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Comparison of the 1-Hr and 8-Hr National Ambient Air Quality Standards for Ozone Using Models-3

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ABSTRACT

In 1997, the U.S. Environmental Protection Agency revised the National Ambient Air Quality Standard governing ozone (O_3), adding an 8-hr standard of 0.08 ppm and phasing out the 1-hr requirement of 0.12 ppm. The 8-hr standard is intended to provide greater protection for human health. This research examines spatial and temporal patterns of exceedances of the standards using monitoring data and modeled estimates. The Penn State/National Center for Atmospheric Research Mesoscale Model and Models-3 framework were used to estimate hourly O_3 concentrations for 4-km resolution in the Maryland/Virginia/Delaware/Washington, DC, and northern Georgia domains.

Results reveal that the spatial and temporal nature of compliance is considerably different under the 8-hr standard. In the modeling simulations, the 8-hr standard was exceeded 2–5.2 times more often and in a 1.8–16.2 times larger area than the 1-hr standard. The 8-hr standard was exceeded in areas that generally comply with the 1-hr standard and are not well covered by the monitoring network.

These results imply that a larger population resides in areas with unhealthy O_3 levels than noncompliance with the original 1-hr standard suggests. For the MD/VA/DE/DC domains, 80 and 98% of the total population live in areas with 8-hr National Ambient Air Quality Standards (NAAQS) exceedances for the 1990 and 1995 episodes, respectively.

IMPLICATIONS

This research implies that compliance with the 1- and 8-hr NAAQS will differ spatially and temporally, with exceedances of the 8-hr requirement occurring more frequently and over a larger area. This presents challenges for those who design and implement O_3 reduction strategies. Many regions that generally meet the 1-hr standard will likely go out of compliance. These areas often are not well covered by the existing monitoring network, which tends to focus on urban and suburban regions. Results imply that a larger population resides in areas with unhealthy O_3 levels than compliance with the 1-hr standard would suggest.

INTRODUCTION

The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) for criteria pollutants, including tropospheric ozone (O_3). The standards are set at levels intended to protect human health with an adequate margin of safety. On July 18, 1997, EPA proposed a revision to the NAAQS for O_3, adding an 8-hr standard of 0.08 ppm and phasing out the 1-hr requirement of 0.12 ppm.[1] The new requirement is anticipated to be more stringent than the 1-hr standard and will cost hundreds of millions if not billions of dollars to achieve, triggering a series of lawsuits from private industry and some states.[2]

The 8-hr standard is intended to provide greater protection for human health, especially for susceptible populations such as children, asthmatics, and the elderly. It is based on a review of epidemiologic, human clinical, and animal toxicological studies that show evidence of harmful health effects at O_3 levels below the 1-hr standard (for examples, see references 3–8). The 0.12-ppm 1-hr standard remains in effect until an area has achieved compliance for three consecutive years.

In addition to the longer averaging time and lower concentration level, the new standard differs in its form. Compliance with the 1-hr standard is achieved when there is no more than one day per year with a maximum 1-hr concentration higher than 0.124 ppm, averaged over 3 years. Compliance with the 8-hr standard is achieved when the 3-year average of the annual 4th-highest daily maximum 8-hr O_3 concentration is 0.084 ppm or less.

Areas that do not comply with the 1-hr NAAQS are designated as nonattainment areas and are classified according to the severity of noncompliance. The classifications are extreme (e.g., Los Angeles, CA), severe (e.g., Philadelphia, PA, and Baltimore, MD), serious (e.g., Atlanta, GA, and Phoenix, AZ), moderate (e.g., St. Louis, MO, and Atlantic City, NJ), and marginal (e.g., Birmingham, AL, and Reno, NV). Nonattainment areas for the 8-hr standard have not yet been designated.

The spatial and temporal patterns of NAAQS violations under the 8-hr standard may differ with a higher frequency of violations and exceedances over a larger geographic area. Noncompliance areas for the 1-hr standard are generally urban or suburban; however, the nature of the O_3 problem differs in rural areas. In urban areas, O_3 concentrations follow a diurnal pattern relating to the sun and emissions patterns. Rural areas, which are a higher distance from transportation and utilities emitting O_3 precursors, have less variation.[9] Such areas, which generally comply with the 1-hr standard, may be susceptible to violations of the 8-hr requirement.

Three high O_3 episodes and two geographic areas were used as case studies to examine the nature of compliance with the 1- and 8-hr NAAQS. Exceedances of the 1- and 8-hr standards were determined from estimates generated from an air pollution modeling system and from monitor measurements for the case study time periods and regions. Additionally, all 1995 monitoring data for Maryland were analyzed.

METHODS

Exceedances of the 1- and 8-hr NAAQS for O_3 were evaluated in three ways. Analyses were performed for (1) estimated O_3 concentrations generated through air pollution modeling for three case studies; (2) monitor measurements corresponding to two of the case studies; and (3) monitor measurements for Maryland in 1995. The nature of exceedances for each standard then was compared spatially and temporally to determine if the 8-hr standard is exceeded with higher frequency and over a different geographic area. Analysis focused on concentrations above the standards rather than on attainment status. Determination of a violation or noncompliance requires data from a longer timeframe than the case studies because of the form of the standards.

