Ambient Fine Particulate Matter ($PM_{2.5}$) Research Program –Upper Ohio River Valley Project: Data Management and Analysis

Project Report

Submitted to the Project Sponsor

NATIONAL ENERGY TECHNOLOGY LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

Project Manager: William Aljoe

Authors

Kevin Crist, Ph.D.
Associate Professor
Ohio University
Athens Ohio
Ph: (740) 593-2096
Email cristk@ohiou.edu

Kuruvilla John, Ph.D.
Associate Professor & Graduate Coordinator
Department of Environmental Engineering
Texas A&M University - Kingsville
Kingsville, Texas 78363

Table of Contents

1.0 INTRODUCTION

There has been increased attention on the potential health impacts of fine particulate matter ($PM_{2.5}$). (Particles with an aerodynamic diameter equal to or less than 2.5-micron size are designated $PM_{2.5}$.) Recently this attention has been focused the anthropogenic sources of $PM_{2.5}$ and its precursors (e.g. coal fire power plants) in the Ohio River Valley. The United States Department of Energy, Environmental Protection Agency, and Ohio EPA have launched several extensive research programs in the Ohio River Valley to measure and characterize ambient $PM_{2.5}$.

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) is currently performing/supporting extensive $PM_{2.5}$ and priority pollutant monitoring campaigns in the Upper Ohio River Valley. The Upper Ohio River Valley Project (UORVP), operated by Advanced Technology Systems, Inc. (ATS) under contract to DOE, is one of the major monitoring campaigns supported by NETL. The goal of this monitoring program, which includes two urban, and two rural monitoring sites is to provide a solid scientific foundation for $PM_{2.5}$ regulatory decisions. This monitoring campaign evaluates a host of atmospheric species, including $PM_{2.5}$ and PM_{10} (with speciation), SO_2, O_3, NH_3, CO, HNO_3, NOx, and NOy. In addition, pertinent meteorological parameters such as temperature, wind speed, wind direction, UV flux, and barometric pressure are included.

This project provided data management and analysis support for UORVP and included the following:

1. Development and maintenance of a data management system for the Upper Ohio River Valley Project;
2. Provisions for quality control for the data management system; and
3. Support for data analysis for the Upper Ohio River Valley Project.

2.0 SCOPE OF WORK

The data obtained from the continuous analyzers supporting the UORVP project were formatted and maintained on a commercial data base system. Manual and automated reviews of the data were conducted to screen anomalies. Anomalies were then reviewed with ATS. A secure central server was established for data storage and retrieval at Ohio University. The Department of Environmental Engineering at Texas A&M University undertook a comprehensive analysis of the $PM_{2.5}$ data generated from the continuous monitors.

This report provides a preliminary review of the $PM_{2.5}$ data collected to date from the UORVP. The discussion focuses on transport of $PM_{2.5}$ with regard to meteorological parameters during high $PM_{2.5}$ episodes. A description of the sampling methods with additional analyses of the UORVP data sets completed by ATS including data obtained from discrete filter samplers is presented in their semi-annual progress report and is posted on NETL's web site (http://www.netl.doe.gov/coalpower/environment/air_q/am_monitor/uorvp.html).

3.0 METHODOLOGY

3.1 Monitoring Sites

Table 1 shows UORVP and other regional monitoring sites in Ohio and Pennsylvania with latitude and longitude description. For this preliminary study, ambient $PM_{2.5}$ data from four sites in the study region were selected and are indicated in bold type. Data was collected at the Lawrenceville (urban) and Holbrook (rural) sites by ATS under the U. S. Department of Energy sponsored UORVP. The Athens (rural) site was operated by Ohio University through a program sponsored by the Ohio EPA and the Ohio Air Quality Development Authority. The National Energy Technology Laboratory (NETL) operated a suburban site on their grounds in South Park Township. Hourly $PM_{2.5}$ and meteorological data were obtained for Lawrenceville and Holbrook and 3-hour averaged data were collected for NETL and Athens. The $PM_{2.5}$ data utilized in this analysis was obtained with Rupprecht & Patashnick's TEOM 1400a series particulate monitors operating at 50^{o} C.

Table 1. Monitoring Sites

State	Period	Data		Monitoring Sites	Latitude	Longitude
Ohio	1999-2001	Meteorological Data	$PM_{2.5}$	New Albany	40°14"83'	83°35"77'
				Athens	**39°54"32'**	**82°10"24'**
				Steubenville	40°36"17'	80°61"47'
Pennsylvania				**Lawrenceville**	**40°46"53'**	**79°96"03'**
				Holbrook	**39°81"60'**	**80°28"50'**
				NETL	**40°30"65'**	**79°97"94'**
				Kittanning	79°49"00'	40°81"34'
				Liberty	40°04"24'	79°66"03'
			PM_{10}	Flag Plaza	40°44"00'	79°99"00'
				Hazelwood	40°41"30'	79°94"00'
				Greensburg	40°30"21'	79°54"14'

3.2 Regional Analysis

Regional high $PM_{2.5}$ levels from the historical dataset were studied to evaluate high $PM_{2.5}$ episodes for Lawrenceville, Holbrook, Athens, and NETL. Athens was utilized in this analysis as the only upwind monitoring site. Air quality data for Athens were obtained for 1999 and 2000 while the other sites continued measurements through 2001. Regional episodes based on the days when the 24-hour averaged $PM_{2.5}$ values exceeded 25µg/m^3 were examined for the years 1999 through 2001 and are listed in Table 2.

3.3 High $PM_{2.5}$ Episode Analysis

Selected high $PM_{2.5}$ episodes were analyzed against meteorological parameters. High $PM_{2.5}$ episodes were evaluated with respect to characteristics of wind shift and wind speed. At least three consecutive days with 24-hour averaged $PM_{2.5}$ concentrations exceeding 25ug/m^3 were selected as typical high $PM_{2.5}$ episodes.

3.4 Pollution Rose Analysis

Wind direction, wind speed and $PM_{2.5}$ concentration on the days when the 24-hour averaged values exceeded 30 ug/m^3 were plotted with polar charts to evaluate dominant wind speed, and direction during high $PM_{2.5}$ days. This type of analysis is also called a pollution rose analysis.

3.5 Back Trajectory Analysis

Trajectories are used to aid in complex decisions regarding atmospheric transport pathways.[1] This analysis applied the hybrid single-particle lagrangian integrated trajectory (HYSPLIT4) model from the National Oceanic and Atmospheric Administration (NOAA)'s Air Resource Laboratory (ARL) to estimate backward trajectories.[2] The HYSPLIT4 model is used for atmospheric emergencies, diagnostic case studies or climatological analyses.[3] It should be noted that the accuracy of upper air data acquired from the HYSPLIT4 model is not ideal because of the lack of extensive upper air monitoring sites in Ohio. However, if a large amount of trajectories are averaged, the errors are decreased.[4] For this study, 24-hour back trajectories at 500 meters, which is generally in the middle of the mixed layer, were computed for days when the 24-hour averaged $PM_{2.5}$ values exceeded 30 ug/m^3. This study adapted a start time of 16 UTC (noon Eastern Standard Time).

3.6 Cluster Analysis

Cluster analysis of backward trajectories allows for the identification of a pollutant source region. This analysis consists of splitting a data set into several dominant groups that are homogeneous and as different from each other in some particular respect as possible. In this study, the clustering approach proposed by Dorling et al.[5] was chosen and modified. For each one-day (24-hour) back trajectory, six four-hourly x-y coordinates, which are end points of the trajectory location at every four-hour interval, are used as input variables for the clustering algorithm. The original clustering algorithm generated a large number of clusters specified as the seed trajectories. Each of the real trajectories are assigned to the seed that is closest in terms of the distance between their corresponding four hour interval coordinates. Then the seed or average trajectory of each cluster is recalculated with each real trajectory. The number of clusters can be reduced by the same process of merging two clusters whose average trajectories are closest.[4, 5] This algorithm, however, was slightly modified in this study. Each trajectory was assigned to several clusters in terms of the direction of the original source region. This region was defined by the x-y coordinates for the starting point of the 24-hour back trajectory. Main clusters in this study were divided into eight directional components, North, Northwest, West, Southwest, South, Southeast, East, and Northeast. An additional cluster category called "Close" was also added to highlight trajectories from close proximities. The transport path was calculated by averaging trajectories assigned to each cluster. Mercator projection was selected as a plotting projection of each cluster because this study involved a small region and this projection was more convenient to plot clusters than polar stereographic projection.

4.0 RESULTS AND DISCUSSION

4.1 Regional Analysis

An analysis of the regional data shown in Table 2 reveals that most high $PM_{2.5}$ episodes are typically observed over several consecutive days. The shaded values in the table indicate 24 hour averaged $PM_{2.5}$ values exceeding 25 $\mu g/m^3$ and the values in bold indicate exceedances of the NAAQS $PM_{2.5}$

standard of 65 $\mu g/m^3$. Usually high $PM_{2.5}$ values during these episodes occur almost simultaneously at all sites. This tendency is more prominent in 2001 than in 1999 and 2000. There were some missing data sets from the NETL site for 7/1/1999-9/30/1999, at the Athens site for the 9/1/2000-7/31/2001 and 8/12/1999-9/15/1999. During this period only the Lawrenceville site showed an exceedance day (July 17, 1999).

