Air Quality and Pediatric Health in Ohio

OHIO UNIVERSITY
1804

Air Quality and Pediatric Health in Ohio

Kevin Crist
Ohio University
Kuruvilla John
Texas A&M -Kingsville
Bruce Carlson
Ohio University
Michele Morrone
Ohio University
Tim Ryan
Ohio University

Edited by
Michele Morrone

Submitted to Ohio EPA and the Ohio Air Quality Development Authority

Contents

List of Tables *iv*
List of Figures *viii*
Acknowledgments *xv*
Executive Summary *xvi*

Section 1: Overview

Introduction *1*

Section 2: Prospective Study

Chapter 1: Particulate Matter Measurements *13*
Chapter 2: Characterization of $PM_{2.5}$ in Central and Southeastern Ohio *61*
Chapter 3: Health Status Evaluation *127*

Section 3: Retrospective Study

Chapter 1: A Retrospective Analysis of Air Quality Data in Ohio *147*
Chapter 2: Respiratory Illness and Air Quality *229*

Section 4: Air Toxics

Air Toxics Monitoring *247*

Appendices
A *301*
B *327*
C *351*
D *359*
E *461*

TABLES

Section 2

Chapter 1

II.1.1. Summary of the sampling time and samplers used
II.1.2. Statistics of field blanks for personal, indoor, and outdoor $PM_{2.5}$ measurements
II.1.3. Summary of $PM_{2.5}$ sampling completeness, number of days useable samples collected
II.1.4. Summary of collocated monitoring data ($\mu g/m^3$) for each sampler monitored by each sampling methods used in the t-test
II.1.5. Correlations between co-located samplers ($\mu g/m^3$)
II.1.6. Summary of ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) for all study sites during the entire sampling period
II.1.7. Correlations of ambient $PM_{2.5}$ concentrations($\mu g/m^3$) between three sites
II.1.8. Summary of filter-based $PM_{2.5}$ measurements ($\mu g/m^3$) for all study sites.
II.1.9. Summary data for $PM_{2.5}$ average concentrations ($\mu g/m^3$) and I/O ratios during school days and non-school days at all sites.
II.1.10. Summary data for $PM_{2.5}$ sulfate concentration I/O ratios during school days and non-school days at all sites.
II.1.11. Summary of correlations of personal, indoor, and outdoor $PM_{2.5}$ concentrations
II.1.12. Summary of correlations of personal and outdoor $PM_{2.5}$ concentrations ($\mu g/m^3$) by year and by season
II.1.13. Summary of correlations of indoor and outdoor $PM_{2.5}$ concentrations ($\mu g/m^3$) by year and by season
II.1.14. Summary of correlations of personal and indoor $PM_{2.5}$ concentrations ($\mu g/m^3$) by year and by season

Chapter 2

II.2.1. Statistical summary of $PM_{2.5}$mass and its chemical compositions at Athens (February 1999-August 2000)
II.2.2. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at New Albany (February 1999-August 2000)
II.2.3. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Koebel (February 1999-August 2000)
II.2.4. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Athens (February 1999-August 2000)
II.2.5. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at New Albany(February 1999-August 2000)
II.2.6. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Koebel (February 1999-August 2000)

Chapter 3

II.3.1. Summary of media attention
II.3.2. ER Diagnosis Categories And ICD-9 Codes
II.3.3 Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables
II.3.4. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables (micrograms/cubic meter)
II.3.5. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Respiratory Measures

Section 3

Chapter 1

III.1.1. Summary of Air Pollution Trends in Ohio
III.1.2. Geographic location of selected air monitoring sites for ozone
III.1.3. Summary of Data Sampling Protocols and Locations
III.1.4. Number of exceedance days for 1-hour NAAQS ozone standard.
III.1.5. High ozone days exceeding 8-hour threshold level, 1992-2000
III.1.6. R^2 Values of Ozone Spatial Correlation between cities in Ohio
III.1.7. R^2 Values of PM_{10} Spatial Correlation between cities in Ohio.
III.1.8. R^2 Values of CO Spatial Correlation between cities in Ohio
III.1.9. R^2 Values of SO_2 Spatial Correlation between cities in Ohio
III.1.10. R^2 Values of NO_2 Spatial Correlation between cities in Ohio

Chapter 2

III.2.1. Principal Diagnosis codes (ICD-9) Used in this Study

III.2.2. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Cincinnati (Prior to Controlling for Meteorological Effects)
III.2.3. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Cleveland (Prior to Controlling for Meteorological Effects)
III.2.4. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Columbus (Prior to Controlling for Meteorological Effects)
III.2.5. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Dayton (Prior to Controlling for Meteorological Effects)
III.2.6. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Steubanville (Prior to Controlling for Meteorological Effects)

III.2.7. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Toledo (Prior to Controlling for Meteorological Effects)

Section 4

IV.1.1. USEPA Draft List of 15 VOCs of Concern in Urban Settings
IV.1.2. Gas Chromatography/Mass Spectrometer Settings
IV.1.3. VOCs Available to EPA Method 8260 B in Standard Mix, Quantified, and Semi-Quantified
IV.1.4. Dilutions for Standard Curve Generation
IV.I.5. Limits of Detection (LOD) in Ohio 3 School Study as Compared to KV and TEAM Studies
IV.I.6. Statistical Comparison of Personal and Indoor to Outdoor Average Concentrations of VOCs for the Entire Study Period
IV.1.7. Results for Co-located OVM Badges Relative Standard Deviation (RSD) for Co-located Badges at Schools January 3rd to April 3rd, 2000
IV.1.8. Percent of Measurements with Concentrations Greater Than LOD : Comparison with other studies
IV.1.9A. Summary Statistics for Indoor VOC Samples (ug/m^3) for Athens
IV.1.9B. Summary Statistics for Indoor VOC samples (ug/m^3) for Koebel Elementary School
IV.1. 9C. Summary Statistics for Indoor VOC samples (ug/m^3) for New Albany Elementary School
IV.1.10A. Summary Statistics for Outdoor VOC Samples (ug/m^3) for Athens
IV.1.10B. Summary Statistics for Outdoor VOC Samples (ug/m^3) for Koebel
IV.1.10C. Summary Statistics for Outdoor VOC Samples (ug/m^3) for New Albany
IV.1.11A. Summary Statistics for Personal VOC Samples (ug/m^3) for Athens
IV.1.11B. Summary Statistics for Personal VOC Samples (ug/m^3) for Koebel
IV.1.11C. Summary Statistics for Personal VOC samples (ug/m^3) for New Albany
IV.1.12A. Statistical Comparison of Personal and Indoor to Outdoor Average Concentrations of VOCs for Athens
IV.1.12B. Statistical Comparison of Personal and Indoor to Outdoor Average Concentrations of VOCs for Koebel
IV.1.12C. Statistical Comparison of Personal and Indoor to Outdoor Average Concentrations of VOCs for New Albany
IV.1.13. Seasonality Trends in TVOC for All Schools and All Sample Types (µg/m^3)

IV.1.14A. New Albany Concentrations[a] versus Los Angeles,New Jersey Summer and Region V(Indoor)
IV.1.14B. New Albany Concentrations[a] versus Los Angeles,New Jersey Summer and Region V(Outdoor)

FIGURES

Section 2

Chapter 1

II.1.1. Overview of Study Area
II.1.2. Location of Study Area
II.1.3. A typical set-up of the ambient monitoring system
II.1.4. Personal Samplers
II.1.5. Humidity controlled microenvironment
II.1.6. Co-located ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) measured by personal, indoor samplers, and the ACCU system plotted against those measured by the TEOMs
II.1.7. Diurnal distribution of ambient $PM_{2.5}$ at all sites (1999 data).
II.1.8. Monthly ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) monitored by TEOMs in 1999
II.1.9. Monthly ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) monitored by TEOMs in 2000
II.1.10. Inter-site correlation of ambient $PM_{2.5}$.
II.111. Typical daily variations of ambient $PM_{2.5}$ at three sites
II.1.12. Correlations of ambient $PM_{2.5}$ concentrations of the sites from this study and the corresponding sites within the region
II.1.13. Monthly average filter-based $PM_{2.5}$ concentrations ($\mu g/m^3$) at all sites.
II.1.14. School day I/O ratios vs. non-school day I/O ratios at three sites, 2000. I/O ratios greater than 5 are not included in the graph.
II.1.15. Personal-outdoor relationships during the sampling period.
II.1.16. Personal-indoor relationships during sampling period.
II.1.17. Indoor-outdoor relationships during sampling period
II.1.18. Monthly variations of correlation coefficients of personal (P), indoor (I), and outdoor (O) concentrations at all three sites

Chapter 2

II.2.1. Scatter plot of sum of species versus mass outdoor concentrations for Athens site samples (May- August 2000)
II.2.2. Scatter plot of sum of species versus mass outdoor concentrations for New Albany site samples (May-August 2000)
II.2.3. Scatter plot of sum of species versus mass outdoor concentrations at Koebel site samples (May-August 2000)
II.2.4. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Koebel outdoor samples (May-August 2000)
II.2.5. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for New Albany outdoor samples (May-August 2000)
II.2.6. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Athens outdoor samples (May-August 2000)

II.2.7. Scatter plot of cation and anion balance for Athens outdoor samples (May-August 2000)
II.2.8. Scatter plot of cation and anion balance for New Albany outdoor samples (May-August 2000)
II.2.9. Scatter plot of cation and anion balance for Koebel outdoor samples (May-August 2000)
II.2.10. Concentrations of the chemical components present in the samples at Athens outdoor site (February 1999-August 2000)
II.2.11. Concentrations of the chemical components present in the samples at New Albany outdoor site (February 1999-August 2000)
II.2.12. Concentrations of the chemical components present in the samples at Koebel outdoor site (February 1999-August 2000)
II.2.13. $PM_{2.5}$ components of outdoor ambient air (February 1999–August 2000) at Athens
II.2.14. $PM_{2.5}$ components for outdoor ambient air (February 1999–August 2000) at New Albany
II.2.15. $PM_{2.5}$ components for outdoor ambient air (February 1999–August 2000) at Koebel
II.2.16. Temporal variations in sulfate concentrations for Athens outdoor samples for the study period (February 1999-August 2000)
II.2.17. Temporal variations in sulfate concentrations for New Albany outdoor samples (February 1999-August 2000)
II.2.18 Temporal variations in sulfate concentrations for Koebel outdoor samples (February 1999-August 2000)
II.2.19. Correlations between $PM_{2.5}$ and weather components at New Albany, Ohio in 1999: (a) $PM_{2.5}$ vs. wind speed and (b) $PM_{2.5}$ vs. wind direction
II.2.20. Correlations between $PM_{2.5}$ and weather components at New Albany, Ohio in 1999: (c) $PM_{2.5}$ vs. temperature and (d) $PM_{2.5}$ vs. relative humidity
II.2.21. Correlations between $PM_{2.5}$ and weather components at Koebel, Columbus, Ohio in 1999: (a) $PM_{2.5}$ vs. wind speed and (b) $PM_{2.5}$ vs. wind direction
II.2.22. Correlations between $PM_{2.5}$ and weather components at Koebel, Columbus, Ohio in 1999: (c) $PM_{2.5}$ vs. temperature and (d) $PM_{2.5}$ vs. relative humidity
II.2.23. Correlations between $PM_{2.5}$ and weather components at Athens, Ohio in 1999: (a) $PM_{2.5}$ vs. wind speed and (b) $PM_{2.5}$ vs. wind direction
II.2.24. Correlations between $PM_{2.5}$ and weather components at Athens, Ohio in 1999: (c) $PM_{2.5}$ vs. temperature and (d) $PM_{2.5}$ vs. relative humidity
II.2.25. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1999-2000: (a) New Albany and (b) Koebel
II.2.26. (a) Cluster plot at New Albany, 1999-2000 (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at New Albany, 1999-2000
II.2.27. (a) Cluster plot at Koebel, 1999-2000 (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at Koebel, 1999-2000
II.2.28. (a) Cluster plot at East Athens, 1999-2000 (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at Athens, 1999-2000
II.2.29. Correlations between $PM_{2.5}$ and ozone in 1999: (a) New Albany and (b) Koebel

II.2.30. Correlations between sulfate and weather at New Albany, Ohio in 1999: (a) sulfate vs. wind speed and (b) sulfate vs. wind direction
II.2.31. Correlations between Sulfate and weather at New Albany, Ohio in 1999: (c) sulfate vs. temperature and (d) sulfate vs. relative humidity
II.2.32. Correlations between sulfate and weather at Koebel Elementary, Columbus, Ohio in 1999: (a) sulfate vs. wind speed and (b) sulfate vs. wind direction
II.2.33. Correlations between sulfate and weather at Koebel Elementary, Columbus, Ohio in 1999: (a) sulfate vs. temperature and (b) sulfate vs. relative humidity
II.2.34. Correlations between sulfate and weather components at East Elementary, Athens, Ohio in 1999-2000: (a) sulfate vs. wind speed and (b) sulfate vs. wind direction
II.2.35. Correlations between sulfate and weather at East Elementary, Athens, Ohio in 1999: (c) sulfate vs. temperature and (d) sulfate vs. relative humidity
II.2.36. Scatter plot of sum of species versus mass concentrations at East site indoor samples (May-August 2000)
II.2.37. Scatter plot of sum of species versus mass concentrations at New Albany site indoor samples for May to August 2000
II.2.38. Scatter plot of sum of species versus mass concentrations at Koebel site indoor samples for May to August 2000
II.2.39. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Athens indoor samples (May to August 2000)
II.2.40. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for New Albany indoor samples (May to August 2000)
II.2.41. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Koebel indoor samples (May to August 2000)
II.2.42. Scatter plot of cation and anion balance for Athens indoor samples (May to August 2000)
II.2.43. Scatter plot of cation and anion balance for New Albany indoor samples (May to August 2000)
II.2.44. Scatter plot of cation and anion balance for Koebel indoor samples (May to August 2000)
II.2.45. Concentrations of the chemical components present in the indoor samples at East site for February 1999 to August 2000
II.2.46. Concentrations of the chemical components present in the indoor samples at New Albany site for February 1999 to August 2000
II.2.47. Concentrations of the chemical components present in the indoor samples at Koebel site for February 1999 to August 2000
II.2.48. Indoor $PM_{2.5}$ chemical composition for Athens site during February 1999 – August 2000)
II.2.49. Indoor $PM_{2.5}$ chemical composition for New Albany site (February 1999–August 2000)
II.2.50. Indoor $PM_{2.5}$ chemical composition for Koebel Site (February 1999–August 2000)
II.2.51. Temporal variations in indoor sulfate concentrations for Athens samples from February 1999 to August 2000

