THE RATIO OF PEAK 1-HOUR AVERAGE CONCENTRATIONS TO PEAK CONCENTRATIONS OF OTHER AVERAGING TIMES FOR VARIOUS POLLUTANTS AND DIFFERING SOURCES

by

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Abstract. This study compares maximum observed 1-hour averaged concentrations to the maximum observed concentrations for averaging times ranging from 5 minutes to 1 year. Pollutants considered include CO, HC, NO, NO_2, NO_x, O_3, and SO_2. The types of sources include rural power plants and numerous urban complexes.

The ratio $\chi_{max}(1\text{-hour})/\chi_{max}(t)$ appears to be represented by the function at^b, where t is averaging time in hours. The exponent, b, appears to vary between 0.1 and 0.7 depending primarily on averaging time and source type. Strong similarity is shown for pollutants from similar source types.

Introduction

Numerous investigators have compared peak short term concentrations with longer term average concentrations. Several investigators including Montgomery and Coleman, and Martin and Reeves have compared peak SO_2 concentrations of differing averaging times around power plants.[1,2] Larsen has developed models for calculating statistically expected pollutant concentrations (including peak concentrations) for monitoring site locations for which records of monitoring data are available.[3,4,5] The purpose of this paper is to compare the ratios of peak 1-hour average concentrations to peak concentrations of other averaging times for various pollutants and differing sources.

Peak to peak ratios can provide insight into various areas of current interest. These ratios can be utilized in the assessment of the relative severity of ambient air quality standards in an area. Such information is of value, for example, in estimating whether a short term ambient air quality standard will be exceeded when only a longer term average concentration is known. Peak to peak ratios can also aid in assessing the constraining averaging time for purposes of designing modeling and monitoring investigations.

Analysis Procedure

This paper considers two different general source categories of available data for analysis. One category is SO_2 monitoring data from monitoring networks around power plants. The other category is CO, HC, NO, NO_2, NO_x, O_3 and SO_2 records from single monitoring sites in the vicinity of each of 8 urban areas.

From the available data, the maximum concentration for each reported averaging time for each pollutant and each monitoring site is selected. Only one maximum for each reported averaging time is selected from the complete period of record available from each monitoring site. The periods of record vary depending upon the particular monitoring site. In general, several years of data are available from each monitoring site.

Ratios are then developed to compare the peak 1-hour average concentration to the peak concentrations of each of the other reported averaging times. Reported averaging times ranged from 5 minutes to 1 year. Ratios are developed for each pollutant by monitoring site, and averaged by monitoring network for each source category (power plants and urban areas).

As expected, the longer the averaging time (t), the lower the peak concentration for that averaging time ($\chi_{max(t)}$). Therefore, it is also obvious that the ratio of the peak 1-hour concentration ($\chi_{max(1\text{-}hour)}$) to the peak concentration for another averaging time ($\chi_{max(t)}$) will increase as t increases.

Ratios (R_t) of $\chi_{max(1\text{-}hour)}/\chi_{max(t)}$ can be grouped by averaging time, pollutant, monitoring site, monitoring network, and source category. From these groupings, the variations in ratios can be studied.

Power Plant Related Observations

TVA Power Plants

Montgomery and Coleman have compiled peak to peak ratios for 8 power plants in the Tennessee Valley Authority (TVA) system. For the TVA power plants studied, data were available from the one to sixteen SO_2 monitors in operation for two to four years in the vicinity of each TVA power plant. In total, 39 monitors were in operation for on the average of three years each. The ratios reported for each power plant represent the average of the ratios obtained from all monitoring sites in the vicinity of each power plant.

Table 1 presents the ratios reported by Montgomery and Coleman. Also indicated on Table 1 are the ranges of ratios as well as the geometric means of the ratios.

Table 1. Peak 1-hour concentration to peak 3-hour, 24-hour, 1-month, and annual concentration ratios for SO_2 measurements in the vicinity of 8 TVA power plants.