Table 2. Regional High $PM_{2.5}$ Days

Date	NETL	Lawrenceville	Holbrook	Athens
1-Jul-99		28	24	36
2-Jul-99		14	23	33
3-Jul-99		21	26	27
4-Jul-99		22	31	35
5-Jul-99		16	29	37
6-Jul-99		16	26	31
7-Jul-99		11	11	10
8-Jul-99		13	13	25
9-Jul-99		27	26	13
10-Jul-99		11	12	9
11-Jul-99		8	10	12
12-Jul-99		12	11	10
13-Jul-99		15	12	9
14-Jul-99		20	13	30
15-Jul-99		31	26	41
16-Jul-99		57	54	19
17-Jul-99		**66**	57	11
18-Jul-99		49	40	12
19-Jul-99		31	25	19
20-Jul-99		22	30	17
21-Jul-99		35	30	25
22-Jul-99		21	24	20
23-Jul-99		26	25	20
24-Jul-99		25	27	15
25-Jul-99		18	13	21
26-Jul-99		19	15	19
27-Jul-99		29	23	24
28-Jul-99		38	24	19
29-Jul-99			19	34
30-Jul-99			28	27
31-Jul-99			33	13
7-Aug-99		28	20	26
8-Aug-99		25	25	27
9-Aug-99		7	6	10
10-Aug-99		19	14	22
11-Aug-99		24	22	28
12-Aug-99		23	18	
13-Aug-99		31	25	
14-Aug-99		14	11	
15-Aug-99		9	13	
16-Aug-99		20	20	
17-Aug-99		36	27	
23-Aug-99		22	23	
24-Aug-99		33	26	
25-Aug-99		16	13	
26-Aug-99		16	16	
27-Aug-99		28	26	
28-Aug-99		32	26	
29-Aug-99		20	18	
1-Sep-99		26	14	
2-Sep-99		26	16	
3-Sep-99		25	19	
4-Sep-99		25	15	
5-Sep-99		13	8	
6-Sep-99		22	18	
7-Sep-99		26	21	
8-Sep-99		36	23	
9-Sep-99		47	22	
10-Sep-99		30	11	
11-Sep-99		24	13	
12-Sep-99		29	17	
13-Sep-99		36	22	
14-Sep-99		29	19	
15-Sep-99		23	11	
16-Sep-99		16	11	10
17-Sep-99		12	8	9
18-Sep-99		23	10	14
19-Sep-99		35	17	23
20-Sep-99		41	27	28
21-Sep-99		10	5	6
22-Sep-99		12	7	6
23-Sep-99		26	9	10
24-Sep-99		29	16	11
25-Sep-99		28	22	
26-Sep-99		30	22	
27-Sep-99		31	15	
29-Oct-99	18	27	17	27
30-Oct-99	26	31	26	29
31-Oct-99	24	33	24	26
1-Nov-99	22	30	19	21
9-Nov-99	17	24	21	17
10-Nov-99	25	29	27	22
11-Nov-99	8	14	17	21
12-Nov-99	15	17	19	17
13-Nov-99	25	28	26	24
14-Nov-99	17	22	27	13
15-Nov-99	3	5	4	17
16-Nov-99	3	5	5	
17-Nov-99	6	9	7	28
18-Nov-99	22	25	13	38
19-Nov-99	23	30	20	16
20-Nov-99	21	20	25	22

Date	NETL	Lawrenceville	Holbrook	Athens
4-May-00	20	26	18	10
5-May-00	25	32	24	
6-May-00	23	30	27	13
7-May-00	27	33	27	13
8-May-00	21	33	22	16
9-May-00	22	30	21	9
10-May-00	6	15	13	6
11-May-00	11	14	9	8
12-May-00	29	32	27	13
13-May-00	13	19	15	8
31-May-00	29	26	20	23
1-Jun-00	24	27	30	37
2-Jun-00	28	35	36	33
3-Jun-00	6	8	6	12
4-Jun-00	19	19	17	14
5-Jun-00	19	19	27	23
6-Jun-00	6	9	12	8
7-Jun-00	14	14	10	12
8-Jun-00	18	20	17	19
9-Jun-00	29	29	26	27
10-Jun-00	39	38	32	29
11-Jun-00	30	34	24	32
12-Jun-00		17	16	29
13-Jun-00		25	29	31
14-Jun-00		27	29	24
9-Jul-00		36	28	36
10-Jul-00	25	37	32	41
11-Jul-00	13	16	19	23
12-Jul-00	11	11	14	24
13-Jul-00		31	31	
14-Jul-00		29	26	29
15-Jul-00		14	12	14
16-Jul-00		18	12	11
17-Jul-00	8	19	17	12
18-Jul-00	13	21	18	28
26-Jul-00	16	22	25	22
27-Jul-00	19	20	39	24
28-Jul-00	26	33	28	27
29-Jul-00	23	26	19	22
30-Jul-00	19	26	22	16
31-Jul-00	16	23	18	16
1-Aug-00	21	24	20	22
2-Aug-00	27	32	24	27
3-Aug-00	19	23	21	19
4-Aug-00	6	8	14	11
5-Aug-00	10	13	12	12
6-Aug-00	24	29	24	29
7-Aug-00	9	16	21	16
8-Aug-00	19	26	21	21
9-Aug-00	15	22	18	17
15-Aug-00	24	33	26	31

Date	NETL	Lawrenceville	Holbrook	Athens
22-Aug-00	30	38	29	34
23-Aug-00	30	35	32	31
24-Aug-00	15	18	16	17
25-Aug-00	17	17	18	20
26-Aug-00	26	28	27	28
27-Aug-00	28	35	34	18
28-Aug-00	14	20	13	26
1-Sep-00	19	16	24	
2-Sep-00	19	15	24	
3-Sep-00	27	26	30	
4-Sep-00	19	24	23	
15-Oct-00	27	25	20	
16-Oct-00	27	24	24	
17-Oct-00	26	22	16	
18-Oct-00	22	20	19	
19-Oct-00	17	21	13	
20-Oct-00	18	23	13	
21-Oct-00	21	26	17	
22-Oct-00	18	19	21	
23-Oct-00	15	16	15	
24-Oct-00	26		17	
25-Oct-00	26		15	
26-Oct-00	21	23	18	
27-Oct-00	29	33	27	
2-Nov-00	22	21	9	
3-Nov-00	31	32	20	
4-Nov-00	12	19	9	
5-Nov-00	7	9	6	
6-Nov-00	9	13	6	
7-Nov-00	21	20	16	
8-Nov-00	34	34	16	
30-Apr-01	30	17	10	
1-May-01	33	23	20	
2-May-01	45	29	16	
3-May-01	51	36	16	
4-May-01	25	34	19	
5-May-01	13	17	24	
6-May-01	14	8	8	
7-May-01	17	8	10	
8-May-01	18	11	12	
9-May-01	27	16	7	
10-May-01	26	25	9	

Date	NETL	Lawrenceville	Holbrook	Athens
9-Jun-01	20	17	12	
10-Jun-01	35	22	14	
11-Jun-01	35	36	26	
12-Jun-01	27	35	25	
13-Jun-01	47	25	16	
14-Jun-01	31	43		
15-Jun-01	18	31	21	
16-Jun-01	12	16	11	
17-Jun-01	22	13	6	
18-Jun-01	29	23	11	
19-Jun-01	25	32	15	
20-Jun-01	27	34	19	
21-Jun-01	16	28	16	
22-Jun-01	13	16	12	
23-Jun-01	17	14	11	
24-Jun-01	30	19	11	
25-Jun-01	33	26	18	
26-Jun-01	32	30	24	
27-Jun-01	31	40	18	
28-Jun-01	34	35	23	
29-Jun-01	24	45	28	
30-Jun-01		34	14	

4.2 High $PM_{2.5}$ Episodes Analysis:

Figures 2 through 4 show characteristics of wind shift and speed with $PM_{2.5}$ concentration during high $PM_{2.5}$ days. Two major patterns are seen with these episodic events which occurred during the spring and summer months. First , are the $PM_{2.5}$ episodes associated with a wind shift followed by calm winds, which would indicate the impact of local sources. A typical example of this was observed at the Lawrenceville site May 4th through the 6th (Figure 2-1) and May 2nd through the 4th (Figure 2-2), which experienced northerly calm winds during the episode. The second pattern observed on high $PM_{2.5}$ days was associated with strong southerly winds (from the southeast through the southwest), which would indicate the transport of pollutant concentrations across the region. This pattern was typical for a majority of the Holbrook events and was also observed during the May 8th and 9th high $PM_{2.5}$ days at Lawrenceville (figure 2-1).

This analysis reveals several consistent patterns during high $PM_{2.5}$ episodes. However, in order to evaluate these tendencies more detail analyses of synoptic surface winds, local emissions, and photochemical influences needs to be conducted.

