



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

April 5, 2011

MEMORANDUM

SUBJECT: Investigation of 1-hour PM_{2.5} Mass Concentration Data from EPA-Approved Continuous Federal Equivalent Method Analyzers

FROM: Mark Evangelista, OAR/OAQPS/AQAD /s/

TO: PM_{2.5} NAAQS Review Docket (EPA-HQ-OAR-2007-0492)

Summary

This memorandum documents systematic analyses of hourly PM_{2.5} mass concentration data obtained from continuous Federal Equivalent Method (FEM) analyzers operated by state and local air monitoring agencies and reported to EPA's Air Quality System (AQS). The quality of hourly data from FEM analyzer is of interest in connection with the current review of the secondary PM_{2.5} NAAQS, due to the possible use of such data to calculate PM_{2.5} light extinction on a sub-daily basis (e.g., 1 hour or 4 hours).

Calendar year 2009 data from 109 FEM instruments were obtained from AQS. As discussed later, three sites were eliminated from further consideration based on an obvious data validation failure. Of the remaining 106 instruments (105 sites) only one site had collocated instruments of the same model, such that instrument readings could be compared to get a sense of data reproducibility. At the other 104 single-instrument sites, the analyses of the quality of hourly data were based on "common sense" expectations for the range and temporal patterns of actual ambient concentrations.

The following observations were reached:

- Although FEM instruments are capable of being paired with a digital data logging system, not all monitoring programs do so. Some reported concentrations of approximately 1000 µg/m³ were traced to the pairing of one particular instrument model with older analog data logging systems. Armed with this awareness, it should be possible for monitoring agencies to avoid reporting such erroneous data in the future, even if they continue to rely on older analog systems.
- Data from the one available pair of collocated instruments of the same model show periodic inconsistencies in hour-to-hour PM_{2.5} data. On 26 days in 2009, there was at least one hour during which the instruments differed by at least 10 µg/m³, with one

monitor reading below $10 \mu\text{g}/\text{m}^3$ and the other reading above $20 \mu\text{g}/\text{m}^3$. However, the annual 90th and 95th percentile daily maximum 1-hour concentrations for the two instruments, respectively, were within 10 percent of each other, indicating that for this site and this year the errors did not happen in a pattern that would have greatly affected compliance determinations against a standard with this statistical form.¹ Nevertheless, this observation from a single year of such data from a single instrument does not provide much confidence that measurement errors for hourly concentrations would not affect compliance determinations at least some times if NAAQS implementation were based on a network of monitoring sites using this instrument model.

- When data from this same pair of collocated instruments are used to calculate moving 4-hour average concentrations, the results from the instruments become more similar to each other and the occurrence and magnitude of extreme values are reduced, confirming the expected tendency of multi-hour averages to mute the effect of hourly measurement errors.
- Among the 106 individual instruments, instances of very high reported 1-hour concentrations and/or patterns involving isolated high peaks in concentration were never so frequent as to significantly affect the annual 95th percentile or annual 90th percentile daily maximum 1-hour concentration, if such 1-hour concentrations were assumed to be incorrect readings and were replaced by much lower values.

It has not been possible to assess the representativeness of the vast majority of the moderately high concentrations reported by the 104 single-instrument sites because of the lack of any known value for “true” hourly concentrations. Nevertheless, the findings for the one site with a pair of collocated instruments, the occurrence of very high and/or highly peaked values at some single-instrument sites, and the hour-to-hour variability seen in visual time series displays of the concentration data suggest that considerable caution is warranted when contemplating the use of hourly data from these FEM instruments in any calculations of $\text{PM}_{2.5}$ light extinction.

Background

Consideration of potential revised secondary standards for $\text{PM}_{2.5}$ to address PM-related welfare effects involves addressing visibility impairment, which is caused by light scattering and absorption by suspended particles and gases. Initial drafts of the Policy Assessment for the current review of the secondary $\text{PM}_{2.5}$ NAAQS contemplated the use of calculated $\text{PM}_{2.5}$ light extinction, estimated based on 24-hour $\text{PM}_{2.5}$ speciation data and hourly $\text{PM}_{2.5}$ mass data, as an indicator for a revised secondary standard. The contemplated method includes simple algorithms to estimate light extinction attributed to each of the major $\text{PM}_{2.5}$ components. By applying the speciation profile associated with a Chemical Speciation Network monitor to the hourly $\text{PM}_{2.5}$ concentration values reported by a collocated continuous mass monitor implementing a Federal

¹ A revised $\text{PM}_{2.5}$ NAAQS could be based on a three-year 90th or 95th percentile form. To calculate these percentiles, I determined a percentile value depending upon the number of days in the data set, rounded up to the nearest 10 (for the 90th percentile case) or 20 (for the 95th percentile case) days. For example, for a full year of data (365 days) the 95th percentile daily maximum value is the 19th highest value. This method is based on the method used to identify 98th percentile concentrations for the 2006 24-hour $\text{PM}_{2.5}$ NAAQS, as described in 40 CFR 50 Appendix N.

Equivalent Method (FEM), hourly values of the major PM_{2.5} components could be estimated and input into a version of the IMPROVE algorithm for calculating light extinction.

The analyses in this memo were designed to highlight outlier concentration values that were so high that they seemed highly unlikely to represent actual ambient conditions, especially if they were frequent and had no obvious explanation based on the monitoring site. However, some of the same (largely unknown) causes of such very high outlier concentrations may, to a lesser degree, also affect reported concentration values in or near the range 20-50 µg/m³. This range of PM_{2.5} concentration is of interest because, depending on species mix and relative humidity, PM_{2.5} concentrations in this range can translate into PM_{2.5} light extinction levels in the range of 25-30 deciviews, which is the range of most interest in the Policy Assessment.

Federal Equivalent Method Monitors and the Data Set Used in this Investigation

Monitor models, manufacturers, and monitoring methods used to obtain the data set for this investigation are listed in Table 1.

Table 1. Information about monitoring instrumentation. The legend for the table is found in the first row.

Number of Monitors in 2009 Data Set	Monitor Model Name <u>Website of the monitor model manufacturer</u> <i>Federal Equivalent Method [and reference location]</i>
91*	Met One BAM-1020 Mass Monitor w/VSCC
	www.metone.com/particulate.php
	Method EQPM-0308-170 [Federal Register: April 25, 2008 (Vol. 73, Num 81) Pg. 22362-22363]
1	Thermo Scientific 1405-DF Dichotomous FDMS
	www.globalspec.com/FeaturedProducts/Detail/ThermoFisherScientificAirQualityInstruments
	Method EQPM-0609-182 [Federal Register: June 17, 2009 (Vol. 74, Num 115) Pg. 28696-28698]
15	Thermo Scientific 8500C FDMS w/VSCC
	www.thermoscientific.com/wps/portal/ts/products/detail
	Method EQPM-0609-181 [Federal Register: June 17, 2009 (Vol. 74, Num 115) Pg. 28696-28698]
2	Thermo Scientific Model 5030 SHARP w/VSCC
	www.globalspec.com/FeaturedProducts/Detail/Model_5030_RealTime_Part particulate_Monitor/17839/0
	Method EQPM-0609-184 [Federal Register: June 17, 2009 (Vol. 74, Num 115) Pg. 28696-28698]
* Data from three of the sites with this instrument model were set aside early in the conduct of these analyses, as described in the body of this memo.	

I examined hourly PM_{2.5} concentration values reported by FEM monitors for 2009. The investigation began in early 2010, and 2009 provided the latest seasonally-balanced data set for an entire year at that time.

For this investigation, I obtained data from all 109 FEM monitors that had some data for 2009. Of the 109 monitors, 53 reported data for the entire year 2009, 21 monitors reported about 9 months of data, 15 monitors reported about six months of data, and 20 monitors reported data for 3 months or less. I included data from all monitors in the analyses without regard for data completeness. Of course, determination of design values for regulatory purposes would depend upon data completeness.

Instructions for access to the data used in this investigation are given in Appendix A.

First Indication of a Data Quality Issue

One of the first observations in examining the data set was that three sites had reported PM_{2.5} concentration values of 985 µg/m³. These values were considered to represent self-evident monitoring system errors, and their cause was investigated by EPA staff in the Ambient Air Monitoring Group. It was determined that the Met One BAM-1020 Mass Monitor used at these three sites, when paired with an analog data logging system, is typically run with a voltage range from 0 to 1 volt corresponding to a concentration range from -0.015 mg/m³ to 0.985 mg/m³ (i.e., -15 µg/m³ to 985 µg/m³). This offset allows for slight negative values, which may be within the noise of the instrument output when the atmosphere approaches an ambient concentration value near zero, to be included in the reported hourly data. As a means of sending an error code when a malfunction or out-of-limits condition is detected, the monitor is programmed to send its analog output to the full-scale voltage of 1 volt, rather than report a questionable concentration value.² If the data logger (and/or downstream data processing steps) is designed to convert every recorded voltage into a concentration using a simple linear algorithm, the hour for which the voltage output was 1 volt will be treated as having a concentration value of 985 µg/m³.

I eliminated these three sites from the investigation data set, leaving data from 106 instruments at 105 monitoring sites. Additionally, OAQPS and Regional Office staff are discussing this issue with Met One and with State monitoring operators to encourage corrective action, and to ensure monitoring agencies remove such clearly incorrect data before submission.

Analytical Approaches

Several analytical approaches were followed.