II.2.52. Temporal variations in indoor sulfate concentrations for New Albany samples from February 1999 to August 2000
II.2.53. Temporal variations in indoor sulfate concentrations for Koebel samples from February 1999 to August 2000
II.2.54. Ammonium ion distribution in Ohio (Feb. 1999 – Aug. 2000)
II.2.55. Sulfate ion distribution in Ohio (Feb. 1999 – Aug. 2000)
II.2.56. Nitrate ion distribution in Ohio (Feb. 1999 – Aug. 2000)

Chapter 3

II.3.1. Location of Hospitals in Columbus Ohio where Emergency room data was obtained for 1999 through August of 2000
II.3.2. General health status 1998-99 sample
II.3.3. General health status 1999-2000 sample
II.3.4. Respiratory Symptoms 1998-99 sample
II.3.5. Respiratory Symptoms 1999-2000 sample
II.3.6. Responses from Parents Relative to Child's Respiratory Status
II.3.7. Responses from Parents Relative to Child's Respiratory Status

Section 3

Chapter 1

III.1.1. Geographic location of selected air monitoring sites for ozone; city and site name.
III.1.2. Fourth Highest 8-hour Averaged Ozone Concentration, Chesapeake
III.1.3. Fourth Highest 8-hour Averaged Ozone Concentration, Cincinnati
III.1.4. Fourth Highest 8-hour Averaged Ozone Concentration, Dayton
III.1.5. Fourth Highest 8-hour Averaged Ozone Concentration, Maple Canyon
III.1.6. Fourth Highest 8-hour Averaged Ozone Concentration, Marietta
III.1.7. Fourth Highest 8-hour Averaged Ozone Concentration, Steubenville
III.1.8. Fourth Highest 8-hour Averaged Ozone Concentration, Akron
III.1.9. Fourth Highest 8-hour Averaged Ozone Concentration, Cleveland
III.1.10. Annual Averaged PM_{10} in 1992-2000
III.1.11. Second Highest 8-hour Averaged CO in 1992-2000
III.1.12. Annual Averaged SO_2 in 1992-2000
III.1.13. Annual Averaged NO_2 in 1992-2000
III.1.14. Monthly PM_{10} distribution in: (a) Cincinnati, 1992-1999 and (b) Maple Canyon, 1992-2000
III.1.15. Monthly PM_{10} distribution in 1992-2000: (c) Chesapeake and (d) Cleveland
III.1.16. Monthly PM_{10} distribution in 1992-2000: (e) Steubenville
III.1.17. Monthly 8-hour average CO distribution in 1992-2000: (a) Cincinnati and (b) Dayton
III.1.18. Monthly 8-hour average CO distribution in: (c) Chesapeake, 1992-2000 and (d) Maple Canyon, 1993-2000

III.1.19. Monthly 8-hour average CO distribution in 1992-2000: (e) Akron and (f) Cleveland
III.1.20. Monthly 8-hour average SO_2 distribution in 1992-2000: (a) Cincinnati and (b) Dayton
III.1.21. Monthly 8-hour average SO_2 distribution in 1992-2000: (c) Chesapeake and (d) Cleveland
III.1.22. Monthly 8-hour average SO_2 distribution in 1992-2000: (e) Akron and (f) Steubenville
III.1.23. Monthly 8-hour average NO_2 distribution in: (a) Cincinnati 1992-2000 and (b) Cleveland, 1992-1999
III.1.24. Monthly 8-hour average NO_2 distribution in: (c) Steubenville, 1992-1997
III.1.25. High ozone occurrences by day of the week, 1992-2000: (a) Cincinnati and (b) Dayton
III.1.26. High ozone occurrences by day of the week (c) Columbus (Maple Canyon), 1999-2000 and (d) Columbus (Chesapeake), 1992-1999
III.1.27. High ozone occurrences by day of the week, 1992-2000: (e) Cleveland and (f) Toledo
III.1.28. High ozone occurrences by day of the week, 1992-2000 (g) Akron and (h) Marietta
III.1.29. High ozone occurrences by day of the week, (i) Steubenville, 1992-2000
III.1.30. Weekly PM_{10} distribution in 1992-1999: (a) Cincinnati
III.1.31. Weekly PM_{10} distribution in 1992-2000: (b) Maple Canyon and (c) Chesapeake
III.1.32. Weekly PM_{10} distribution in 1992-2000: (d) Cleveland and (e) Steubenville
III.1.33a. KZ[365,3] of O_3 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]
III.1.33b. KZ[365,3] of O_3 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]
III.1.34. KZ[365,3] of PM_{10} levels in Ohio: Gray line is raw data and blue line is KZ[365,3]
III.1.35. KZ[365,3] of CO levels in Ohio: Gray line is raw data and blue line is KZ[365,3]
III.1.36. KZ[365,3] of SO_2 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]
III.1.37. KZ[365,3] of NO_2 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]
III.1.38. Correlations between ozone and weather components at Cincinnati, Ohio in 1992-2000: (a) ozone vs. wind speed and (b) ozone vs. wind direction
III.1.39. Correlations between ozone and weather components at Cincinnati Ohio in 1992-2000: (c) ozone vs. temperature and (d) ozone vs. relative humidity
III.1.40. Correlations between PM_{10} and weather components at Cincinnati, Ohio in 1992-1999: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction
III.1.41. Correlations between PM_{10} and weather components at Cincinnati Ohio in 1992-1999: (c) PM_{10} vs. temperature and (d) PM_{10} vs. relative humidity

III.1.42. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati
III.1.43. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (b) Dayton and (c) Maple Canyon
III.1.44. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (d) Chesapeake and (e) Cleveland
III.1.45. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (f) Toledo and (g) Akron
III.1.46. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (h) Marietta and (i) Steubenville
III.1.47. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati and (b) Maple Canyon
III.1.48. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1992-2000: (c) Chesapeake and (d) Cleveland
III.1.49. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1992-2000: (e) Steubenville
III.1.50. (a) Cluster plot in Cincinnati, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Cincinnati, 1992-2000
III.1.51. (a) Cluster plot in Dayton, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Dayton, 1992-2000
III.1.52. (a) Cluster plot in Maple Canyon, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Maple Canyon, 1992-2000
III.1.53. (a) Cluster plot in Chesapeake, 1992-1999 (b) Frequencies and average ozone concentrations by cluster in Chesapeake, 1992-1999
III.1.54. (a) Cluster plot in Cleveland, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Cleveland, 1992-2000
III.1.55. (a) Cluster plot in Toledo, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Toledo, 1992-2000
III.1.56. (a) Cluster plot in Akron, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Akron, 1992-2000
III.1.57. (a) Cluster plot in Marietta, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Marietta, 1992-2000
III.1.58. (a) Cluster plot in Steubenville, 1992-2000 (b) Frequencies and average ozone concentrations by cluster in Steubenville, 1992-2000
III.1.59. (a) Cluster plot at Cincinnati, 1992-1999 (b) Frequencies and average PM_{10} concentrations by cluster at Cincinnati, 1992-1999
III.1.60. (a) Cluster plot at Maple Canyon, 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Maple Canyon, 1992-2000
III.1.61. (a) Cluster plot at Chesapeake, 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Chesapeake, 1992-2000
III.1.62. (a) Cluster plot at Cleveland, 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Cleveland, 1992-2000
III.1.63. (a) Cluster plot at Steubenville 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Steubenville, 1992-2000

Chapter 2

III.2.1. Smoothed Time Series of Cleveland Respiratory Admissions
III.2.2. Smoothed Time Series of Columbus Respiratory Admissions
III.2.3. Smoothed Time Series of Cincinnati Respiratory Admissions
III.2.4.a. Relative Risk of Respiratory Illiness (Northeast Ohio Cities)
III.2.4.b. Relative Risk of Respiratory Illness (Central and Western Cities)
III.2.5.a. Relative Risk for Children's Asthma (Northeast Ohio Cities)
III.2.5.b. Relative Risk for Children's Asthma (Central/Western Ohio Cities)

Section 4

IV.1.1. Diagram of a 3M Passive Organic Vapor Monitor
IV.1.2A. Co-locate Data for Four Compounds at East Elementary School
IV.1.2B. Co-locate Data for Four Compounds at Koebel Elementary School
IV.1.2C. Co-locate Data for Four Compounds at New Albany Elementary School
IV.1.3A. Indoor Concentrations vs. Personal Exposures for Benzene at Athens($\mu g/m^3$)
IV.1.3B. Indoor Concentrations vs. Personal Exposures for Benzene at Koebel Elementary School ($\mu g/m^3$)
IV.1.3C. Indoor Concentrations vs. Personal Exposures for Benzene at New Albany Elementary School ($\mu g/m^3$)
IV.1.4A. Athens Monthly Averaged Outdoor O-Xylene Concentrations
IV.1.4B. Koebel Monthly Averaged Outdoor O-Xylene Concentrations
IV.1.4C. New Albany Outdoor Monthly Averaged Outdoor O-Xylene Concentrations
IV.1.5A. Athens Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.
IV.1.5B. Koebel Elementary School Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.
IV.1.5C. New Albany School Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels
IV.1.6A. Weekday and Weekend Comparison of O-xylene Concentrations at Athens
IV.1.6B. Weekday and Weekend Comparison of O-xylene Concentrations at Koebel School
IV.1.6C. Weekday and Weekend Comparison of O-xylene Concentrations at New Albany School
IV.1.7. TVOC and $PM_{2.5}$ Relationship
IV.1.8. Benzene and $PM_{2.5}$ Relationship

Acknowledgments

First and foremost we would like to thank Ohio EPA and the Ohio Air Quality Development Authority for financial support and guidance on this project. This project was a cooperative research effort involving all academic units at Ohio University and the Environmental Engineering Program at Texas A&M University – Kingsville. Through this research project, and with in-kind support from the institutions, twelve graduate and five undergraduate students participated and most received tuition waivers and stipends. A majority of the graduate students completed their thesis requirements from this project. Special thanks to the following students whose efforts had significant impact on this research: Peg Conley, who received here B.S. degree in Industrial Hygiene. Peg established the QA/QC guidelines for the air monitoring and lab procedures at Ohio University. Peg is currently an Environmental Manager for a private corporation in Utah; Bian Liu, who completed her M.S. in Environmental Studies, was involved with the monitoring and analysis of $PM_{2.5}$ at the elementary schools. Bian is currently working on her PhD at the University of Michigan; Laura Simons, who worked on the data sets and statistical analysis. Laura is currently pursuing her PhD at the University of Georgia; Mayra Alvarado was responsible for the chemical analysis of the $PM_{2.5}$ samples and received an M.S. in Environmental Engineering from Texas A&M University - Kingsville; and Ieesuck Jung conducted the meteorological and trend evaluations and received an M.S. in Environmental Engineering from Texas A&M University - Kingsville.

We would also like to acknowledge the elementary schools involved in this program, Koebel Elementary in the Columbus School district, New Albany Elementary in the New Albany School district and East Elementary in Athens. The project could not have been completed without the support of the local school boards and the Principals. Specifically, we would like to mention the involvement of Principal Denny Boger at East Elementary and Principal Steve Stone at Koebel Elementary who worked with us very closely throughout the project. And most importantly the teachers who were responsible for the day to day operation of the indoor and personal sampling and the health monitoring; Pam Smith at Koebel, Ronald Whitacre at New Albany and Stephanie Purcell at East Elementary.

Finally, we would also like to thank Dr. Ann Fingar and Dr. Robert Woodworth, faculty in the Ohio University College of Osteopathic Medicine, for designing and supervising the medical monitoring section of this project.

EXECUTIVE SUMMARY

The Air Pollution and Pediatric Health Impact Assessment project is a comprehensive health-based study evaluating the impact of air pollution on children and the general population in Ohio. Air quality data was obtained from the state and local air agency monitoring sites and monitoring sites at elementary schools in Columbus, New Albany, and Athens. Health information data was obtained from the Ohio Hospital Association, local Hospitals (emergency room admissions), and non-invasive medical monitoring at the elementary schools.

The project was a collaborative effort of researchers from Ohio University and Texas A&M University-Kingsville. The three components of the project includes a prospective analysis of air quality and the corresponding impact on respiratory health, a retrospective analysis of air quality across the state and the corresponding impact on respiratory health, and an analysis of ambient, indoor, and personal air toxic concentrations.

PROSPECTIVE ANALYSIS

The prospective analysis was designed to measure air pollution levels and exposures of children at three study locations in central and southeastern Ohio. Three components comprise the prospective analysis: particulate matter measurements, chemical characterization of particulate matter, and a health status evaluation of students involved in the study.

Particulate Matter Measurements

Personal, indoor, and outdoor $PM_{2.5}$ mass concentrations were monitored at three elementary schools in central and southeastern Ohio. A rural site was represented by East Elementary School and located in Athens, which is in Southeastern Ohio. Koebel Elementary School located in South Central side of

Columbus represented the urban testing center. A suburban site was located in New Albany and was represented by New Albany elementary school.