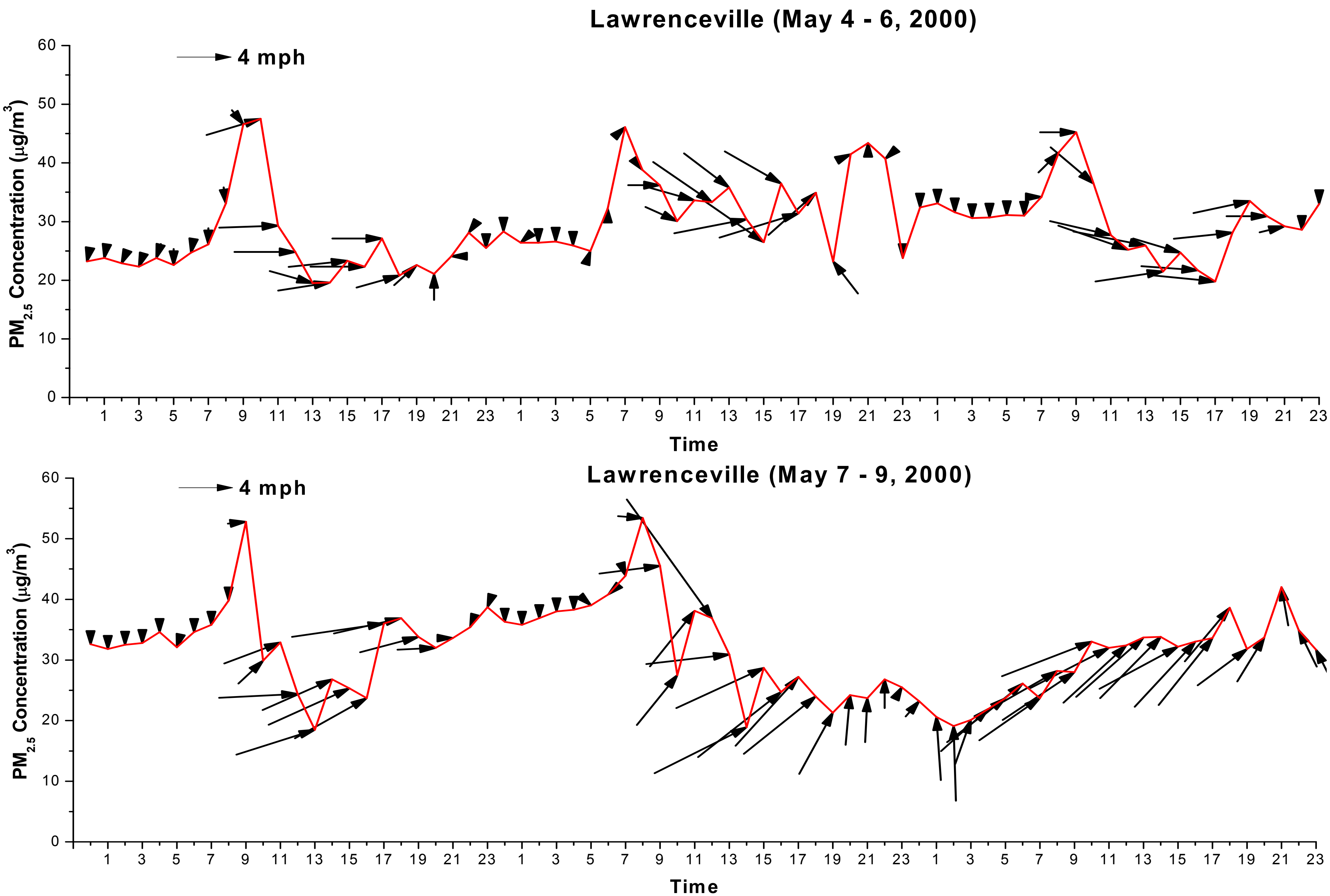


Figure 2-1. High PM Episodes in Lawrenceville (May 4-9, 2000)

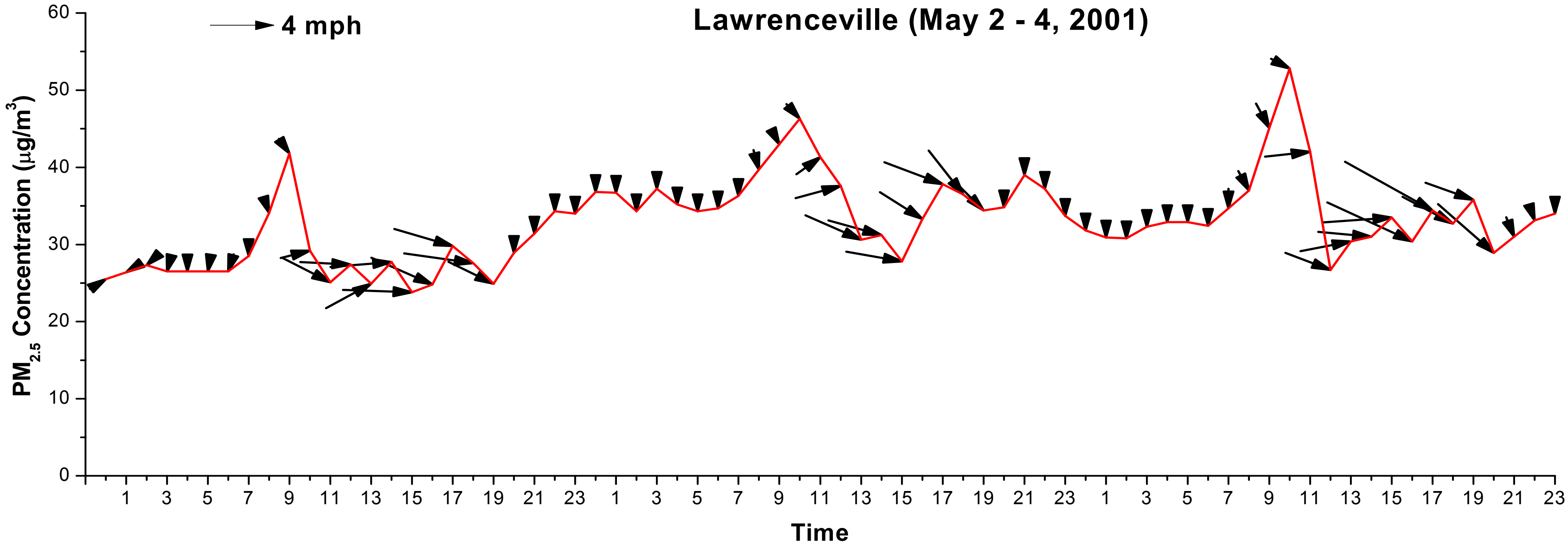


Figure 2-2. High PM Episodes in Lawrenceville (May 2-4, 2001)