1. A qualitative, exploratory data inspection in which time series graphics were generated for every FEM monitor with at least one “daylight” 1-hour concentration in excess of 150 µg/m³.
2. Graphical analysis of the time-matched data from the one site with a pair of collocated instruments.
3. Analysis of the effect of 4-hour averaging on the annual daily maximum concentration values.
4. Application of two different approaches for qualitatively defining (“flagging”) what data could potentially be erroneous. Data identified by these approaches were graphically

² When the instrument is paired with a digital data logger, a separate data channel is used to report such conditions explicitly.

inspected in temporal and spatial context to determine whether it might be plausible that the data represent legitimate measurements.

5. An analysis in which reported 1-hour concentrations that arguably could be potentially erroneous, as identified by Approach 4, were replaced with plausible values. The point of the substitution process was to produce an alternate data set that might better represent true ambient concentrations, to create a baseline for quantifying the effect of possible measurement errors in the actual reported data. I examined how the substitutions affected the annual maximum, the annual 95th percentile, and the annual 90th percentile values of the daily maximum 1-hour PM_{2.5} concentration values. The effect of errors/substitutions on the annual 95th percentile and annual 90th percentile values of the daily maximum 1-hour PM_{2.5} concentration values was of interest because a revised PM_{2.5} NAAQS could be based on a three-year 90th or 95th percentile form.

1. Qualitative, Exploratory Data Inspections

I immediately noticed that some FEM monitors occasionally reported high hourly PM_{2.5} concentrations. These concentration spikes sometimes occur for only one hour, with the hours immediately before and after showing a significantly lower concentration. Other high hourly PM_{2.5} concentration values appear to take several hours to build and subside. Also, there were cases in which a very high reading was unique during the year and other cases where high readings occur more frequently. For example, a time series of hourly data reported by a monitor in Zion National Park, UT (AQS ID 49-053-0130) for 2009 (Figure 1) shows one hourly concentration of nearly 250 µg/m³, but no other hourly concentration values greater than 80 µg/m³ were reported in all of 2009. In contrast, Figure 2 shows the hourly time series for 2009 concentrations at a monitor in Allentown, PA (AQS ID 42-095-0025), where high concentrations occurred several times during the year. In both cases, these high concentration values may represent the actual pattern of ambient particulate matter. Or, they may be erroneous values that are due to instrument issues such as siting, maintenance, calibration, instrument design, or one-off instrument defects. Errors in data handling and transfer are also a possibility.

I next conducted a visual inspection of the hourly data from each monitor that included at least one “daylight” concentration value in excess of 150 µg/m³. This was the lowest round value that would cause both sites mentioned in the previous paragraph to be included. I used a smaller dataset of only “daylight” hours for expediency.³ In the 2009 data, I identified 12 monitors that had at least one “daylight” concentration value greater than 150 µg/m³. Figure 3 shows the highest daily maximum concentration value for each of these monitors, compared to the second highest daily maximum concentration value. Figure 4 shows the annual time series for the site at Turlock, CA (AQS ID 06-099-0006, denoted as monitor 3 in Figure 3). This time series shows

³ The methods contemplated in the Policy Assessment to estimate visibility from, among other information, PM_{2.5} values reported by FEM monitors, involve several steps and inputs. Two such steps are screening the data to include only daylight hours, and screening the data to include only those hours when relative humidity is reported below a certain value. To allow full use of values from sites with only a few months of reported data, and because there was no *a priori* reason to suspect that the time of day or high humidity play a role in the generation of questionable concentration values, I tested most flagging algorithms on the full data set without filtering for relative humidity or daylight hours. However, computational limitations sometimes required a smaller data set, and in those cases the test was performed on data for only a subset of hours. Those tests performed on this subset—referred to as “daylight” hours, defined as the hours 5:00 AM to 7:00 PM local time (no Daylight Savings correction)—are clearly identified.

one value above $150 \mu\text{g}/\text{m}^3$, but several other high values as well. In this context, perhaps the high value is valid as there are other days with relatively high concentrations in the same period.

Of the 12 monitors, only one had a second highest daily maximum also greater than $150 \mu\text{g}/\text{m}^3$. In fact, four monitors had a second highest daily maximum below $75 \mu\text{g}/\text{m}^3$, less than one-half the highest value. These four monitors each appeared to have one high concentration value unique to the rest of the year's data. Figures 5-7 each depict a time series of the 2009 hourly concentration values for one of these monitors. In Figure 5, the high value at the Honolulu site may have resulted from an upstream volcanic eruption. Figure 6 shows another high value that, while it is much lower than the highest value, may lend plausibility to that highest value. Additionally, the high value occurs within 90 days of the start of monitoring operation, perhaps suggesting an instrument issue. This possibility is more clearly illustrated in the time series for another monitor in Figure 7.

2. Examination of Data from One Site with a Pair of Collocated Instruments

In 2009, data was reported from only one site with collocated FEM monitors—Missoula, Montana (AQS ID 30-063-0024, POC3 and POC4)—of the same model and method (Met One BAM-1020 Mass Monitors w/VSCC, Method ID EQPM-0308-170). Hourly $\text{PM}_{2.5}$ mass measurements were reported from both Missoula monitors for the full year 2009. Figure 8 shows a scatter plot of the paired hourly $\text{PM}_{2.5}$ measurements reported by both monitors. I identified 26 days on which there was an hour when the concentration measured by one monitor was reported to be greater than $20 \mu\text{g}/\text{m}^3$, while the measurement by the collocated monitor for the same hour was reported to be less than $10 \mu\text{g}/\text{m}^3$. I examined these individual days in greater detail. Time series for some of these days are found in Figures 9-11. In the figures, differences up to $10 \mu\text{g}/\text{m}^3$ for the same hour can sometimes be seen between POCs 3 and 4, and these differences generally lasted 4 or more hours when they did occur.

High $\text{PM}_{2.5}$ concentration measurements are not specific to one single monitor at this site. Both monitors did report high $\text{PM}_{2.5}$ concentration values, but never on the same day. The monitor identified as POC3 reported more high values than POC4. Figure 9 illustrates all days on which POC3 reported a high $\text{PM}_{2.5}$ concentration while POC4 did not. Figure 10 illustrates all days on which POC4 reported a high concentration while POC3 did not. Additionally POC4 reported measurements in a more erratic pattern than POC3 on several days, as illustrated by Figure 11, while POC3 exhibited no such erratic pattern.

3. Analysis of 4-Hour Averages

Four-hour averages were determined from the hourly data. If one hourly measurement was missing, an average was determined of the remaining three hourly measurements. If there were two or more missing hourly measurements, the 4-hour average was not computed.

The 4-hour averaging was applied to the data from the one site with a pair of collocated instruments. Scatter plots of the 4-hour averages are shown in Figure 12. Not surprisingly, correlation of the 4-hour averages (0.910) was greater than correlation of the hourly data shown in Figure 8 (0.825). Figure 12 does not have any 4-hour values above about $100 \mu\text{g}/\text{m}^3$, while the 1-hour data set depicted in Figure 8 contained three such values. Also, there are fewer cases

in Figure 12 of data pairs in which the two POCs reported much different 4-hour values than there are of cases in Figure 8 in which they reported much different 1-hour values.

Figure 13 shows a scatter plot of the annual maximum daily maximum PM_{2.5} concentrations for 1-hour vs. 4-hour values. Figures 14 and 15 show the same comparisons for the 95th and 90th percentiles.

Averaging would obviously reduce the impact of an outlier value, and it is reasonable to find several points in Figure 13 that represent 1-hour values greater than 50 µg/m³, and therefore highly likely to correspond to a light extinction value that exceeds 30 deciviews (dv), with a corresponding 4-hour average value within the 20-50 µg/m³ range, where light extinction values greater than 30 dv may be less likely given other atmospheric circumstances. Figure 14 shows the same comparison for the 95th percentile and has a similar number of points of the same type as Figure 13. Figure 15, representing the comparison for the 90th percentile has fewer points of this type, as one would expect from the lower percentile. Additionally, some 95th and 90th percentile 4-hour average values are less than 20 µg/m³ with a corresponding 1-hour value well within the 20-50 µg/m³ range.

4. Application of Two Data Flagging Algorithms

Algorithms using two different methods were developed for this portion of the investigation: flagging data greater than a certain threshold value (“high value”), and flagging data exceeding the average of adjacent values by a threshold (“spikes”). These algorithms were applied to the full 2009 dataset, and the flagged data were examined for plausibility. Similar results were obtained from applying the two algorithms. For illustration, I will describe only the algorithm and results for flagging data spikes exceeding the average of adjacent values by a threshold.

This algorithm flagged any value more than 75 µg/m³ greater than the average of concentration values immediately before and after the examined value. In other words, the concentration value was compared to the average of the concentration values for the previous hour and the following hour. This average is the linearly interpolated value between those adjacent hours, which would be a reasonable initial estimate of a missing value between these adjacent values. If the measured concentration value exceeded the interpolated value by more than 75 µg/m³, the concentration value was flagged. This threshold value was chosen because one hourly value 75 µg/m³ higher than the adjacent average would be sufficient to create 4-hour averages above 20 µg/m³ even if the other hourly values in the average were very low.

Of the 106 instruments in the 2009 data, this algorithm flagged data for 31 instruments. Ten monitors had 2-4 flagged concentration values, and 20 monitors had only one hour flagged. The only monitor with more than 4 flagged concentration values was located in the West Yellowstone City Center, Montana (AQS ID 30-031-0016), which had 9 such hourly values. Most of the flagged hours were in the evening or night and all were in the cool season, indicating possible wood burning under night time inversions as the cause of legitimate measurements rather than instrument errors. The 2009 time series for this monitor is shown in Figure 16.