Power Plant	R_3	R_{24}	R_{730}	R_{8760}
Shawnee	1.6	5.8	32	82
Kingston	1.5	6.0	51	120
Johnsonville	1.5	5.8	61	130
Colbert	1.2	5.8	50	110
Allen	1.7	6.8	64	110
Gallatin	1.3	5.1	34	120
Paradise	1.4	6.2	60	120
Bull Run	1.7	8.2	56	190
Geometric Mean	1.5	6.2	50	120
Range:				
Low	1.2	5.1	32	82
High	1.7	8.2	64	190

Note, Montgomery and Coleman suggest that the ratios increase as average stack height increases. The power plants shown on Table 1 are arranged in order of lowest (Shawnee) to highest (Bull Run) average stack height.

Table 1 indicates that the means for R_3 and R_{24} are 1.5 and 6.2 respectively; thus, $R_{24}/R_3 = X_{max}$ (3-hour)/ X_{max} (24-hour) = 4.1. The 3-hour National Ambient Air Quality Standard (NAAQS) for SO_2 (1300 ug/m^3) divided by the 24-hour NAAQS for SO_2 (365 ug/m^3) is 3.6. Thus, based on monitoring in the vicinity of TVA power plants, it should be expected in general that the 3-hour NAAQS is the more controlling standard with respect to regulating SO_2 emissions from the TVA plants.

AEP Power Plants

Martin and Reeves have provided SO_2 data from which maximum ratios can be derived for several American Electric Power (AEP) power plants in the Ohio River Valley. The data presented by Martin and Reeves are the observations made at the 33 monitoring sites comprising 5 monitoring networks for various AEP power plants.

Martin and Reeves provided data on peak 1-hour, 3-hour, and 24-hour concentrations observed during 1975 at each of the 5 monitoring networks. Each monitoring network consisted of 4 to 11 monitoring sites.

Table 2 provides information similar to that provided for the TVA power plants identified in Table 1. Table 2 data represents the averages of ratios from the individual monitors comprising a monitoring network. The plants shown on Table 2 are arranged in order of lowest (Tanners Creek) to highest (Big Sandy) average stack height.

Note, from the ratios indicated for the AEP power plant monitoring networks, it does not readily appear that ratios increase with increasing stack height as suggested by Montgomery and Coleman.

Table 2 indicates that the means for R_3 and R_{24} are 1.3 and 3.5 respectively. R_{24}/R_3 = 2.7; thus, based on existing monitoring data in the vicinity of the AEP plants it should be expected that, in general, the 24-hour NAAQS is the more controlling standard with respect to regulating SO_2 emissions from the AEP plants.

Table 2. Peak 1-hour concentration to peak 3-hour and 24-hour concentration ratios for SO_2 measurements in the vicinity of several AEP power plants in the Ohio River Valley.

Power Plant	R_3	R_{24}
Tanners Creek	1.3	3.3
Cardinal-Tidd	1.2	2.9
Kyger-Gavin-Sporn	1.3	4.0
Clifty Creek	1.5	4.2
Big Sandy	1.3	3.5
Geometric Mean	1.3	3.5
Range:		
Low	1.2	2.9
High	1.5	4.2

Obviously, there are several major differences to be observed between the data presented for the TVA and AEP power plants. Such differences include the magnitude of the ratios, and the NAAQS for SO_2 which appears to be more constraining.

Ohio River Valley Power Plants

Because only 3-hour and 24-hour maximums for only one year of data were available for the AEP power plants studied by Martin and Reeves, as well as the presently unexplained differences noted above, further data were collected from power plant monitoring networks in the same general area. The data collected consists of four years of data from monitors located in the vicinity of power plants in the Ohio River Valley.

Data were obtained from 6 power plant associated monitoring networks (identified as monitoring networks A-F) in the Ohio River Valley (ORV). The data available represented the period 1974 thru 1977 and came from 35 ORV monitoring sites. There were 4 to 7 monitoring sites in each of the 6 ORV monitoring networks.

Table 3 presents categories of information for the ORV power plants similar to that provided for the TVA plants in Table 1 and the AEP plants in Table 2. The monitoring networks shown in Table 3 are arranged in order of lowest (A) to highest (F) average power plant stack height in the vicinity of the monitoring network.