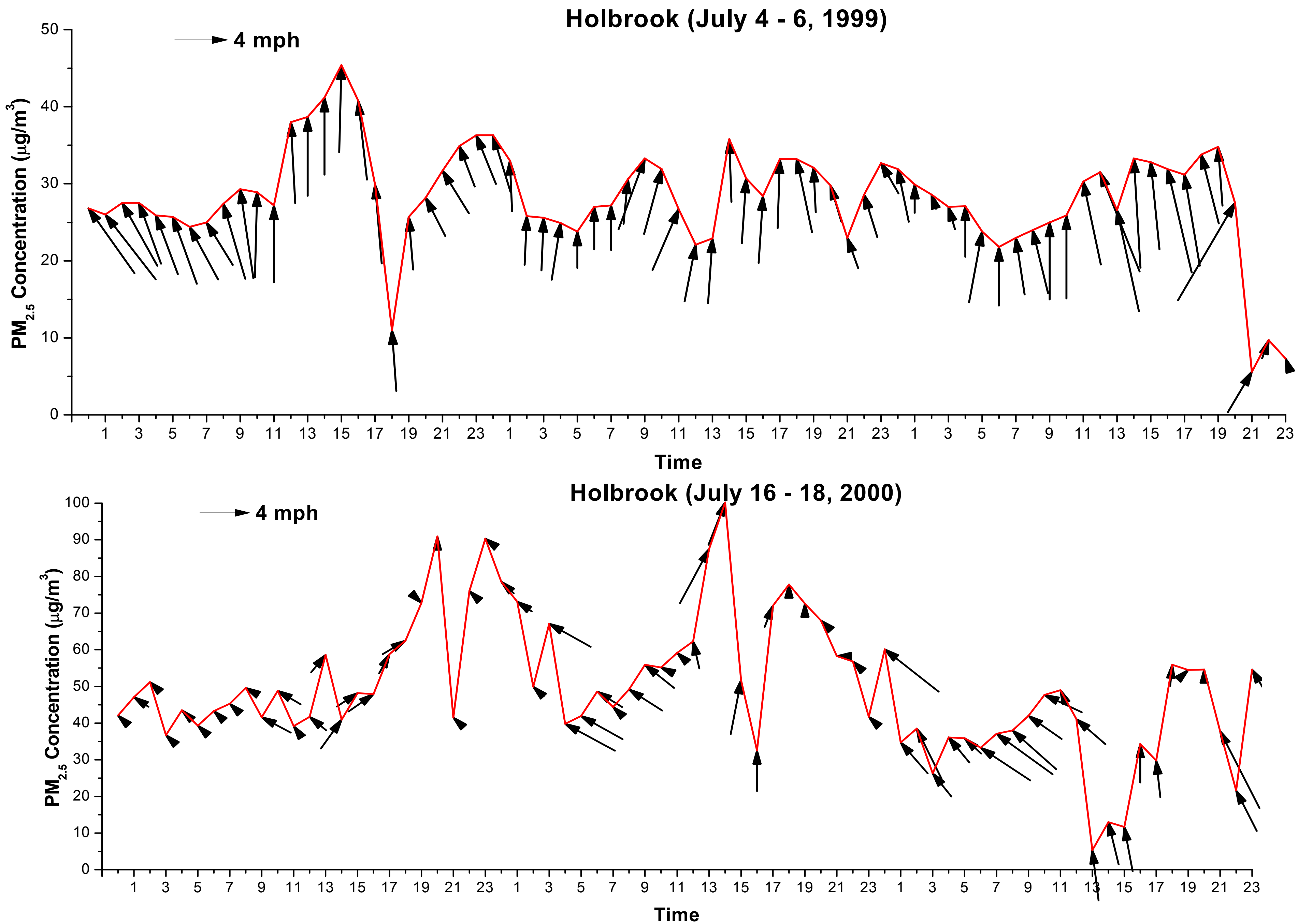


Figure 3-1. High PM Episodes in Holbrook (July 4-6, 2000 and July 16-18, 2000)

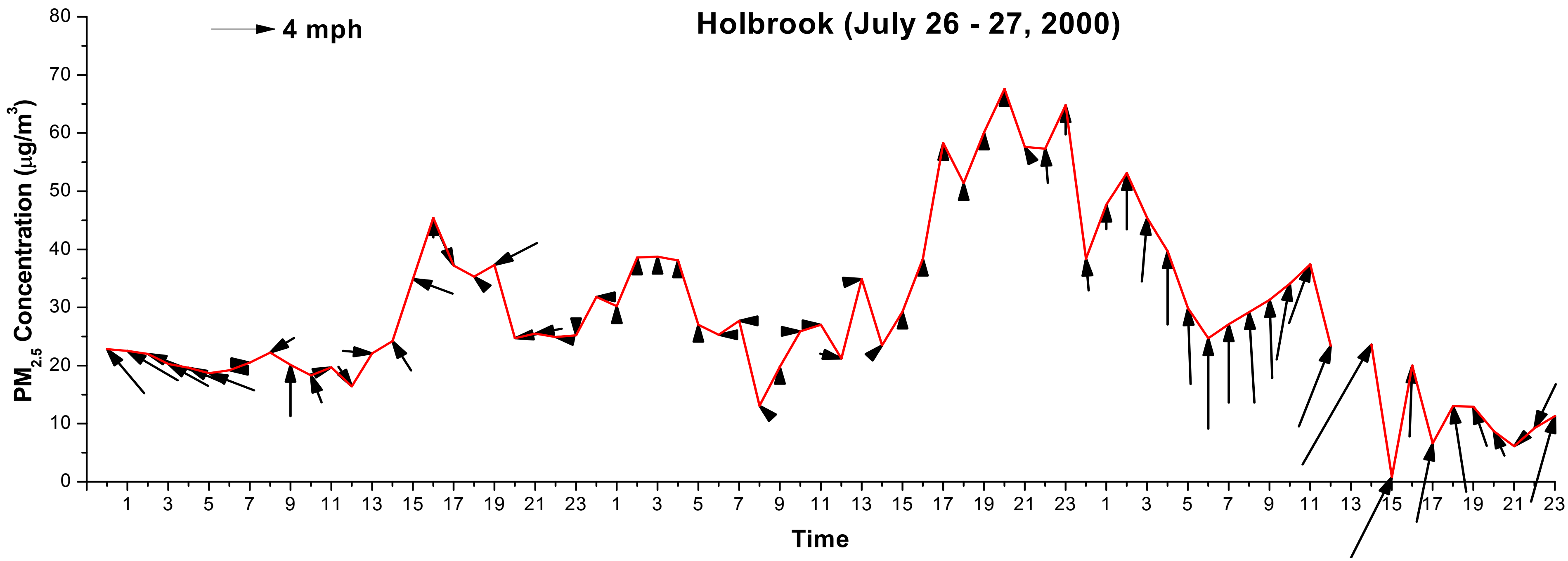
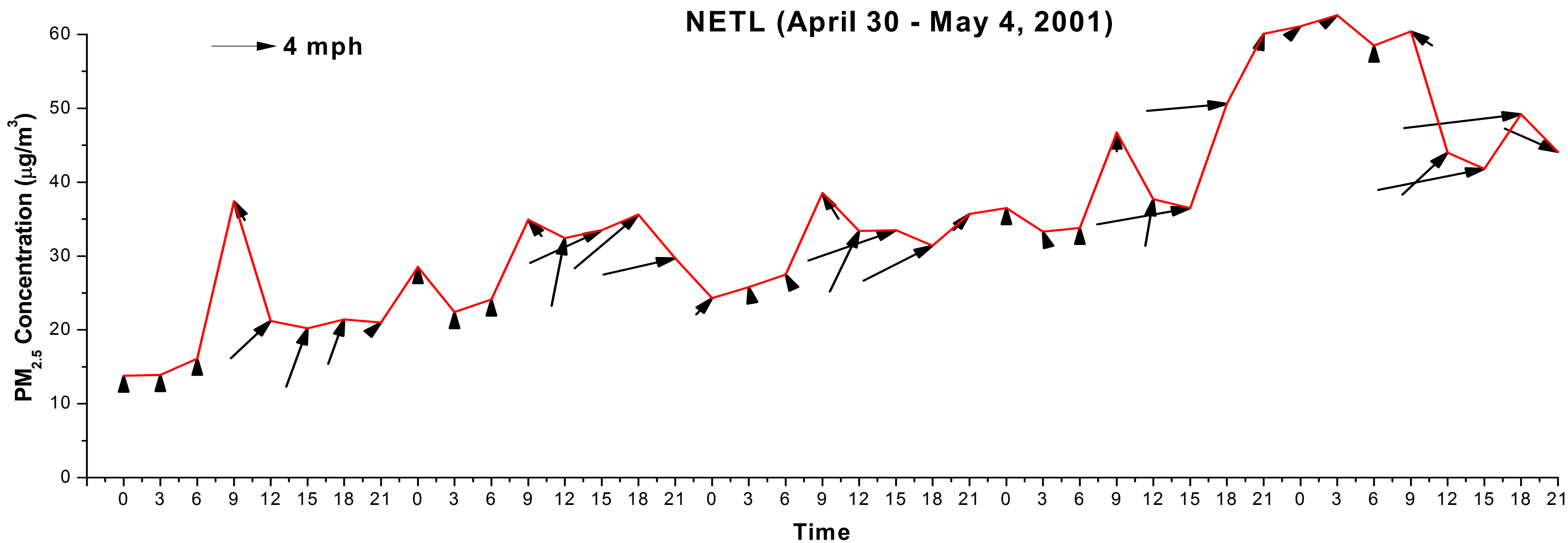


Figure 3-2. High PM Episodes in Holbrook (July 26-27, 2000)