5. Analysis of Data Substitution Algorithms

Hourly concentration values that had been flagged by two algorithms in Approach 4—high-value and spikes—were eliminated from the data and replaced by predetermined concentration values. Daily maximum PM_{2.5} concentrations for the data set including the substituted values were compared to daily maximum PM_{2.5} concentrations for the original data without any flagging or substitution. Comparisons involving the two flagging/substitution algorithms yielded similar results. This analysis involving the spike algorithm is explained in detail.

I assumed all the flagged concentrations values were invalid, and I substituted the linearly interpolated values for the flagged values at these 31 monitors. The annual maximum daily maximum concentration values for the 2009 data with replacement of flagged values was compared to that for the 2009 data without any replacement in Figure 17. Replacement of data flagged using this algorithm appeared to affect the annual 95th percentile daily maximum concentration values at about 10% of the monitors (Figure 18). The annual 90th percentile daily maximum concentration values at only three monitors appeared to be affected by the flagging and substitution algorithm (Figure 19).

The flagging and substitution approaches were also applied to the data from both POCs at the collocated site, and the results compared. Table 2 shows the annual maximum daily maximum, the annual 95th percentile daily maximum, and the annual 90th percentile daily maximum for POC3 and POC4, determined from the original data, as well as from the results of substitution by two different algorithms.

The high-value algorithm did not change the annual 95th percentile daily maximum or the 90th percentile daily maximum at POC3, presumably because the day with the flagged concentration value did not fall below the percentile day when re-ranked after substitution or, if the day fell below the 95th or 90th percentile day, the next day was also 37.1 µg/m³. However, the spike algorithm and substitution did change the annual 95th and annual 90th percentile daily maximum values, presumably because the 3 flagged values did not all occur on the same day, and the substituted days changed the ranking of the percentile days. These changes were less than 10 percent.

At POC4, neither substitution algorithm altered the annual 95th or 90th percentile daily maximum concentration values, presumably because the day with the flagged concentration value did not fall below the percentile day when re-ranked after substitution or, if the flagged day fell below the 95th or 90th percentile day, the next day was of the same value as the original 95th or 90th percentile day.

The flagging and techniques do not offer much if any insight into the unexplained serious lack of reproducibility in the bulk of the collocated data.

Table 2. Comparison of Annual Daily Maximum values for the collocated monitors at the Missoula MT site (AQS ID 30-063-0024). Values are substituted by the algorithm to flag values above a threshold (Hi-Val) and by the algorithm to flag values considered sudden spikes (Spike). Column designated Original is data without any flagging or substitution.

Algorithm	Annual Maximum Daily Maximum (µg/m ³)			Annual 95 th Percentile Daily Maximum (µg/m ³)			Annual 90 th Percentile Daily Maximum (µg/m ³)			Hourly Values Flagged	
	Original	Hi-Val	Spike	Original	Hi-Val	Spike	Original	Hi-Val	Spike	Hi-Val	Spike
POC 3	187.8	128.6	105.7	37.1	37.1	34.8	30.9	30.9	30.7	1	3
POC 4	201.2	99.0	99.0	40.1	40.1	40.1	32.5	32.5	32.5	1	1

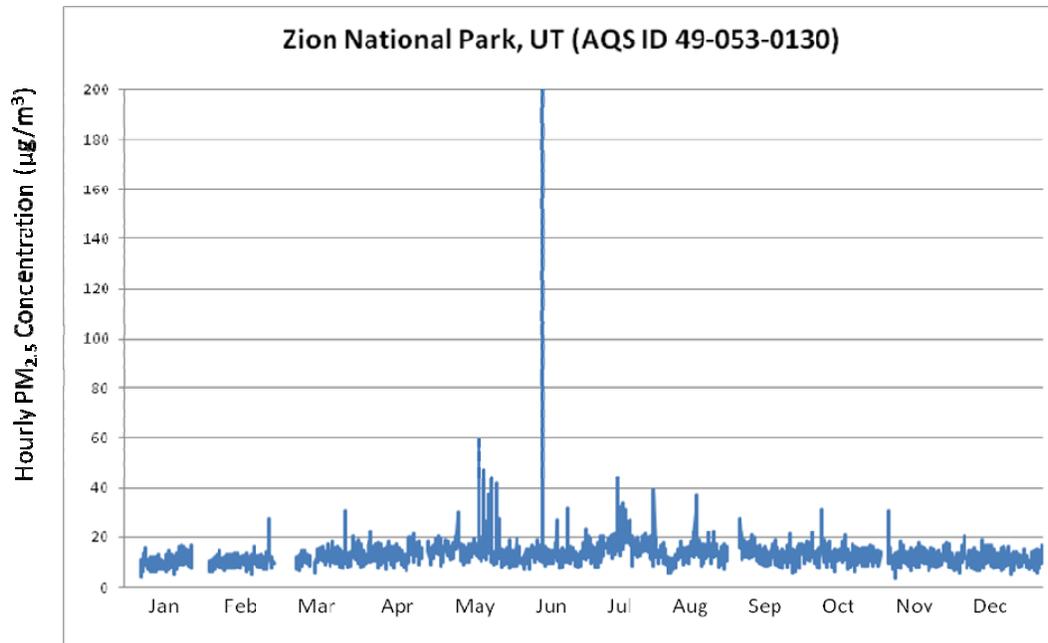


Figure 1. Time series of hourly PM_{2.5} concentration values for 2009.

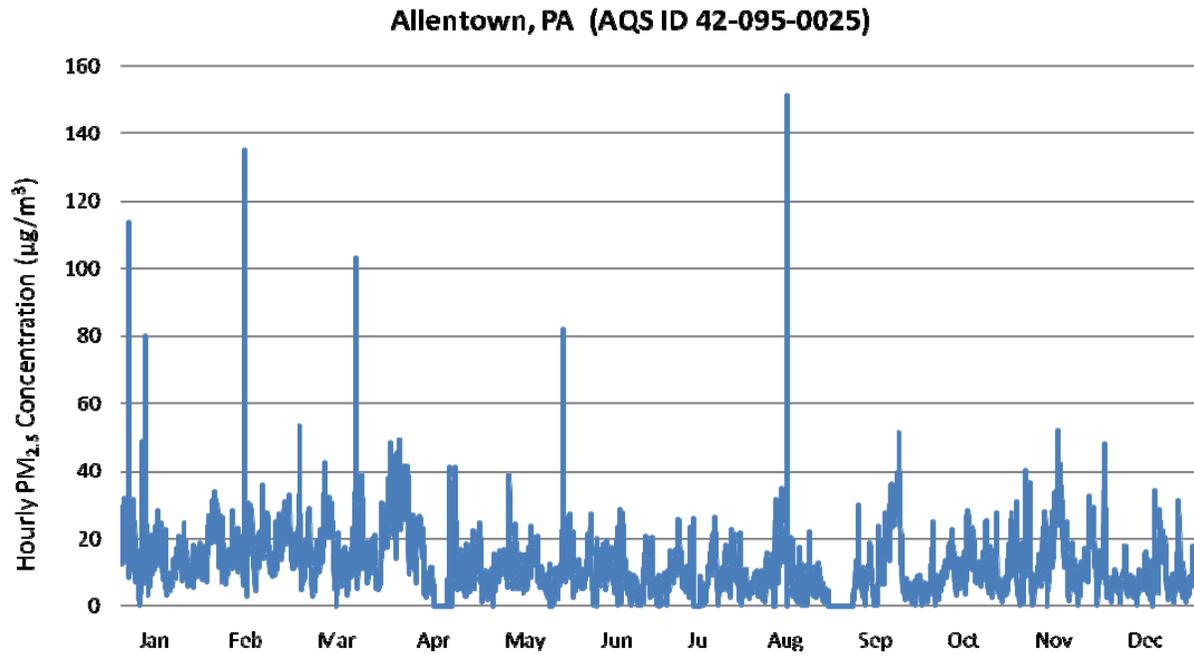


Figure 2. Time series of hourly PM_{2.5} concentration values for 2009

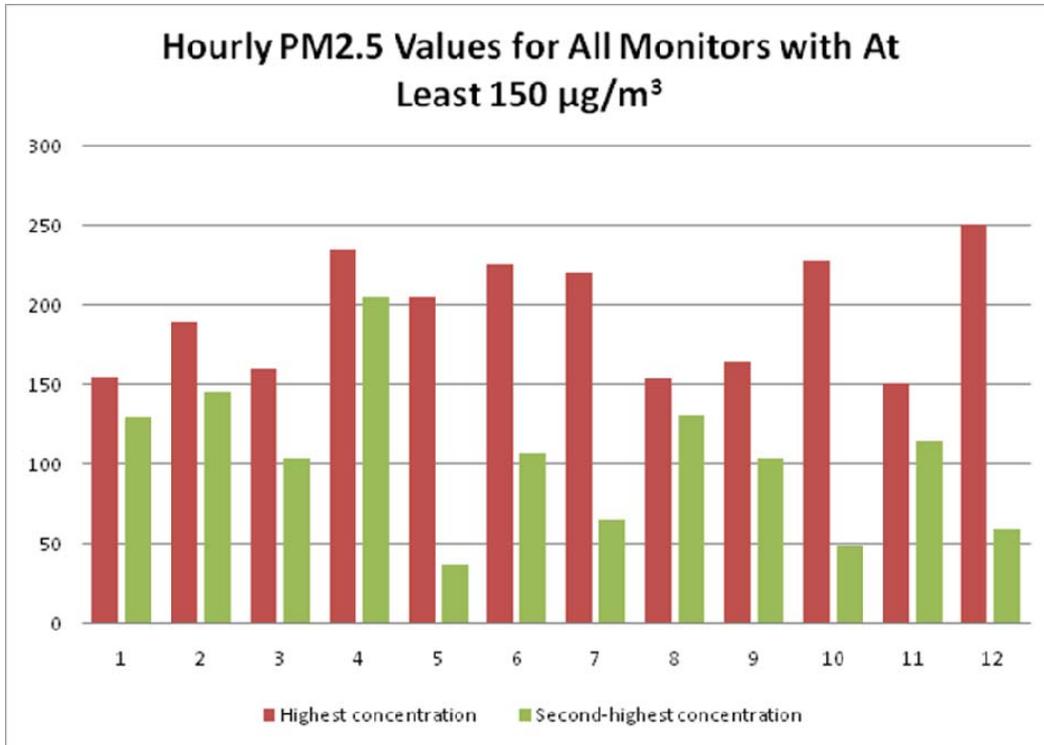


Figure 3. Highest, and second-highest hourly concentration values for 12 monitors in the 2009 “daylight” data set that had at least one value >150 $\mu\text{g}/\text{m}^3$. Note that only one site had a second-highest value >150 $\mu\text{g}/\text{m}^3$.

