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Modeling Analyses of the Effects of Changes in Nitrogen Oxides Emissions from the Electric Power Sector on Ozone Levels in the Eastern United States

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ABSTRACT

In this paper, we examine the changes in ambient ozone concentrations simulated by the Community Multiscale Air Quality (CMAQ) model for summer 2002 under three different nitrogen oxides (NO_x) emission scenarios. Two emission scenarios represent best estimates of 2002 and 2004 emissions; they allow assessment of the impact of the NO_x emissions reductions imposed on the utility sector by the NO_x State Implementation Plan (SIP) Call. The third scenario represents a hypothetical rendering of what NO_x emissions would have been in 2002 if no emission controls had been imposed on the utility sector. Examination of the modeled median and 95th percentile daily maximum 8-hr average ozone concentrations reveals that median ozone levels estimated for the 2004 emission scenario were less than those modeled for 2002 in the region most affected by the NO_x SIP Call. Comparison of the "no-control" with the "2002" scenario revealed that ozone concentrations would have been much higher in much of the eastern United States if the utility sector had not implemented NO_x emission controls; exceptions occurred in the immediate vicinity of major point sources where increased NO titration tends to lower ozone levels.

IMPLICATIONS

Since 1995, two regulations issued by the U.S. Environmental Protection Agency, namely, the Acid Rain Program and the NO_x SIP Call, have led to large reductions in NO_x emissions from the electric power industry. A demonstration of the improvements in ozone air quality attributable to regulatory actions is desirable, but is difficult because of variable meteorology and economic activity. In this study, the CMAQ model is used to simulate changes in ambient ozone air quality from NO_x emission reductions. The use of identical meteorological conditions on three different emission scenarios controls variations in air quality due to meteorology. The effect of increasing economic activity is assessed via a modeling scenario on the basis of pre-control NO_x emissions and current energy use by the utility sector.

INTRODUCTION

Ozone is not directly emitted into the troposphere, but is formed from the photochemical interaction involving ozone precursors (nitrogen oxides [NO_x] and volatile organic compounds [VOCs]) and sunlight. Despite substantial reductions in the emissions of NO_x and VOCs during the past three decades, ground-level ozone concentrations in the United States continue to exceed the 8-hr average ozone National Ambient Air Quality Standard (NAAQS) in many parts of the country. According to the U.S. Environmental Protection Agency (EPA),[1] the major sources of NO_x in the eastern United States during 2004 were on-road vehicles (36%), followed by the power industry (23%), off-road mobile sources (19%), and the remainder attributed to area sources.

Since 1995, EPA has successively issued two regulations, namely, the Acid Rain Program (ARP) and the NO_x State Implementation Plan Call (NO_x SIP Call), which resulted in NO_x emissions reductions from the electric power industry. Initiated in January 1995, Phase I of the ARP was intended to control emissions from two types of boilers, dry-bottom wall-fired boilers and tangentially fired boilers, to yearly averages of 0.50 and 0.45 lb NO_x per MMBTU (million British thermal units) utilized, respectively. A total of 445 units in 110 electric utility plants located in the eastern and midwestern United States were subject to this phase of the ARP. Phase II, which began in the year 2000, tightened the annual emissions limits imposed to units already targeted in phase I and extended to existing units serving large generators (output capacity $>$ 25 MW) and all new utility units for a total of approximately 2000 units.

In 1998, the Ozone Transport Assessment Group (OTAG) showed through computer simulations that interstate transport of ozone and its precursors was contributing to the ozone nonattainment problem in the northeastern states.[2] More specifically, the OTAG final report stated that emissions along the Ohio River Valley (ORV) in the central part of the OTAG domain appeared to be associated with many regional-scale ozone episodes in the

Northeast and emission reductions from that region would benefit many downwind areas.

Acknowledging the OTAG results and the necessity of a regional rather than a "unit-by-unit" management of NO_x emissions, EPA issued a regulation, namely, the NO_x SIP Call, requiring 21 states in the eastern United States and Washington, DC to reduce their summer NO_x emissions. These states are listed in Table 1. This new rule established statewide NO_x emission budgets for four classes of pollutant emitters: electric generation units (EGUs), other industrial point sources, highway vehicles, and nonroad mobile sources. The state air pollution control agencies affected by the NO_x SIP Call were then asked to identify the emission control measures they would implement to meet these new NO_x budgets in their State Implementation Plan (SIP). In contrast to the ARP, the NO_x SIP Call did not target specific facilities or equipment and the states were given the flexibility to develop their own control strategies, provided the NO_x budgets were achieved. The NO_x budgets were not as strict for all classes of emitters but they required the most significant changes from point sources, particularly from the utility sector. In essence, the new budget for the utility sector is based on the premise that major facilities would be operating with an emission rate of 0.15 lb/MMBTU, obtainable with selective catalytic reduction.[3] The NO_x SIP Call was fully implemented by May 31, 2004.