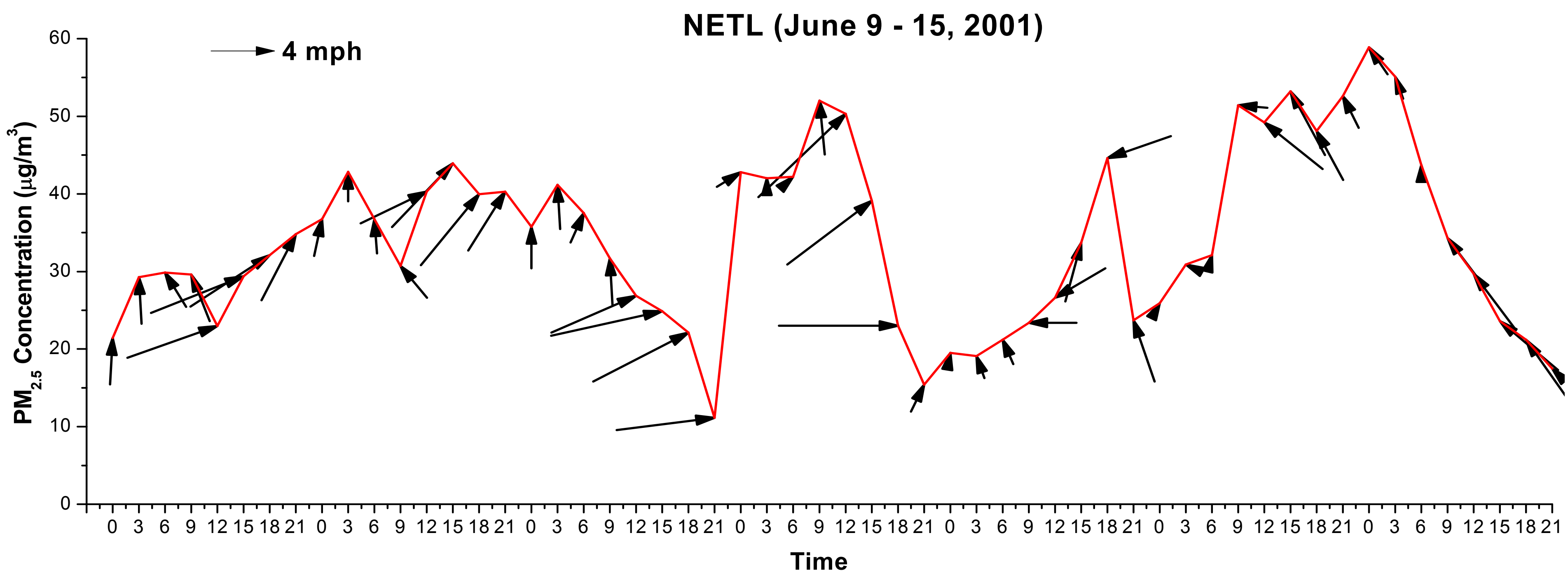


Figure 4. High PM Episodes in NETL (April 30-May 4, 2001 and June 9-15, 2001)

4.3 Pollution Rose Analysis

Wind frequencies along with wind speed and $PM_{2.5}$ concentration are plotted in Figures 5 through 7. High $PM_{2.5}$ days, (when the 24 hour average exceeded 30 μg/m^3), were selected for 1999 and 2000 at Lawrenceville, Holbrook, and NETL. It was observed that winds during high $PM_{2.5}$ days for Lawrenceville were distributed from the north to the southeast. For this site the southwesterly wind was the dominant direction, with the northerly winds mainly associated with calm conditions. Wind speeds during high $PM_{2.5}$ episodes were generally within 6 mph.

At Holbrook high $PM_{2.5}$ levels were frequently associated with winds out of the southwest to the southeast. At NETL the winds were mainly out of the south and southwest.