Case Studies for Air Pollution Modeling Simulations

Air pollution modeling was performed for two geographic areas, the Maryland (MD)/northern Virginia (VA)/Delaware (DE)/Washington, DC (DC), region and northern Georgia. Both domains encompass areas that are currently noncompliant with the NAAQS for O_3. The Baltimore area has a nonattainment classification of severe, whereas the Atlanta and Washington, DC, areas are classified as serious nonattainment. For air pollution modeling estimates, concentrations from the highest resolution domain were used in the analysis. Grid cells for this domain are 4 km $\times$ 4 km in the horizontal. The MD/VA/DE/DC and northern Georgia domains have 2700 and 2880 such grid cells, respectively.

Slow-moving or stagnant air conditions, clear skies, and high temperatures generally characterize the meteorology associated with high O_3 episodes. Calm winds allow O_3 and its precursors to accumulate. Two high O_3 episodes were modeled for the MD/VA/DE/DC domain. The first episode was from June 27 (hour 00) to June 30 (hour 00), 1990 (Greenwich Mean Time [GMT]). The peak observed O_3 concentration was 155 ppb at 2:00 p.m. on June 29 (local time), occurring at a monitor in Delaware. Observed concentrations peaked at approximately 11:00 a.m.–3:00 p.m. each day (local time). The second episode modeled for this domain was from July 13 (hour 00) to July 16 (hour 00), 1995 (GMT). The peak observed concentration was 184 ppb at 6:00 p.m. on July 15 (local time), observed at a Delaware monitor. O_3 concentrations in the northern Georgia region were modeled from August 15 (hour 00) to August 18 (hour 00), 1995 (GMT). The peak observed concentration was 198 ppb, occurring at 2:00 p.m. on August 15 (local time). For additional information on conditions affecting tropospheric O_3 formation, including some detail about the specific episodes modeled, see references 10–21.

Meteorological and Air Pollution Modeling

Design of the Modeling System. Hourly estimates of O_3 concentrations were generated through meteorological and air pollution modeling. The Penn State/National Center for Atmospheric Research (NCAR) 5th-Generation Mesoscale Model (MM5) Version 3–4[22] was used to produce estimates of meteorological variables (e.g., temperature, wind speed, and direction), which serve as inputs to the air pollution modeling system. MM5 uses terrain and land-use information, initial estimates of meteorological variables, and radiosonde and surface observations to provide three-dimensional estimates of meteorological variables at specified time intervals. The model was modified to allow four-dimensional data assimilation (fdda) and one-way nesting.[23,24] Fdda was used for the 108, 36, and 12-km domains to nudge analysis toward three-dimensional analyzed fields of observational data. MM5 results were used as input to the Models-3 air pollution modeling system, which performs meteorological pre- and post-processing that converts MM5 output variables into the fields required by the chemistry and emissions components of the air pollution modeling system.

Meteorological simulations were performed for four spatial domains of varying resolution, employing square grid cells with horizontal dimensions of 108, 36, 12, and 4 km, respectively. One-way nesting allows the results from a larger domain to be used as initial and boundary conditions for an internal (i.e., nested) domain of finer resolution. The meteorological domains for the northern Georgia domain are shown in Figure 1.

EPA's third-generation air pollution modeling framework, Models-3, was used to generate estimated ambient concentration fields for tropospheric O_3. Models-3 is a multiscale, multipollutant, photochemical air quality modeling system that can be used for many functions, such as simulation of air pollution concentrations and evaluation of emissions control strategies.[25–28] It was designed to incorporate state-of-the-art science for numerous pollutants in a "one atmosphere" approach, allowing for simulations on multiple spatial scales (e.g., urban and regional). Inputs to Models-3 include descriptions of the spatial domain and episode; meteorological fields generated through a meteorological model, such as MM5; emissions inventories; and land-use information.

The Models-3 simulations used three domains (the MM5 domains minus a peripheral buffer) with square grid cell resolutions of 36, 12, and 4 km. One-way nesting was used so that results from a larger domain functioned as initial and boundary conditions for an internal (i.e., nested) domain of finer resolution. Modeling results produced an estimated O_3 concentration for each grid cell of the domain for each hour of the simulation. Analysis used estimates from the surface layer of the domain with the highest resolution, with grid cells that are 4 km $\times$ 4 km in the horizontal.

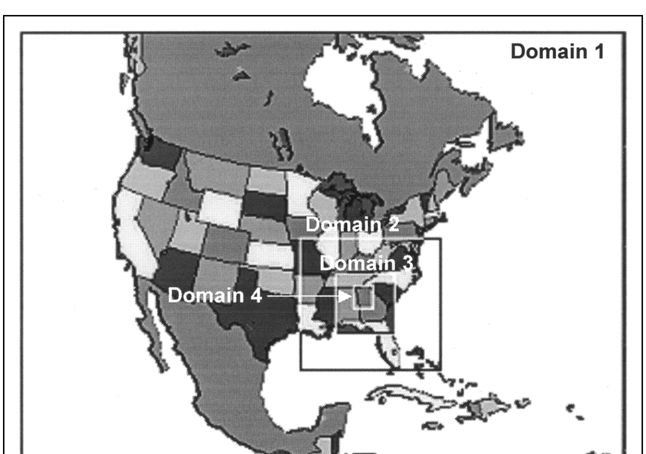

Figure 1. Nested meteorological domains for the northern Georgia simulation.

