



Minnesota Pollution
Control Agency

Technical Guidance

Filling Missing Ozone Data for OLM and PVMRM Applications

I. INTRODUCTION

As noted in a June 28th, 2010 [EPA memo](#) from Tyler Fox to the regional air division directors, with the new 1-hour NO₂ NAAQS standards, more attention must be paid to ozone concentrations that go into modeled NO₂ calculations.

“The representativeness of (ozone data) takes on somewhat greater importance in the context of a 1-hour NO₂ standard than for an annual standard, for obvious reasons. In the case of hourly background ozone concentrations, methods used to substitute for periods of missing data may play a more significant role in determining the 1-hour NO₂ modeled design value, and should therefore be given greater scrutiny, especially for data periods that are likely to be associated with peak hourly concentrations based on meteorological conditions and source characteristics. In other words, ozone data substitution methods that may have been deemed appropriate in prior applications for the annual standard may not be appropriate to use for the new 1-hour standard.”

In addition, the memo stated that, “hourly monitored ozone concentrations used with the OLM and PVMRM options must be concurrent with the meteorological data period used in the modeling analysis.”

Currently the MPCA uses concurrent hourly monitored ozone files in OLM and PVMRM applications. While ozone monitors are sparse in some parts of Minnesota, these hourly ozone files contain the most refined data available for use in model calculations. Unfortunately, along with the sparsity of monitors comes the problem of missing data. In light of EPA’s statements above on the importance of ozone substitution methods pertaining to missing data, this paper examines a technique that will refine the way missing ozone hours are filled when using Minnesota ozone data.

II. OZONE BEHAVIOR

In order to understand how to accurately represent missing hours, it’s important to understand the behavior of ozone in Minnesota. Data from the Shakopee, MN (summer) and Blaine, MN (winter) monitors from 2006-2010 have been combined to show how average ozone varies seasonally in Minnesota (Figure 1). Sunlight helps create ozone so it makes sense that the longer days of the warm season produce more ozone than the shorter days of the cold season. For instance in figure 1 you can see a general increase in ozone as length of day increases and a general decrease as length of day decreases. The exact cause of the April peak in this data is unknown. In a study conducted between 1977 and 1981 in Minnesota by Pratt et al (1983) a similar spring peak in average ozone was noted, however the peak was in May instead of April. That study cited work by Johnson and Viezee (1981) that showed stratospheric intrusions of ozone have a higher impact on tropospheric ozone values in the spring. Another possibility is that smoke from seasonally prescribed burns contributes higher levels of background ozone.

Seasonal Cycle

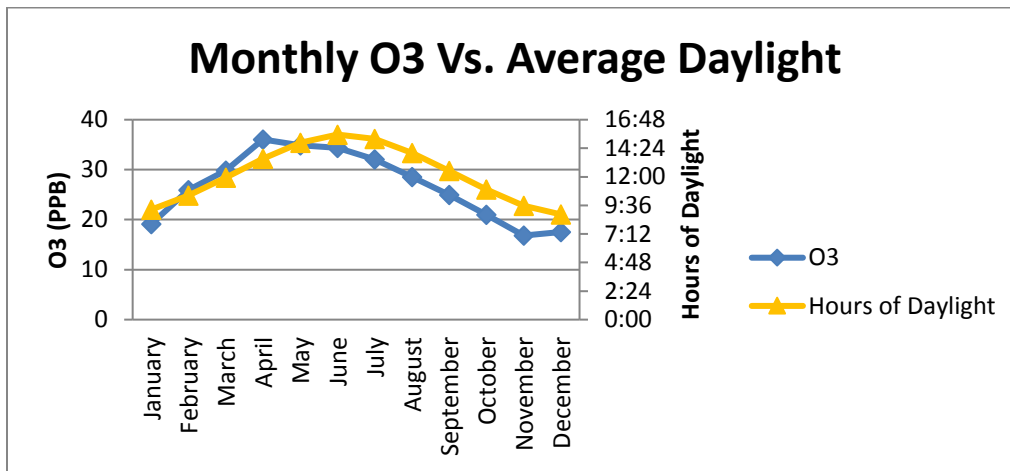


Figure 1: The more daylight, the more ozone

In addition to the seasonal ozone cycle, there's also a daily ozone cycle. Since sunlight helps create ozone, the longer the sun has been up, the more ozone that's potentially produced. That's one reason ozone is normally highest in the afternoon. Ozone values are also normally highest in the afternoon because the reactions that create ozone speed up with warmer temperatures. On the flip side, the lowest ozone values normally occur after the sun has been down for a significant length of time; during the cool morning hours. Figure 2 shows maximum and average values of ozone for morning, afternoon and night for each month in the Shakopee and Blaine data. The time periods were partitioned with morning starting at sunrise and running until noon, afternoon starting at noon and running until sunset, and night starting at sunset and running until sunrise. Average monthly sunrise and sunset times in Minneapolis were used for the calculations.