Illustrating the magnitude of the response of point-source emitters to these two regulations, Figure 1 displays the ozone season NO_x emissions and heat input (the energy content of the fuel used to generate electricity) in Ohio from 1995 to 2005, as inferred from the Continuous Emissions Monitoring System (CEMS) database.[4] Although the heat input reported for the ozone season of 2002 (May 1 to September 30) was 8% more than in 1997, NO_x emissions were only 72% of what they were in 1997. In 2004, NO_x reductions were less than one-fifth of what they were in 1997, due in part to a reduction in heat input (80% of 1997 values) attributable to milder weather. In 2005, however, NO_x emissions were 25% of their 1997 level despite a heat input increase of approximately 10%, confirming the persistence of the improvement achieved. Note that after 2008, EPA will no longer administer the NO_x SIP Call trading program but will focus on the Clean Air Interstate Rule (CAIR), the latest federal incentive to improve ozone and PM air quality. Additional details on this can be found at www.epa.gov/interstateairquality.

The objective of this study was to examine the changes in ambient ozone concentrations brought about

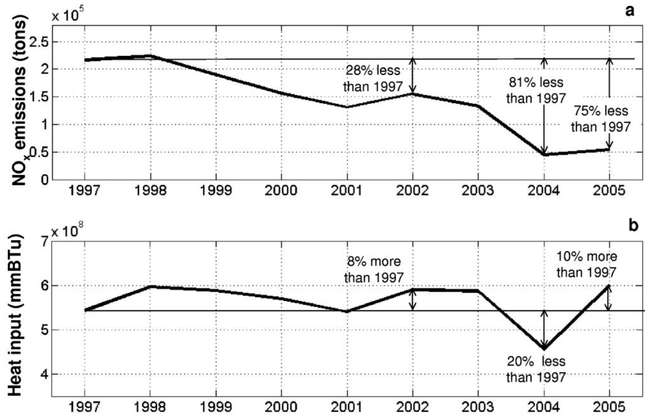

Figure 1. Change in ozone season (a) NO_x emissions and (b) heat input from 1997 to 2005 in the state of Ohio.

by NO_x emission reductions from the power industry through the ARP and the NO_x SIP Call. An air quality simulation model with three distinct emission scenarios was used to accomplish this task. Two scenarios were used to simulate the prevailing emissions during 2002 and 2004, as best inferred from available emission data. These two scenarios characterize emissions before and after the official deadline for implementation of the NO_x SIP Call, respectively. Note that some EGU operators started using the selective catalytic reduction system during summer 2002. As a result, the distinction between the before and after NO_x SIP Call periods is not as sharp as stated above. Our assessment of the effectiveness of this latter regulation to reduce ambient ozone concentrations is the modeling counterpart of several observation-based studies.[1,5,6] The third scenario represents a hypothetical rendering of what NO_x emissions would have been in 2002 had there been no emission controls on the utility sector.

Table 1. States affected by the NO_x SIP Call.

Alabama	Maryland	North Carolina
Connecticut	Massachusetts	South Carolina
Delaware	Michigan	Pennsylvania
Georgia	Missouri	Rhode Island
Illinois	New Jersey	Tennessee
Indiana	New York	Virginia
Kentucky	Ohio	West Virginia
Washington, DC		

BRIEF DESCRIPTION OF THE MODELING SYSTEM AND ITS SETTING

The modeling system used is the Community Multiscale Air Quality (CMAQ) model (version 4.5).[8] The simulated domain encompasses most of the eastern United States and includes all states subject to the NO_x SIP Call. The horizontal grid cell size was set to 12 × 12 km; 14 vertical layers were used, with the first layer being approximately 38-m thick. CMAQ was run with the Carbon-Bond 4 (CB4 version 4.2) gas-phase chemical mechanism module.[9] The lateral boundary conditions utilized correspond to "clean air" assumptions for the entire period simulated (see Godowitch et al.[10] for further information on the CMAQ setup).

Period Simulated

The modeling simulations extend from June 1 to August 31, 2002, not counting the model spin-up time. To focus our attention on the ozone changes resulting from emission reductions, the effects of different meteorological conditions were eliminated by applying the same meteorology to all three emission scenarios. Utilizing the meteorology of summer 2002 rather than that of summer 2004 was considered preferable because meteorological conditions in 2002 were more conducive to ozone formation and accumulation than in 2004.

Meteorological Fields

Meteorological fields were produced by MM5[11] (Penn State/National Center for Atmospheric Research Mesoscale Model, version 3.6.3) with a 12- × 12-km horizontal cell size and 34 vertical layers, reorganized and compacted into 14 layers by MCIP (Meteorology-Chemistry Interface Processor) for integration into CMAQ.