Note, based on the ratios indicated for the ORV monitoring networks, it is not apparent that ratios increase as average power plant stack height increases as suggested by Montgomery and Coleman.

Table 3 indicates that the means for R_3 and R_{24} are 1.4 and 4.5 respectively. R_{24}/R_3 = 3.2, thus based on the existing monitoring data in the vicinity of the ORV power plants it should be generally expected, as was also indicated for the Martin and Reeves data, that the 24-hour NAAQS is the more controlling standard with respect to regulating SO_2 emissions from the ORV power plants analyzed here.

Table 3. Peak 1-hour concentration to peak 3-hour, 24-hour, and annual concentration ratios for SO_2 measurements from 6 monitoring networks located in the vicinity of power plants in the Ohio River Valley.

Monitoring Network	R_3	R_{24}	R_{8760}
A	1.5	5.0	24
B	1.3	4.3	28
C	1.3	3.8	18
D	1.4	4.7	21
E	1.4	6.0	32
F	1.4	3.6	17
Geometric Mean	1.4	4.5	23
Range:			
Low	1.3	3.6	17
High	1.5	6.0	32

Differences Between TVA and ORV Ratios

It can be observed in comparison of the data presented in Tables 1, 2, and 3 that monitoring in the vicinity of power plants in the Ohio River Valley does not appear to yield ratios as high as those indicated based on monitoring in the vicinity of TVA power plants.

Several different factors may be responsible for the differences in ratios seen from plant to plant and more sharply between the TVA and the AEP and ORV power plants. Montgomery and Coleman suggest that the variation among TVA plants can be attributed to the differences in average stack height for the plants. It was not found that average stack height alone could account for the differences among the non-TVA plants studied. Other factors influencing observed differences in ratios may include: 1) differences in power plant design and operation, 2) meteorological differences which result in differences in maximum ground level concentrations, 3) terrain differences which affect the transport, dispersion, and impacts of the power plant plumes, 4) differences in regional background concentrations of pollutants which may make-up a larger portion of the concentrations observed for the Ohio River Valley located monitors, and 5) differences in the location of monitors with respect to the areas of impact due to power plant emissions (eg. it may be possible that monitors located in the vicinity of TVA power plants are located closer to areas of maximum short-term (3-hour) impact than are the AEP power plant monitors).

Urban Area Related Observations

Larsen has compiled data for 8 urban areas. These data include 5-minute, 1-hour, 8-hour, 24-hour, 1-month, and 1-year observations of CO, HC, NO, NO_2, NO_x, O_3, and SO_2 from a monitoring site in each of the 8 urban areas. The monitoring periods from which these data were compiled range from 2 to 8 years for each pollutant in each city.

The available data were analyzed by each pollutant as monitored in each city (tables not shown), and by the average of all pollutant ratios for each city, (see table 4) and for each pollutant by the average from all cities (see table 5). Ratio variation was greater from pollutant to pollutant within the same city than was the variation in ratios for a single pollutant compared to the same pollutant's ratio in each other city.

It can be seen, by comparing tables 4 and 5, that there is less variation about the mean for ratios from city to city than for pollutant to pollutant. Pollutants with the lowest ratios in urban areas are CO and HC which presumably are largely a result of near ground level automotive emissions over broad areas.

Table 5 indicates that the geometric mean of R_8 ($R_8 = X_{max}$ (1-hour)/X_{max} (8-hour)) for CO is 1.6. The 1-hour NAAQS for CO is (40 mg/ m^3) divided by the 8-hour NAAQS for CO (10 mg/m^3) is 4.0. Thus, based on monitoring in the vicinity of the 8 cities analyzed, it is expected in general that the 8-hour NAAQS for CO is the more controlling standard with respect to regulating CO emissions in urban areas. Note, all of the cities analyzed in this study have R_8 for CO ≤ 2.6; therefore, the 8-hour NAAQS for CO appears to be the controlling standard for all cities analyzed here.

Table 4. Peak 1-hour concentration to peak 5-minute, 8-hour, 24-hour, 1-month, and annual concentration ratios for 8 cities based on the average of ratios of 7 pollutants measured in each city.