Daily Cycle

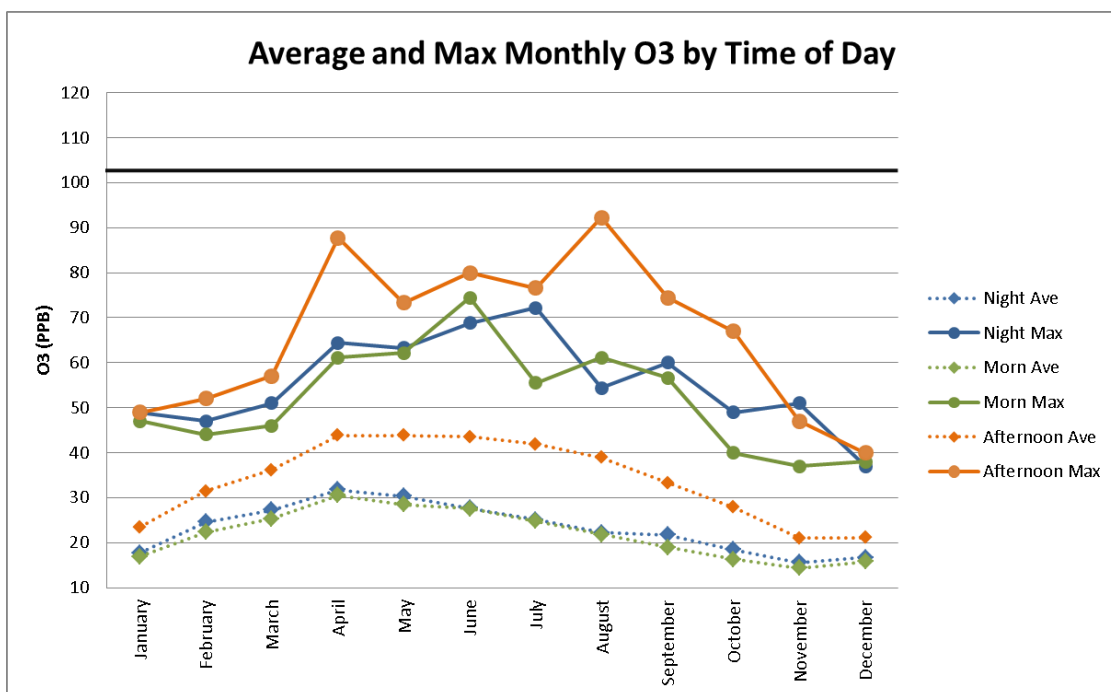


Figure 2: Ozone is normally at its peak in the afternoon, while minimums occur in the morning.

As expected, the highest maximum values normally occurred during the afternoon, while the lowest values normally occurred in the morning. Since each season and hour have different potential for ozone production, a representative method for filling missing data must take into account the seasonal and diurnal variation of ozone.

III. OLM AND PVMRM MISSING HOURS

The tier 3 NO₂ modeling methods of OLM and PVMRM outlined in 40 CFR Part 51 section 5.2.3 are becoming increasingly common as facilities try to meet the 1-hr NO₂ standards. The OLM method converts NO_x to NO₂ by reacting NO_x with ambient ozone. NO₂ formation is limited if the O₃ concentration is less than the NO_x concentration. If the O₃ concentration is greater than or equal to the NO_x concentration, all NO_x is converted to NO₂. PVMRM calculates NO_x plume volume at each receptor and then takes the ratio of the number of moles of O₃ in the plume to the number of moles of NO_x in the plume. That ratio is then multiplied by the NO_x concentrations modeled in AERMOD to determine the final NO₂ concentrations. While OLM and PVMRM applications at the MPCA use hourly monitored ozone data, we found there was no consistent agency wide approach for filling in missing hours. This challenge came to light when a value of **102 ppb (bold line Figure 2)** was proposed for filling in missing hours in the Shakopee/Blaine ozone data above. There are two potential problems with using 102 ppb:

- 1) That value is a max hourly value from data recorded in 2012, while the meteorological data came from the 2006-2010 timeframe. As stated in the EPA memo at the start of this paper, the ozone data must be concurrent with the meteorological data.
- 2) That value is not representative on multiple fronts. First it's 10 ppb higher than any value recorded in the Shakopee/Blaine data within the 2006-2010 timeframe. Second, it's a significant overestimate during the cold season and for many night and morning hours as it lacks any of the observed seasonal and diurnal variations.