Emission Fields

As noted before and recapitulated in Table 2, three emission scenarios were considered for this study: the 2002 emissions and the 2004 emissions, inferred from the available emission data, and a no-control case scenario. Although the two first scenarios are more realistic, the third depicts a situation that would have been encountered in 2002 if no point-source emission controls were implemented. More specifically, emission fields were created with the Sparse Matrix Operator Kernel Emission (SMOKE) program,[12] version 2.2, by assembling emissions from mobile, biogenic, anthropogenic area, and industrial point sources. Gridded mobile emissions were calculated with the Mobile 6 program, on the basis of the projected vehicle miles traveled for 2002 and 2004 and appropriate fleet factors. Natural biogenic emissions were calculated with the Biogenic Emission Inventory System algorithm (version 3.13), used in conjunction with the MM5-derived meteorological estimates. Area anthropogenic emissions (not tied to large industrial sources) were derived from EPA's National Emission Inventory (NEI) 2001. Because meteorology was frozen to the 2002 situation, the biogenic and anthropogenic area emissions were the same for the three emission scenarios tested. Industrial point-source emissions for the 2002 and 2004 scenarios were directly retrieved from the CEMS database.

For the hypothetical no-control case, point-source emissions were calculated for each day and EGU by the product of 2002 daily heat input (MMBTU) and the 1997 daily NO_x emission rate, i.e., the ratio of 1997 emissions (NO_x lbs) and 1997 heat input (MMBTU). For units coming on line after 1997, the 1997 state average of NO_x emission rate identified for the state the unit is located in was utilized.

Figure 2 displays the location of the 987 EGUs in the model domain and identifies the 50 largest NO_x emitters in 2002 (Figure 2a) and for the no-control case (Figure 2b). Differences between Figure 2, a and b, reflect the diversity of emission rates observed before the application of NO_x emission control regulations. Figure 2c shows the sum of all NO_x emissions and emissions from EGUs during the simulated period and the three emissions scenarios considered in this study. NO_x emissions from EGUs in 2004 were only 63% of what they were in 2002 because of the application of the NO_x SIP Call. However, the utility sector is only one of the many sources of NO_x and this large reduction from the utility sector amounted to only a 7% reduction in the total NO_x emission burden in the model domain. Utilizing the NO_x emission rate of 1997 and the heat input of 2002 to build the no-control scenario, we found that NO_x emissions from EGUs would have been 186% greater than what they actually were in 2002, reflecting a 40% increase in total NO_x emissions over the model domain.

Table 2. Meteorology and point-source emissions scenarios simulated.

Name of Scenario	Meteorology	Point-Source NO_x Emissions
Base-case	Summer 2002	CEMS data for summer 2002
2004	Summer 2002	CEMS data for summer 2004
No-control	Summer 2002	2002 heat input (MMBTU) multiplied by the 1997 NO_x emission rate

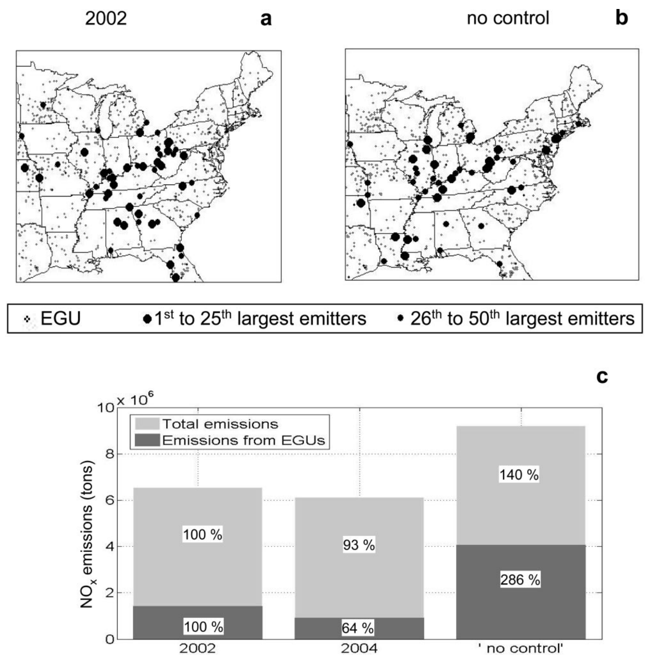

Figure 2. Location of 50 largest NO_x emitters in relation to (a) the 2002 emission scenario and (b) the no-control scenario. (c) Comparison of NO_x emissions (total and from EGUs only) in the three emission scenarios utilized.

DATA ANALYSIS METHODS

Model estimates of ozone concentrations in response to the three emission scenarios were analyzed by examining the medians and 95th percentiles of modeled daily maximum 8-hr average ozone concentrations for the different emission cases. The daily maximum 8-hr average ozone concentrations were first calculated from model hourly estimates for each grid cell and the three emission scenarios; the medians and 95th percentiles were then identified. Examination of both the medians and the 95th percentiles was performed to determine whether NO_x emission controls identically affected the central tendency and the upper tail of simulated ozone. Differences between ozone estimates corresponding to the 2002 and 2004 emission scenarios were calculated to assess the impact of the NO_x SIP Call. Differences between the 2002 and no-control scenario were analyzed to measure the impact of the absence of the NO_x

control policy. The changes interpreted here are expressed in terms relative to the 2002 concentrations. Examination of relative changes was thought to be preferable to the inspection of absolute changes (ppb) because a given absolute change may be considered both as trivial in heavily polluted areas and consequential in rural or remote regions. As model estimates pertaining to the 2002 emission scenario are used as a basis for comparison, they hereafter are refereed to as the "base-case" results.