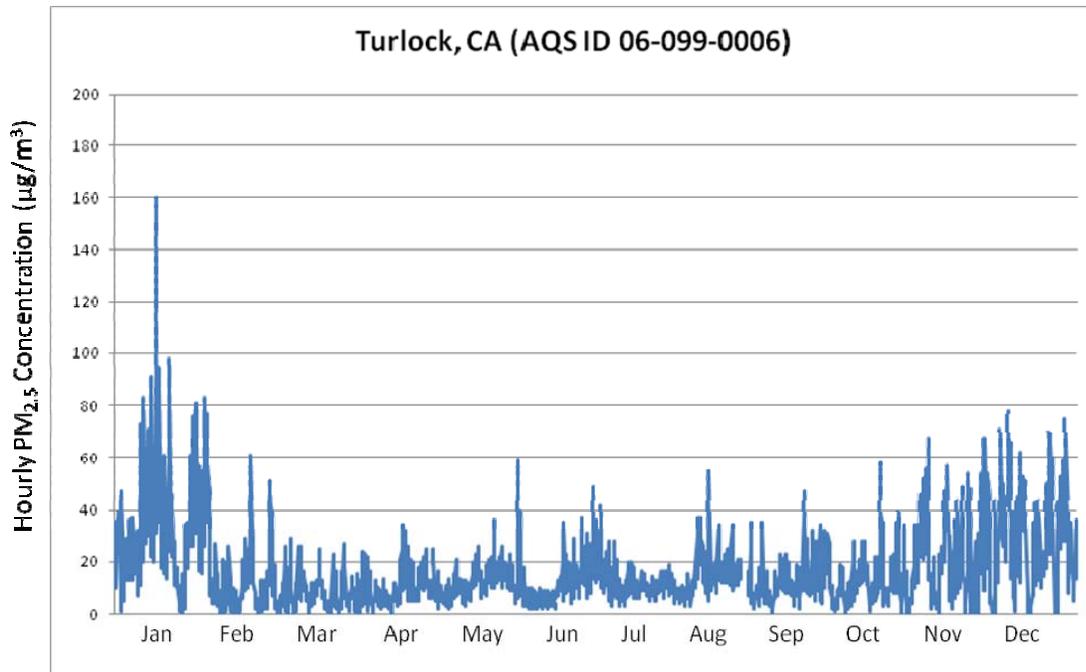


Figure 4. Time series of hourly PM_{2.5} concentration values for 2009

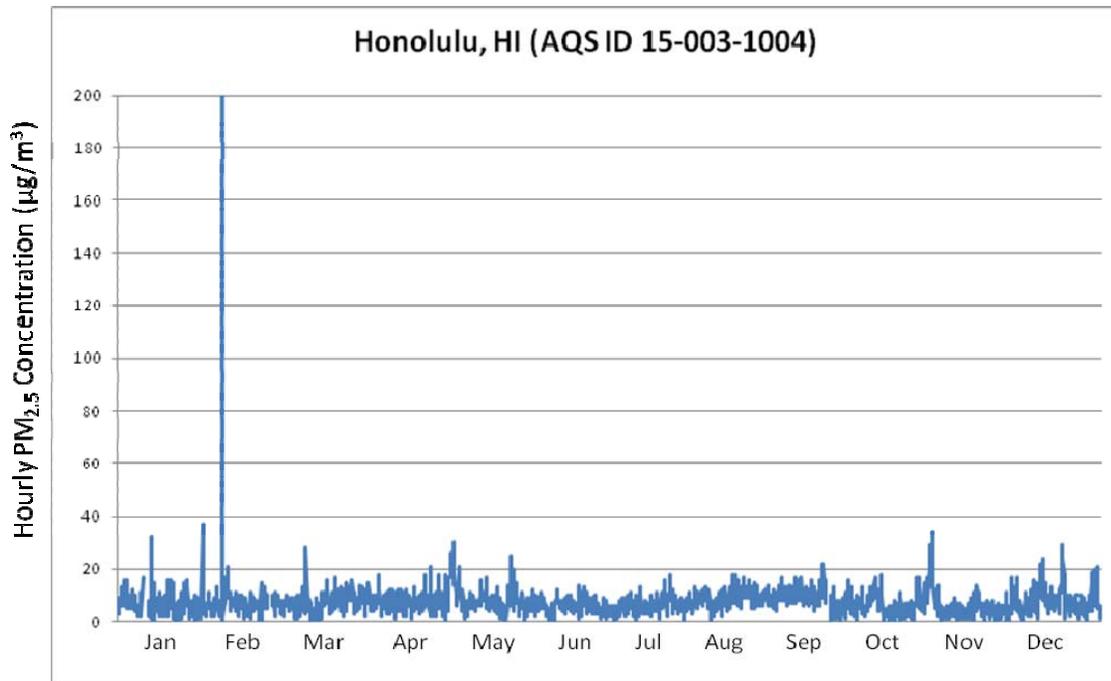


Figure 5. Time series of hourly PM_{2.5} concentration values for 2009

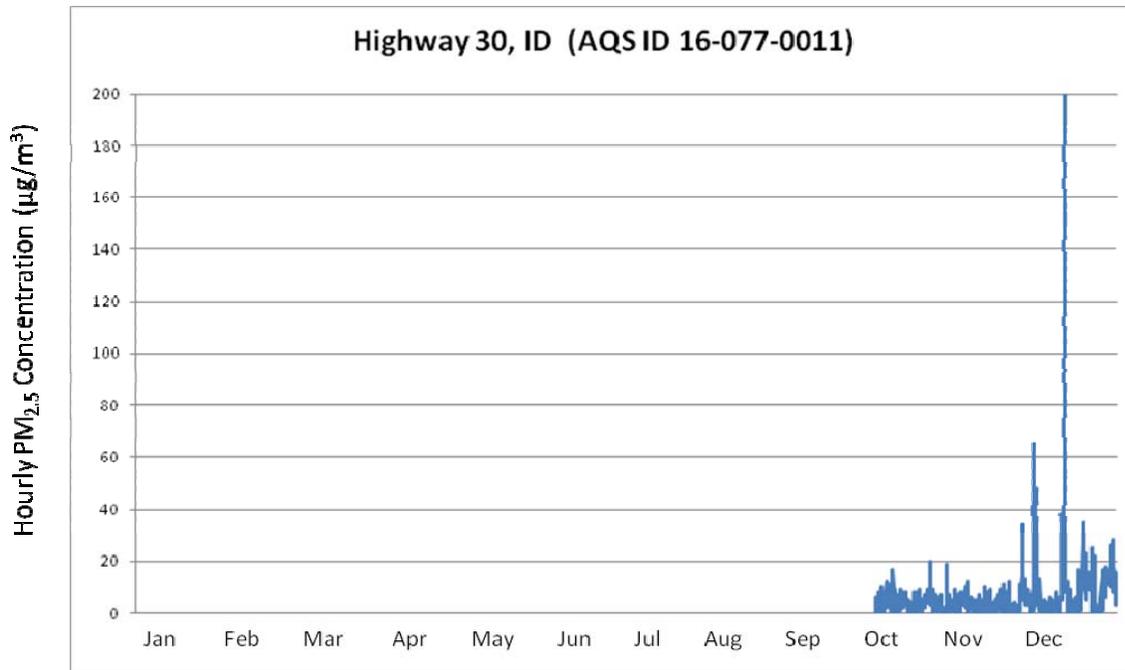


Figure 6. Time series of hourly PM_{2.5} concentration values for 2009.