City	$R_{0.08}$	R_8	R_{24}	R_{730}	R_{8760}
Chicago	0.73	1.7	2.3	4.4	6.5
Cincinnati	0.69	1.7	2.7	7.4	12.3
Denver	0.68	2.0	3.1	6.7	10.8
Los Angeles	0.52	1.8	2.5	5.5	10.0
Philadelphia	0.84	1.6	2.5	7.0	12.2
St. Louis	0.69	2.0	2.5	6.6	9.0
San Francisco	0.79	2.0	2.9	6.2	9.2
Washington, D.C.	0.81	1.7	2.5	6.6	9.7
Geometric Mean	0.71	1.8	2.6	6.2	9.8
Range:					
Low	0.52	1.6	2.3	4.4	6.5
High	0.84	2.0	3.1	7.4	12.3

Table 5. Peak 1-hour concentration to peak 5-minute, 8-hour, 24-hour, 1-month, and annual concentration ratios for 7 pollutants based on the average of pollutant ratios from measurements in 8 cities.

Pollutant	$R_{0.08}$	R_8	R_{24}	R_{730}	R_{8760}
CO	0.72	1.6	2.1	4.0	5.9
HC	0.70	1.5	2.1	4.0	5.9
NO	0.87	2.1	3.1	9.3	19.2
NO_2	0.68	1.9	2.8	6.4	8.1
NO_x	0.90	1.9	2.7	7.6	12.2
O_3	0.62	1.7	2.8	6.1	10.0
SO_2	0.55	2.0	3.0	8.2	13.2
Geometric Mean	0.71	1.8	2.6	6.2	9.8
Range:					
Low	0.55	1.5	2.1	4.0	5.9
High	0.90	2.1	3.1	9.3	19.2

O'Donnell has reported proposed 1-hour standards for NO_2.[6] He indicates that the World Health Organization, (WHO), U.S. Environmental Protection Agency (EPA), and Ford Motor Company have suggested 1-hour NO_2 standards in the ranges of 0.10-0.17 ppm, 0.25-0.50 ppm, and 0.50-0.75 ppm respectively. The present annual NAAQS for NO_2 is 0.05 ppm. Thus, ratios of proposed 1-hour NO_2 standards to the existing annual NAAQS for NO_2 have ranges of 2.0-3.4, 5.0-10.0, and 10.0-15.0 for WHO, U.S. EPA, and Ford Motor Co. suggested standards respectively. From Table 5 it can be seen that R_{8760} for NO_2 is 8.1. Therefore, based on the monitoring data analyzed here, it could be expected that if the established 1-hour standard for NO_2 is less than 0.4 ppm (8.1 X 0.05 ppm), in general the 1-hour standard would become the controlling standard with respect to regulating NO_2 emissions in urban areas. Note, if the established 1-hour standard for NO_2 is less than 0.27 ppm, the 1-hour standard would become the controlling standard for each of the 8 cities for which monitoring data were analyzed (St. Louis had the lowest R_{8760} = 5.5; 5.5 X 0.05 ppm = 0.275 ppm). Similarly, if the established 1-hour standard for NO_2 is greater than 0.70 ppm, the annual NAAQS would remain the controlling standard for each of the 8 cities for which monitoring data were analyzed (Cincinnati had the highest R_{8760} = 14.0; 14.0 X 0.05 ppm = 0.70 ppm).

Discussion

One method of summarizing the data which has been tabulated is to plot the ratios as a function of averaging time on log-log scale graph paper. Figure 1 graphically summarizes the geometric means of peak to peak ratios for the TVA, ORV, and urban areas, which were tabulated in Tables 1, 3, and 5 respectively.

The main features to be observed from the comparison information provided in Figure 1 is that ratios and slopes of curves displayed are greatest for the TVA data and lowest for the urban area data. The most probable cause for such differences are due to differences in the distribution of concentrations to be monitored and differences in the location of monitors to measure pollutant concentrations.