Changes were calculated for the 28,347 grid cells covering the land portion (water bodies not included) of the model domain, and then spatially averaged. It is well known that spatially averaging data covering large domains, although useful for concise characterization of the results, blends important spatial information. Therefore, histograms defining the range of differences found at each grid cell are also presented, along with images identifying locations where the largest differences were found.

As stated in the OTAG report,[2] NO_x emissions from the heavily industrialized ORV region were thought to be major contributors to the ozone NAAQS exceedances encountered in the northeastern United States. To further investigate this statement, calculation of the ozone changes in the Northeast was also performed after separation of days when transport is from the southwest (SW) direction (i.e., over the ORV) from days when transport was from other directions. Daily synoptic weather maps and modeled wind flow fields were examined to identify the days during summer 2002 corresponding to SW flow regimes.[13]

RESULTS

Figure 3 displays the median and the 95th percentile daily maximum 8-hr average ozone concentrations modeled by CMAQ for the 2002 (Figure 3, a and d), 2004 (Figure 3, b and e) and the no-control (Figure 3, c and f) emission scenarios, all driven by the 2002 meteorology. Because the position of the highly industrial and urban zones did not vary from 2002 to 2004, the locations of high and low concentration zones are similar on all maps. Figure 3a shows that the highest median ozone values are encountered in the eastern urban corridor from Washington, DC to Connecticut, and in the South along an arc extending from Atlanta (northern Georgia) through South and North Carolina. Joint examination of the maps describing the 2002 and 2004 scenarios reveals that implementation of the NO_x SIP Call (changes between 2002 and 2004) led to a reduction of ozone median concentrations in the heart of the NO_x SIP Call territory, namely, along the southern border of Indiana, Ohio, Kentucky, and West Virginia. The maps reflecting the no-control scenario reveal that, but for the NO_x emission controls, 60-ppb median values would have been commonly reached, and much of the model domain would have been experiencing significantly higher ozone concentrations.

Contrasts among the 95th percentile ozone concentrations (Figure 3, d–f) appear more pronounced than at the median concentration levels, suggesting that NO_x emission controls have affected the upper tail of the distribution of modeled daily maximum 8-hr average concentrations (fourth-highest simulated values) more intensively than the median (background) values. The areal extent of 80-ppb exceedances is noticeably greater for the 2002 than the 2004 emissions, confirming ozone improvements due to the implementation of the NO_x SIP Call. Decreases of approximately 4 ppb between the 2002 and 2004 emission scenarios are common throughout the simulated domain, with the greatest changes (percentage-wise) along the border between Pennsylvania and Virginia, and in Tennessee and western Kentucky. Changes are also visible further south in Alabama, Georgia, South Carolina, and North Carolina. Figure 3f shows that ozone 95th percentile values would have been higher than they were in 2002 in most of the domain if NO_x emission controls had not been implemented. However, some areas, e.g., Connecticut and Rhode Island, would apparently benefit from lower ozone concentrations, a finding further discussed below.

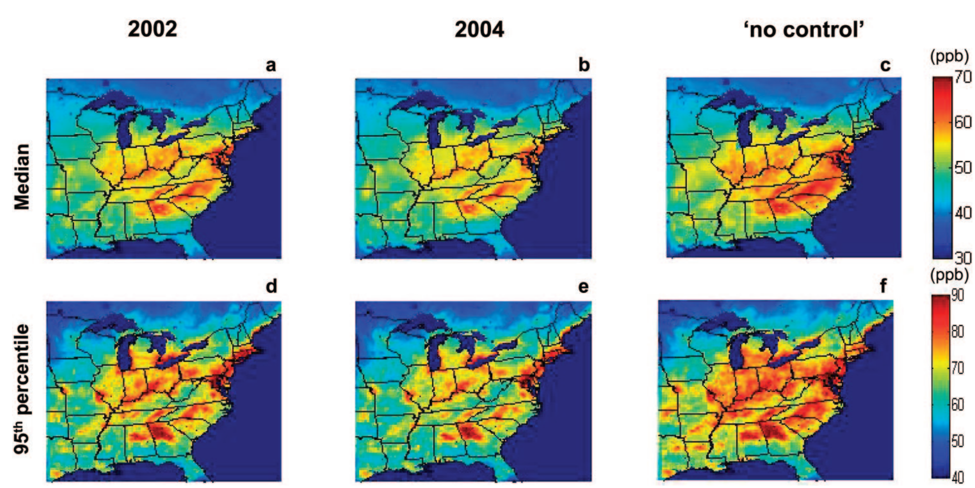

Figure 3. Median and 95th percentile daily maximum 8-hr average ozone concentrations (ppb) modeled in response to the (a and d) base-case, (b and e) 2004, and (c and f) no-control emission scenarios.