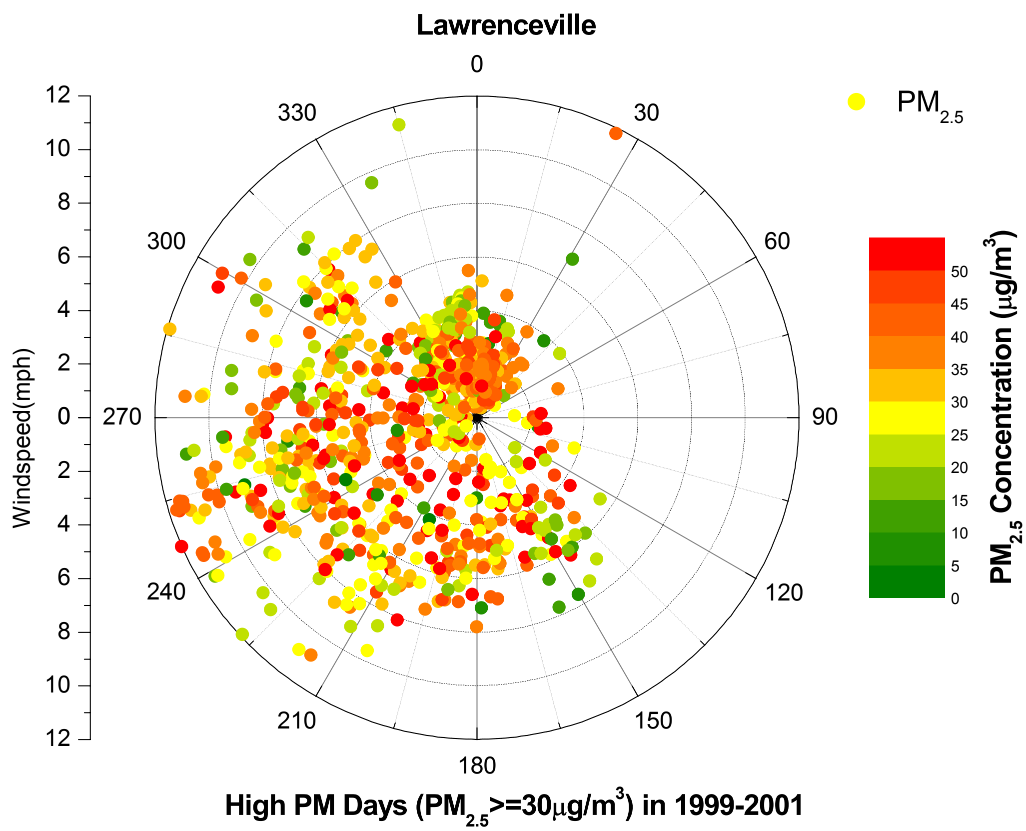


Figure 5. Pollution Rose for Lawrenceville, 1999-2001

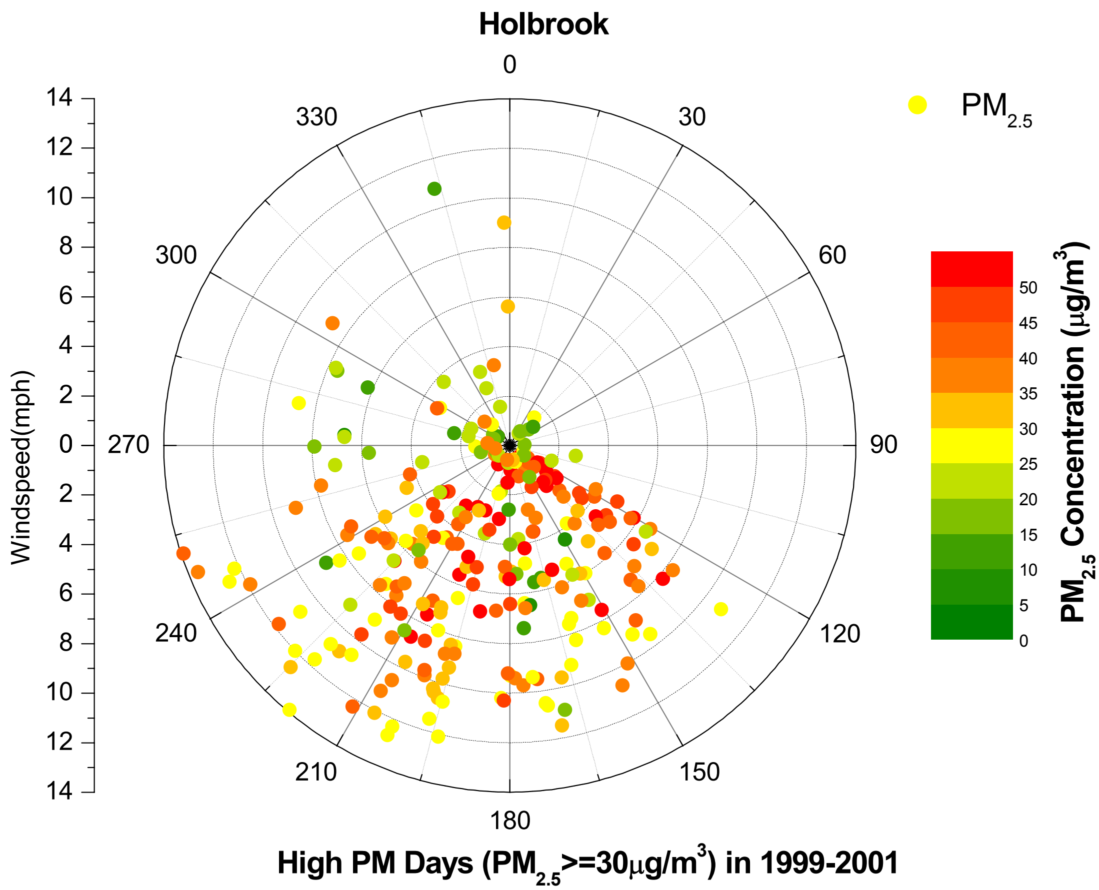


Figure 6. Pollution Rose for Holbrook, 1999-2001

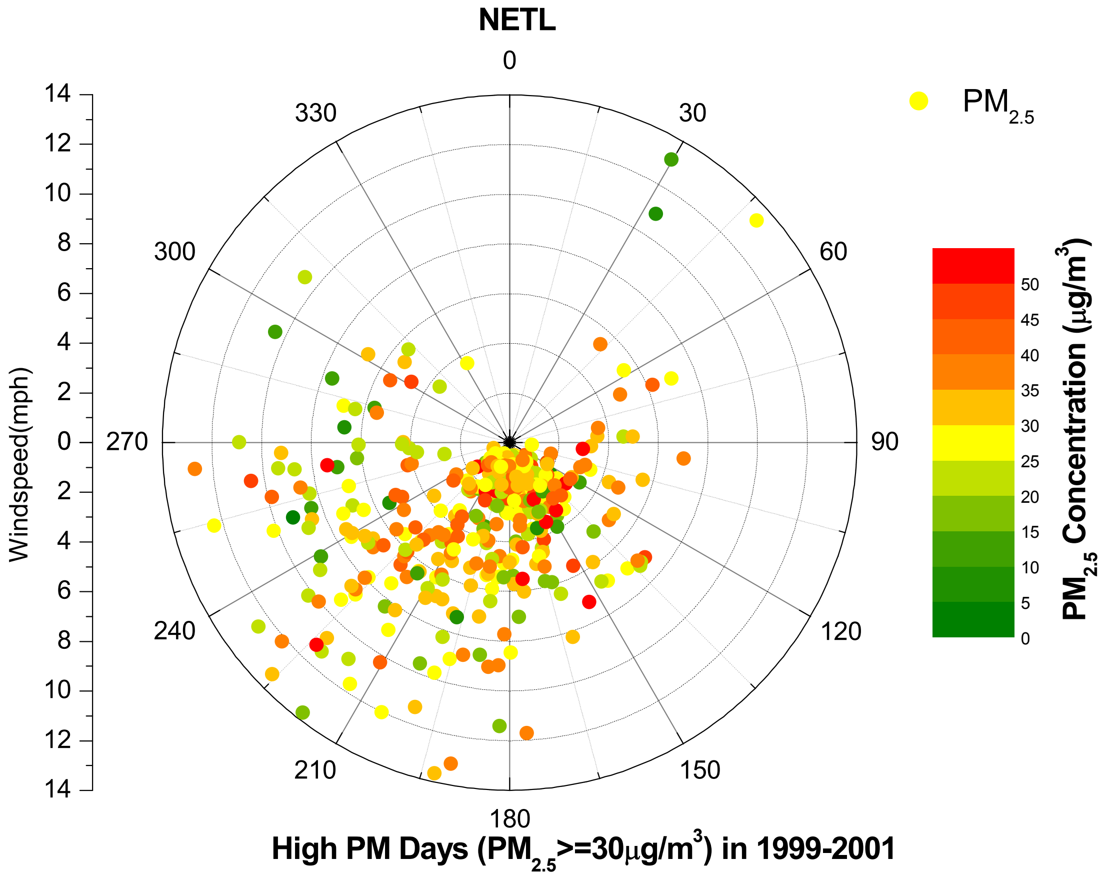


Figure 7. Pollution Rose for NETL, 1999-2001

4.4 Back Trajectory Analysis

Back trajectories can indicate potential source regions. For the study period, (1999 through 2001), 24-hour back trajectories at 20 UTC and 500 meters for high $PM_{2.5}$ days (>30 $\mu g/m^3$) were obtained using the HYSPLIT4 model from NOAA's Air Resource Laboratory (ARL) and are presented in Figures 8 through 10. These plots indicate that the major air parcel during high $PM_{2.5}$ days came across southeast Ohio with a few trajectories from the west and the south.

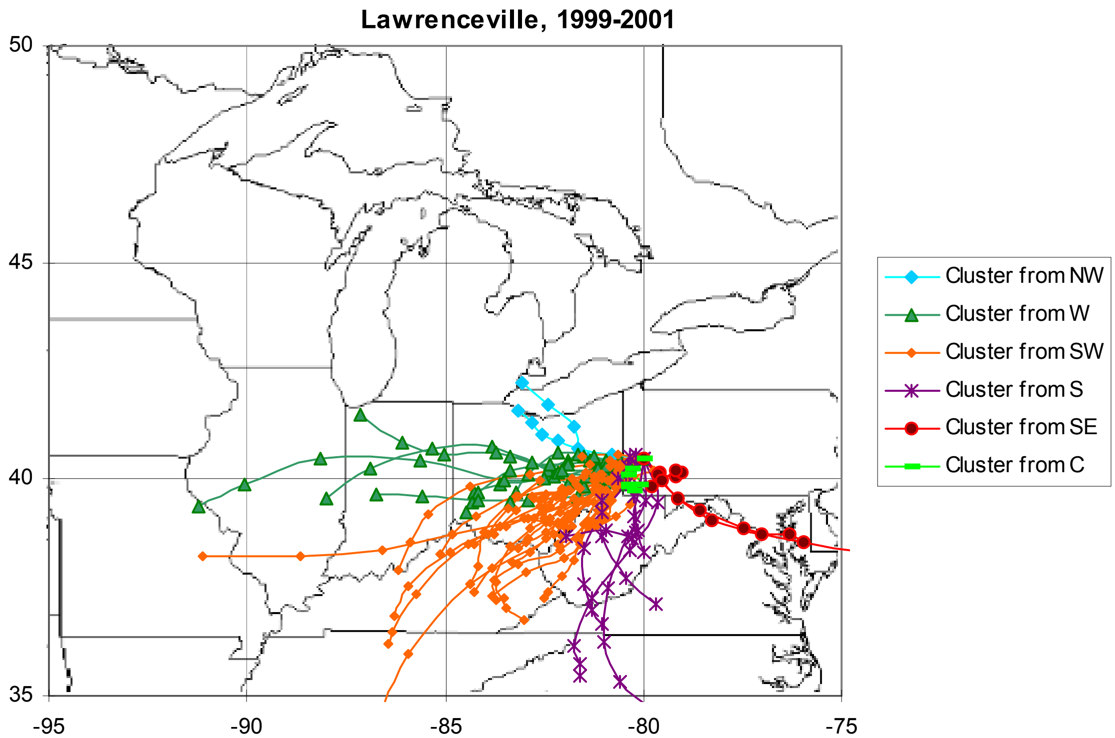


Figure 8. Back Trajectories on high $PM_{2.5}$ days for Lawrenceville, 1999-2001, 20 UTC, 500m

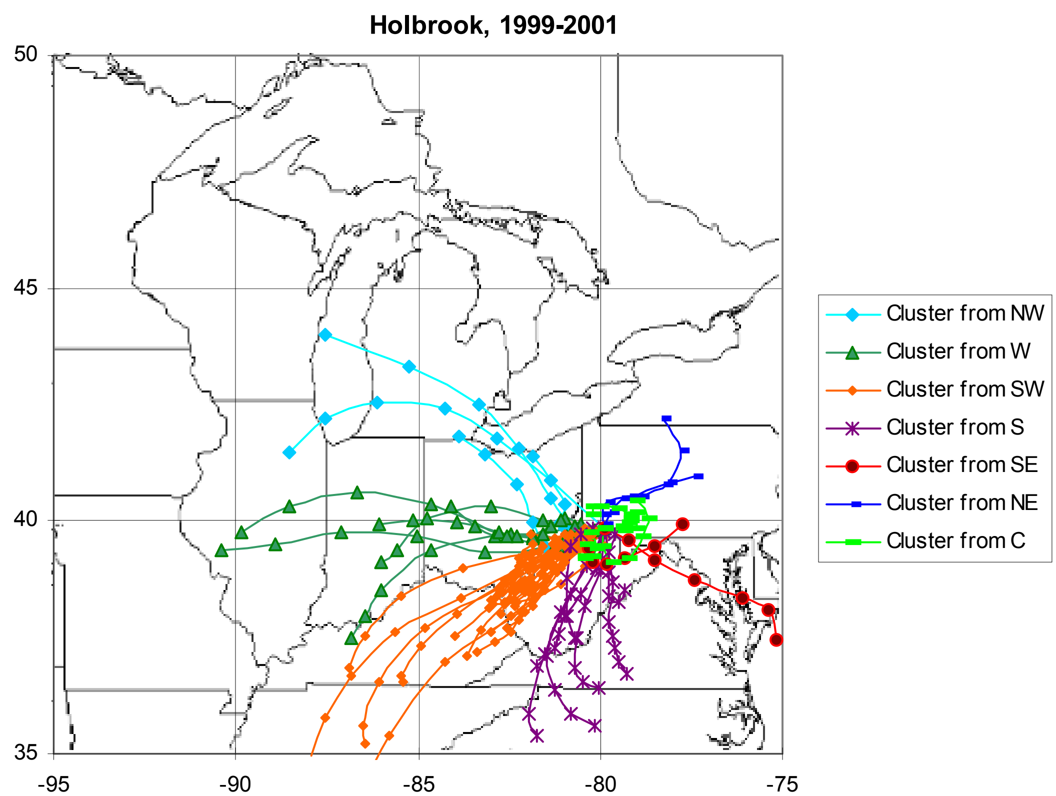


Figure 9. Back Trajectories on high $PM_{2.5}$ days for Holbrook, 1999-2001, 20 UTC, 500m