This report focuses on the temporal and spatial variations of ambient $PM_{2.5}$, and the relationships between personal, indoor, and outdoor $PM_{2.5}$ concentrations. The $PM_{2.5}$ measurements were conducted from January 1999 through August 2000. At each monitoring location, personal, indoor, and ambient $PM_{2.5}$ measurements were obtained. Three groups of 4th and 5th grade students, approximately 30 students at each site, participated in the project.

Ambient $PM_{2.5}$ displays an apparent seasonal trend and homogeneous spatial distribution. No clear seasonal or spatial patterns exist for indoor and personal $PM_{2.5}$ concentrations. However, high variations of personal and indoor concentrations occurred during school days at all three sites. Indoor $PM_{2.5}$, generated by human activities (such as walking) was an important determinant of personal $PM_{2.5}$ exposures. As a result of indoor sources, personal exposures and indoor $PM_{2.5}$ concentrations tend to be higher than corresponding outdoor concentrations at all sites. When students were not in the buildings, indoor and outdoor $PM_{2.5}$ concentration (I/O) ratios and sulfate (SO_4^{2-}) I/O ratios decreased.

Indoor $PM_{2.5}$ also influences the relationship between personal and outdoor $PM_{2.5}$ concentrations. Personal $PM_{2.5}$ concentrations were more aligned with indoor levels than with outdoor levels. Moderate personal-outdoor correlations occurred at Koebel ($R= 0.32$, $P<0.0001$) and Athens ($R=0.27$, $P=0.0001$). No significant personal-outdoor correlation was found at New Albany. On the other hand, personal and indoor $PM_{2.5}$ concentrations are highly correlated at all three sites with the R-values ranging from 0.30 to 0.68 ($P<0.0001$). Moderate indoor-outdoor correlations were found at Koebel ($R =0.26$) and New Albany ($R= 0.30$). At Athens, although there was a weak correlation between indoor and outdoor concentrations of $PM_{2.5}$ ($R= 0.13$), it was not statistically significant.

The analysis of correlations between personal, indoor, and outdoor $PM_{2.5}$ are crucial in understanding the health effects in epidemiological studies. The central assumption of epidemiological studies is that ambient PM concentration, monitored by a fixed site, is a sufficient surrogate for personal exposure. In this study, ambient $PM_{2.5}$ distributed homogeneously throughout the study area. This indicates that ambient $PM_{2.5}$ concentrations monitored from a fixed site can represent the average ambient $PM_{2.5}$ level over a large area. However, high variations occurring with indoor and personal concentrations indicates that the ambient $PM_{2.5}$ may not be a strong indicator for indoor concentrations or total personal exposures.

Characterization of Particulate Matter

Chemical characterization analysis of fine particulate matter ($PM_{2.5}$) was measured at the elementary schools for the outdoor and indoor monitors. The collected filter samples were analyzed at Texas A&M University–Kingsville. using an ion chromatography unit and an X-ray fluorescence spectrophotometer. Concentrations of Cl^-, NO_3^-, SO_4^{-2}, PO_4^{-3}, Li^+, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}, Si, P, S, Cl, K, Ca, Ti, Co, Ni, V, Mn, Fe, Cu, and Zn were determined for each site and compared. Sulfate comprised the largest fraction (~20-25%) of the total $PM_{2.5}$ mass.

High sulfate concentrations were found at the East (rural) site, which is located near the Ohio River valley, a significant source of sulfur dioxide emissions. Other abundant components included nitrate and ammonium ions and silicon. The anion and cation average concentrations followed the pattern $SO_4^{-2} > NO_3 > Cl^-$ and $NH_4^+ > Ca^{+2} > Na^+ > K^+ > Mg^{+2}$. Significantly higher levels of sodium, chloride, and potassium were found in the rural samples. Heavy metals such as titanium, vanadium, manganese, iron, copper, and zinc were found in all the samples. Iron was the most abundant metal found on the filter samples.

In the outdoor environment, sulfate ion concentration showed strong seasonal variation with maximum concentrations observed during the summer months. In the indoor environment, the percentage of soil in the samples was higher than the outdoor samples.

Additional data analysis included a comparison of $PM_{2.5}$ with meteorological parameters such as temperature, relative humidity, wind direction, and wind speed. It was noted that $PM_{2.5}$ concentrations tend to increase with rising temperatures, and decrease with increasing wind speeds. Correlating wind direction with $PM_{2.5}$ at the New Albany site indicated that the $PM_{2.5}$ concentration was highest when the winds were blowing from the southeast despite the low frequency of occurrence of this particular wind direction. A similar pattern was observed at the Koebel site in Columbus. The East site, however, showed a slightly different pattern; the $PM_{2.5}$ concentration was highest when the winds were blowing from the south and the southeast direction. This analysis suggests that when the PM levels are elevated, the Ohio River valley appears to be one of the main sources.

Health Status Evaluation

Longitudinal studies were conducted at all three elementary schools providing an opportunity to assess different patterns of exposures to air pollutants. All students enrolled in 4th and 5th grades were considered eligible

for the study. Components of the prospective health status evaluation included: 1) emergency room visits, 2) daily monitoring of pulmonary function, 3) daily school and class absenteeism, and 4) a cross-sectional health survey.

There were few consistent relationships between respiratory measures and air quality measures, after controlling for seasonality and weather. At two of the three sites (Koebel and New Albany), indoor filter weights were negatively related to attendance of students who had a prior history of respiratory illness. At New Albany, outdoor filter weights were negatively related to mean standardized peak flow, but this relationship was statistically significantly for all students in 2000, not just those students with a history of respiratory illness. However, in 1999, outdoor filter weights were negatively related to mean standardized peak flow only for students with a history of respiratory illness. Although negative correlations between peak flow and outdoor filter weights were observed at the other two sites in 2000, none were statistically significant.

RETROSPECTIVE ANALYSIS

The retrospective analysis was comprised of two major activities: analysis of historical air quality trends in Ohio and analysis of hospital admissions data.

Air Quality Data

Air quality and meteorological data from monitoring sites located in Cincinnati, Dayton, Toledo, Columbus, Chesapeake, Cleveland, Akron, Marietta, and Steubenville for the period of 1992-2000 were obtained from the Ohio EPA and Ohio University. Time series analysis, statistical analysis and meteorological analysis were applied to achieve the objectives of this study which were: 1) to analyze time series and long-term trends of the air pollutants; 2) to characterize meteorological parameters that impact air pollutant levels in Ohio; and 3) to identify atmospheric patterns associated with the transport of air pollutants to and from Ohio.

Long-term trends of ozone, PM_{10}, CO, SO_2, and NO_2 concentrations in the major urban centers were analyzed using an advanced technique called the Kolmogorov-Zurbenko (KZ) filter. Long-term trends analysis for ozone at several of the sites shows an increase trend in ozone levels. For PM_{10} the trend line remained fairly constant at all sites. All the sites showed visible decreasing trends in CO and SO_2, while NO_2 concentrations slightly increased.

Most high ozone episodes in the state last for several consecutive days. High ozone values during these episodes occur on the same day for most of the sites, a tendency that is prominent in the 8-hour ozone distribution rather than the 1-hour ozone distribution. This suggest that the new 8-hour NAAQS for ozone could result in the spatial expansion of the ozone problem in Ohio. Many urban areas in attainment of the current 1-hour ozone NAAQS will

become a non-attainment area under the new standard. Evaluation of back trajectories revealed that high ozone days occurred more frequently when winds were out of the southwest but the highest average ozone concentrations appeared with the south and the southeast wind direction.

Temperature, wind speed, and wind direction were significantly correlated with PM_{10} concentrations. High PM_{10} concentration levels were generally observed when the wind speed was lower than 8 mph and temperature was higher than 70°F or 80°F. Concentrations were also high when the winds were blowing from the south and east direction.

Cluster analysis was used to trace PM source regions and the pollutant's impact on the receptor sites. The results of this analysis showed that most high PM days occurred along the southwest cluster, but the highest average PM concentrations appeared along the southeast or north clusters.

Monthly distributions indicated that the mean CO and SO_2 concentrations are high during the winter months and low during the summer months, implying that CO and SO_2 concentrations are affected by seasonal impact. Weekdays are relatively higher than weekends in weekly distribution of CO, SO_2, and NO_2. The daily peak concentrations of CO were measured at 7 am and at 8am for SO_2 and NO_2.

Hospital Admissions Data

An examination of the zero-order correlations between respiratory health and air pollution reveals a significant amount of consistency across the eight sites included in the study. At every site, O_3 is significantly negatively correlated with hospital admissions for all respiratory illnesses and for asthma in children. Ozone is also significantly negatively correlated with hospital admissions for COPD in the elderly at two sites and with total respiratory deaths at five sites. This analysis suggests that high levels of ozone are not related to hospital admissions for respiratory illness in children or the elderly, a result that was unexpected, but explainable.

The negative zero order correlations can be related to a couple of factors. First, respiratory illness peaks during the winter months and drops steadily through July while ozone shows an inverse temporal pattern typically peaking in July and is relatively low during the cooler months. Second, the zero order correlations do not account for lags, the time between the hospital admission and the preceding high ozone event, that may trigger respiratory conditions. These differences in seasonal patterns highlight the importance of accounting for the confounding effects of seasonality and meteorology when statistically evaluating the relationships between air quality and respiratory illness.

The other pollutants that were also negatively correlated with respiratory health were NO_2 and PM_{10}. Surprisingly, the correlation between respiratory health and PM_{10} varied substantially from one site to another. For example, the correlation between total respiratory illness and PM_{10} was positive at Akron, negative at Cincinnati, Cleveland, and Columbus, and non-significant at Steubenville and Youngstown.

Not unexpectedly, CO and SO_2 were generally positively correlated with respiratory illness. The results from the eight sites were far from unanimous however, as many of the correlations were not statistically significant, suggesting that CO and SO_2 were either uncorrelated or weakly correlated with respiratory health at many of the sites.

After partitioning out the effects of seasonality and weather, there was little evidence of a consistent relationship between any of the air pollutants and any of the measures of respiratory health across the eight sites. No general pattern for a given pollutant across the state was identified.

Even after controlling for seasonality and weather, respiratory health and air pollution remained correlated with one another, although to a far lesser extent than what would have been expected after an examination of the correlations between the air pollutants and the respiratory health measures. This suggests that a sizeable amount of the relationship between air pollution and respiratory health can be attributed to other factors.

AIR TOXICS MONITORING

Air toxics monitoring was conducted for VOCs identified by the EPA to have the greatest potential effect on the public and the environment. Environmental measurements of VOC levels were made during the school year from September 1999 to May 28, 2000. Indoor, outdoor, and personal concentrations of 45 volatile organic compounds were simultaneously assessed at the three elementary schools participating in this study. Samples were collected with passive dosimeters analyzed by gas chromatography and mass spectrometry. VOC measurements included benzene, 1-3-butadiene, carbon tetrachloride, chloroform, methylene chloride, 1,1,2,2-tetrachloroethane, and trichloroethylene.

In general, very low total VOCs were found in this study. Like several other studies examining background, or baseline, concentrations of VOCs in nonproblematic settings, levels found in this study were in the low ug/m^3 range. The significance of exposures to VOC mixtures at low levels is unclear. Although specific VOC concentrations were not distinctly affected by weekly temperature or relative humidity, this study shows a significant seasonality to VOC prevalence. Higher levels of most chemical species occurred in spring months as compared to either winter or summer.

Indoor concentrations typically exceeded outdoor levels, and personal exposures were generally the highest of the three levels analyzed. Of the three locations studied, the rural setting had the highest TVOC levels. This was unexpected and contradicts the intuitive expectation that the inner city site, with ostensibly greater local emissions, would contain the highest levels of TVOCs. This finding indicates that location may not always determine the concentration of VOCs present at a site, and that local variability may play a greater role in contaminant levels present. This study further confirms earlier work showing that indoor and personal sample VOC concentrations are higher than outdoor concentrations.

Many studies have examined VOC concentrations, but this study is one of a very few to examine ambient and personal VOC concentrations in elementary schools. This work is also notable in that it employed a passive dosimeter for the assessment of these low-level organic contaminants. Despite difficulties with elevated background concentrations of benzene on some dosimeters, passive dosimeters show promise for ambient air monitoring.

Section 1, Introduction

The relationship between air pollution and human health has attracted the attention of the public, scientists, and policy makers worldwide. Despite the mounting evidence identifying a relationship between air pollution and negative health effects, few data are available to make informed decisions in Ohio. Epidemiological data from one region are not necessarily applicable to another; therefore, it is necessary to evaluate air pollution levels and their influence on public health as it relates to specific geographic regions.

Although the adverse health effects of some air pollutants have been extensively studied, data on the relationship between fine particulate matter, $PM_{2.5}$, and public health are still somewhat limited. This gap in the data is important considering that fine particulate matter may impose a considerably greater health threat than other air pollutants. This imposing threat is due to the origin and size of $PM_{2.5}$, which allows it to be inhaled more deeply into the lungs than the components of larger particulate matter.[1]

Recognizing the gap in the data about the health effects of fine particles, the need for geographically-based research, and the emphasis on children's health issues, the Ohio Environmental Protection Agency (EPA) issued a requests for proposals (RFP). Responding to the RFP researchers at Ohio University and Texas A&M University initiated the *Air Pollution and Pediatric Health Impact* project. This project was designed to study the health status of affected populations through a series of non-invasive health assessment methods. The project has two components: prospective and retrospective.

LITERATURE REVIEW

Past research about air pollution and human health effects include studies that have examined the relationship between air pollution and mortality rates, pulmonary and cardiovascular effects of particulate matter, including short and

long term influences of various air pollutant components on human health. Additional research examines the effect of air pollution on human health in susceptible populations, such as children, the elderly, and patients with various pulmonary and cardiovascular diseases.

Air pollution and mortality

Associations between air quality and mortality rates have been widely studied with respect to ambient levels of particulate matter.[2] The results of these studies have been surprisingly consistent considering that this research has occurred in various parts of the world.