IV. REVIEW OF STATE SPECIFIC METHODS

A review of state specific methods yields a range of processes and approaches to filling missing ozone hours. Several states mentioned allowing linear interpolation for short periods of missing data. Table 1 shows which time periods were chosen by each of those states and the year the recommendations were made.

	4 Hours	3 Hours	1 Hour
Michigan (2010)	X		
Florida (2010)		X	
California (2010)			X
California (2011)			X
Florida (2013)		X	

Table 1. Time periods of missing data where linear interpolation was recommended

When data was missing for a period longer than the allowed linear interpolation period, a variety of other methods were recommended. Table 2 contains a brief summary of those methods as well as the year the recommendations were made.

A few of the methods from table 2 will not be considered for implementation in Minnesota at this time:

- 1) The Nearby Monitor method used by California assumes there are other monitors in the vicinity that are available to supplement ozone data when a primary monitor is not collecting data. This may be true in some

states with an abundance of monitors, but in Minnesota there's no guarantee another monitor will be available to fill in missing hours.

- 2) The Day Before/After method used by Florida substitutes hourly values from the day before or after the day with the missing data. This method assumes there are not more than two consecutive days of missing data. That assumption was not true of the Shakopee and Blaine dataset which had entire months missing.
- 3) The Monthly Average method used by South Dakota takes an average of all the hours in a month for the entire modeled period and substitutes the average value for any missing hours. This method ignores diurnal variability and therefore has the potential to underestimate afternoon and evening ozone concentrations.

The methods found to be most feasible, protective and representative for Minnesota are methods that have been discussed by California(2011) and Arizona (2012, 2013). Those states offered a variety of options ranging from conservative to more representative methods. The most conservative options use either the H1H from the modeled period or a H1H annual value for each modeled year. The more representative options offer max seasonal, max monthly, and finally max monthly/hourly values to fill in missing hours. This final option captures both the seasonal and diurnal variability of ozone.

	Period H1H	Max Annual	Max Seasonal	Max Monthly	Month/hour max	Nearby Monitor	Day Before/After	Monthly Ave.
Michigan (2010)				X				
Florida (2010)							X	
California (2010)						X		
South Dakota (2011)								X
California (2011)		X	X	X	X			
Arizona (2012)					X			
Florida (2013)							X	
Arizona (2013)	X		X	X	X			

Table 2. Methods applied to fill in longer periods with missing data

In an August 2012 correspondence between the Arizona Department of Environmental Quality (ADEQ), Rosemont Copper and JBR Environmental Consultants, Inc. in relation to an Environmental Impact Statement, the ADEQ stated that in order to be defensible, the potential maximum ozone concentrations for specific missing hours should be estimated and input to the ozone file during pre-processing. ADEQ then provided a table broken down into monthly/hourly maxima that occurred over the modeled period to be substituted for missing hours. MPCA proposes using a strategy similar to the ADEQ strategy, thereby capturing both the seasonal and diurnal variability in ozone background files.

V. NEW METHOD FOR MINNESOTA

In the interest of protecting the NAAQS but striving for seasonally and diurnally representative ozone data, MPCA is adopting the following strategy for creating ozone files for OLM and PVMRM applications.

- 1) Ozone gaps should be filled in during preprocessing
- 2) Use linear interpolation for single missing hours
- 3) When missing more than a single hour, replace data gaps with monthly/hourly maxima from MPCA tables.

VI. EXAMPLES OF MINNESOTA'S NEW METHOD

The following observations are taken from the same Shakopee/Blaine dataset discussed above. The -99000 indicates hour 3 is missing from the January 7th, 2006 ozone data. Since this is just one missing hour, the value should be filled using linear interpolation.