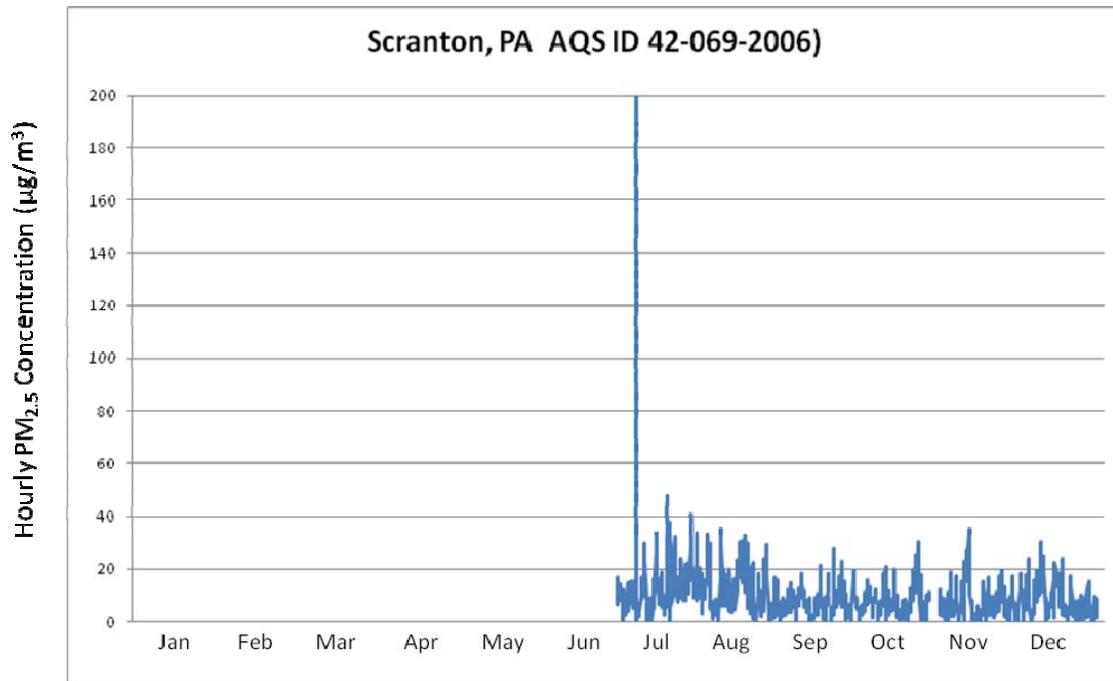


Figure 7. Time series of hourly PM_{2.5} concentration values for 2009

Hourly PM_{2.5} Concentration ($\mu\text{g}/\text{m}^3$) $r=.825$

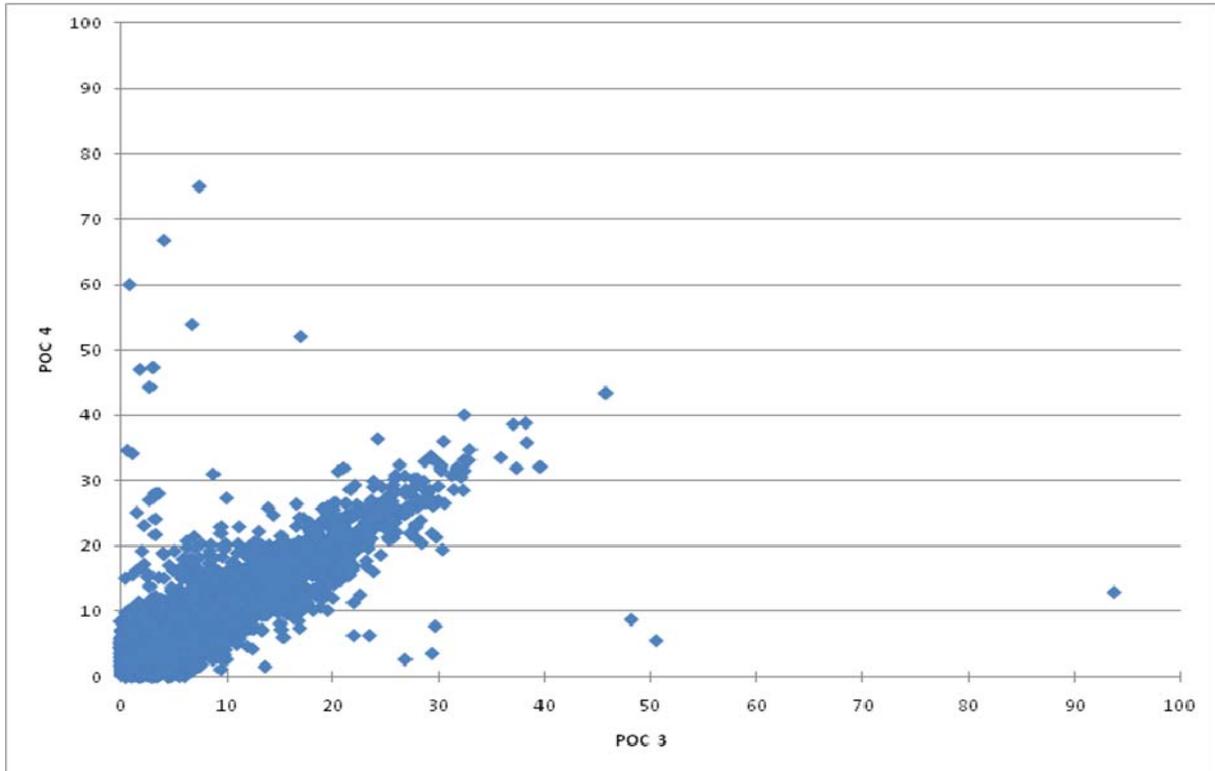


Figure 8. Scatter plot of hourly concentration values for two collocated FEM monitors at the Missoula, MT (AQS ID 30-063-0024). Correlation coefficient $r=.825$. [Note: Three data points (105.7, 99), (128.6, 8.2), (187.8, 201.2) were omitted from the graph for scale.]

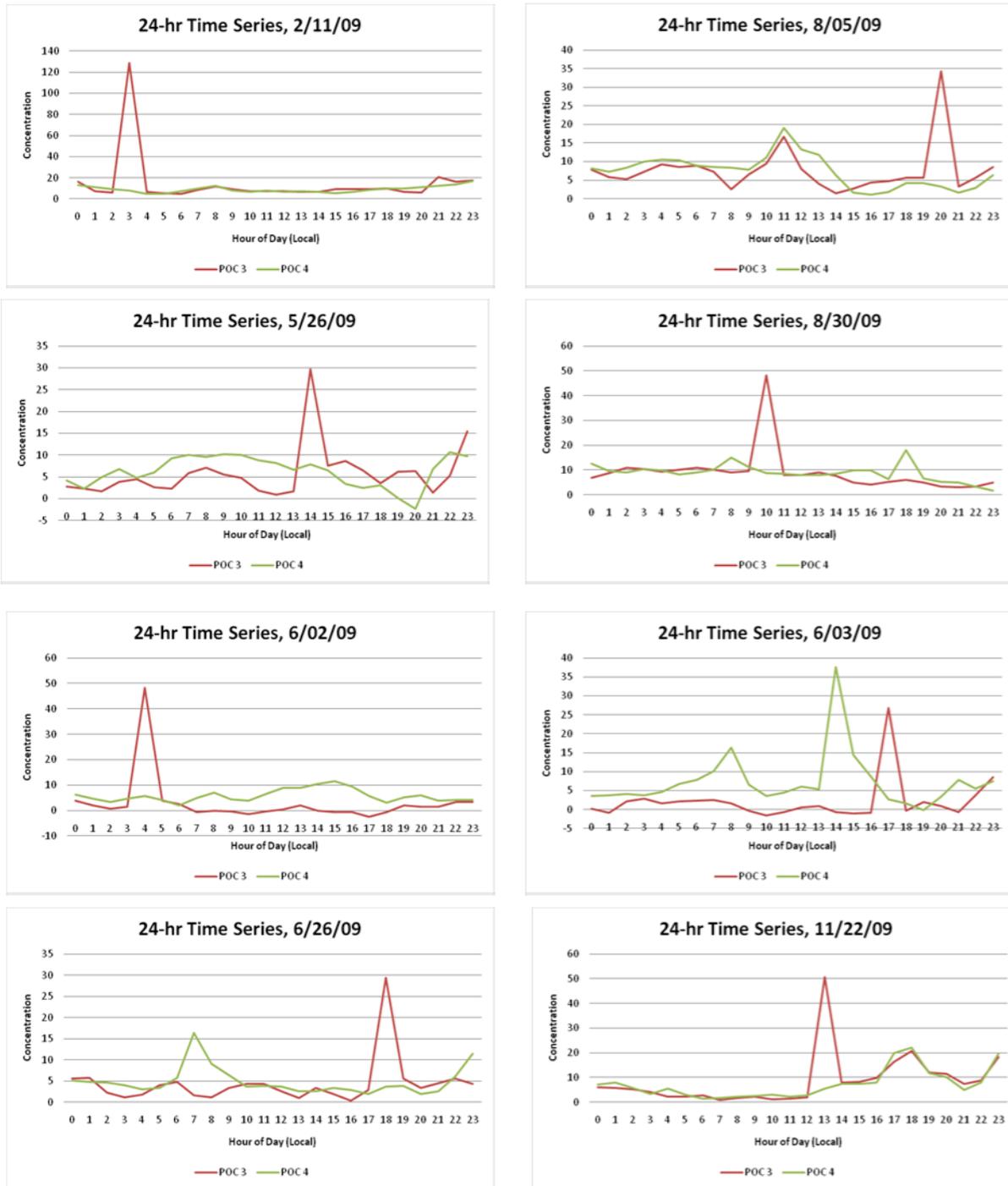


Figure 9. Various 24-hr time series of hourly PM_{2.5} concentration ($\mu\text{g}/\text{m}^3$) for the two collocated monitors at the Missoula, MT site. On these days, POC 3 reported a high concentration value while POC 4 did not.