Differences between the 2004 and Base-Case Emissions Scenarios

At the Median Level. The overall spatial average of the changes between the 2004 and the base-case (2002) emission scenarios, expressed at each grid cell as percentages of the median value in response to the 2002 emission scenario, is only about −0.9%. However, as shown by the histogram of changes at individual grid cells (Figure 4a), 10% of the model grid cells experienced an improvement (i.e., decreased ozone) of 3% or more, whereas 2% of them experienced a slight increase. Figure 4b shows the location of cells with the biggest changes. It can be seen that the heart of the NO_x SIP Call region is the area benefiting from the largest decrease in ozone concentrations whereas the few grid cells that experienced higher median concentrations (+1% change) are mostly located out of the NO_x SIP Call domain, i.e., at the western boundary of the model domain and in Florida.

At the 95th Percentile Level. At the 95th percentile level, the spatially averaged changes between the 2004 and the base-case emission scenarios is −2%. Once again, this averaging masks an ozone improvement of 3% or better encountered in one-third of the inland domain, including a 5% or better ozone improvement in 10% of all grid cells (Figure 5). As with the median values, the grid cells that encountered the greatest ozone improvements (5% or more) are located in the center of the NO_x SIP Call domain, a region that was home to the largest EGUs in 2002, whereas a slight increase (1% or more) was modeled for some cells in states not subject to the NO_x SIP Call.

In related observational studies utilizing data from the Clean Air Status and Trend Network (CASTNet),[21] EPA[1] estimated that ozone air quality improved by 1–13% from 2002 to 2004 after adjustment for weather-induced variations, values corroborated by Zheng et al..[5] Gégo et al.,[6] also using CASTNet data, assessed that meteorologically adjusted daily maximum 8-hr average ozone concentrations during the 2003–2004 ozone seasons from 3 to 27% were less than during the 1997–1998 seasons, with the smallest improvements found in the northeastern corner of the United States and the largest in the ORV and some southern states (Mississippi, Alabama, North Carolina). When compared with any of the above three studies, the CMAQ-predicted changes are less than those observed from the implementation of the NO_x SIP Call. Differences between the modeling and observational results may stem from the fact that CMAQ results were not adjusted for meteorology (meteorological conditions were frozen to those of summer 2002 but their impact was not eliminated) whereas the observations were. They may also arise from the fact that CASTNet observations, unlike CMAQ estimates, represent "point measurements" and not "volume-average" values. Other possible explanations for these differences are discussed in ref 7.

Transport from the SW Direction. After examination of daily synoptic maps and modeled wind fields, it was determined that transport to the northeast region did originate from the SW direction during 19 of the 92 days simulated. Ozone results for these 19 days, hereafter referred to as the "SW days," were separated from model estimates characterizing the other 73 days (not-SW days). Changes linked to the three emission scenarios were calculated separately for these two groups of days (SW days vs. not-SW days).

Figure 6 shows maps of changes between the 2004 and the base-case emission scenarios in the daily maximum 8-hr average concentrations for the 19 SW days (Figure 6, a and c) and the not-SW days (Figure 6, b and d) at the median and the 95th percentile level. It can be seen that ozone air quality improvement is larger when transport is from the SW direction than from other directions, both at the median and the 95th percentile levels, a result that is not surprising because the ORV region is one of the areas that experienced the largest NO_x emission reductions from 2002 to 2004. Consequently, the effects of NO_x emission changes on ozone ought to be more evident when transport was over the ORV region than from other directions. When examining the 92 simulated days as a whole, the northeastern United States was not identified as the region with the largest changes (see Figures 4 and 5). However, the median daily maximum 8-hr average ozone concentrations of SW days are typically at the extreme end of the

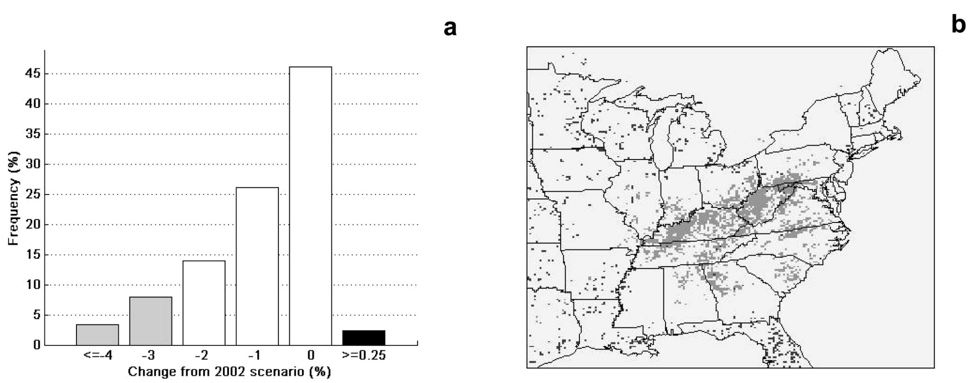

Figure 4. (a) Histogram of change (%) between the median daily maximum 8-hr average ozone concentrations modeled at each cell in response to the 2004 and base-case emission scenarios. (b) Location of model cells with the largest changes, i.e., corresponding to the gray and black bars of panel a.