Differences between the TVA and ORV data and potential contributing factors have been previously presented. Several of these same potential contributing factors would be applicable for suggested explanation of the difference between the ratios indicated for power plant monitoring networks and the ratios indicated for urban area monitors. Differences in the distribution of concentrations to be monitored are in part due to differences in interaction of other contributing sources and background. The greater the number of sources contributing to monitored pollution levels or the higher the background pollution levels, the lower the peak to peak ratios. Differences in the location of monitors also would result in differences in observed peak to peak ratios. The further removed from the areas of maximum short term concentrations that monitoring sites are located, the lower the expected peak to peak ratios.

The curves shown in Figure 1 can be approximated by relationships of the form:

$$R_t = at^b$$

where a is a constant, t is the averaging time, and b is the slope of the curve (line between the ratios for two different averaging times).

Based on analyses of the data, the slopes appear to vary between 0.1 and 0.7 depending on source category and averaging period. It is also obvious that the greater the peak to peak ratios, the greater the average slope over all averaging periods. Not shown or obvious from Figure 1 is the significant variation about the means of ratios (slopes) which combine to provide the averages displayed.

Also not shown, by Figure 1, but can be discerned from analyses of Tables 1-5 and the data upon which these tables are based, is the similarity of ratios (and slopes) for similar source categories and pollutant species.

In comparing the curves shown on Figure 1 for the various source categories indicated, the curve shown for the urban areas is the smoothest of the three. This is as expected, as Larsen has previously shown monitored concentrations in urban areas to be log normally distributed as a function of averaging time.