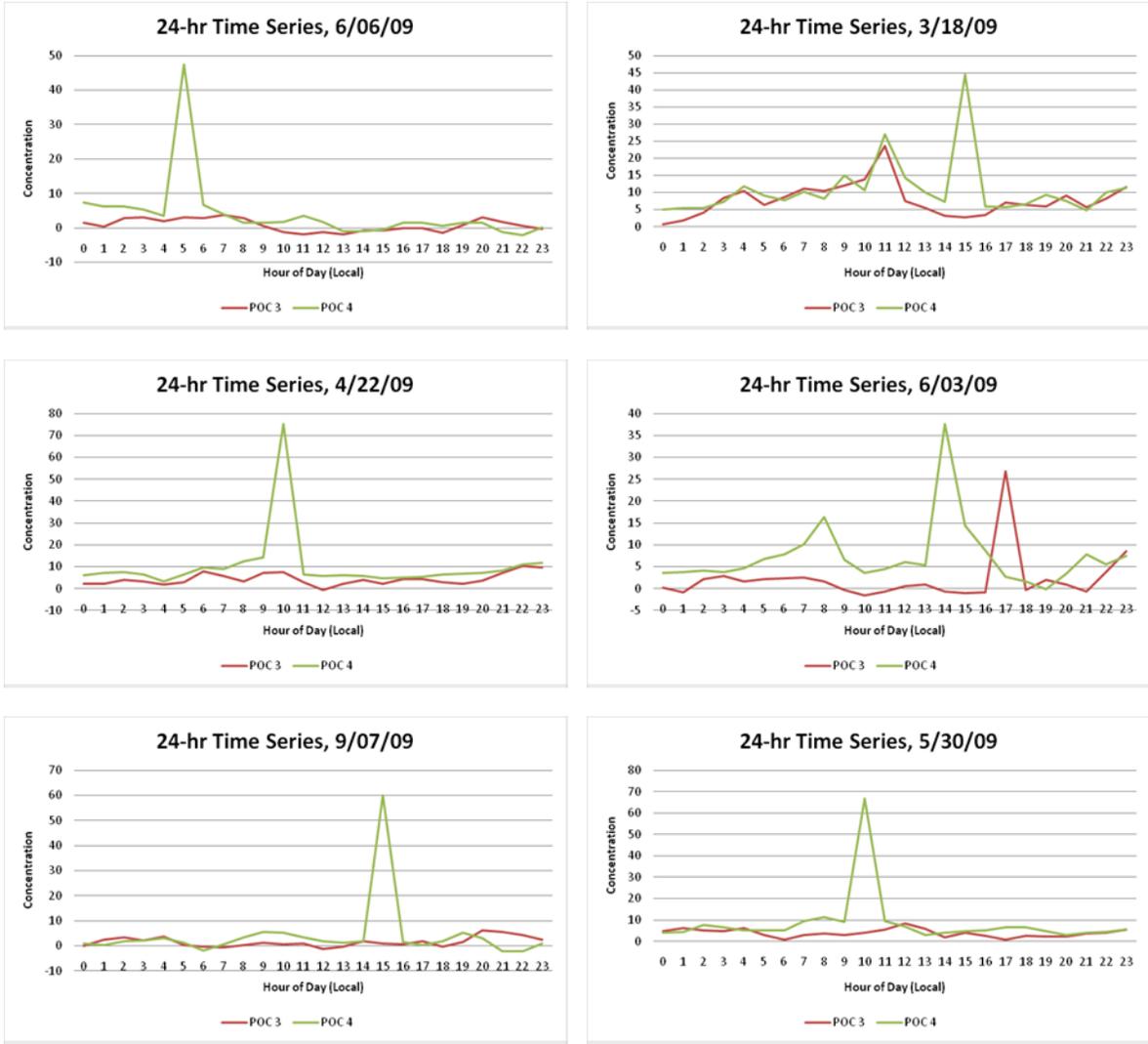


Figure 10. Various 24-hr time series of hourly $\text{PM}_{2.5}$ concentration ($\mu\text{g}/\text{m}^3$) for the two collocated monitors at the Missoula, MT site. On these days, POC 4 reported a high concentration value while POC 3 did not.

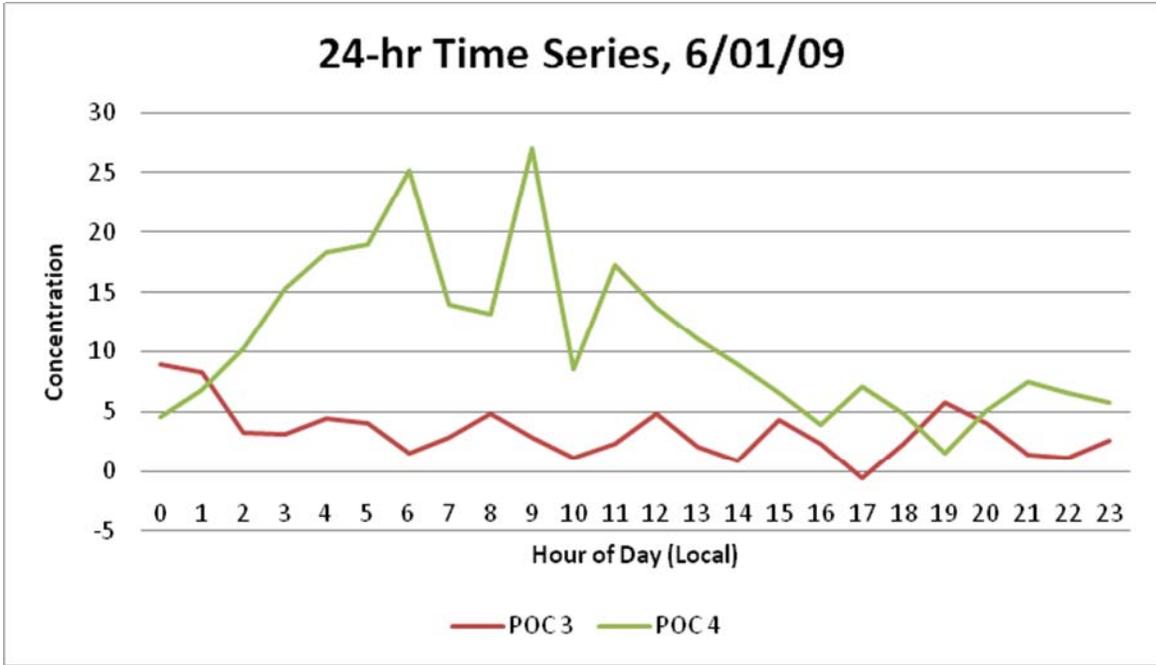


Figure 11. 24-hr time series of hourly PM_{2.5} concentration (µg/m³) for the two collocated monitors at the Missoula, MT site, on a day that POC4 exhibited erratic measurements while POC 3 did not.

4-hour Average PM_{2.5} Concentration (μg/m³) r=0.910

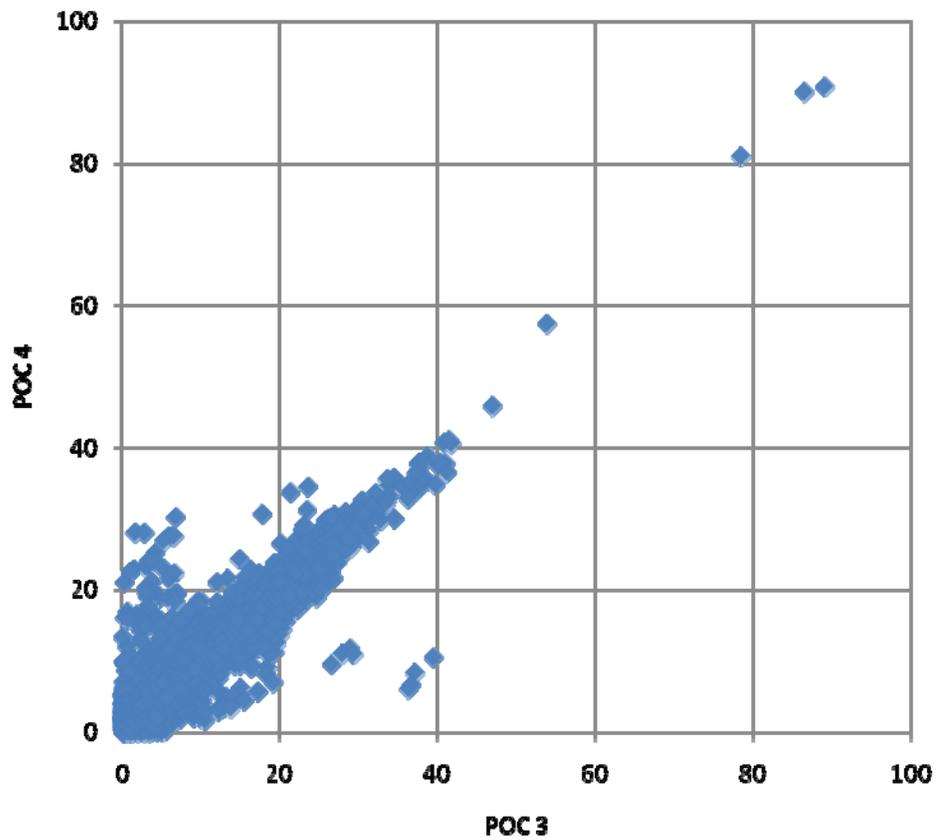


Figure 12. Scatter plot of 4-hour average concentration values for two collocated FEM monitors at the Missoula, MT (AQS ID 30-063-0024). Correlation coefficient r=0.910.