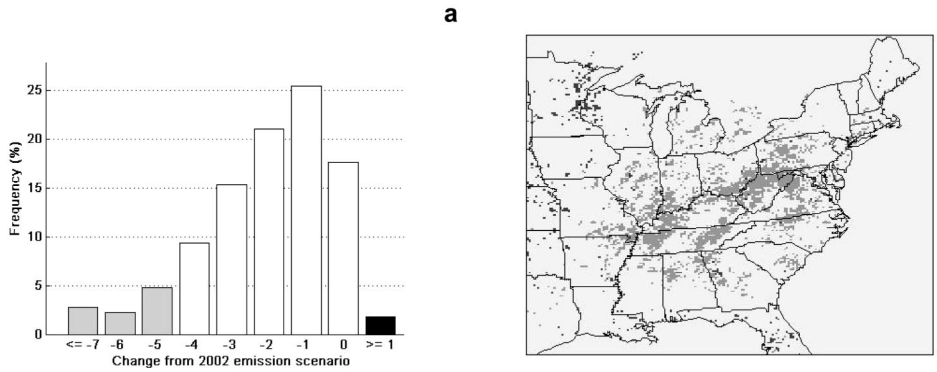

Figure 5. (a) Histogram of change (%) between the 95th percentile daily maximum 8-hr average ozone concentrations modeled at each cell in response to the 2004 and base-case emission scenarios. (b) Location of model cells with the largest changes, i.e., corresponding to the gray and black bars of panel a.

distribution of modeled changes, with typical values 2–5% less than the base case. At the 95th percentile level, SW transport conditions also lead to larger ozone decreases than other transport directions, as revealed by differences between Figure 6, c and d. These model-based results are in accordance with the observation-based assessment of the impact of NO_x emissions reduction in the ORV on ozone air quality in the eastern United States.[6] Note that contrary to the results reported in ref 6, we examine in this paper the actual ozone predictions without attempting to mitigate the effects of various meteorological conditions. There is a possibility that winds predominantly from the SW concur in the MM5/CMAQ modeling system with days

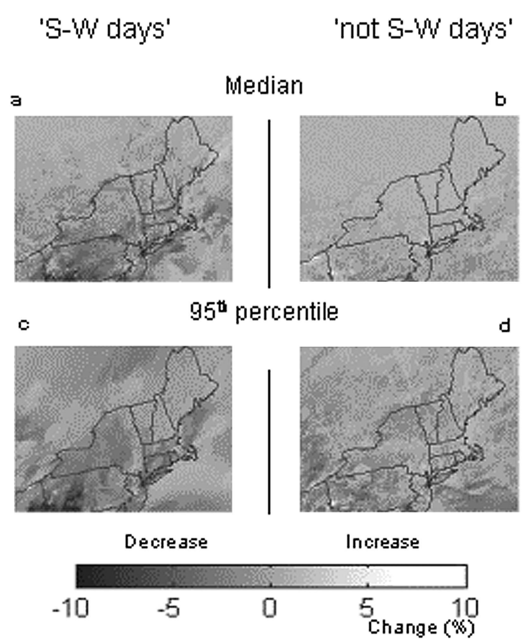

Figure 6. Comparison of changes (%) in the median and 95th percentile daily maximum 8-hr average ozone concentrations in response to the 2004 and the base-case emission scenarios when transport is from the SW direction (a and c) vs. other directions (b and d).

more conducive to ozone formation than other days. Without additional analyses utilizing meteorologically adjusted ozone values, one may not affirm or discount the concurrence of SW transport and local conditions favorable to ozone formation.

Differences between the No-Control and the Base-Case Emission Scenarios

As detailed in the section *Brief Description of the Modeling System and Its Setting*, the no-control scenario is built from the actual 2002 (base-case) emission fields by modifying EGU emissions, the latter being calculated as the product of the actual 2002 heat input at each EGU with its 1997 NO_x emission rate. Although NO_x emissions from EGUs in 2004 were 37% less than in 2002 (leading to a 7% reduction in the total NO_x emissions over the model domain), NO_x emissions from EGUs in the no-control scenario correspond to a 186% increase over the 2002 level, which also equates to a 40% increase in total NO_x emissions (Figure 2). On the basis of these figures and knowing that the 2002 meteorological conditions were used for all simulations, one may speculate that ozone air quality changes measured between the no-control and the base-case emission scenarios should be more important than those assessed between the 2004 and the base-case emissions.