Studies of daily mortality and PM_{10} levels in Utah Valley found that mortality averaged 4-5 percent higher than normal for each 50 $\mu g/m^3$ incremental increase of PM_{10} on the same day.[3] Furthermore, mortality rates averaged approximately 6-8 percent higher than normal for each 50 $\mu g/m^3$ incremental increase of five-day lagged moving average of PM_{10}.

The Harvard Six-Cities Study is one of the most prominent to compare the health effects of coarse (PM_{10}) and fine ($PM_{2.5}$) particles.[4] The results of the six-city study point to a significant correlation between cause-specific mortality and size of particulate matter. Specifically, a slight increase of $PM_{2.5}$ was associated an increase in pneumonia, COPD, and ischemic mortality rates. The study also stressed the importance of the PM and ischemic heart disease mortality association by suggesting that PM-related mortality is a major component of death due to ischemic disease. The Six City Study was replicated by other researchers with similar results.[5]

The population in the Harvard Six Cities Study[6] was the basis for a comparative study of the health effects of air pollution from several communities.[7] This study revealed an association between mortality due to respiratory diseases and air pollution levels and no association between air pollution and deaths from other all causes considered together. Furthermore, mortality was most strongly associated with exposure to fine particulate matter.

Other countries with different climate and pollution patterns than those in the U.S have also demonstrated associations between air pollution and increased mortality risk. In the Netherlands, researchers have demonstrated an association between total daily mortality and levels of PM_{10}, black smoke, O_3, SO_2, and NO_2.[8] Research in South Korea also identified a relationship between respiratory-related mortality and ambient levels of PM_{10}, SO_2, and CO.[9] One study in the Toronto area demonstrated statistically significant associations between PM, O_3, and various categories of daily mortality.[10]

Additional research suggesting that $PM_{2.5}$ has greater impact on daily mortality than PM_{10} was completed in Chile[11] and Philadelphia,

Pennsylvania.[12] The researchers in the Philadelphia study argue that, in the northeastern United States, $PM_{2.5}$ exacerbates adverse health effects associated with PM_{10}.

Not all research has shown a statistically significant relationship between PM and specific health outcomes. For example, a study conducted in California did identify a relationship between various sizes of particle matter and cardiovascular mortality; however, there was no observed relationship between fine particles and respiratory mortality.[13] Similarly, research conducted in Melbourne from 1991-1996 did not identify an association between PM_{10} and $PM_{2.5}$ and mortality levels.[14] The Melbourne study attributed respiratory mortality in the summer period to photochemical smog.

The inconsistency in the findings of the California and Melbourne studies with earlier research may be attributed to different statistical models, inclusion of different co-pollutants, weather covariates, and confounding problems. To address some of these factors Schwartz analyzed confounding factors, effect modification, and thresholds in the association between ambient particles and daily mortality.[15] He found an association of daily deaths with airborne particulate pollution that cannot be attributed to any other air pollutants.

Schwartz also identified a higher association between air pollution and outpatient mortality than with hospital mortality. This finding suggests that increased cardiopulmonary mortality risk of non-terminally ill patients may be attributed to airborne air pollutants. Schwartz concluded that interventions that decrease average levels of particulate matter benefit public health better than those that address peak pollution days.

Exposure to particulate matter in the ambient environment is not the only exposure of concern. There is evidence to suggest that people are exposed to higher levels of PM in indoor air than outdoor air.[16] Possible mechanisms for increased indoor exposure include smoking, dusting, vacuuming, and cooking and there is recent research suggesting that indoor air pollution may contribute to infant mortality.[17] Hence, there is the need to further study both outdoor and indoor personal exposure to particulates

Air pollution and morbidity

Short and long term effects of air pollution on human health have been of special interest to many researchers. Adverse health effects associated with air pollution include the exacerbation of chronic pulmonary diseases, an increase in pulmonary symptoms, and increase in respiratory and cardiovascular distress. The indicators for morbidity are largely tied to hospital admissions, emergency room visits, school absenteeism, and peak flow measurements.

Air pollution and respiratory health

Numerous studies have used hospital admissions to demonstrate the negative respiratory health effects of air pollution.[18] For example, a time-series study in Southern Ontario analyzed the relationship between air pollution and respiratory hospital admissions.[19] Data on SO_2, SO_4, and NO_2 were correlated with the number of hospital admissions in winter and summer. A significant relationship was noted between air pollution and hospital admissions for both children and the elderly.

Another Ontario study focused on the effects of acid aerosols on respiratory admissions during the summer, finding a significant correlation between O_3, SO_4, and H^+ and hospital admissions due to acute respiratory symptoms and asthma.[20] The relevance and importance of this study was that it demonstrated a correlation between hospital admissions and fine, rather than coarse, particulate matter.

Schwartz is one of the most active researchers involved in studying the health effects of air pollution. He has reported an association between PM_{10} and increased hospital admissions for elderly patients with respiratory diseases,[21] including pneumonia.[22] In examining asthma, he noted that emergency room visits due to asthma is correlated with increased concentrations of PM_{10}.[23]

Air pollution and cardiovascular health

Some studies have analyzed hospital admissions for the relationship between air pollution and cardiovascular conditions.[24] Associations have been noted between hospital admissions for cardiac conditions and air pollution regardless of age, gender, or time period.[25] Specifically, both respiratory and cardiac admission rates increased with increasing concentrations of sulfates (SO_4).

Other studies support the relationship between cardio-respiratory hospital admissions and PM_{10} among elderly patients[26] and between particulate air pollution and hospital admissions for all respiratory and cerebrovascular conditions on the same day.[27] Levels of all ambient air pollutants have been associated with cardio-respiratory hospital admissions.[28] However, there appears to be a relationship between hospital admissions and mean particulate matter concentrations as well.

Fine Particles and Chemical Components

Since there is little data on ambient levels of $PM_{2.5}$, PM_{10} is considered an indicator for finer particles.[29] Respiratory symptoms such as coughing, wheezing, phlegm production are related to both pollutants. While research

suggests that adverse health effects of PM_{10} and $PM_{2.5}$ are similar; effects of $PM_{2.5}$ are more cumulative than PM_{10}. Hence, PM $_{2.5}$ may more realistically relate to potential adverse effects of particulate exposure.[30] Also, due to a longer lifetime and indoor penetration of $PM_{2.5}$ it may be a better indicator of overall (indoor plus outdoor) personal exposure to ambient pollution.

There is a correlation among chemicals coming from the same emission source, so, it is difficult to separate the health effects of particulate matter and other chemical substances. Nevertheless, previous research has analyzed adverse health effects specifically from aerosols including O_3, NO_2, SO_2, and SO_4. Upper respiratory infections in children have been associated with high levels of SO_2, NO_2, particulates, and hydrogen sulfide in Finland.[31] Another European study showed that children from more polluted areas had a higher frequency of respiratory symptoms and diseases than their peers in less polluted areas.[32] Severe asthma attacks have been found to be associated with air pollutants, especially NO_2.[33]

Air Pollution and Health of Susceptible Populations

It is generally accepted by the medical community that children are highly susceptible to adverse health effects from air pollution exposure.[34] However, research regarding the relationship of fine particles and morbidity are somewhat controversial, and the available data is still limited. Limited experimental studies on different deposition patterns of PM, based on age, have attempted to explain increased susceptibility to the adverse effects of PM in children and the elderly. Results range from showing no age-dependent deposition patterns to a slightly higher deposition in children than adults.

There is evidence of an association between COPD admissions of children and elderly patients and NO_2 and particulates.[35] In particular, childhood asthma has shown significant correlations with levels of NO_2. In addition, the increase of 1-hour maximum PM concentration was associated with a 5.29 percent increase in hospital admissions of asthmatic children and a 4.6 percent increase in COPD admissions. Increased levels of NO_2 concentrations, increase 1-hour max ozone concentrations, and daily mean particulate concentrations were respectively associated with a 6.71, 2.45, and 2.82 percent increase in hospital admissions of elderly people with cardiac diseases.

According to the Behavior Risk Factor Surveillance System (BRFSS), asthma in the United States is one of the "most common chronic diseases."[36] Asthma is more prevalent among blacks and lower income people than other groups. Examining asthma prevalence in children underscores the fact that this illness is a major public health problem. According to the Centers for Disease Control and Prevention, since 1980, the prevalence of childhood asthma has increased "dramatically."[37] Excluding accidents, asthma is the leading cause of

children's emergency room visits. These facts emphasize the need to investigate environmental factors endangering children's health.

The negative impact of air pollution on pediatric health starts early and may even begin before the child is born. One study identified an influence of PM_{10}, $PM_{2.5}$, and other associated air pollutants on fetal growth in the early gestation period.[38] Both PM_{10} and $PM_{2.5}$ exhibited significant correlations with retarded intra-uterine growth that negatively affects the structure and function of a range of organs and tissues including the pulmonary system.

The correlation between air pollution and health status of asthmatic children was extensively studied in a sample of asthmatic children living in Mexico City, which has a reputation as one of the most polluted cities. Emergency room (ER) visits of asthmatic children are associated with ozone and SO_2 levels.[39] Specifically, an increase of 50 ppb in the 1-hour ozone level lead to a 43 percent increase in the number of ER visits on the following day. Ozone level increases of more than 110 ppb for two consecutive days led to a 68 percent increase in ER visits. Sulfur dioxide (SO_2) concentrations were also related to respiratory ER visits, including asthma. Additional studies with active children in Mexico City showed significant decreases in lung function during exposure to high levels of ozone.[40] The study also stated that despite chronic exposure to high levels of ozone, exercising children responded acutely to a 1-hour exposure of ozone above 150ppb.

Additional studies with youth have been completed in Seattle,[41] Hong Kong,[42] southern California,[43] South Karelia,[44] and with college students.[45] These studies report associations between respiratory responsiveness in children and air pollution. In the Hong Kong study, respiratory function improved after a regulation restricting the concentration of SO_2 in fuel to 0.5 percent was imposed. In one German study, the researchers concluded that SO_2 is related to bronchitis is children; however, although SO_2 and PM are correlated, there was not relationship between particulates and bronchitis.[46] The German researchers explain that additional research is needed to examine relationships between particulate matter and health effects in children.

Norris and colleagues (1999) studied the association between fine particles and asthma emergency department visits for children in Seattle.[47] Significant associations were found between fine particulate matters, CO, SO_2 and emergency department visits of children from the inner city. The associations between emergency room visits and air pollution have also been noted in Santiago, Chili.[48] The Chilean study reported a stronger association between fine particles and children respiratory illness' than with coarse components.

Although there are numerous studies regarding the health effects of ozone, the majority deal with acute health effects. Due to the complexity of personal exposure measurement there still is ambiguity regarding the chronic effects of

ozone and its mechanism of action. Geyh and colleagues studied chronic ozone exposure of children in two California communities.[49] The study measured outdoor, indoor, and personal exposure of 224 children from mountain and upland areas in southern California for the period from 1995 to 1996. In addition to wearing personal ozone samplers, children kept personal activities dictionaries; parents completed questionnaires characterizing each participant's house. The study revealed considerable differences between outdoor, indoor, and personal ozone exposure. Children from mountain areas experienced higher outdoor, indoor, and personal exposure during ozone periods. Boys experienced higher exposure than girls.

There is evidence that socioeconomic factors are related to increased asthma morbidity in children, especially in relation to home allergens. Studies have shown that family income, maternal education, and race-ethnicity factors are associated with levels and types of indoor air allergens.[50] These factors should be considered when analyzing asthma morbidity data for urban communities.

Schwartz analyzed possible reasons for elevated asthma and wheezing rates among black children as compared to white children.[51] The study showed that higher exposure to environmental pollution is one of the reasons for higher asthma morbidity rates among black children. Low-income areas experience higher per capita exposure to ozone above National Ambient Air Quality Standards and consequently, higher respiratory disease rates than high-income areas.

In one survey of 5,072 students using an adapted WHO Childhood Respiratory Questionnaire, students of urban areas had consistently higher rates of respiratory symptoms and diseases than students living in rural communities.[52] Although the study suggested a relationship with ambient air pollution, it could not confirm a causal relationship due to many confounding factors and recommended further research. Additional research demonstrates that mean lung function growth rate is lower among children living in more polluted urban areas.[53]

A study by Weaver and colleagues supports that exposure of children to various environmental factors requires further extensive study.[54] Potentially increased absorption of air pollutants by children can be attributed to high hand-to-mouth activity, different levels of metabolism and dermal exposure. The study also stressed the importance of further research of the health of urban children and their exposure to specific pollutants such as benzene and volatile organic components.

Reliability of results is of great concern when a study investigates cause and dose-response relationships between air pollution components and human health. However, the aforementioned studies showed consistency in findings

regarding the positive relationships between air pollution and adverse health effects, despite the variety of geographic areas, climates, air pollution components, groups, and health effects that were studied.

Biological Mechanisms of Adverse Pollution Effects

Neas summarized several toxicological studies related to short and long term cardiopulmonary PM effects.[55] Physical characteristics such as gravimetric mass, particle number, size, and surface area are important properties of particulate matters responsible for persistent pulmonary inflammation. Chemical characteristics of PM have direct effects on organs in which they are deposited. Acidity has been shown to have a direct negative impact on airways and alveoli. Biological characteristics such as the presence of endotoxins may trigger immune mediated inflammation that decreases pulmonary function. Further reduction of pulmonary capacity among individuals with previously reduced pulmonary function (e.g. asthmatics, patients with pulmonary diseases, the elderly) can result in ER visits, hospitalizations, or even death.

Brief intense airborne exposure deposits tremendous amounts of particles in alveolar cells. Inhibited particle clearance results in prolonged internal pulmonary exposures. Persons with damaged clearance mechanisms such as asthmatics may clear fine particles less efficiently than normal individuals, thereby, increasing their internal exposure to pollutants. Finally, prolonged exposure to fine particles may lead to irritation and potential reduction in alveolar surface area responsible for gas exchange. Consequently, these changes may cause cardiopulmonary stress, cardiac arrhythmias, and apneas.