Annual Maximum Daily Maximum 4-hour Average PM_{2.5} Concentration (µg/m³)

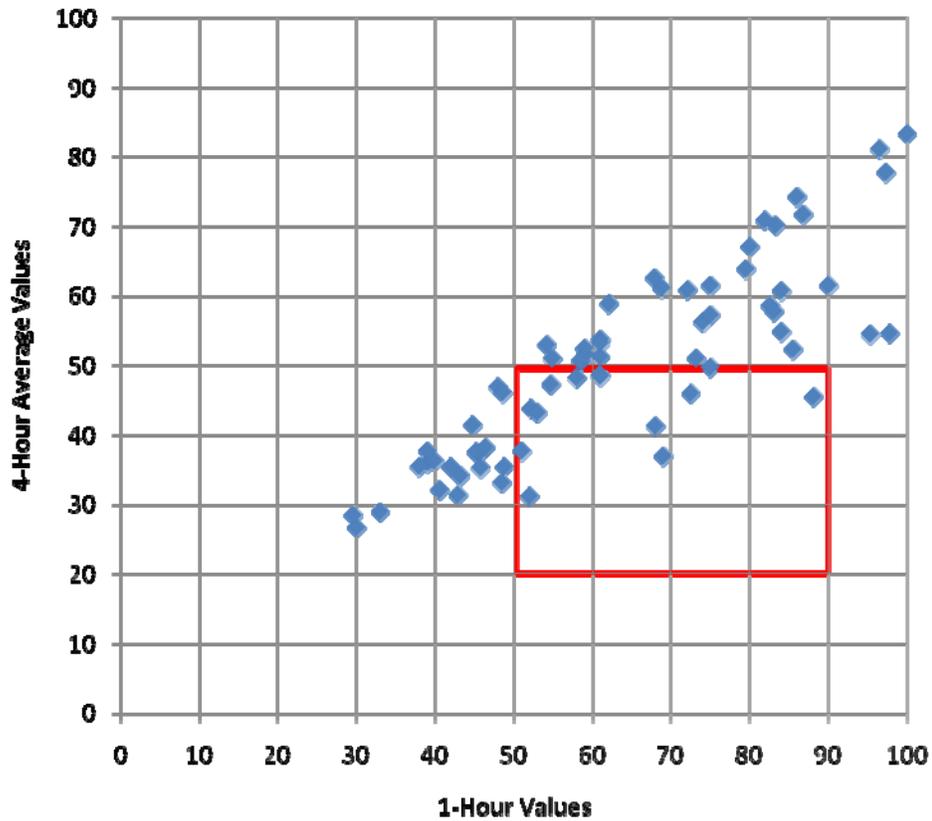


Figure 13. Magnified scatter plot of annual maximum daily maximum concentration values for 1-hour values vs. 4-hr average values. (Only pairs with both values less than 100 are shown.) Points in the red box represent a 1-hr value higher than 50 and a corresponding 4-hr average value within the 20-50 range of interest.

Annual 95th Percentile Daily Maximum 4-hour Average PM_{2.5} Concentration (µg/m³)

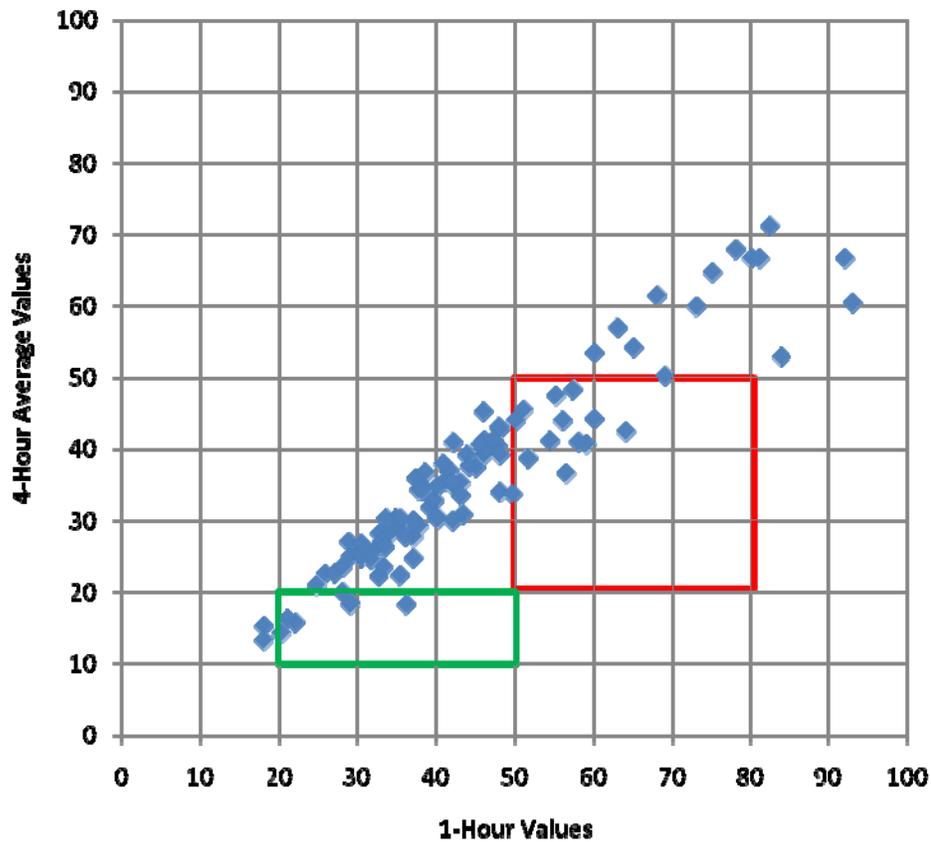


Figure 14. Scatter plot of annual 95th percentile daily maximum concentration values for 1-hour values vs. 4-hr average values. Points in the red box represent a 1-hr value higher than 50 and a corresponding 4-hr average value within the 20-50 range of interest. Points in the green box represent a 1-hr value within the 20-50 range of interest and a corresponding 4-hr average value less than 20.

Annual 90th Percentile Daily Maximum 4-hour Average PM_{2.5} Concentration (µg/m³)

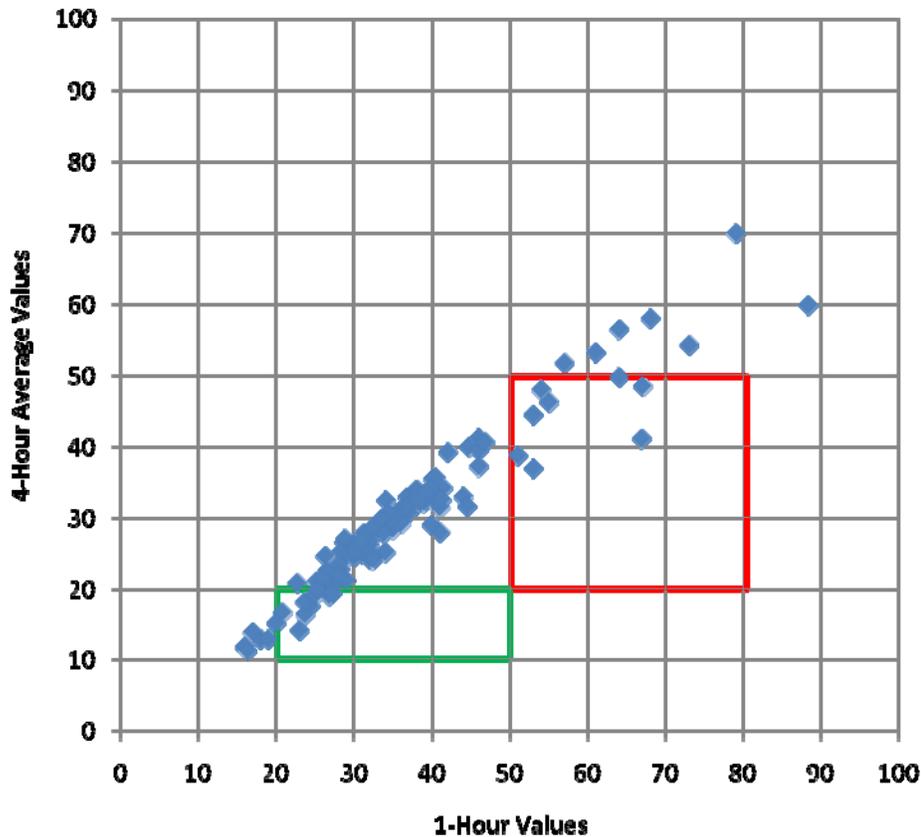


Figure 15. Scatter plot of annual 90th percentile daily maximum concentration values for 1-hour values vs. 4-hr average values. Points in the red box represent a 1-hr value higher than 50 and a corresponding 4-hr average value within the 20-50 range of interest. Points in the green box represent a 1-hr value within the 20-50 range of interest and a corresponding 4-hr average value less than 20.