Assessment of the Modeling System. The use of model simulations requires evaluation of model estimates to determine if they reasonably reflect the natural system. EPA and many model developers recommend several measures of model performance but warn against strict standards.[29–31] Several approaches to evaluate modeling systems have been used, many of which involve comparisons of model estimates to monitor measurements.

The modeling system used in this study was assessed using numerous graphical and statistical measures, including EPA-recommended approaches. Evaluations were performed for all three case study episodes. Several indicators of model performance were examined, including the mean bias, normalized bias, gross error, and the unpaired highest-prediction accuracy. The modeling system generally performed as well as or better than EPA-recommended benchmarks or other assessments of tropospheric O_3 modeling systems (e.g., references 29, 32–39). This indicates that the modeling system reasonably approximates actual ambient O_3 concentrations and is an appropriate tool for this analysis. The details of the numerous assessment measures of this modeling system are presented elsewhere.[40,41] A sample comparison of model estimates and measurements is provided in Figure 2. This graph shows the hourly measured O_3 concentrations for a monitor located in Millington, MD, and the hourly model estimated values for the grid cell in which the monitor is located.

The grid cells in which monitors were located were analyzed for exceedances of the 1- and 8-hr standard and compared with measured exceedances. Generally, the measurement and estimate for the corresponding grid cell were in agreement (77%) as to whether an exceedance occurred. Of the cases in which there was disagreement, some showed an exceedance in the monitor but not the model estimate and some vice versa; however, most disagreements resulted from an observed exceedance that was not estimated by the model. This was especially true for the 1-hr requirement. This may indicate that the model underestimates some peak values and, thereby, exceedances of the standards.

Air Pollution Monitors

NAAQS exceedances were evaluated for two sets of monitor measurements. The first consists of monitoring data corresponding to the MD/VA/DE/DC case studies, which also were used for air pollution modeling: June 27–29, 1990, GMT; and July 13–15, 1995. Data were available for 23 monitors for the 1990 episode (14 in Maryland, 6 in Virginia, and 3 in Delaware) and for 24 monitors for the 1995 episode (13 in Maryland, 8 in Virginia, and 3 in Delaware). The final domains with 4-km resolution are shown in Figures 3 and 4. Circles represent monitoring

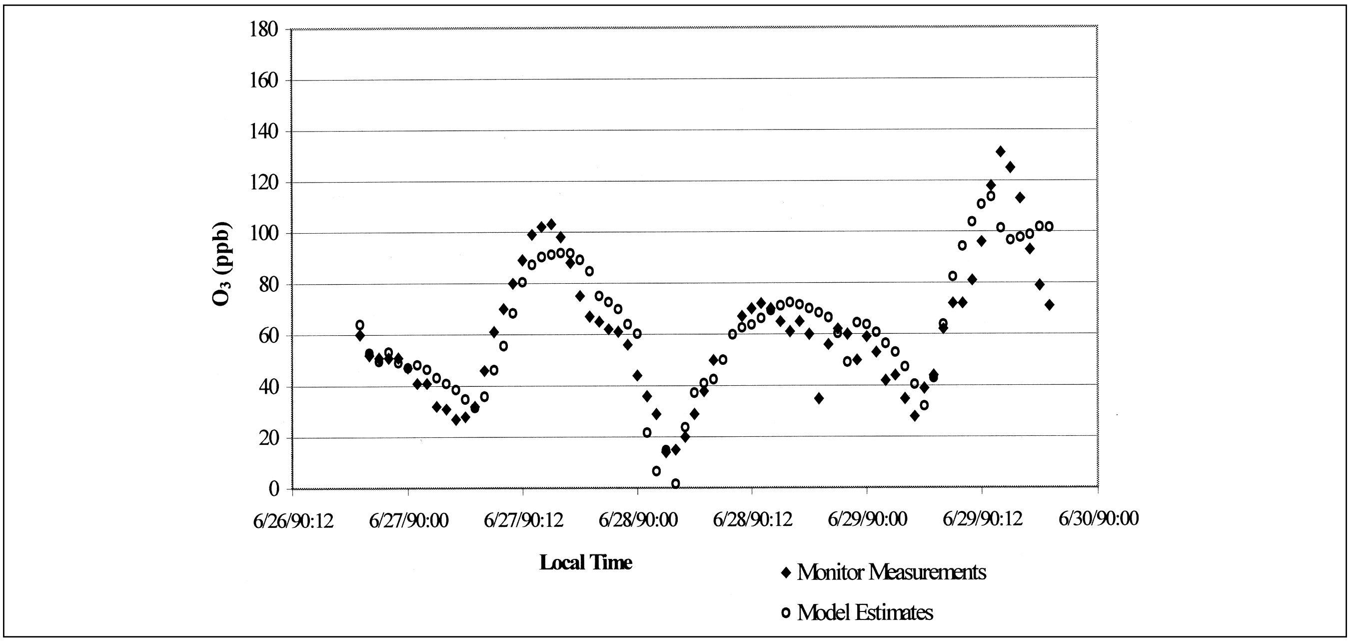

Figure 2. Sample comparison of model estimates and monitor measurements for a monitor located in Millington, MD.

locations. This does not represent all monitors for these areas but those for which data were available for the modeled episodes. The MD/VA/DE/DC domain map indicates which monitors had data for each episode. This domain consists of 2700 grid cells per vertical layer, with 60 columns and 45 rows. The northern Georgia domain has 2880 grid cells, with 48 columns and 60 rows. Results from the surface layer were used in all analyses. A separate analysis of monitor measurements was conducted for April 1–October 31, 1995, for monitors in Maryland. Data were available for 14 monitors and were obtained from the Maryland Department of the Environment.