ORGANIZATION OF REPORT

The remainder of this report is organized into three sections. Section 2 focuses on the prospective health study and includes three chapters: 1) particulate matter measurements; 2) chemical characterization of particulate matter; and 3) health evaluation of study participants. Section 3 contains two chapters: 1) retrospective evaluation of air quality data; and 2) evaluation of hospital admissions and air quality data. Section 4 focuses on air toxics monitoring at the study sites.

NOTES

1. D. Dockery, C.A. Pope, III, X. Xu, J. Spengler, J. Ware, et al., An association between air pollution and mortality in six U.S. cities. *Journal of Medicine* 329 (1993):1753-1760.

2. J. Wordley, S. Walters, J. Avres, Short term variations in hospital admissions and mortality and particulate air pollution. *Occupational and Environmental Medicine* 54 (1997): 108-116; W. Dab, S. Medina, P. Quenel, Y. Le Mooullec, A. Le Tertre, et al., Short term respiratory health effects of ambient air pollution: results of the APHEA project in Paris. *Journal of Epidemiology and Community Health* 50 (1996):S42-S46; J. Schwartz, Air pollution and daily mortality in Birmingham, Alabama. *American Journal of Epidemiology* 137 (1993): 1136-1147.

3. C.A. Pope III, J. Schwartz, & M. Ransom, Daily mortality and PM 20 pollution in Utah valley. *Archives of Environmental Health* 47 (1992): 3, 211.

4. J. Schwartz, D. Dockery, & L. Neas, Is daily mortality associated specifically with fine particles? *Journal of Air Waste Management,* 46 (1996): 927-936.

5. R. Klemm, R. Mason, & C. Heilig, C. "Update on the Six City study: replication, augmentation, and interpretation," in *Conference proceedings*: *Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

6. See note 5 above.

7. See note 1 above.

8. G. Hoek, A. Verhoeff, P. Fischer, B. Brunekreef, & J. Wijnen, "Daily mortality and air pollution in the Netherlands," in *Conference Proceedings*: *Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

9.Y. Hong, J. Leem, E. Ha, & D. Christiani, PM 10 exposure, gaseous pollutants, and daily mortality in Inchon, South Korea. *Environmental Health Perspectives*, 107 (1999): 873-878.

10. H. Ozkaynak, J. Xue, H. Zhou, M. Raizenne, R. Burnet, R. et al., "Associations between daily mortality, PM, and motor vehicle pollution in Toronto, Canada," in *Conference proceedings Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

11. L. Cifuentes & L. Lave, "Effect of fine fraction versus coarse mass in Santiago, Chile," in *Conference proceedings:Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

12. G. Thurston, K. Ito, R. Lall, & W. Wilson, "Influence of alternative PM components in mass associations with Philadelphia, PA mortality and hospital admissions" in *Conference proceedings:Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

13 .B. Ostro, & M. Lipsett, "Coarse and fine particles and daily mortality in the Coachella Valley, California: A follow-up study," in *Conference proceedings:Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

14. R. Simpson, A. Petroeschevsky, L. Denison, L. Thalib, & G. Williams, "Effects of ambient particle pollution on daily mortality in Melbourne, 1991-1996," in *Conference proceedings: Particulate Matter and Health. The Scientific Basis for Regulatory Decision-making* (Sewickley, PA: Air and Waste Management Association, 2000).

15. J. Schwartz, Assessing confounding, effect modification, and thresholds in the association between ambient particles and daily deaths, *Environmental Health Perspectives*, 108 (2000): 563-568.

16. H. Ozkaynak, J. Xue, L. Wallace, E. Pellizzari, & P. Jenkins, Personal exposure to airborne particles and metals: Results from the particle team study in Riverside, California, *Journal of Exposure Analysis and Environmental Epidemiology*. 6 (1996): 57-78.

17. F. W. Lipfert, J. Zhang, and R.E. Wyzga, Infant mortality and air pollution: a comprehensive analysis of U.S. data for 1990, *Journal of the Air and Waste Management Association* 50 (2000): 1350-1366.

18. See Dab et al. in Note 2 above.

19. D. Bates, & R. Sizto, Air pollution and hospital admissions in Southern Ontario: The acid summer haze effect. *Environmental Research* 43 (1987): 317-331.

20. G. Thurston, K. Ito, C. Hyes, D. Bates, & M. Lippman, M. Respiratory hospital admissions and summertime haze air pollution in Toronto, Ontario: Consideration of the role of acid aerosols, *Environmental Research*. 65 (1994): 271-290.

21. J. Schwartz, Short term fluctuations in air pollution and hospital admissions of the elderly for respiratory disease, *Thorax*. 50 (1995): 531-538.

22. J. Schwartz, Air pollution and hospital admissions for the elderly in Detroit, Michigan, *American Journal of Respiratory and Critical Care Medicine* 150 (1994): 648-655; J. Schwartz, PM10, ozone, and hospital admissions for the elderly in Minneapolis-St. Paul, Minnesota, *Archives of Respiratory Health* 49 (1994): 366-374.

23. See Schwartz et al., 1993 in Note 2 above.

24. W. Linn, Y. Szlachcic, H. Gong, P. Kinney, & K. Berhane, K. Air pollution and daily hospital admissions in metropolitan Los Angeles, *Environmental Health Perspectives* 108 (2000): 427-434.

25. R. Burnet, R. Dales, D. Krewski, R. Vincent, T. Dann, et al., Association between ambient particulate sulfate and admissions to Ontario hospitals for cardiac and respiratory diseases, *American Journal of Epidemiology* 142(1995): 1, 15-22.

26. G. Morgan, S. Corbett, & J. Wlodarczyk, Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994, *American Journal of Public Health*. 88(1998):1761-1766.

27. See Wordley et al., 1997 in Note 2 above.

28. R. Burnett, S. Cakmak, J. Brook, & D. Krewski, The role of particulate size and chemistry in the association between ambient air pollution and hospitalization for cardiovascular diseases, *Environmental Health Perspectives* 105(1997): 6, 614-620.

29. W. Wilson, & H. Suh, Fine particles and coarse particles: concentration relationships relevant to epidemiologic studies, *Journal of Air & Waste Management Association* 47(1997):1238-1249.

30. E. Romieu, F. Meneses, S. Ruiz, J. Sienra, J. Huerta, et al., Effects of air pollution on the respiratory health of asthmatic children living in Mexico City, *American Journal of Respiratory Critical Care* 154 (1996): 300-307.

31. J. Jaakkola, M. Paunio, M. Virtanen, & O. Heinonen, Low-level air pollution and upper respiratory infections in children, *American Journal of Public Health* 81(1991):1060-1063.

32. F. Forastiere, C. Corbo, P. Michelozzi, R. Pistelli, & N. Agabiti, Effects of environment and passive smoking on the respiratory health of children, *International Journal of Epidemiology*. 21(1992): 66-73.

33. O. Rossi, V. Kinnula, J. Tienari, & E. Huhti, Association of severe asthma attacks with weather, pollen, and air pollutants, *Thorax* 48 (1990): 244-248.

34. W. Bennett, K. Olivier, K. Zeman, K. Hohneker & E. Boucher, Effect of uridine 5'-triphosphate plus amiloride on mucociliary clearance in adult cystic fibrosis, *American Journal of Respiratory Critical Care Medicine*. 152 (1996): 1796-1801.

35. See Note 25 above.

36. MMWR, Self-Reported Asthma Prevalence Among Adults ---United States, 2000, *MMWR* 50 (2001): 32: 682-686.

37. MMWR, Measuring Childhood Asthma Prevalence Before and After the 1997 Redesign of the National Health Interview Survey --- United States, *MMWR* 49 (2000); 40, 908-911.

38. J. Dejmek, S. Selevan, I. Benes, I. Solansky, & R. Sram, Fetal growth and maternal exposure to particulate matter during pregnancy, *Environmental Health Perspectives* 107 (1999): 475-480.

39. E. Romieu, F. Meneses, J, Sienra-Monge, J. Huerta, S. Velasco, et al., Effects of urban air pollutants on emergency visits for childhood asthma in Mexico City, *American Journal of Epidemiology* 141 (1995): 546-553.

40. M. Castillejos, D. Gold, A. Damokosh, P. errano, & G. Allen, Acute effects of ozone on the pulmonary function of exercising schoolchildren from Mexico City, *American Journal of Critical Care Medicine* 152 (1995): 1501-1507.

41. J. Koenig, T. Larson, Q. Hanley, V. Rebolledo, & K. Dumpler, (1993). Pulmonary function changes in children associated with fine particulate matter. *Environmental Research*, No. 63.

42. C. Wong, T. Lam, J. Peters, A. Hedley, & S. Ong, Comparison between two districts of the effects of an air pollution intervention on bronchial responsiveness in primary school children in Hong Kong, *Epidemiological and Community Health* 52 (1998); 571-578.

43. R. McConnel, K. Berhane, F. Gilliland, S. London, & H. Vora, Air pollution and bronchitic symptoms in Southern California children with asthma, *Environmental Health Perspectives*, 107 (1999): 757-760.

44. O. Martila, J. Jaakkola,, V. Vilkka, P. Jappinen, & T. Haahtela, The South Karelia air pollution study: The effects of malodorous sulfur components from pulp mills on respiratory and other symptoms in children, *Environmental Research* 66 (1994): 152-159.

45. A. Galizia, & P. Kinney, Long-term residence in areas of high ozone: Associations with respiratory health in a nationwide sample of nonsmoking young adults, *Environmental Health Perspectives* Vol. 107 (1999): 675-679.

46. O. Herbarth, G. Fritz, P. Krumbiegel, U. Diez, U. Franck & M. Richter, Effect of sulfur dioxide and particulate pollutants on bronchitis in children—a risk analysis, *Environmental Toxicology* 16 (2001): 269-276.

47. G. Norris, S. Young Pong, J. Koenig, T. Larson, & L. Sheppard, An association between fine particles and asthma emergency department visits for children in Seattle, *Environmental Health Perspectives* 107 (1999): 489- 493.

48. M. Ilabaca, I. Olaeta, E. Campos, J. Villaire, & I. Romieu, Association between levels of fine particles and emergency visits for pneumonia and other respiratory illness among children in Santiago, Chile, *Journal of the Air & Waste Management Association* 49 (1999): 154-163

49. A. Geyh, J. Xue, H. Ozkaynak, & J. Spengler, J., The Harvard Southern California chronic ozone exposure study: Assessing ozone exposure of grade-school-age children in two Southern California communities, *Environmental Health Perspectives* 108 (2000): 265-270.

50. B. Kitch, G. Chew, H. Burge, M. Muilenberg, & S. Weiss, Socioeconomic predictors of high allergen levels in homes in the greater Boston area, *Environmental Health Perspectives* 108 (2000): 301-307.

51. J. Schwartz, D. Gold, D. Dockery, S. Weiss, & F. Speizer, Predictors of asthma and persistent wheeze in a national sample of children in the United States, *American Review of Respiratory Diseases* 142 (1990): 555-562.

52. P. Chen, Y. Lai, C. Yang, J. Hwang, & H. Kuo, Adverse effect of air pollution on respiratory health of primary school children in Taiwan, *Environmental Health Perspectives* 106 (1998): 331-335; P. Chen, Y. Lai, C. Chan, J. Hwang, & J. Wang, Short term effect of ozone on the pulmonary function of children in primary school, *Environmental Health Perspectives* 107 (1998): 921-925.

53. W. Jedrychowski, E. Flak, & E. Mroz, The adverse effect of low levels of ambient air pollutants on lung function growth in preadolescent children, *Environmental Health Perspectives* 107 (1999): 669-674.

54. V. Weaver, T. Buckley, & J. Groopman, Approaches to Environmental Exposure Assessment in Children, *Environmental Health Perspectives* 106 (1998): 827-832.

55. Neas, L.M.,Fine particulate matter and cardiovascular health, *Fuel Processing Technology* 65 (2000): 55-67.

Section 2, Chapter 1
PARTICULATE MATTER MEASUREMENTS

INTRODUCTION

Fine particulate matter, or $PM_{2.5}$, refers to a mixture of solid and liquid atmospheric particles with an aerodynamic diameter (d_{ae}) less than 2.5 micrometers. It arises mainly from anthropogenic sources such as fossil fuel combustion by electric utilities and motor vehicles, wood burning, and the smelting or other processing of metals. $PM_{2.5}$ consists of sulfate, elementary carbon, nitrate, ammonium, organic compounds, trace elements, elemental carbon, and water.[1] The majority of $PM_{2.5}$ components are secondary materials, derived from the chemical reactions of gaseous precursors such as SO_2, NO_x, volatile organic compounds (VOCs), organic and elemental carbon, and a range of trace metals.

In 1997, the U.S. Environmental Protection Agency (USEPA) established a standard for $PM_{2.5}$ of 15 ug/m^3 for an annual arithmetic mean and 65 ug/m^3 for a 24-hour average concentration based on assessments of three consecutive years.[2] USEPA based this standard on an extensive review of numerous epidemiological studies. Recent studies suggest that $PM_{2.5}$ is more strongly correlated with adverse health effects than particles in other size ranges.[3] These health effects range from slight respiratory symptoms to increased mortality rates. In a study of six eastern U.S. cities, Schwartz et al. reported a 10 μg/m^3 increase in the two-day mean $PM_{2.5}$ concentration associated with a 1.5 percent increase in total daily mortality.[4] Certain population groups such as seniors, respiratory and cardiovascular patients, and children are most susceptible to particle pollution.

The association between ambient $PM_{2.5}$ concentrations and a variety of adverse health outcomes suggest that ambient concentration may be an indicator for personal $PM_{2.5}$ exposure, and ambient $PM_{2.5}$ should correlate with indoor and personal $PM_{2.5}$ concentrations.[5] However, epidemiological study results are questionable due to concerns involving inconsistent correlations between outdoor, indoor, and personal levels.[6] Numerous factors exist that can affect relationships including: spatial variability of outdoor concentrations, classification of $PM_{2.5}$ exposure into different microenvironments, the role of chemical components, influence of co-pollutants, and meteorological confounders.