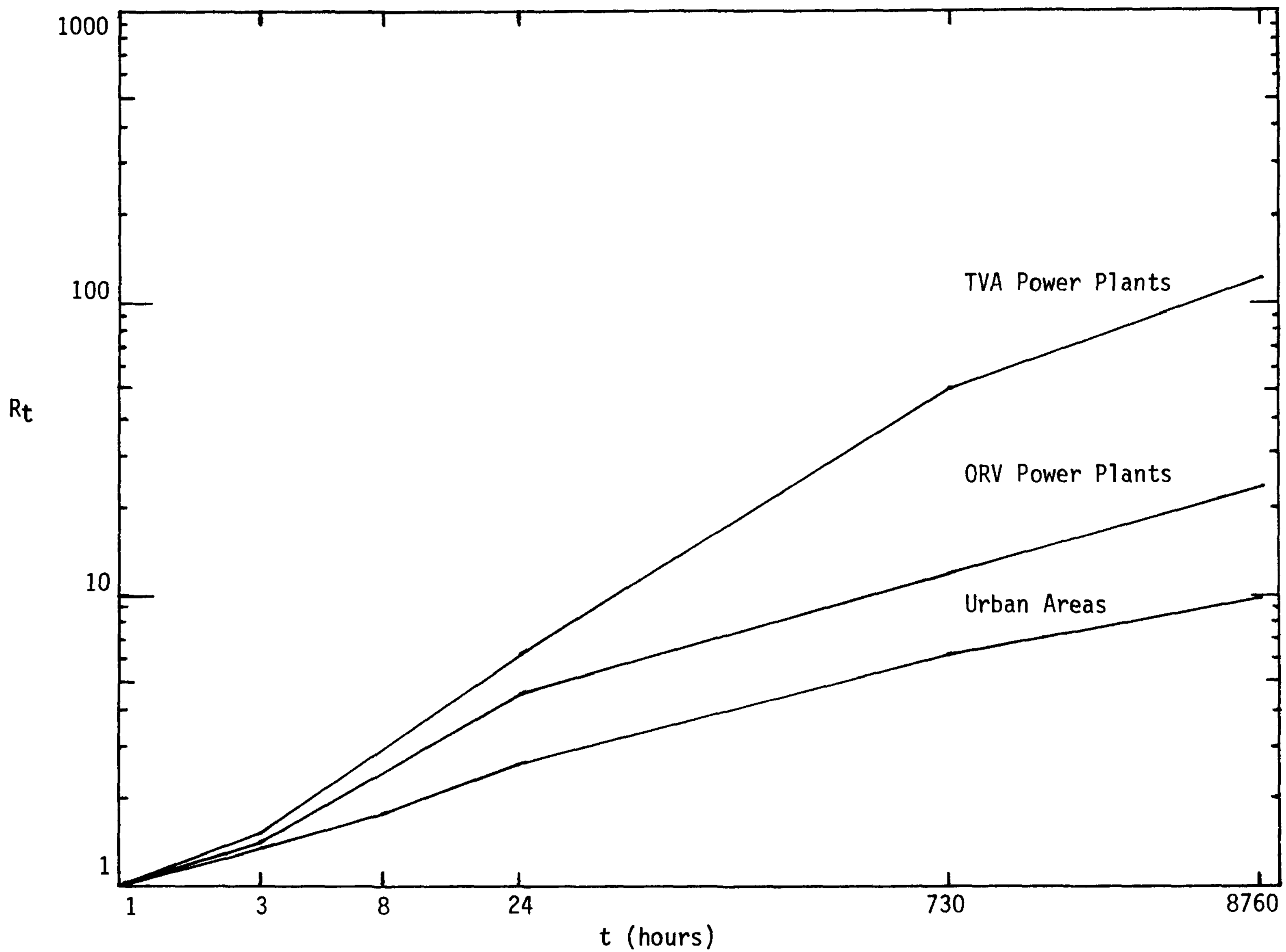

Figure 1. Ratios (R_t) of peak 1-hour concentrations to peak concentrations for other averaging times plotted as a function of averaging time (t) for different source categories.

Some of the irregularity (changing slopes) of the curves shown for power plant source categories in Figure 1 may be due to the limited spatial and temporal resolution of the monitoring data.

It is currently planned that further investigation will focus on the differences observed between the power plant data analyzed in this paper. Meteorological data, power plant parameters, source emission and background air quality data, and monitoring location effects should be investigated. Further analyses should also compare ratios developed based on model calculated maximum concentrations. Such analyses may provide further insight as to the proper development of both air quality monitoring networks and the development and validation of air quality predictive models.

Summary and Recommendations

Peak 1-hour averaged concentrations are compared to peak concentrations for averaging times ranging from 5-minutes to 1-year. Pollutants considered include CO, HC, NO, NO_2, NO_x, O_3, and SO_2. Source categories consisted of various rural power plants and numerous urban complexes.

The ratio, R_t ($R_t = \chi_{max}(1\text{-hour}) / \chi_{max}(t)$), can be represented by the function $R_t = at^b$, where t is the averaging time in hours. The exponent, b, appears to vary between 0.1 and 0.7 depending primarily on averaging time and source type. Strong similarity is shown for pollutants from similar source types.

It is expected that the causes for differences in peak to peak ratios among similar pollutants from similar sources include: differences in the distribution of concentrations and differences in the location of monitors to measure the pollutant concentrations. It is suggested that the differences in the distribution of concentrations to be monitored are attributable to differences in emission source characteristics (including height of release, distribution of points or areas of emission, and modes of source operation), meteorology, terrain, and background air quality.

It is recommended that the causes of the observed ratio differences be the focus of future investigation. It is also recommended that future investigations should also seek to compare peak to peak ratios developed based on model calculated maximum concentrations. Such further analyses may provide additional guidance as to the proper development of air quality monitoring networks and the development of validation tools for air quality predictive models.

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Captions

Tables

Table 1. Peak 1-hour concentration to peak 3-hour, 24-hour, 1-month, and annual concentration ratios for SO_2 measurements in the vicinity of 8 TVA power plants.

Table 2. Peak 1-hour concentration to peak 3-hour and 24-hour concentration ratios for SO_2 measurements in the vicinity of several AEP power plants in the Ohio River Valley.

Table 3. Peak 1-hour concentration to peak 3-hour, 24-hour, and annual concentration ratios for SO_2 measurements from 6 monitoring networks located in the vicinity of power plants in the Ohio River Valley.

Table 4. Peak 1-hour concentration to peak 5-minute, 8-hour, 24-hour, 1-month, and annual concentration ratios for 8 cities based on the average of ratios of 7 pollutants measured in each city.

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Figures

Figure 1. Ratios (R_t) of peak 1-hour concentrations to peak concentrations for other averaging times plotted as a function of averaging time (t) for different source categories.