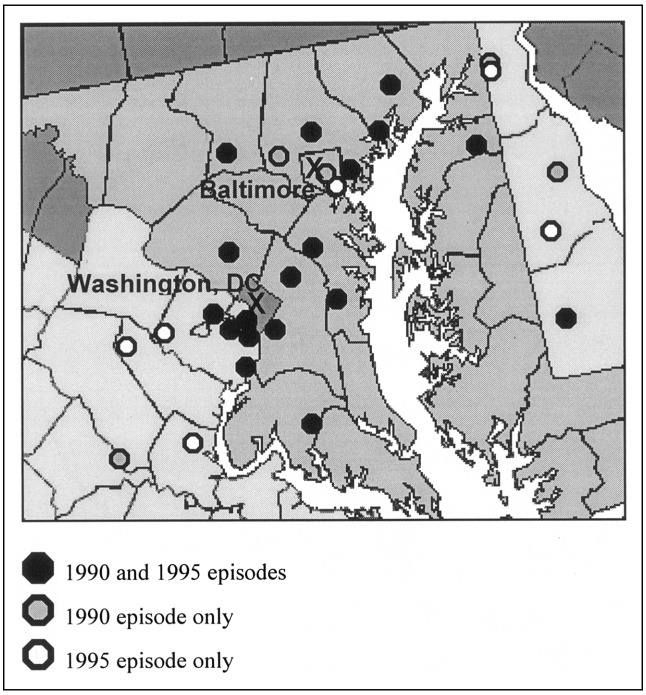

Figure 3. Four-kilometer resolution modeling domain for MD/VA/DE/DC with monitoring network.

Population

Population data at the census tract and block level were obtained from the 2000 U.S. census data sets (U.S. Census Bureau 2000).[42] The population of each census tract or block was allocated among the 4-km by 4-km grid cells of

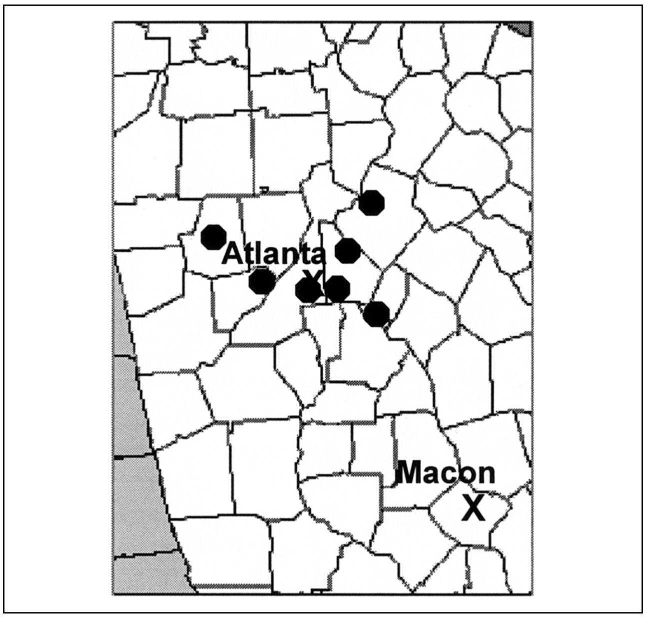

Figure 4. Four-kilometer modeling domain for northern Georgia with monitoring network.

the air pollution modeling domain according to the fraction of the census tract or block's area that is located within each grid cell.

RESULTS

Estimated Concentrations from Air Pollution Modeling Simulations

Spatial Patterns of Exceedances. The 8-hr standard proved to be more stringent spatially than the 1-hr requirement with significantly more areas exceeding the standard. Figures 5 and 6 depict the areas with estimated O_3 concentrations that exceed the standards for the MD/VA/DE/DC 1995 episode and the northern Georgia episode. Areas in dark gray exceed the standard for at least one time period during the simulation, whereas areas in light gray comply with the standard throughout the simulation period.

For the MD/VA/DE/DC 1995 episode, the 1-hr standard is exceeded in parts of central Maryland and in a band downwind of major urban sources including Baltimore and the District of Columbia (see Figure 5). The areas of exceedances of the original standard during this episode follow a similar pattern to the placement of monitoring stations as shown in Figure 3, reflecting the design of the monitoring network, which places monitors in areas of high population density where air pollution is anticipated to be high. For the northern Georgia episode, a substantial portion of the domain exceeds the 1-hr standard, including the urban areas in and surrounding Atlanta, which is roughly in the center of the domain (see Figure 6). As shown in Figure 4, the monitoring network for this region focuses on the Atlanta area.

The 8-hr standard is exceeded at some point in time for almost the entire domain for all simulations. The concentrations rise above the 1-hr standard in much smaller portions of the domain. As seen in Figures 5 and 6, areas that exceed the 8-hr standard include the urban regions that exceeded the 1-hr standard and more rural regions.