Spatial Variability of Ambient $PM_{2.5}$ Concentrations

Generally, the ambient $PM_{2.5}$ concentration measured by a fixed central monitoring site is used as a proxy for individual $PM_{2.5}$ exposure in epidemiological studies.[7] For uniformly distributed pollutants such as secondary pollutants, a fixed-site monitor provides applicable data in estimating exposures for regional air pollution.[8]

Fine particles have low deposition rates and long atmospheric residence time (days or weeks) resulting in transportation over thousands of kilometers. Consequently, the distribution of ambient $PM_{2.5}$ tends to be homogeneous over urban areas and large regions. Several studies conducted in the U.S. and Europe have reported a uniform distribution of ambient $PM_{2.5}$ across multiple sites over large geographic areas.

Classification of $PM_{2.5}$ Exposures

Total personal exposure to $PM_{2.5}$ is the result of encounters with $PM_{2.5}$ in a variety of microenvironments. The $PM_{2.5}$ concentrations in these microenvironments are a combination of ambient and non-ambient sources. The nonambient $PM_{2.5}$ consists of indoor-generated $PM_{2.5}$ and personal-activity $PM_{2.5}$.

Separating exposure into ambient and non-ambient $PM_{2.5}$ is necessary due to their differences in sources, compositions and driving forces. The formation of ambient $PM_{2.5}$ depends on the photochemical smog processes, which increases with sunlight and temperature but is reduced dramatically indoors. Emission rate changes from mobile sources, utilities, and industrial processes, and meteorological conditions influence ambient $PM_{2.5}$.

Indoor $PM_{2.5}$ includes ambient outdoor $PM_{2.5}$ that has infiltrated indoors, and indoor-generated $PM_{2.5}$. Human activities, cooking, household appliances, and room ventilation conditions affect indoor $PM_{2.5}$ concentrations.[9] The mean indoor/outdoor (I/O) concentration ratio can increase dramatically during the day but decreases at night when human activities are reduced.[10] Three major studies evaluating indoor and outdoor $PM_{2.5}$ show increases of $PM_{2.5}$

concentrations ranging from 25-45 ug/m^3 due to smoking.[11] In the six-city and New York State studies, mean indoor concentrations were double the outdoor levels.[12] As a result of multiple sources, indoor $PM_{2.5}$ is often higher than ambient concentrations.

Personal $PM_{2.5}$ is measured by personal exposure monitors worn by subjects. It can also be obtained by integrating the time-weighted concentration of different microenvironments. Several studies reported increased personal exposure compared to either indoor or outdoor concentrations with exceptions of some studies of elderly or disabled subjects.[13] The increased personal exposure compared to indoor or outdoor concentrations is called personal-activity $PM_{2.5}$ or "personal cloud."[14] Studies also found that the personal cloud increases during the day when personal activity was high.[15] The origin of personal cloud is still unknown.[16]

According to USEPA, U.S. citizens spend about 90 percent of their time inside, and only about 6 percent outdoors.[17] Because a large proportion of personal exposure occurs indoors, indoor $PM_{2.5}$ is a great contributor to personal $PM_{2.5}$ exposure.[18] In a study of 10 subjects with chronic obstructive pulmonary disease (COPD), Bahadori found personal concentrations more closely correlated to the indoor levels (a Pearson's R= 0.72) than to the outdoor levels (a Spearman's R= 0.30).[19]

Correlations of Personal and Outdoor $PM_{2.5}$ Concentrations

Historically, correlations of ambient outdoor and personal $PM_{2.5}$ concentrations vary considerably with correlation coefficients (R) ranging from near zero to near one, which is due to the influence of non-ambient PM regardless the difference in study designs.[20]

The influence of indoor $PM_{2.5}$ provides a plausible explanation for the varying correlations between personal and outdoor $PM_{2.5}$ in epidemiological studies.[21] Relatively strong correlations result for subjects with limited nonambient $PM_{2.5}$ sources.[22] This trend is more obvious in a longtitude-designed study.[23] Longitudinal studies, tracking correlations on individuals over time, illustrate better correlations than studies with cross-sectional designs. [24] Strong correlations occur on subjects with limited nonambient sources due to their sedentary lifestyles, or no apparent indoor source exposure such as environmental tobacco smoke (ETS) exposures.[25] For example, studies in the 13 primary school children in the Netherlands documented that the median R-value for personal-outdoor correlation improved from 0.86 to 0.92 when children with smoking parents were excluded from the analysis.[26]

High correlations also occur for subjects who spend more time in outdoor microenvironments, or live in micronenvironments with high air exchange rates.[27] Indoor $PM_{2.5}$ concentrations decrease as air exchange rates or ventilation conditions improve.[28] In examining the impacts of ventilation

conditions, Sarnat et al. reported that the coefficient of determination (R^2) of personal and ambient concentrations in well ventilated, moderately ventilated, and poorly ventilated indoor environments were 0.88, 0.59, and 0.25 respectively.[29] In summary, correlation variations found in PM studies actually reflect the impact of individual lifestyles and the conditions of the microenvironments in which the subjects spend time.[30]

RESEARCH METHODOLOGY

This study was conducted in central and southeastern Ohio (Figure II.1.1) from January 1999 through August 2000. Fourth and fifth grade classes in two schools in Columbus (Koebel Elementary School and New Albany Elementary School) and one school in Athens (East Elementary School) comprised the monitoring sites. Approximately 30 students at each site were involved.

Figure II.1.1. Overview of Study Area

The three elementary schools are in residential neighborhoods. The location of these sites is illustrated in Figure II.1.2. Koebel is located on the south side of Columbus in the industrial center of the city. The industrial activities include foundries, plastic facilities, and gravel/quarrying operations. This site is also located within 0.5 km of a major transportation artery. New Albany is approximately 8 km northeast of downtown Columbus and is approximately 32 km northeast of Koebel. New Albany is a bedroom community of Columbus with few commercial facilities and no significant industrial operations within the municipal boundary. Since the prevailing winds are from the southwest, transport of $PM_{2.5}$ precursors from the Columbus area may influence the particle pollution at this site.

The third site, Athens, is approximately 120 km southeast of Columbus and is a rural location. Athens is a university town with a population of 20,000. The site is in a residential area and the only significant local stationary pollution source is Ohio University's coal-fired power plant. Athens is about 32 km west of the Ohio River Valley, which has numerous coal-fired power generation facilities, chemical manufacturing facilities, and industrial operations. Athens is an upwind remote site for the Department of Energy's Ohio River Valley $PM_{2.5}$ monitoring projects.[31]

The Koebel school is a one-story building while the New Albany and Athens schools are two-story buildings. Classrooms at each elementary school used for indoor monitoring were selected as far as possible from the kitchen facilities to reduce the impact of cooking-generated $PM_{2.5}$. The classrooms at Athens and New Albany are air-conditioned. Koebel elementary school has a central heating system but no central air conditioning system. All three schools use natural ventilation during the warm months, so classroom windows are typically open during the months of April, May, June, September, and part of October. With central air conditioning, Athens and New Albany may close their windows during very warm days. However, windows are open a majority of the school days during the spring and fall.

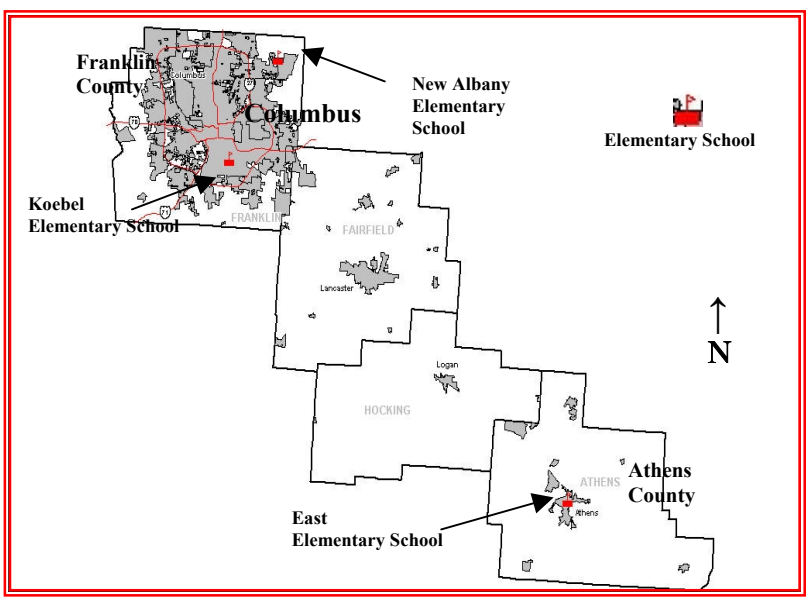


Figure II.1. 2. Locations of the three sites involved in the study.

Measurement Methods

$PM_{2.5}$ data were collected from January 1999 through August of 2000. Filter-based ambient, indoor, personal $PM_{2.5,}$ and continuous ambient $PM_{2.5}$

were measured concurrently at all three sites. The monitoring scheme is outlined in Table II.1.1.

Table II.1.1. Summary of the sampling time and samplers used.

Sampling Type	Sample Sampling Period	Schedule Sampling time	Monitor	Vendor
Continuous Ambient $PM_{2.5}$	Jan, 99 ~Aug, 00	Daily-24 h	TEOM® Series 1400a	Rupprecht & Patashnick (R&P) Co., Inc.
Filter Based Ambient $PM_{2.5}$	Jan~Jun, 1999	School Day- 8 a.m. – 3 p.m.	ACCU™ System	
	Sep, 99~ Aug, 00	Daily-24 h		
Filter Based Indoor $PM_{2.5}$	Jan, 99~Jun, 00	School Day - 8 a.m. – 3 p.m.	URG-2000-30EH URG-3000-02Q	University Research Glass (URG) Corporation
	Jun, 00~Aug, 00	Non-school day Daily-24 h		
Filter Based Personal $PM_{2.5}$	Jan, 99~Aug, 00	School Day - 8 a.m. – 3 p.m.	URG-2000-25F	

Ambient $PM_{2.5}$ Measurements

Continuous ambient $PM_{2.5}$ concentrations were measured using Tapered Element Oscillating Microbalances (TEOMs) series 1400a equipped with 2.5-µm inlets (URG-2000-30EH). Produced by Rupprecht & Patashnick (R&P), TEOM usage occurs widely in PM monitoring around the world.[32] Airflow through a cyclone at 16.67 L/min is isokinetically split into a 3 L/min main flow for the continuous ambient $PM_{2.5}$ sample, and a 13.67 L/min bypass flow. TEOMs were operated at 50 °C to reduce humidity, which might lead to some loss of semi-volatile materials.[33] The 3 L/min air stream passes through a Teflon-coated borosilicate glass fiber filter, which is on the narrow end of a hollow tapered tube. The frequency of the tapered element changes according to filter mass changes under the control of an electronic circuit. A precision electronic counter senses this frequency in a 2-second period and computes the mass of the particulate collected on the filter. The TEOMs were set to run 24 hours seven days a week.

Filter-based outdoor $PM_{2.5}$ concentrations were measured from an Automatic Cartridge Collection Unit (ACCU) System, which was connected to the TEOMs. The ACCU system redirects the bypass flow through one of eight flow channels that are controlled by the TEOM software. Sample media included 47 mm Whatman Teflon® filters (2-µm pores size), which were kept in standard 47 mm Teflon filter holders, at 13.67 L/min. The ACCU $PM_{2.5}$ were measured 24 hours Monday through Friday.

The TEOMs at Athens and Koebel were located on the roofs of the buildings used for the indoor $PM_{2.5}$ monitoring. The inlets for the monitors were within a 10-meter distance above the ground. At New Albany, the TEOMs were on top of a high school building approximately 200 meters from the site of the indoor monitoring. The monitor's inlet was within 13 meters of the ground. In addition, all three TEOMs were in secure limited access locations. A typical set-up of the ambient monitoring system is shown in Figure II.1.3.

Indoor $PM_{2.5}$ Measurements

Indoor monitors were operated at 10 L/min using flow-controlled indoor sampling pumps (Model 3000-02Q, URG). Measurements of indoor $PM_{2.5}$ concentrations were made using 2.5 µm cyclones (URG-2000-30EH). The inlets were specifically chosen to match the TEOMs & ACCU system inlets. The inlets were approximately 1.2 m above the floor. Whatman 37 mm Teflon filters with 2-µm pores size were held in 37 mm Teflon holders. Indoor monitors were timed to run from 8:00 a. m. to 3:00 p. m. from Monday to Friday throughout the school year.

Figure II.1. 3. A typical set-up of the ambient monitoring system.

Continuous ambient 24-hr $PM_{2.5}$ concentrations and filter based outdoor $PM_{2.5}$ concentrations were measured with TEOMs (middle) and ACCU system

(right) respectively from the roofs of the buildings where indoor were measured. Weather monitors (left) were set side-by-side with the $PM_{2.5}$ monitors.

Personal $PM_{2.5}$ Measurements

Personal $PM_{2.5}$ measurements were conducted using impactors (URG-2000-25F) with a $PM_{2.5}$ cut point. The inlets were placed within 0.25 m meters of the breathing zone directly below the shoulders of the subject minimizing the impact of expired air as a potential $PM_{2.5}$ source. Air sampling pumps (Model AirPro® 6000D, BIOS International Co.) were operated at a flow rate of 5 L/min and resided in an acoustic shell to reduce pump noise levels (Figure II.1.4). During non-sampling times, personal pumps were charged using direct plug-in converters. The personal $PM_{2.5}$ sampler devices were placed in personal backpacks (Camelback, Hydrate or Die®, 100oz. H.A.W.G.) that were worn by selected students during the school day (Figure II.1.4). Students were instructed to wear the sampling system throughout the sampling period. They were allowed to place the sampler nearby during indoor sedentary activities (i.e., reading, writing) or activities during which wearing the sampler would be inconvenient or impossible (i.e., sporting activities). The $PM_{2.5}$ samples were collected on Whatman 37 mm Teflon filters with 2-µm pores size, which were held in 37 mm Teflon holders.