	Year	Month	Day	Hour	(ppm)	(ppb)
142	6	1	6	22	0.008	8
143	6	1	6	23	0.016	16
144	6	1	6	24	0.018	18
145	6	1	7	1	0.019	19
146	6	1	7	2	0.021	21
147	6	1	7	3	-99	-99000
148	6	1	7	4	0.02	20
149	6	1	7	5	0.019	19
150	6	1	7	6	0.018	18
151	6	1	7	7	0.014	14
152	6	1	7	8	0.013	13

Table 3. Sample data with a single missing hour

$$\text{Hour 2} = 21$$

$$\text{Hour 4} = 20$$

$$\frac{21 + 20}{2} = 20.5 \text{ After rounding, Hour 3 should be replaced with 21}$$

The next example is from the same dataset a few days later. As shown in table 4, we're missing hours 14, 15 and 16.

	Year	Month	Day	Hour	(ppm)	(ppb)	
249		6	1	11	9	0.001	1
250		6	1	11	10	0.005	5
251		6	1	11	11	0.009	9
252		6	1	11	12	0.015	15
253		6	1	11	13	0.017	17
254		6	1	11	14	-99	-99000
255		6	1	11	15	-99	-99000
256		6	1	11	16	-99	-99000
257		6	1	11	17	0.003	3
258		6	1	11	18	0.002	2
259		6	1	11	19	0.002	2
260		6	1	11	20	0.002	2
261		6	1	11	21	0.002	2

Table 4. Sample data with more than a single missing hour

In this case the recommendation is to use the following table of maximum monthly and hourly values from the Shakopee and Blaine 2006-2010 data, produced by the MPCA to replace the missing hours.

Example Table

Hour	January	February	March	April	May	June	July	August	September	October	November	December
1	44	44	45	60	60	60	61	50	59	43	44	37
2	45	43	46	59	57	59	58	49	58	38	44	37
3	44	42	46	58	56	60	57	50	56	36	43	37
4	46	42	44	58	52	60	56	51	50	37	42	36
5	45	42	43	57	52	56	51	52	48	30	40	36
6	49	42	44	54	57	58	53	52	44	37	38	35
7	47	42	44	51	62	57	50	52	46	38	36	36
8	46	41	42	47	54	53	48	43	44	39	37	37
9	46	41	42	49	57	60	50	44	46	38	37	37
10	46	43	44	53	57	70	53	52	52	40	37	37
11	45	44	46	61	60	74	56	61	57	38	37	38
12	44	46	48	68	68	76	63	63	60	44	38	39
13	48	47	49	69	72	78	71	72	61	52	43	40
14	49	49	51	70	72	79	72	87	63	58	46	40
15	48	49	57	70	72	77	70	92	64	63	47	40
16	47	52	57	86	73	77	74	90	69	67	47	39
17	45	51	57	88	72	80	76	86	74	64	43	36
18	46	49	56	74	72	78	77	66	70	54	45	36
19	46	47	52	76	70	73	71	63	58	49	50	37
20	47	41	51	71	66	70	61	54	54	45	51	37
21	49	43	47	64	63	69	60	53	54	42	47	36
22	49	43	48	62	60	69	72	54	58	41	44	35
23	45	42	47	60	58	68	66	54	58	45	43	36
24	45	44	45	56	59	62	63	52	60	44	45	37
Max	49	52	57	88	73	80	77	92	74	67	51	40

Table 5. Sample max monthly/hourly table of ozone values (ppb) to replace missing data

As seen in table 5, hours 14-16 would be replaced with 49, 48, and 47 ppb respectively. Looking back at table 4, these numbers are likely still very conservative estimates for these hours, but they are also much more representative than using the 102 ppb value originally proposed.

VII. EFFECT OF THE NEW METHOD ON MODELED RESULTS

MPCA conducted a sensitivity test using this new method to determine whether it could have practically significant effects on modeled NO2 results. The outcome of this testing showed that if the modeled maximum occurs on an hour with missing data, this method could have significant effects on modeled results depending on release height, release temperature and emission rate.

The following is example output from this testing. The example uses flat terrain, a stack height of 11m (mode of all permitted NOx sources in MN), a release temperature of 447 K (mean of all permitted NOx sources in MN), a diameter of .3m (mode of all permitted NOx sources in MN) and the tier 3 method of OLM.