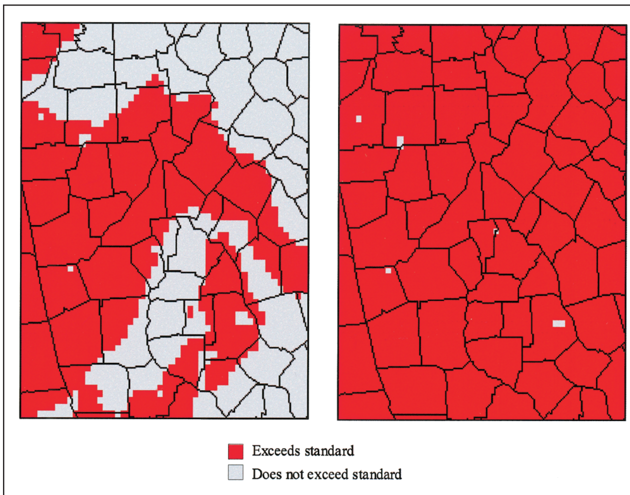

Figure 6. Exceedances of the 1- (left) and 8-hr (right) O_3 NAAQS—northern Georgia domain.

Table 1 provides the percent of the domain (i.e., percent of grid cells) that exceeded the standards for the modeling simulations. The revised standard is exceeded for a much larger portion of the domain than the 1-hr standard, and exceedances occurred in many places that did not exceed the 1-hr standard. No grid cell exceeded the 1-hr standard but not the 8-hr standard, in any of the three simulations. Only a very small portion of the domains did not exceed either standard. These results imply that many areas that comply with the 1-hr standard will be in violation of the 8-hr standard.

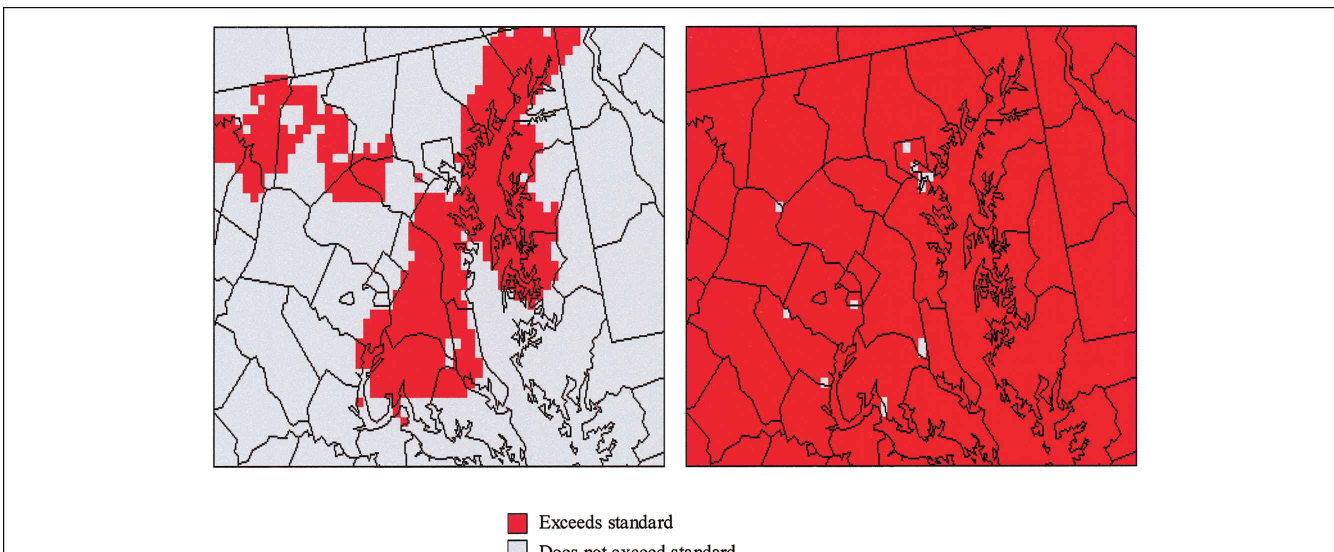

Figure 5. Exceedances of the 1- (left) and 8-hr (right) O_3 NAAQS—MD/VA/DE/DC domain, 1995 episode.

Table 1. Percentage of the modeling domain that exceeds the 1- and 8-hr O_3 NAAQS.

	MD/VA/DE/DC, June 27–29, 1990	MD/VA/DE/DC, July 13–15, 1995	Northern GA, Aug 15–17, 1995
1-hr NAAQS only	0	0	0
8-hr NAAQS only	91.2	75.4	45.4
Both standards	6	24.1	54.3
Neither standard	2.7	0.5	0.2
Totals: 1-hr NAAQS	6	24.1	54.3
8-hr NAAQS	97.2	99.5	99.7

Temporal Patterns of Exceedances. The 8-hr standard also is more stringent from a temporal perspective, with a higher frequency of exceedances for all episodes and domains. Every exceedance of a 1-hr standard was accompanied by an exceedance of the 8-hr standard for the same time period. In all simulations, the 8-hr standard was exceeded far more often than the 1-hr standard.