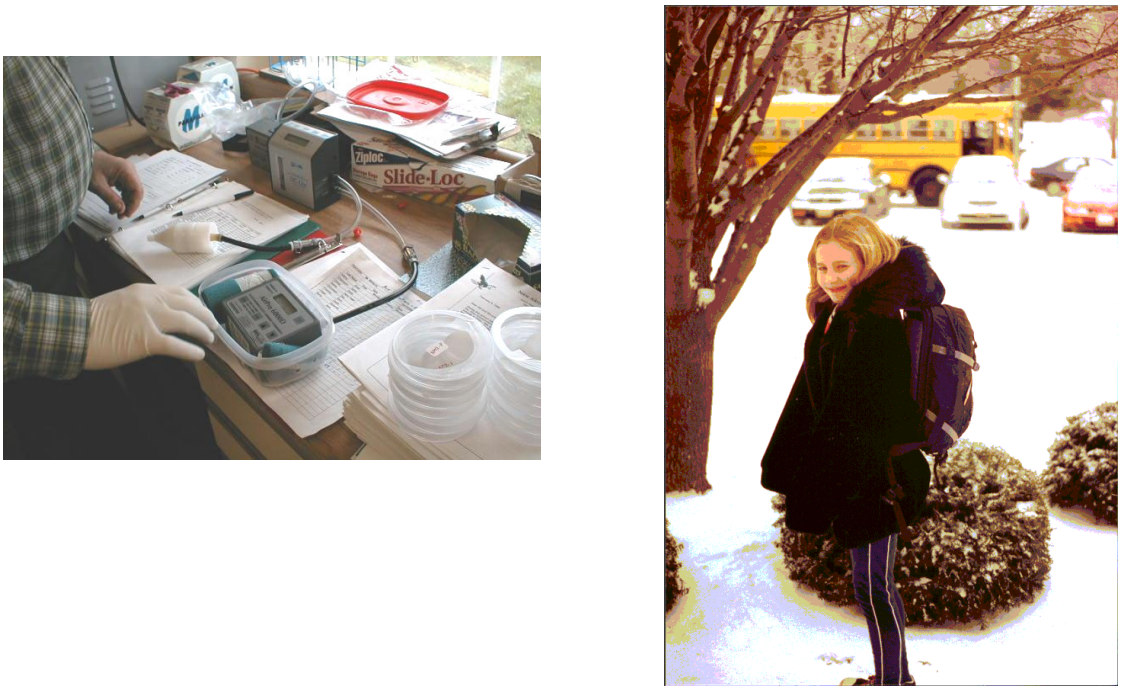


Figure II.1.4. Personal Samplers. Personal pump was placed in an acoustic shell (left) to reduce pump noise levels. Personal sampler devices were then placed in a personal backpack and could be carried by subjects (right).

Meteorological Monitoring

A MetOne AutoMET Meteorological Monitoring System station (Model 460 A, Serial U3439, Met One Instruments) was adjacent to the ambient $PM_{2.5}$ monitors at each site. Using Weather View 32 software, the weather stations recorded data including wind direction, wind speed, precipitation, barometric pressure, and solar radiation.

Gravimetric Measurements

Gravimetric measurements were conducted at Ohio University's Air Quality Laboratory. Filters were weighed in a temperature and humidity controlled microenvironment (environmentally controlled glove-box, PLAS-LABS, Figure II.1.5). As an alternative to the traditional weighing-room, the glove box provides an inexpensive, reliable, and convenient method for gravimetric measurements.[34] The specified temperature range was 20-23 ºC with a variability of no more than ±2 ºC over 24 hours, and 30-35% relative humidity with a variability of no more than ±5 percent over 24 hours.

Each filter was weighed in duplicate - both before and after sampling using a Sartorius analytical microbalance (MC5 UL), with a readability of 1 µg. When these two weights differ by more than 3 µg, the filter was reweighed until sequential weights agree within the specified range. The average of the two closest weights was the final weight.

Figure II.1.5. Humidity controlled microenvironment

Quality Control

In this study, $PM_{2.5}$ monitoring, filter handling and weighing protocols followed the standard quality assurance/quality control (QA/QC) procedures, which are on file at Ohio University. This section highlights the QA/QC procedures that were used during sampling (field procedures) and in the laboratory.

Field Procedures

For the purpose of chemical analysis, filter-based $PM_{2.5}$ mass measurements were collected concurrently with TEOM measurements. Ambient, indoor, and personal monitoring instruments were established in the same school building or at an adjacent building at each site. Prior to the study's commencement, all of the $PM_{2.5}$ monitoring instruments were calibrated. During the study period, trained field technicians visited each site weekly to collect data, transport samples, and perform quality control checks on the equipment.

During each site visit, continuous ambient $PM_{2.5}$ data were downloaded using a portable notebook computer. Filter-based samples were collected and transported in insulated coolers with frozen refrigerant gel packs to maintain a temperature below 4°C, which was monitored by a VWR brand® High/Low Memory Alarm thermometer. At this time, used personal impactors were also collected. New filters and cleaned personal impactors were deposited at the sites prior to the new sampling cycle. Quality control checks were also completed on the TEOMs, the ACCU systems, indoor, and personal monitoring instruments (on file at Ohio University).

One science teacher at each school was identified to support the monitoring program. The teachers attended a one-day training session at Ohio University prior to the initiation of the monitoring program to review quality control and monitoring protocols. The teachers were responsible for daily calibration of the personal pumps prior to and after the sampling period, setting up samples for the personal and indoor monitors, retrieving samples from the monitors, and maintaining sampling records.

Laboratory Procedures

Three sets of blank filters were used to insure the quality of the filter weighing and handling procedures. A lot blank was used to distinguish each batch of filters purchased. To test the stability of a filter batch, a randomly selected filter from each batch (lot blank) was weighed in a 5-day sucession. Only when the successive mass weighing of the lot blank was within 15 µg, was the new filter batch accepted. With each round of filters (i.e. two week sampling period) a lab blank and a field blank was also prepared. Lab blanks were used to assess the environmentally-controlled weighing chamber. Field blanks were used to evaluate the potential contamination during the processes of filter assembly, de-assembly, and transport.

Once the samples were preweighed, the lab blank remained in the controlled microenvironment. The field blank and field samples were placed into their sample cassettes inside an environmentally-controlled assembly hood (Captair Filtair®, 804C type, Captair Labx, Inc.). The assembly hood was cleaned with alcohol wipes (VWR Scientific Premoistened Clean-Wipes ™ ,

Alcohol/DI) prior to each assembly (and de-assembly) procedure. The filter cassettes were placed in individual petri dishes, parafilmed, double bagged, and transported to the morning sites.

After sampling, each filter was inspected before conditioning in the controlled microenvironment for post weighing. The filter holders were cleaned with alcohol wipes before reuse. After post weighing, the filters were placed in their corresponding petri dishes, parafilmed, bagged, and stored in the freezer at a temperature below 0°C. Outdoor and indoor $PM_{2.5}$ filters were sent by overnight service to Texas A&M University in Kingsville, Texas, for chemical composition analysis. The filters were transported in insulated Styrofoam coolers with frozen refrigerant gel packs to maintain a temperature below 4 °C.

Laboratory Qualification

Ohio University's Air Quality Laboratory is one of 9 laboratories participating in an ongoing Laboratory Inter-Comparison program sponsored by the USEPA/Harvard Particle Health Effects Center.[35] The round robin program is designed to assess the performance of each lab in handling weighing PM_{10} and $PM_{2.5}$ samples. The concluding remarks from the first and second rounds indicate that the Ohio University is proficient in analysis of low mass (25-1000 μg) gravimetric filter samples.

Data Validation and Analysis

In this study, data analyses complied with the published North American Research Strategy for Tropospheric Ozone (NARSTO) Data Management Handbook.[36]

The $PM_{2.5}$ concentration was determined by dividing the mass with the sample volume (the production of flow rate and sampling time). In this study, the continuous ambient 24-hr $PM_{2.5}$ concentrations were based on the 30-minute average readings of the TEOMs that were compiled by the TEOM software. Filter-based $PM_{2.5}$ concentrations were computed using the mass difference between the filter's initial and final weight obtained from gravimetric measurements.

All sample weights were corrected by subtracting the mean field blank weights. Samples from 1999 and 2000 were adjusted using the mean field blank of 1999 and of 2000 respectively. The detection limit (DL) was calculated as three times the standard deviation of the field blanks. Limits of detection (LODs) were defined as the ratio of DL to the sampling volume. Data points less than the LODs were included in the data analysis. Negative data points and data points due to operation and equipment failures (i.e. pump malfunction, tube disconnection, short sampling time) were not included in the analysis. Completeness was calculated as the number of collected samples divided by the target number of samples.

The mean, standard deviation, maximum, minimum and median were used to describe the distribution of $PM_{2.5}$ data. Linear regression was performed to determine the relationship between different sample methods, ambient $PM_{2.5}$ across different sites, and personal, indoor, and outdoor concentrations. The correlation coefficient (R) was used to indicate the strength of association between paired data. Also, the co-location data were assessed to detect the bias between each sample method by using paired t-test (at a significance level of 0.05). The results of the data analysis are displayed in tables and graphs. Units for $PM_{2.5}$ mass and $PM_{2.5}$ concentrations are reported in μg and $\mu g/m^3$ respectively.

RESULTS AND DISCUSSION

This section contains the results and the discussion of the data analysis. A short review of the field blanks, data completeness and co-locations is also provided. The data analysis includes; (1) evaluations of temporal and spatial variations of ambient $PM_{2.5}$ mass concentrations; (2) comparisons of personal, indoor, and outdoor $PM_{2.5}$ concentrations; (3) evaluations of indoor/outdoor (I/O) ratios of $PM_{2.5}$ mass concentration and I/O ratios of sulfate component of $PM_{2.5}$; and (4) correlations between outdoor, indoor, and personal $PM_{2.5}$ levels. In addition, the results from this study are compared with similar published studies to further understand the relationships between personal, indoor, and outdoor $PM_{2.5}$ exposures.

Field Blanks and Completeness

The results of the analysis of the field blanks are outlined in Table II.1.2. The overall mean net mass gain was –0.53, 4.11, and 3.35 μg for the outdoor, indoor, and personal measurements respectively. The limits of detection (LOD) for the outdoor, indoor, and personal measurements were 1.41, 6.31, and 9.01 $\mu g/m^3$ respectively.

The data capture was evaluated for each sampling method used in this study. Continuous ambient $PM_{2.5}$, or TEOM $PM_{2.5}$, was measured for approximately 20 months. Each site experienced equipment malfunctions during the study. For example, from the middle of August to December 1999, the TEOMs at Athens were shut down several times due to malfunctions of the mass flow controller. At Koebel, the TEOMs were shut down in part of September, October, and November 1999 due to internal temperature malfunctions. At New Albany, the TEOMs were down for repair during the months of May, July, November, and December in 1999, and during short time intervals in January, and March of 2000.

Table II..1.2. Statistics of field blanks for personal, indoor, and outdoor $PM_{2.5}$ measurements.

	Mean[a]	SD[a]	Max[a]	Min[a]	Size	LOD[b]
1999						
Outdoor	3.11	5.33	19.50	-8.50	44	
Indoor	2.69	4.22	12.00	-5.00	36	
Personal	3.57	3.97	15.50	-2.50	38	
2000						
Outdoor	-4.02	10.77	10.00	-40.00	46	
Indoor	6.43	13.14	33.00	-14.00	22	
Personal	9.00	16.64	39.00	-12.00	16	
Total						
Outdoor	-0.53	9.23	19.50	-40.00	90	1.41
Indoor	4.11	8.83	33.00	-14.00	58	6.31
Personal[c]	3.35	6.31	19.00	-12.00	51	9.01

[a] :µg
[b] :$\mu g/m^3$
[c] :excludes three outliers. (when outliers included, LOD = 13.97 $\mu g/m^3$)

The filter-based measurements included outdoor (ACCU $PM_{2.5}$), indoor, and personal $PM_{2.5}$ concentrations. When sampling problems (i.e. pump or battery failures, tube disconnection) or laboratory irregularities were encountered, the corresponding data points were not included in the analysis. Data capture or completeness was calculated as the number of collected daily samples divided by the target number of samples. Eighty-six percent of the outdoor, 88 percent of the indoor and 82 percent of the personal target samples were completed (Table II.1.3).

Co-locations

Co-locations involved side-by-side sampling for personal, indoor, and outdoor samplers employed in this study. Co-locations were predominantly conducted at Athens with a few conducted at Koebel. The personal and indoor sampling devices were located adjacent to the TEOMs and the ACCU system for the co-locations and 24-hr samples were obtained.

Table II.1.3. Summary of $PM_{2.5}$ sampling completeness, number of days useable samples collected.

Completed Samples	Personal	Indoor	Outdoor	
			ACCU	TEOM
Athens	207	298	300	442
Koebel	194	251	303	493
New Albany	205	270	297	554
Total Completed Samples	606	819	900	1489
Target Samples	742	926	1036	1830
Total Completeness	82%	88%	87%	81%

The $PM_{2.5}$ concentration monitored by separate devices, were assumed to be independent from each other. Bias between each sampler was determined by using a paired t-Test (at a significance level of 0.05). In this study, the paired t-Tests included:

- TEOMs versus ACCU system
- TEOMs versus indoor monitor
- TEOMs versus personal monitor
- ACCU system versus indoor monitor
- ACCU system versus personal monitor
- Indoor monitor versus personal monitor

Results from the t-test indicated that $PM_{2.5}$ concentrations obtained from each sampler were not significantly different from each other at the 0.05 level. From the simultaneous sampling, determination of $PM_{2.5}$ concentrations resulted in the mean concentrations ranging from 10.34 to 15.58 $\mu g/m^3$ as presented in Table II.1.4. The difference between the two mean outdoor concentrations was 1.05 $\mu g/m^3$, while the difference between the indoor and personal mean concentrations was 2.47$\mu g/m^3$.

