.085</u>	0.085	0.079	0.93	<u>0.091</u>
BSHF	<u>0.095</u>	0.083	0.075	0.90	<u>0.085</u>	0.087	0.080	0.92	<u>0.087</u>
WJOH	<u>0.095</u>	0.086	0.075	0.87	0.083	0.081	0.076	0.94	<u>0.089</u>
FRKL	<u>0.093</u>	0.083	0.073	0.88	0.082	0.083	0.079	0.95	<u>0.088</u>
FUQV	<u>0.092</u>	0.088	0.077	0.88	0.081	0.084	0.078	0.93	<u>0.086</u>
DUKE	<u>0.091</u>	0.087	0.076	0.87	0.079	0.087	0.080	0.92	0.084
PITT	<u>0.088</u>	0.085	0.075	0.88	0.077	0.085	0.079	0.93	0.082
DAVI	<u>0.099</u>	0.088	0.079	0.90	<u>0.089</u>	0.091	0.083	0.91	<u>0.090</u>
HTAV	<u>0.097</u>	0.084	0.076	0.90	<u>0.087</u>	0.086	0.080	0.93	<u>0.090</u>
UCRS	<u>0.094</u>	0.083	0.074	0.89	0.084	0.087	0.079	0.91	<u>0.086</u>
CHGR	<u>0.094</u>	0.086	0.077	0.90	<u>0.085</u>	0.087	0.081	0.93	<u>0.087</u>
MLVL	<u>0.094</u>	0.085	0.077	0.91	<u>0.086</u>	0.087	0.079	0.91	<u>0.086</u>
BETH	<u>0.089</u>	0.083	0.073	0.88	0.078	0.087	0.079	0.91	0.081
SHIL	<u>0.089</u>	0.083	0.074	0.89	0.079	0.084	0.079	0.94	0.084
POLL	0.084	0.077	0.069	0.90	0.076	0.080	0.078	0.98	0.082
FRYP	<u>0.094</u>	0.076	0.070	0.92	<u>0.086</u>	0.086	0.083	0.97	<u>0.091</u>
MTMI	<u>0.090</u>	0.080	0.071	0.89	0.080	0.084	0.081	0.96	<u>0.086</u>
BENT	<u>0.088</u>	0.081	0.073	0.90	0.079	0.087	0.084	0.97	<u>0.085</u>
WAYN	0.082	0.078	0.070	0.90	0.074	0.085	0.083	0.98	0.080
FARM	<u>0.093</u>	0.081	0.071	0.88	0.082	0.085	0.083	0.98	<u>0.091</u>
LEGT	<u>0.090</u>	0.082	0.072	0.88	0.079	0.083	0.082	0.99	<u>0.089</u>
KVIL	<u>0.086</u>	0.078	0.071	0.91	0.078	0.074	0.072	0.97	0.083
WADE	<u>0.093</u>	0.083	0.075	0.90	0.084	0.077	0.074	0.96	<u>0.089</u>
HOPE	<u>0.092</u>	0.085	0.077	0.91	0.084	0.078	0.075	0.96	<u>0.088</u>
LENR	<u>0.092</u>	0.074	0.066	0.89	0.082	0.081	0.079	0.98	<u>0.090</u>
ALEX	<u>0.089</u>	0.078	0.069	0.88	0.078	0.081	0.076	0.94	0.084
GAST	<u>0.087</u>	0.082	0.072	0.88	0.077	0.082	0.079	0.96	0.084
LINV	0.082	0.077	0.069	0.90	0.074	0.083	0.080	0.96	0.079
WILM	0.081	0.086	0.077	0.90	0.073	0.084	0.079	0.94	0.076

**Legend:** DVC = current year design value; BY\_M = average MAQSIP base-year O<sub>3</sub>; FY\_M = average MAQSIP future-year O<sub>3</sub>; RRF\_M = MAQSIP relative reduction factor; DVF\_M = MAQSIP future-year design value; BY\_C, FY\_C, RRF\_C and DVF\_C = similar measures for CMAQ.

**Figure 8a:** Difference between predicted future-year design values for CMAQ and MAQSIP, using 7×7 “nearby” cells.



**Figure 8b:** Difference between predicted future-year design values for CMAQ and MAQSIP, using 9×9 “nearby” cells.



## SUMMARY

We applied two different air quality modeling systems, MAQSIP and CMAQ, in a “relative” sense to the June 19-30, 1996 ozone episode in NC, for identical base-year and projected future-year emissions controls, and tested the EPA draft guidance for demonstrating attainment of the 8-h NAAQS for ozone. For the modeled episode period and projected future year emissions controls, we found that the current form of the *modeled attainment test* using both MAQSIP and CMAQ failed to bring portions of the 4-km North Carolina modeling domain into attainment. The modeling systems are only slightly sensitive to the definition of the “nearby” cells (7×7 or 9×9). Also, CMAQ-predicted DVFs were consistently higher than those predicted by MAQSIP. Earlier work performed for model performance evaluation showed that at night, CMAQ overpredicted ozone concentrations on several simulation days, and the values from CMAQ were always higher than those from MAQSIP. This might indicate that CMAQ overestimates regional transport for this episode, thus bringing higher levels of ozone from layers aloft into the surface layer. Some of these differences could be attributable to the differences in the treatment of the boundary layer parameters. During this paper’s preparation, a beta-version of MCIP became available that allows a “pass-through” option for bypassing the meteorological variable recalculation functions of MCIP; this option generates the same meteorological parameter values as those simulated by the meteorological model. We are currently testing the new version of MCIP to prepare identical meteorological fields for input to the two air quality modeling systems.

The results we have presented are particular to the episodic conditions and model inputs used here, and could change with different sets of conditions. We plan to extend the intercomparison to modeling the remaining two episodes (in 1995 and 1997) with CMAQ, to see how they compare with the existing MAQSIP simulations. Furthermore, we plan to conduct additional analyses of model results to develop insights on differing model responses from a model process perspective.

In its draft guidance, EPA has recommended using a *screening test* to account for situations when the model-predicted maximum ozone concentrations at locations without monitors are consistently greater than any predicted in the vicinity of a given monitoring site. We will apply the test in future work if the conditions required for its application are met. Also, additional “weight of evidence” corroboratory analyses, as discussed in the draft guidance, will be considered when the attainment and/or screening tests are not passed. These analyses will include the assessment of other model outputs too.

Results from our ongoing work will be continuously updated and made available on MCNC’s website.<sup>28</sup>

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## KEYWORDS

Ozone, Models-3, CMAQ, MAQSIP, Photochemical, Air Quality, Design value, Draft Guidance, Attainment, State Implementation Planning (SIP), Relative Reduction Factor (RRF), NAAQS