For all simulations and every time period, a larger percent of the domain violates the 8-hr standard than the 1-hr standard. The 8-hr standard is exceeded on days that do not exceed the 1-hr requirement for both MD/VA/DE/DC episodes. Exceedances of the 8-hr standard also tended to last longer than those of the 1-hr standard, starting an average of 2 hr earlier and ended an average of 6 hr later. Figure 7 depicts exceedances across time by providing the percent of the domain that exceeded the 1- and 8-hr standards for each time step of the MD/VA/DE/DC 1995 simulation. This shows the nature of both spatial and temporal compliance. Note that the 8-hr requirement is exceeded on days that meet the 1-hr requirement and is exceeded both earlier and later in the day. Table 2 summarizes the temporal compliance of the standards by providing the percentage of time periods for which the standards were exceeded for each case study.

Population in Areas with Exceedances

The 2000 U.S. Census was used to estimate the population for each grid cell for the 4-km resolution MD/VA/DE/DC domain. The 2000 population in areas with exceedances for both simulations of the MD/VA/DE/DC domain are provided in Table 3. In both cases, far more people reside in regions that exceed the 8-hr standard. For the 1990 episode, 121 times more people reside in areas with 8-hr NAAQS exceedances than 1-hr exceedances.

Monitor Measurements for MD/VA/DE/DC Case Studies

Monitoring networks do not provide uniform spatial coverage because they are generally located in urban, suburban, and industrial areas of high pollution. For example, the monitoring network in Maryland focuses on the Washington, DC, to Philadelphia corridor, with few monitors in western or southeastern Maryland. Hourly monitoring data for the MD/VA/DE/DC case studies, corresponding to the times and spatial areas used in modeling simulations, were evaluated for exceedances of the 1- and 8-hr NAAQS. Data were available for monitors from 29 locations, with 23 providing data for the June 27–29, 1990, episode and 24 monitors for the July 13–15, 1995, episode.

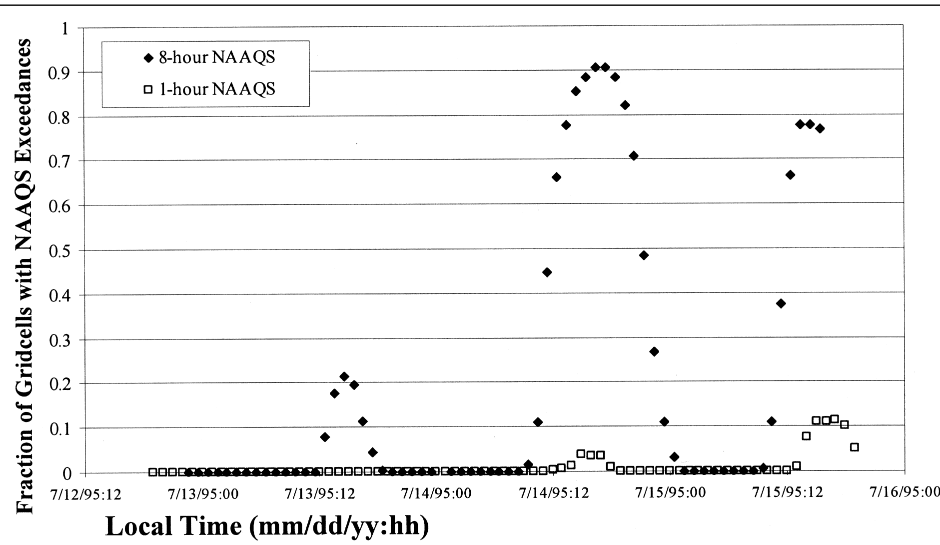

Figure 7. Fraction of domain that exceeded the 1- and 8-hr O_3 NAAQS for each time period of the modeling simulation—MD/VA/DE/DC domain, 1995 episode.

Table 2. Percentage of time periods that exceeds the 1- and 8-hr O_3 NAAQS.

	MD/VA/DE/DC, June 27–29, 1990	MD/VA/DE/DC, July 13–15, 1995	Northern GA, Aug 15–17, 1995
1-hr NAAQS	7.6	18.2	34.8
8-hr NAAQS	39.4	45.4	68.2

Spatial Patterns and Comparison with Modeling Simulations. The percent of monitors that exceeded the standards for each episode is displayed in Table 4. Every monitor location that detected an exceedance of the 1-hr standard also detected an exceedance of the 8-hr standard. The percentages of monitors exceeding the 8-hr standard are comparable for both episodes. The 1990 episode has fewer monitors exceeding the 1-hr standard.

This table can be compared with Table 1, which presents similar information for the model simulations. Both monitors and model simulations detect a large spatial area with exceedances of the 8-hr requirement for the MD/VA/DE/DC case studies (87 and 95.8% of the monitors for the 1990 and 1995 episodes, respectively, as opposed to 97.2 and 99.5% of the modeling simulation domain). Exceedances of the 1-hr standard occurred at a much higher percentage of monitor locations than grid cells in the modeling domains (34.8 and 62.5% of monitors for the 1990 and 1995 episodes, respectively, as opposed to 6 and 24.1% of the modeling domain). This is a function of the monitoring network design, which is aimed largely at detecting violations in urban and suburban areas anticipated to have high pollution and violate the 1-hr standard. The modeling domain covers rural areas that do not violate the 1-hr standard but will likely violate the 8-hr standard.