At the Median Level. A 1.6% spatially averaged increase (rather than a 0.9% improvement) was calculated between median concentrations characterizing the no-control and the base-case emission scenarios. More stringently, the histogram of changes at each grid cell, presented in Figure 7a, reveals that 13% of grid cells would have experienced median concentrations at least 5% higher if NO_x controls were not in place. Interestingly, the histogram also shows that ozone concentrations would actually be less in approximately 6% of the cells if no control measures had been imposed. As detailed in Figure 7b, the greatest concentration increases would have been seen in the states of Mississippi, Tennessee, Kentucky, North Carolina, and Virginia, whereas lower

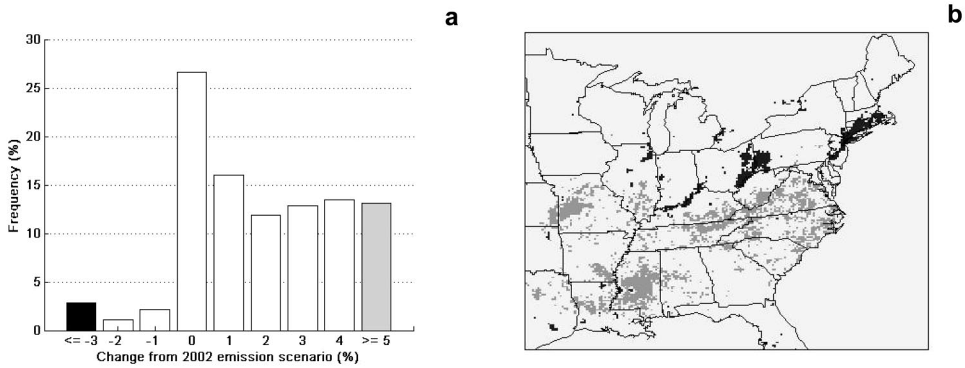

Figure 7. (a) Histogram of change (%) between the median daily maximum 8-hr average ozone concentrations modeled at each cell in response to the no-control and the base-case emission scenarios. (b) Location of model cells with the largest changes, i.e., corresponding to the gray and black bars of panel a.

concentrations would have been encountered in the vicinity of large NO_x-emission areas such as the ORV and the states of New Jersey and Connecticut. The so-called "disbenefit" of emission controls in these areas is due to more intense NO titration, which affects local ozone levels.

At the 95th Percentile Level. The overall spatial average of changes at the 95th percentile level is 4.4%. The histogram of changes at each cell (Figure 8a) reveal that more than half the model cells would experience ozone levels at least 5% higher and a tenth of the domain would see ozone levels 8% greater or more (Figure 8b). Again, some areas in the vicinity of important NO_x sources would benefit from lower ozone concentrations.

As previously noted, when comparing the 2004 and the base-case emission scenarios, CMAQ predicts more important changes, even in terms of percentage, for the extreme values (95th percentile) than for the medians, suggesting that NO_x emission controls from elevated point sources affect higher ozone values more prominently. These results also suggest that emission controls should reduce the severity of ozone episodes, but not affect background values very much.

Transport from the SW Direction. Analogous to Figure 6, Figure 9 display maps of changes between the no-control and the base-case emission scenarios for the 19 SW days (Figure 9, a and c) and the 73 not-SW days (Figure 9, b and d). No major change would be apparent at the median level (Figure 9, a and c) in the absence of emission controls unless transport was from the SW direction. For SW transport days, some areas in the northeastern United States experience an increase in ozone concentrations (south-central Pennsylvania, eastern New York), whereas others, such as the SW corner of Pennsylvania, Connecticut, and Massachusetts, see a sharp decrease. The pattern of areas experiencing increases versus decreases is more intense when transport is from the SW direction, perhaps because of the alignment of major NO_x point sources with the prevailing airflow direction.

At the 95th percentile level, most of the northeastern United States would have experienced ozone concentrations from 10 (New England) to 40% (southern Pennsylvania) higher under the SW transport conditions if point-source NO_x emissions had been left uncontrolled. Under other transport regimes, the Northeast would have seen 5% higher ozone concentrations. The model results we obtained with CMAQ seem to corroborate the OTAG finding that emissions from the ORV were major contributors to the poor ozone air quality encountered in the Northeast, a situation that would not be solved without reducing interstate transport.

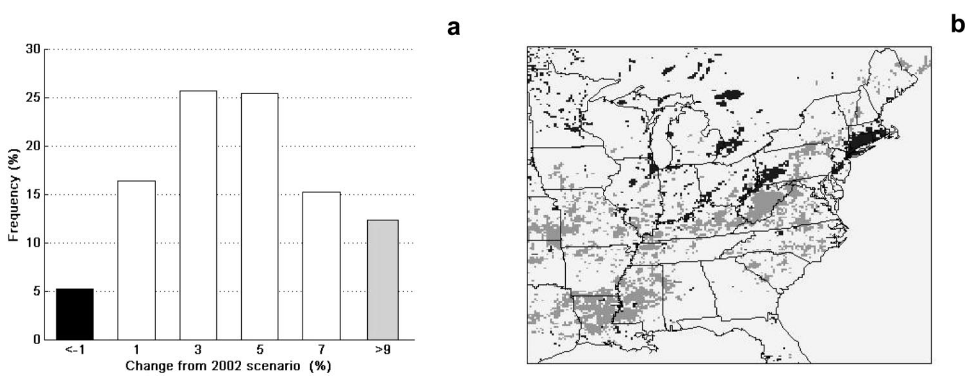

Figure 8. (a) Histogram of change (%) between the 95th percentile daily maximum 8-hr average ozone concentrations modeled at each cell in response to the no-control and the base-case emission scenarios. (b) Location of model cells with the largest changes, i.e., corresponding to the gray and black bars of panel a.