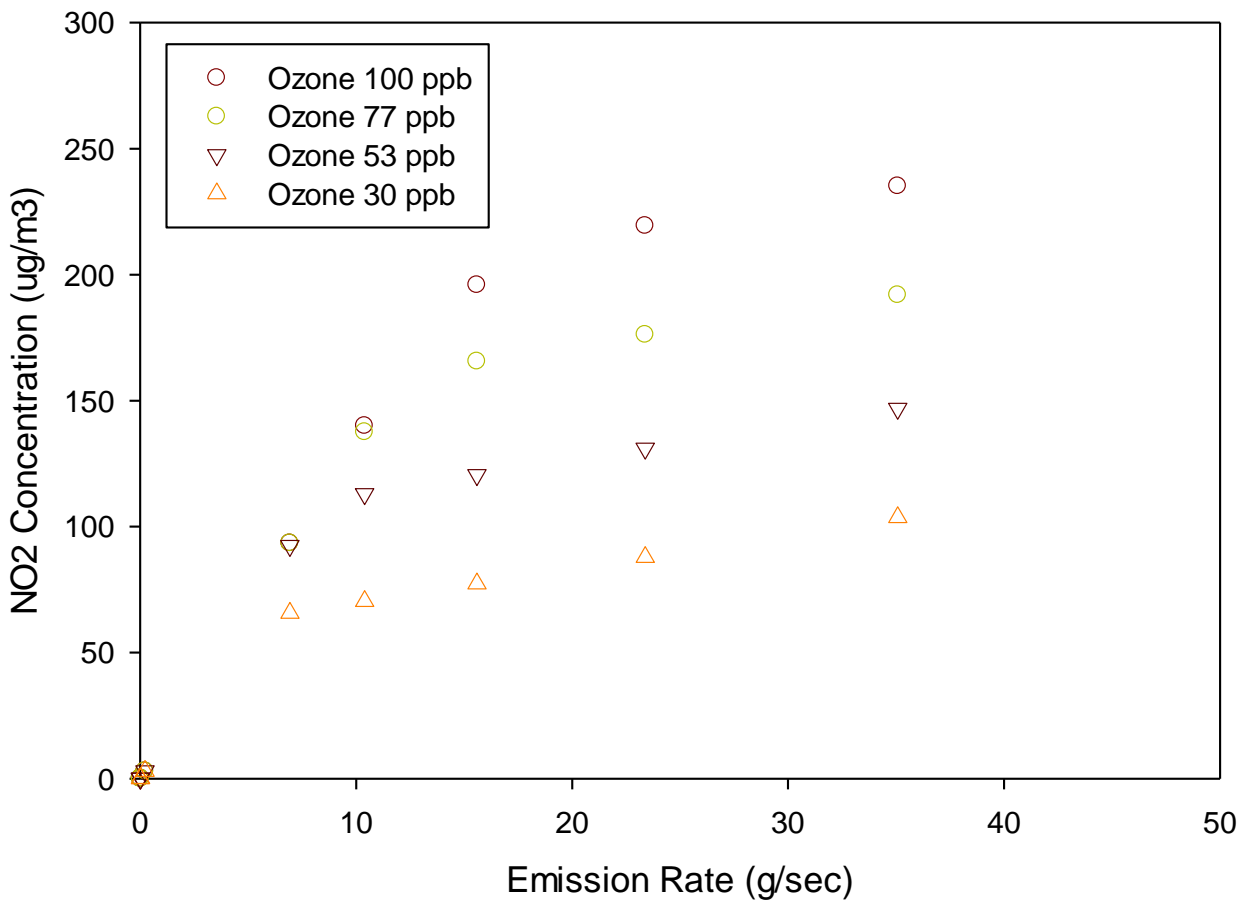


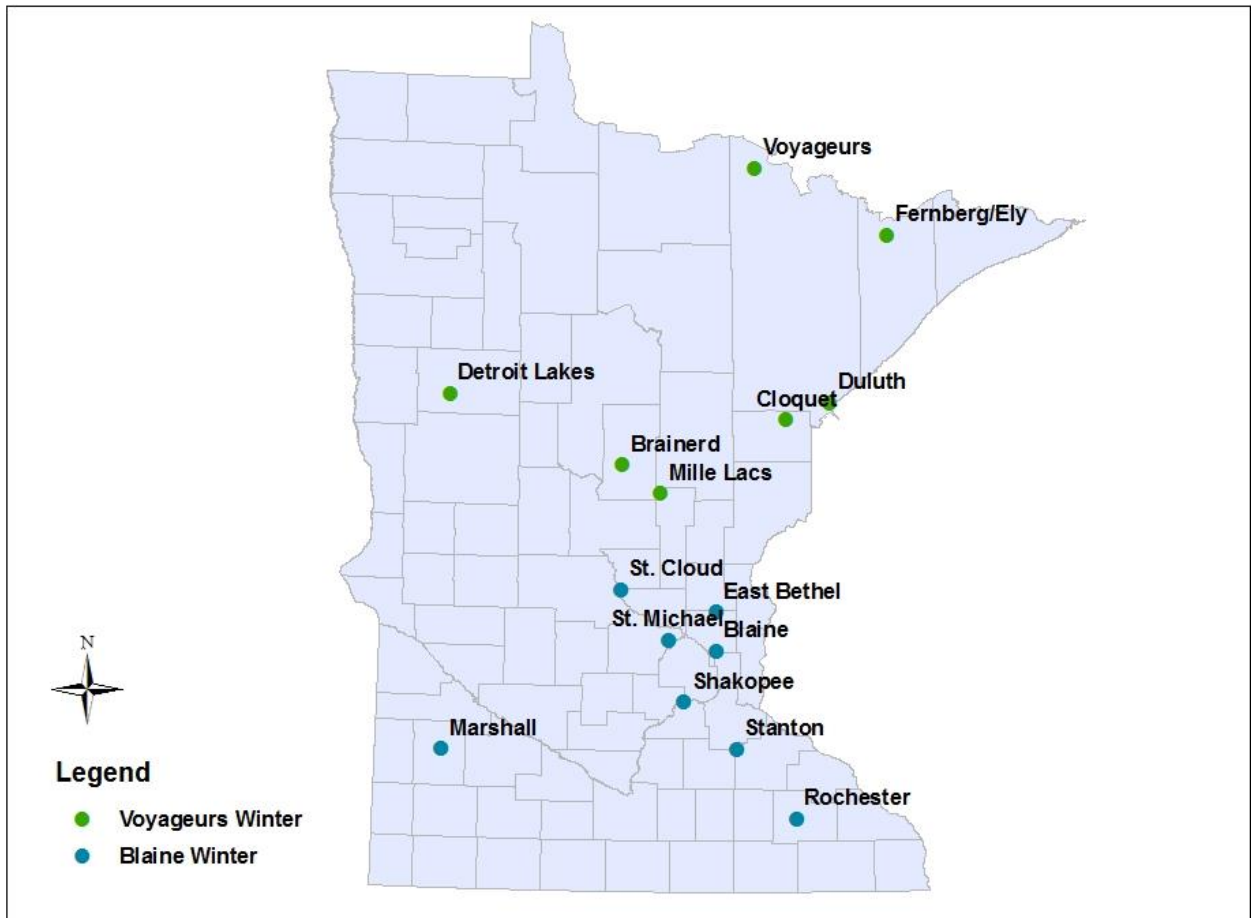
Figure 3. Ozone values can have practically significant impact on modeled results.

If figure 3 is examined for the 10.4 g/s emission rate, substituting 30 ppb instead of 100 ppb gives ~70 ug/m³ decrease in modeled NO2 concentrations. So using more representative but still protective ozone values, can indeed have a significant impact on modeled results.

VIII. IMPLEMENTATION

MPCA has completed automation of the ozone filling methods described in this paper. These methods were used to fill in missing hours during the warm season (April-September) for all monitors in Minnesota and during the cold season for the two cold season monitors: Voyageurs and Blaine. Voyageurs and Blaine were used to fill in Oct-Mar values for all the other monitors. Voyageurs was generally used for monitors in the northern part of Minnesota, with Blaine filling in winter hours for southern Minnesota.

Winter Ozone Assignments



If a project proposer plans to use OLM or PVMRM for an NO₂ modeling demonstration, MPCA recommends contacting the air modeler assigned to the project to request the pre-processed hourly ozone file for the proposed background monitor. The use of the pre-processed data will need to be documented in section K of the modeling protocol form (AQDM-01). The pre-processed ozone files are from 2006-2010 monitoring data to be concurrent with the meteorological data currently processed with AERMET 12345. MPCA is in the process of updating its meteorological data to AERMET 14134 for the period of 2008-2012. As the meteorological data are updated, new concurrent hourly ozone files will be created.

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