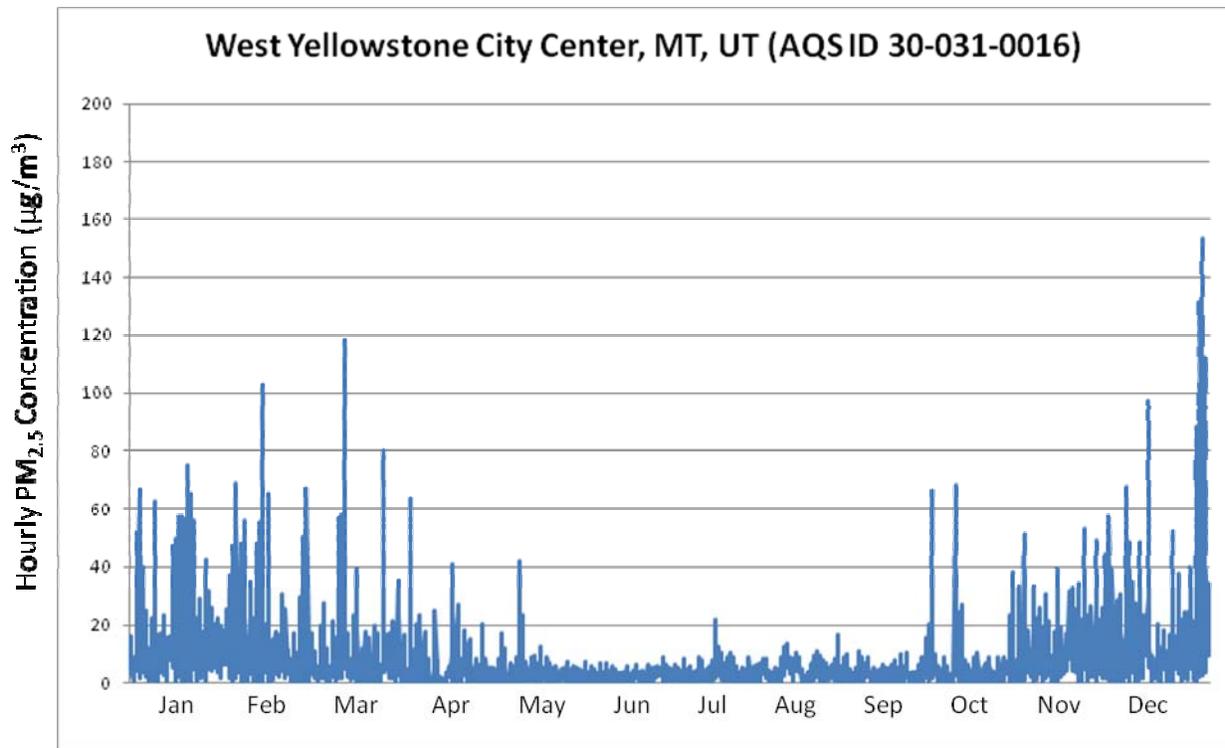


Figure 16. Time series of hourly PM_{2.5} concentration values for 2009

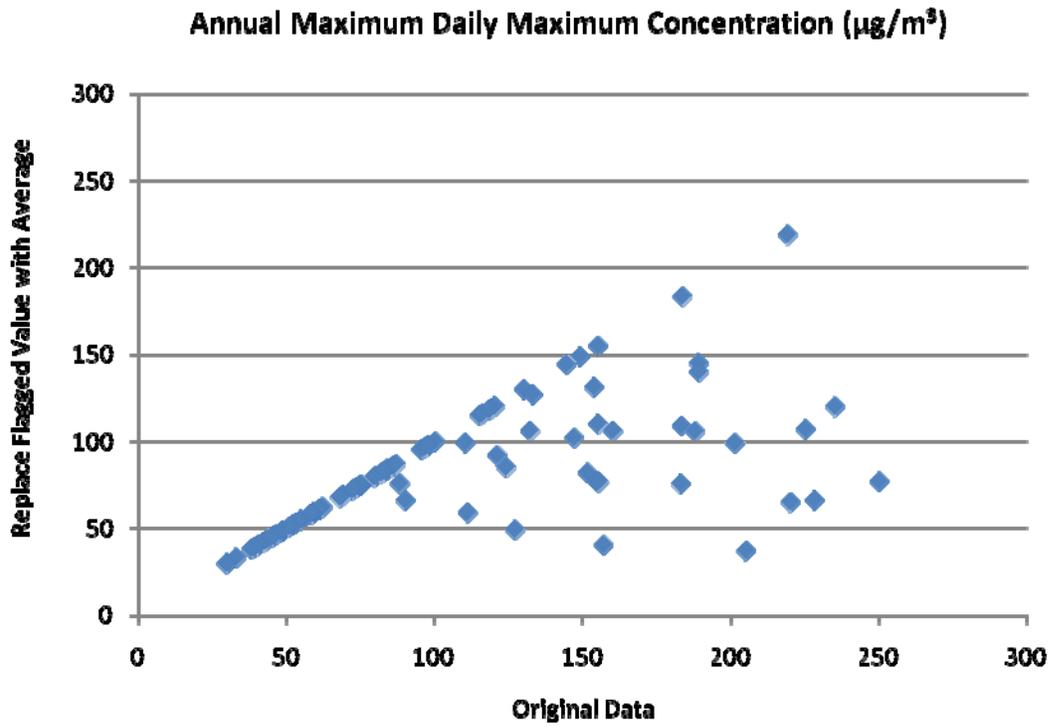


Figure 17. Scatter plots of Daily Maximum Concentration values for the 2009 data after having the sudden spike algorithm applied vs. data without any algorithm application (original).

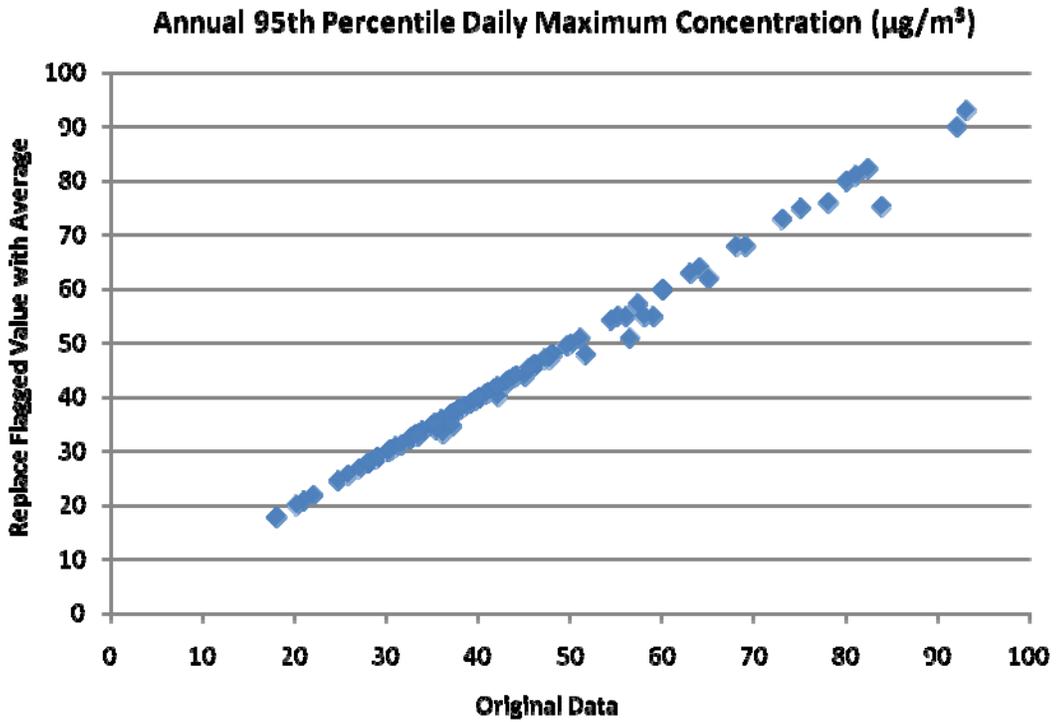


Figure 18. Scatter plots of Daily Maximum Concentration values for the 2009 data after having the sudden spike algorithm applied vs. data without any algorithm application (original).

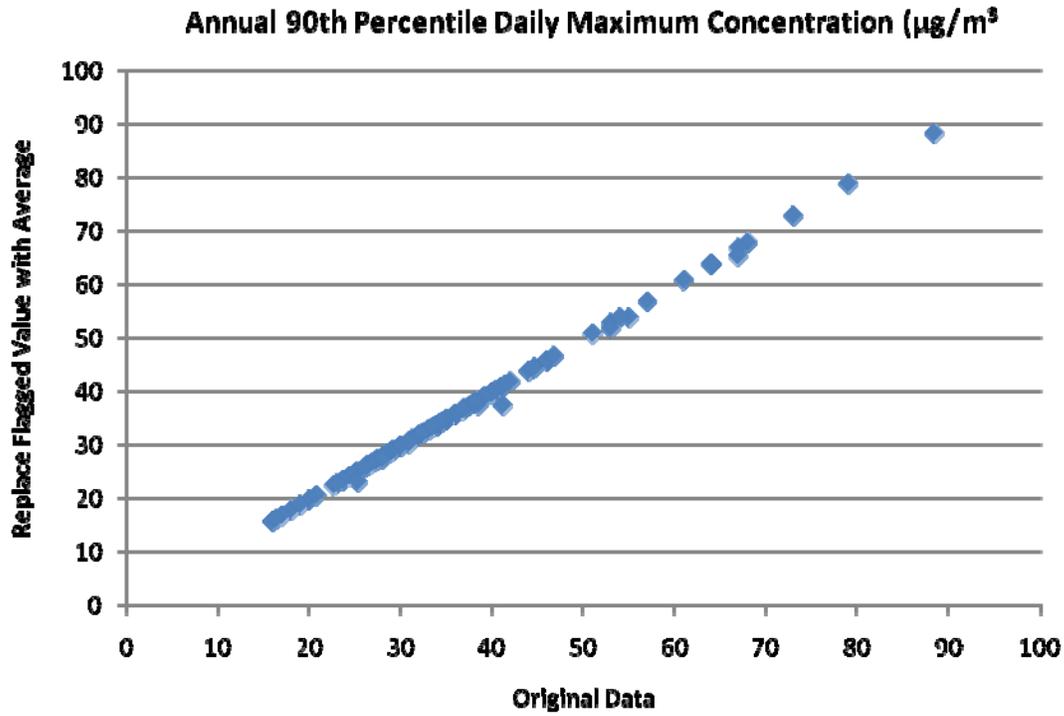


Figure 19. Scatter plots of Daily Maximum Concentration values for the 2009 data after having the sudden spike algorithm applied vs. data without any algorithm application (original).

Appendix A

Instructions for Access to Data Used in This Investigation

2009 Hourly PM_{2.5} concentration values from EPA-Approved Continuous Federal Equivalent Method Monitors.xlsx. This file can be downloaded at: <http://www.epa.gov/ttn/analysis/pm.htm>.

Monitoring site information for PM_{2.5} monitors, including those used in this investigation, can be downloaded at http://www.epa.gov/airexplorer/monitor_kml.htm. Select the file PM_{2.5} CSV (11.4MB) under the heading “Criteria Pollutants.”