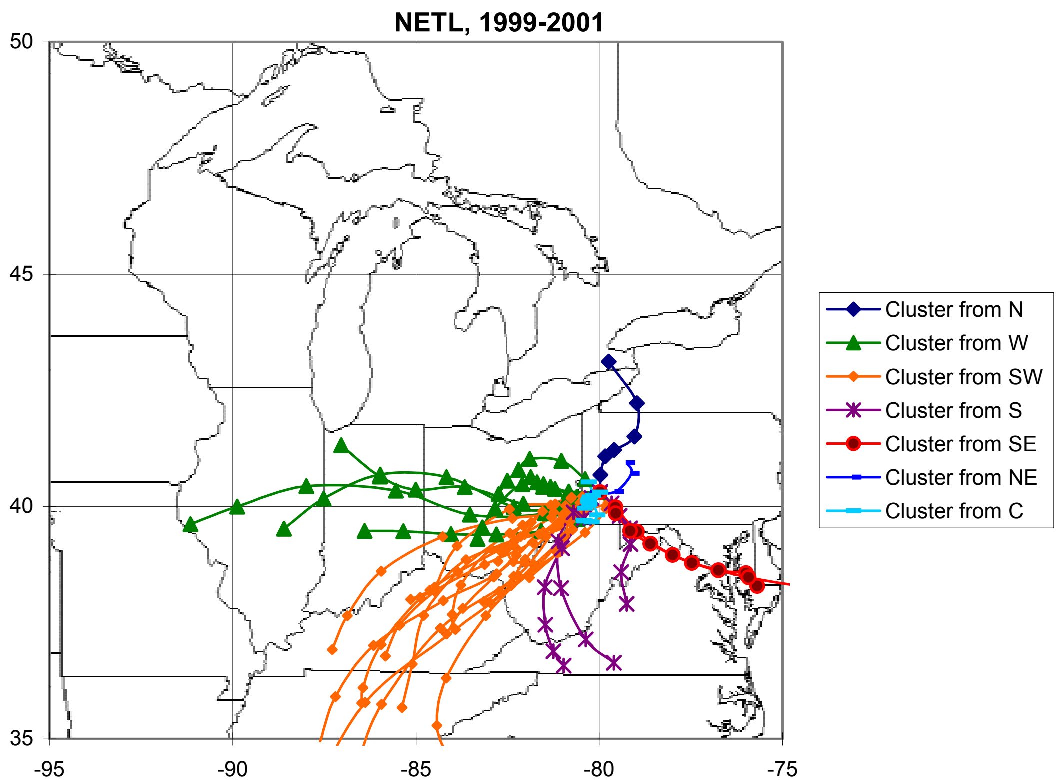


Figure 10. Back Trajectories on high $PM_{2.5}$ days for NETL, 1999-2001, 20 UTC, 500m

4.5 Cluster Analysis

Cluster analysis is an advanced method of trajectory analysis that segregates and merges each trajectory based on its direction and/or similarity. It is useful for tracing pollutant source regions. These clusters, their percentiles, frequencies and average concentrations for the three monitoring sites during 1999-2001 are presented in Figures 11 through 13.

The Lawrenceville site showed that during high $PM_{2.5}$ days the southwest cluster, which passes over the Ohio River Valley significantly, influenced the $PM_{2.5}$ concentration in the study region. Also the second highest frequency of high $PM_{2.5}$ days were associated with the west cluster passing over Columbus, Ohio. The highest average $PM_{2.5}$ concentration was observed along the northwest cluster passing over Detroit, Michigan.

For the Holbrook, site high $PM_{2.5}$ days occurred most frequently when air parcels flowed from the southwest passing over the Ohio River Valley. The next highest frequencies were associated with the west and south clusters passing over Columbus Ohio and West Virginia, respectively.

For the NETL site, the southwest cluster passing over the Ohio River Valley was also significant on high $PM_{2.5}$ days. The second highest frequency for high $PM_{2.5}$ days was associated with the west cluster passing over Steubenville and Marion, Ohio. The highest $PM_{2.5}$ concentration came from the southeast cluster passing over Washington D.C.

In general most of the clusters corresponded with metropolitan areas in neighboring states, which included Columbus and Steubenville in Ohio, Detroit, and Washington D.C. This suggests that these urban centers may affect the PM levels in the UORVP region. Also, since a large percentage of the clusters during high $PM_{2.5}$ days passed over the Ohio River Valley, it would indicate that this area is one of the main source regions of $PM_{2.5}$ and $PM_{2.5}$ precursors affecting pollution levels within the study region.

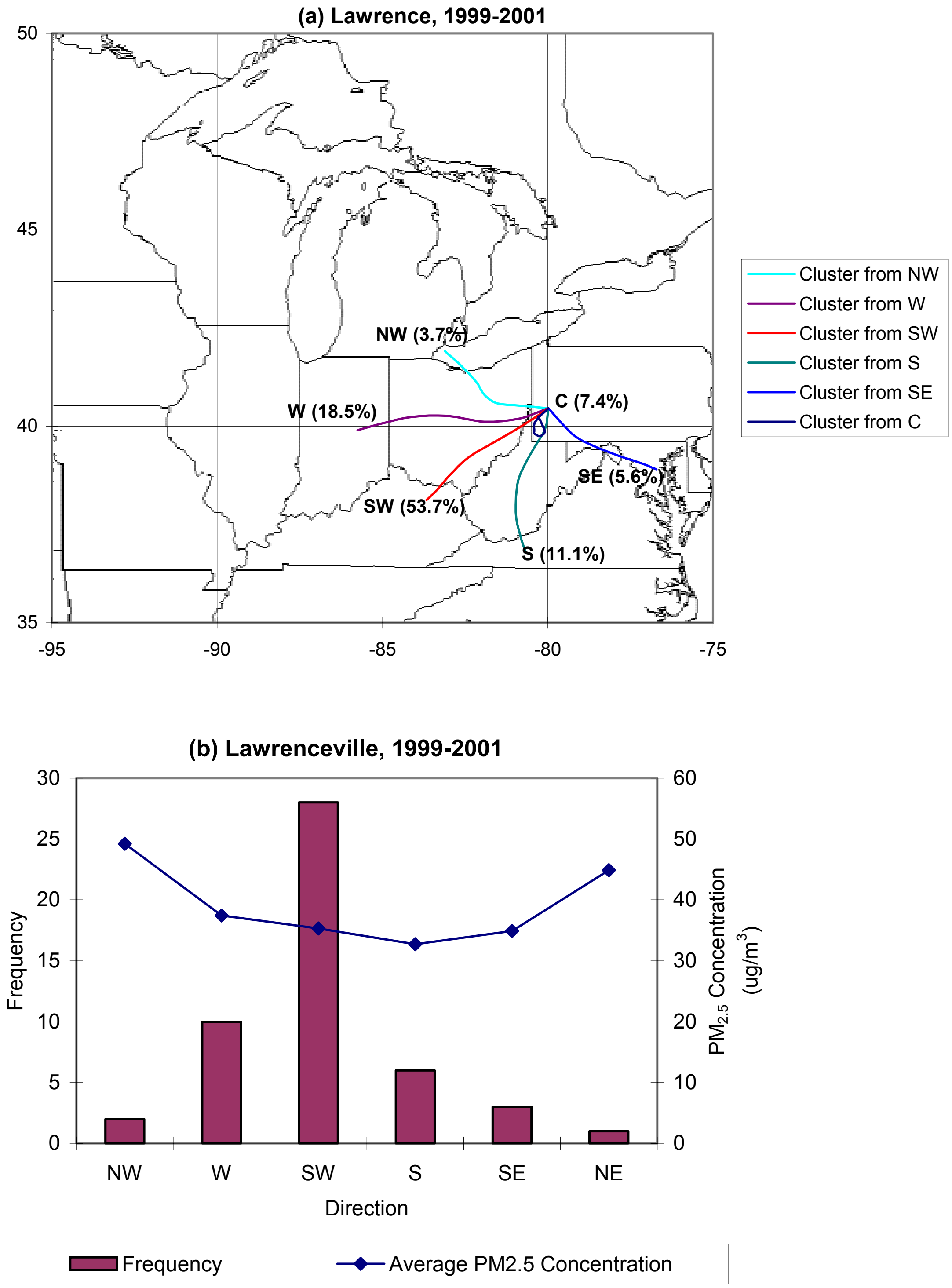


Figure 11. (a) Cluster plot at Lawrenceville (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at Lawrenceville, 1999-2001