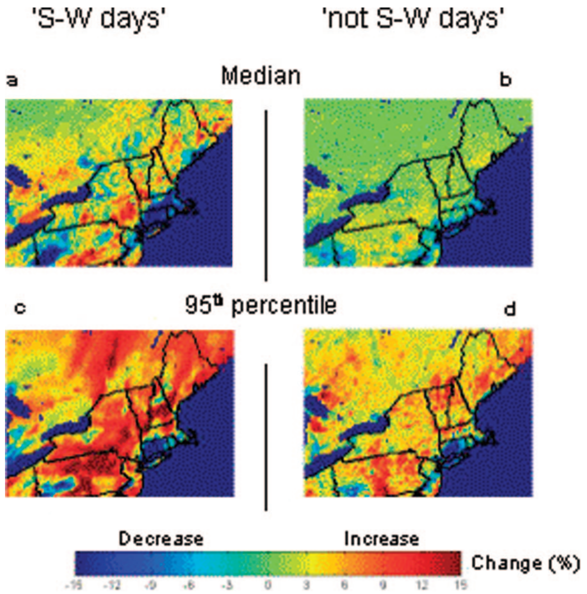

Figure 9. Comparison of changes (%) in the median and 95th percentile daily maximum 8-hr average ozone concentrations in response to the no-control and the base-case emission scenarios when transport is from the SW direction (a and c) vs. other directions (b and d).

SUMMARY

In this study, we examined the changes in ozone concentrations simulated by CMAQ in response to three emission scenarios designed to assess the impact of point-source NO_x emission controls in the eastern United States. Two scenarios represent emissions during the summers of 2002 (base-case emissions) and 2004, as best inferred from available data. Differences between these scenarios allow assessment of the efficacy of the NO_x SIP Call and the 2002 emissions defining the pre-NO_x SIP Call period, and the 2004 emissions reflect the situation after implementation of the NO_x SIP Call. The third emission scenario describes emissions that would have occurred in 2002 if no emission control had been imposed on large point sources. For the latter scenario, emissions from industrial point sources documented in the CEMS database were obtained by multiplying the actual heat input of 2002 by the emission rates (lb NO_x emitted per MMBTU utilized) each unit was operating with in 1997. Emissions from all other sources (mobile, biogenic, anthropogenic area) were not modified, i.e., the 2002 scenario values were utilized. The period simulated was from June 1 to August 31, 2002. Meteorology during this period was reproduced by MM5. To focus attention on the ozone changes resulting from emission reductions only and not from meteorology, the same meteorology (summer 2002) was utilized for all three emissions scenarios.

The results revealed that the median daily maximum 8-hr average ozone concentrations modeled for the 2004 emission scenario were 3% less than those modeled for the base case in many cells in the region most affected by the NO_x SIP Call, namely the ORV and along the southern border of Indiana, Ohio, Kentucky, and West Virginia. More modest ozone reductions were predicted in the southern and northeastern United States. Some widely scattered cells located in states not subject to the NO_x SIP Call (western boundary of model domain) experienced a slight increase in ozone. Air quality improvements calculated at the 95th percentile level are larger than those predicted for the median level. At the 95th percentile, improvements ranging from 3 to 5% were commonly found throughout the simulated domain, with the heart of the NO_x SIP Call region of application showing the largest improvement.

Comparison of the no-control and 2002 scenarios revealed that the daily maximum 8-hr average concentrations median values would have increased in most of the United States (by up to 8%) if the utility sector had not reduced its NO_x emissions. The situation would have been worse at the 95th percentile level, with a 10% increase in ozone over 10% of the domain. However, small areas near major sources would have lower ozone concentrations, probably because of a greater NO_x availability and a more intense titration near the source region.

After identifying transport directions, we showed that ozone air quality improvement in the Northeast from 2002 to 2004 was larger when transport was from the SW than from other directions. The alignment between major NO_x point sources in the ORV and flow direction was hypothesized to explain this finding.

For all comparisons carried out, changes at the upper tail of model estimates were larger than those measured at median levels, suggesting that NO_x emission reductions have a greater effect on high ozone days than on days with background ozone levels. In the real world and in photochemical models, ozone formation and accumulation depend on the prevailing meteorological conditions. In this study, meteorology was held constant at the 2002 conditions that were used in conjunction with the three emission scenarios tested. One should, therefore, keep in mind that our assessment of the magnitude of ozone concentration changes from one emission scenario to another may have been different if we had used the meteorological conditions of a different year in CMAQ.

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