Temporal Patterns and Comparison to Modeling Simulations. The monitoring data for the case studies show that all

Table 3. Population in areas with NAAQS exceedances for the MD/VA/DE/DC modeling case studies.

	June 27–29, 1990	July 13–15, 1995
	1-Hr NAAQS	
Population	54,126	1,685,355
Percentage of total population	0.66%	20.7%
	8-Hr NAAQS	
Population	6,563,049	8,024,040
Percentage of total population	80.5%	98.4%

Table 4. Percentage of monitors that exceeds the 1- and 8-hr O_3 NAAQS for the MD/VA/DE/DC case studies.

	June 27–29, 1990	July 13–15, 1995
1-hr NAAQS only	0	0
8-hr NAAQS only	52.2	33.3
Both standards	34.8	62.5
Neither standard	13	4.2
Totals: 1-hr NAAQS	34.8	62.5
8-hr NAAQS	87	95.8

time periods for which O_3 levels exceeded the 1-hr standard are accompanied by an exceedance of the 8-hr standard, for all monitors and both simulations. The percents of time periods with exceedances for each standard are given in Table 5. The percents of time periods that exceed the 8-hr standard for the monitoring data are similar to that for the modeling simulation for both episodes (36.4 and 48.5% for the monitoring data and 39.4 and 45.4% for the model estimates, for the 1990 and 1995 episodes, respectively). Exceedances of the 1-hr standard are more frequently detected in the monitoring data because of network design.

Monitoring Data for Maryland for 1995

A separate analysis of monitoring data compared the 1- and 8-hr standards using measurements in Maryland from April 1 to October 31, 1995. Data were available for 14 monitors, all of which detected exceedances of both standards. The 8-hr standard was exceeded earlier as well as later in the year than the 1-hr standard. Figure 8 shows the percentage of monitoring locations that detected exceedances of the standards over time from May 24 to September 7, 1995, the first and last days of exceedances.

All monitors recorded values above both standards at some point; however, all sites exceed the 8-hr standard more frequently. Every time period with a 1-hr exceedance also exceeds the 8-hr standard, which is consistent with results from the modeling simulations and measurement analysis for the case studies. For April–October 1995, 6.5% of time periods exceed the 1-hr standard, as

Table 5. Percentage of time periods that exceeds the 1- and 8-hr O_3 NAAQS for the MD/VA/DE/DC case studies.

	June 27–29, 1990	July 13–15, 1995
Number of monitors	23	24
1-hr NAAQS	19.7	25.8
8-hr NAAQS	36.4	48.5

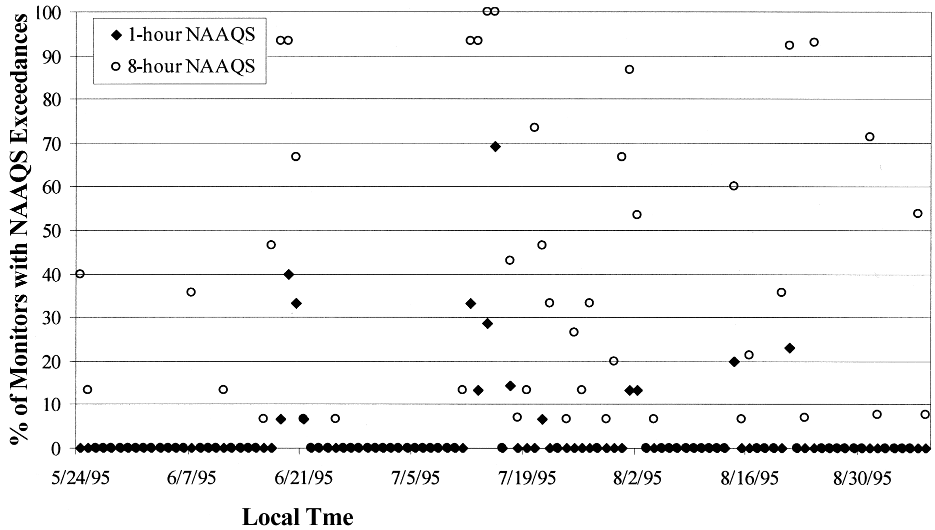

Figure 8. Percentage of Maryland monitors that exceeded the 1- and 8-hr O_3 NAAQS each day in 1995.

compared with 20.1% for the 8-hr standard. For May–September 1995, 9.2% of the time periods exceed the 1-hr standard and 28.1% exceed the 8-hr standard. The 8-hr standard was exceeded on more days than the 1-hr standard for every monitor. The number of 1-hr exceedance days for each monitor ranged from 1 to 7 days, averaging 3.2 days. The number of 8-hr exceedance days ranged from 10 to 25 days, averaging 18.2 days.

The length of episodes (i.e., consecutive exceedance days) was calculated for each standard and monitor. Most episodes exceeding the 1-hr standard lasted a single day, with an average length of 2 days. Exceedances of the 8-hr standard tended to last longer, averaging 2.9 days, with two instances of six consecutive days of exceedances. Figure 9 depicts the number of episodes for various lengths (i.e., number of consecutive days with exceedances) for each standard.