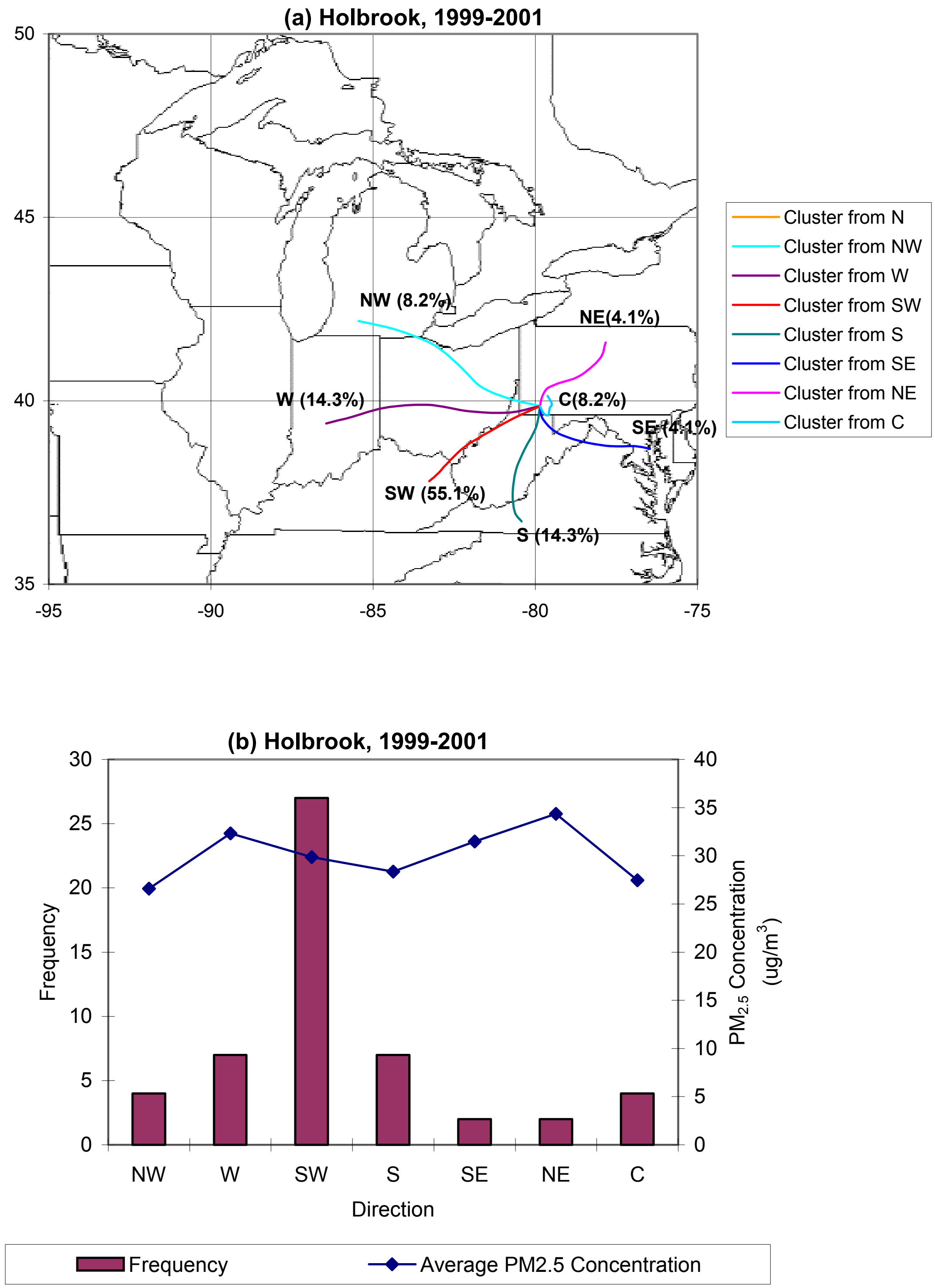
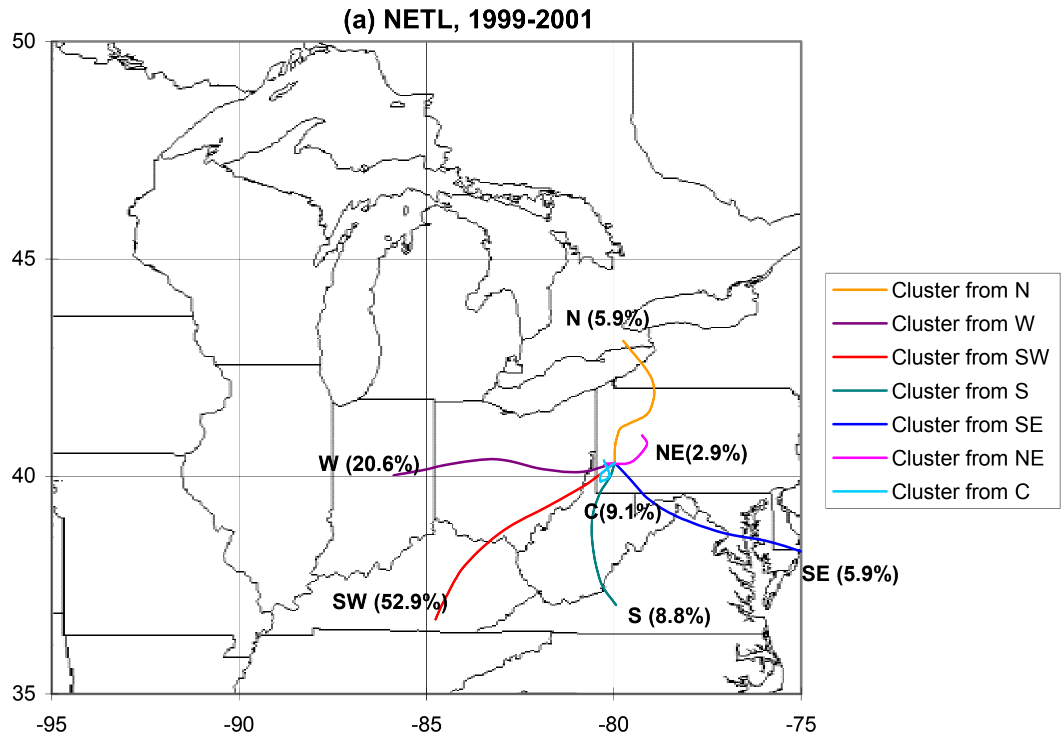


Figure 12. (a) Cluster plot at Holbrook (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at Holbrook, 1999-2001



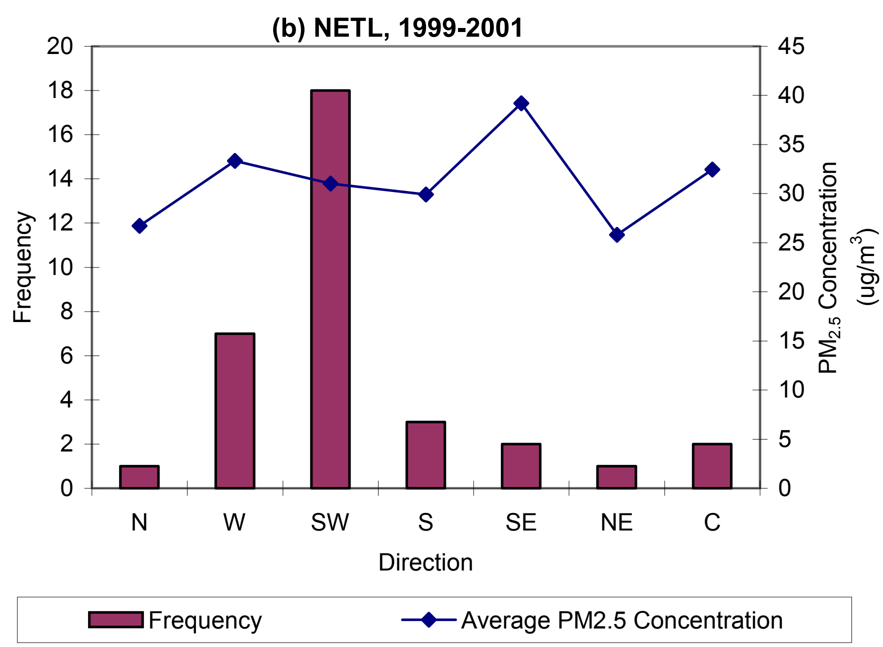


Figure 13. (a) Cluster plot at NETL (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at NETL, 1999-2001

5.0 REFERENCES

1. Draxler, R.R. *Weather and Forecasting,* **1996**, *11*, 111-114.

2. Draxler, R.R.; Hess, G.D. *Description of the HYSPLIT4 Modeling System*, NOAA Tech Memo: 1997; ERL ARL-224.

3. Draxler, R.R.; Hess, G.D. *An Overview of the HYSPLIT4 Modeling System for Trajectories, Dispersion, and Deposition*; Australian Meteorological Magazine, 1998, 47, 295-508.

4. Rao, S.T.; Brankov, E.B.; Porter, P.S. *Atmospheric Environment,* **1998**, *32(9)*, 1525-1534.

5. Dorling, S.R.; Davies, T.D.; Pierce, C.E. *Atmospheric Environment,* **1992**, *26A(14)*, 2575-2581.

6.0 ACKNOWLEDGEMENTS

The authors would like to acknowledge NETL for funding this project and support from ATS who is managing the UROVP project. We would also like to acknowledge Richard Anderson from NETL who supplied $PM_{2.5}$ and meteorological data from the NETL monitoring program and Ohio EPA and the Ohio Air Quality Development Authority for funding the monitoring campaign in Athens Ohio. Finally the authors would like to acknowledge the graduate students who worked on this project including Myoung Kim, Texas A&M – Kingsville and Li Sujuan, Ohio University.