DISCUSSION

Comparison with Previous Research

An air pollution modeling study of the Atlanta region that examined the episode of July 7 and 8, 1988, found that substantial reductions of O_3 precursors would be necessary to achieve compliance with either O_3 NAAQS, but that the 8-hr standard would require larger reductions, indicating the stringency of the 8-hr requirement.[43] Results from this research are consistent with previous studies that compared the 1- and 8-hr O_3 NAAQS using monitoring data, and found exceedances of the 8-hr standard to be more common. Research sponsored by the Mid-Atlantic Regional Air Management Association (MARAMA) evaluated exceedances of the O_3 standards for 1997 using 146 monitors in the Mid-Atlantic region.[44] Exceedances of the 8-hr standard were detected at 89% of the monitors. Only 35.6% of the sites exceeded the 1-hr standard,

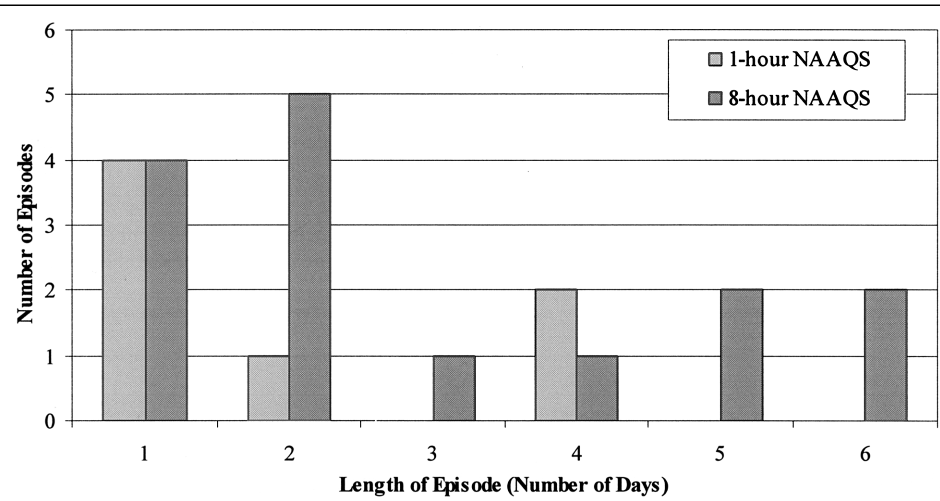

Figure 9. Length of O_3 episodes exceeding the 1- and 8-hr NAAQS for Maryland 1995.

all of which also exceeded the 8-hr requirement. Results from analysis of monitor measurements for the MD/VA/DE/DC case studies are similar to values reported in the MARAMA study.

Other work also has demonstrated the stringency of the 8-hr standard using measurements of ozone concentrations. Analysis of data from five monitors in the Atlanta metropolitan region from 1987 to 1993 found exceedances of the 8-hr standard to be more frequent, with similar meteorological conditions.[45] Monitoring data from the United States for 1980 to 1998 showed exceedances of the 8-hr standard to be more widespread than those of the 1-hr standard.[46]

Baumgardner and Edgerton[47] used Clean Air Status and Trends Network (CASTNet) monitoring data to compare exceedances of the 1- and 8-hr O_3 NAAQS from 1988 to 1995 for the eastern United States. The CASTNet monitoring network provides coverage of rural areas and includes 41 sites east of the Mississippi River, including one each in Maryland and Georgia. The analysis found exceedances of the 1-hr standard to be largely an urban and suburban problem, whereas more exceedances of the 8-hr standard were observed in rural areas. This is consistent with modeling results presented here that estimated exceedances in regions not covered by the standard monitoring network.

A study of 85 monitoring sites in the eastern United States found that only six sites did not attain the 1-hr NAAQS from April to September 1995, whereas 41 were noncompliant with the 8-hr standard.[48] An extension of this work used data from 544 monitoring sites in the eastern United States from 1992 to 1995 and revealed that 15.6% of the sites were noncompliant with the 1-hr standard, compared with 51.3% for the 8-hr standard.[49] When only the 41 rural sites were considered, 2.4% were noncompliant with the 1-hr standard and 34.1% with the 8-hr standard. Results were robust using different definitions of a rural area.

CONCLUSIONS

Exceedances of the 1- and 8-hr O_3 NAAQS have different spatial and temporal patterns, which will present challenges for those who design and implement O_3 reduction strategies. The revised requirement is exceeded more frequently and in more areas according to all analyses including air pollution modeling simulations of case studies, monitoring data for case studies, and all monitoring data for Maryland 1995.

For the air pollution modeling study, the 8-hr standard was exceeded 2–5.2 times more often than the 1-hr standard and in 1.8–16.2 times more area. Results are robust across two geographic domains and three episodes. Monitoring data from areas and time periods corresponding to the modeled episodes also reveal more exceedances of the revised standard.

An implication of this research is that many rural areas, which have thus far been in compliance, will no longer meet the O_3 NAAQS. The current monitoring network, which focuses on urban and suburban areas, is not sufficient to detect exceedances in these areas. Attainment of the revised NAAQS will require new directions in air pollution control because previous efforts have centered on urban areas.[49] If the 8-hr standard is violated in more places than the 1-hr standard and better represents human health effects, a much larger population resides in areas with unhealthy O_3 levels than the noncompliance with the original 1-hr standard suggests.

ACKNOWLEDGMENTS

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