Table II.1.4. Summary of collocated monitoring data (µg/m^3) for each sampler monitored by each sampling methods used in the t-test.

	Mean	SD	Max	Min	N
Personal	10.34	6.63	22.85	1.39	13
Indoor	12.81	6.77	29.84	5.04	13
ACCU $PM_{2.5}$	14.53	7.40	29.85	2.57	13
TEOM $PM_{2.5}$	15.58	6.83	30.59	5.64	13

Correlations between each sampler were also evaluated using linear regression. The strongest agreement between different sampling methods occurred between the ACCU system and the TEOMs (R = 0.87) followed by the personal-indoor monitor (R=0.72). Only modest correlations between other paired methods were found (Figure II.1.6 and Table II.1.5). These moderate correlations may have been the result of problems encountered during the co-location sampling. The indoor and personal monitors were designed for indoor use. During the co-location sampling period, it rained frequently, and the indoor and personal monitors did not operate efficiently under the high humidity conditions.

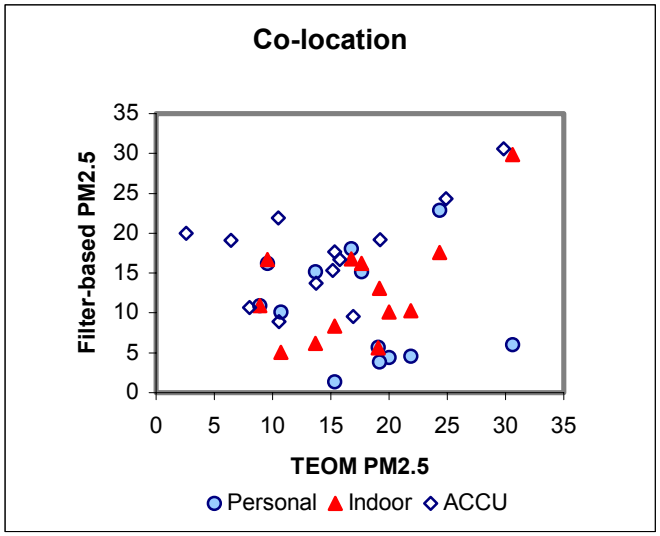


Figure II.1.6. Co-located ambient $PM_{2.5}$ concentrations (µg/m^3) measured by personal, indoor samplers, and the ACCU system plotted against those measured by the TEOMs (n=13).

Table II.1.5. Correlations between co-located samplers (μg/m^3).

	Intercept	Slope	R	N	P
ACCU vs. TEOM	2.48	0.82	0.87	41	<0.0001
Personal vs. TEOM	7.05	0.37	0.28	44	0.06635
Indoor vs. TEOM	8.83	0.41	0.28	35	0.10891
Personal vs. ACCU	5.05	0.48	0.57	30	0.00113
Indoor vs. ACCU	5.63	0.48	0.55	19	0.01486
Personal vs. Indoor	4.61	0.59	0.72	52	<0.0001

Regressing personal and indoor measurements with the ACCU system measurements resulted in similar R-values (0.57-0.55). Regressing personal and indoor measurements with TEOM measurements yielded an equivalent R-value (0.28). Personal and indoor measurements showed a stronger correlation with the ACCU system than with TEOMs. Since three stronger correlations were experienced between the filter-based measurements, the filter-based ambient measurements (ACCU system) were used to evaluate the correlations between personal, indoor, and outdoor concentrations.

Ambient $PM_{2.5}$

The highest ambient $PM_{2.5}$ occurred at the urban site (Koebel), while the lowest concentration occurred at the suburban site (New Albany). Ambient $PM_{2.5}$ illustrated a clear seasonal trend with high concentrations appearing in the warm months and low concentrations appearing in the cold months. The regression of TEOM $PM_{2.5}$ between the sites in the study area revealed a homogeneous distribution of ambient concentrations among the sites. At all three sites, daily ambient $PM_{2.5}$ did not exceed the 24-hr standard (65 μg/m^3). However, the annual standard of 15 μg/m^3 was exceeded at Koebel and Athens.

Ambient $PM_{2.5}$ Concentration

Table II.1.6 presents the results of TEOM monitoring for all three sites. The average annual ambient $PM_{2.5}$ concentrations ranged from 14.72 to 18.47 μg/m^3 for the entire sampling period. Annual average $PM_{2.5}$ concentration was ~3 μg/m^3 greater in the urban locations than in the rural and the suburban locations. Many historical and newly conducted research reviewed by the USEPA, report similar results.[37] These studies indicate that the annual $PM_{2.5}$ standard (15 ug/m^3) will be difficult to reach in most eastern states and in parts of California. The highest 24-hr ambient concentration occurred at Koebel (60.22 μg/m^3), which did not exceed the 24-hr standard of 65 μg/m^3.

Table II.1.6. Summary of ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) for all study sites during the entire sampling period.

Total	Athens	Koebel	New Albany
Mean	15.35	18.47	14.72
SD	7.17	8.64	7.08
Max	40.99	60.22	47.81
Min	4.51	4.89	4.00
Median	13.44	16.61	13.07
25%	10.10	12.28	9.63
75%	18.73	22.44	18.48
N	438	491	552

As expected, the urban site, Koebel, had the highest ambient $PM_{2.5}$ concentration. Figure II.1.7 shows the diurnal variations in $PM_{2.5}$ concentrations. Koebel's ambient $PM_{2.5}$ showed a slightly different diurnal pattern than Athens and New Albany. Two prominent peaks, morning and evening, existed at Athens and New Albany corresponding with daily commuter traffic (from 8:00 a.m. to 10:00 a.m. and from 5:00 p.m. to 9:00 p.m.). The morning peak $PM_{2.5}$ concentrations at Athens were similar with New Albany. While the evening peak of Athens was greater than New Albany and about one hour later. In comparison, Koebel had several peaks during the day.

Overall Koebel's mean hourly ambient $PM_{2.5}$ was consistently higher (range= 15 to 22 $\mu g/m^3$) than the other two sites (range= 12 to 18 $\mu g/m^3$). This difference probably resulted from local sources. Recall that Koebel is located in an industrial center of Columbus and is close to a major transportation artery, so the ambient $PM_{2.5}$ concentration is unavoidably influenced by sources from the surrounding industry and nearby traffic. Röösli et al. reported a 30% increase of $PM_{2.5}$ and PM_{10} concentrations for sites exposed to traffic.[38]

In this study, seasonal trends of $PM_{2.5}$ concentrations existed at all three sites with the maximum $PM_{2.5}$ concentrations occurring during the summer months (Figures II.1.8 and II.1.9). Studies show $PM_{2.5}$ concentrations typically peak in the summer months.[39] This seasonal trend mainly results from the formation of major components of $PM_{2.5}$ such as sulfate (SO_4^{2-}). Sulfate is generated through the oxidation of SO_2 involving OH radicals, O_3, and H_2O_2 species. These species are generated during the photochemical smog processes and their concentrations increase with sunlight and temperature. The seasonal pattern of ambient $PM_{2.5}$ is more pronounced in the eastern U.S. where higher sulfate concentrations appear than the west.

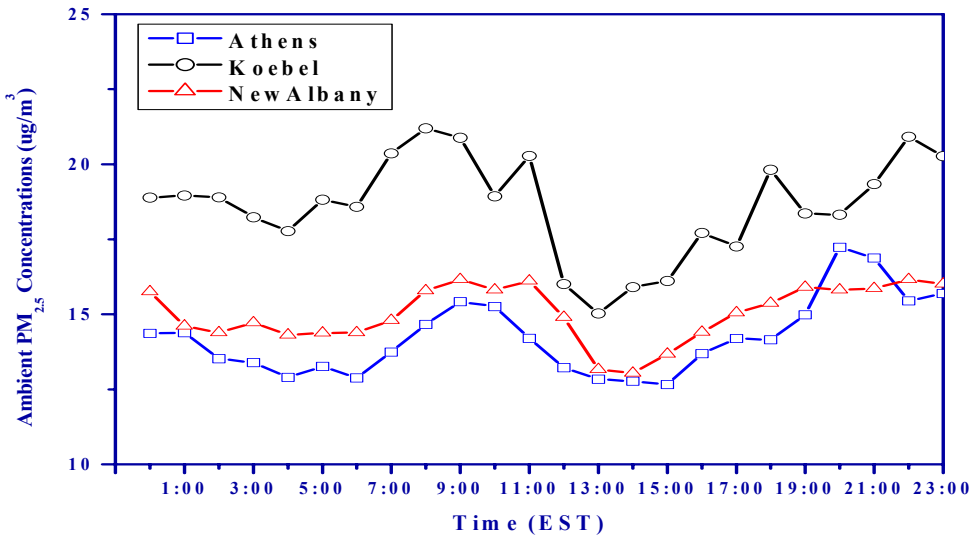


Figure II.1.7. Diurnal distribution of ambient $PM_{2.5}$ at all sites (1999 data).

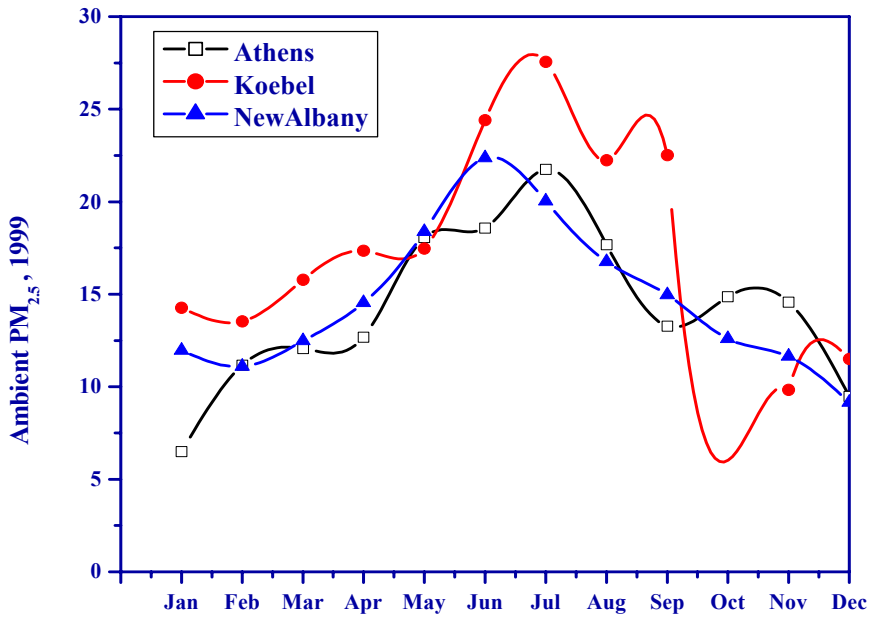


Figure II.1.8. Monthly ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) monitored by TEOMs in 1999.

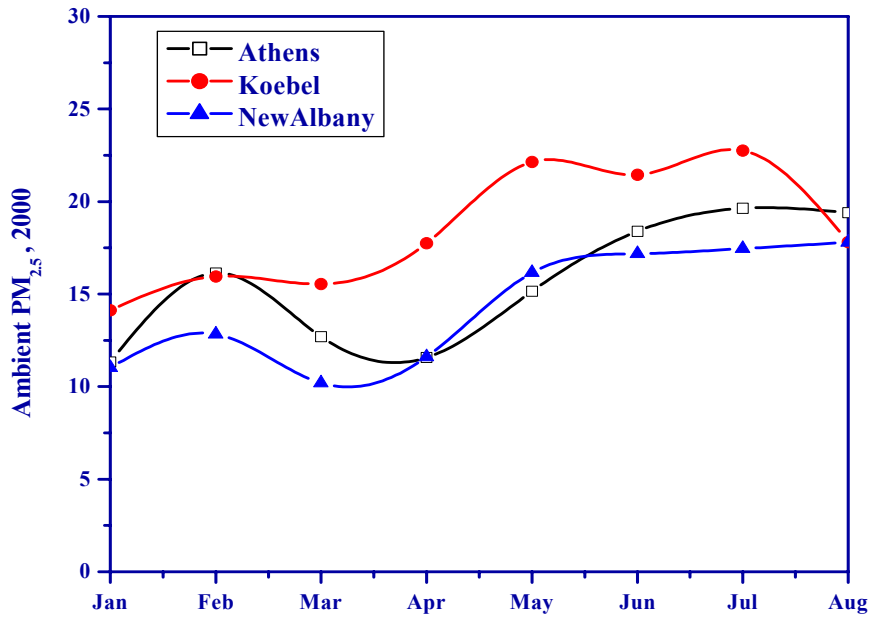


Figure II.1.9. Monthly ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) monitored by TEOMs in 2000.

Spatial Distribution of Ambient $PM_{2.5}$

As shown in Figure II.1.10, strong correlations existed between the ambient $PM_{2.5}$ concentrations measured at all three sites, despite the differences in $PM_{2.5}$ concentrations at individual sites. The linear regression between paired sites produced coefficients (R) raging from 0.60 to 0.78.

When dividing the data into the warm season (April – September) and the cold season (October-March) as shown in Table II.1.7, higher correlations between the sites exist in the warm months (R range = 0.66-0.79) than the cold months (R range = 0.60-0.66), with the exception of the correlation between New Albany and Athens. Overall, the highest correlation occurred between Koebel and New Albany. These limited spatial variations of ambient $PM_{2.5}$ indicate the influence of regional $PM_{2.5}$ sources.

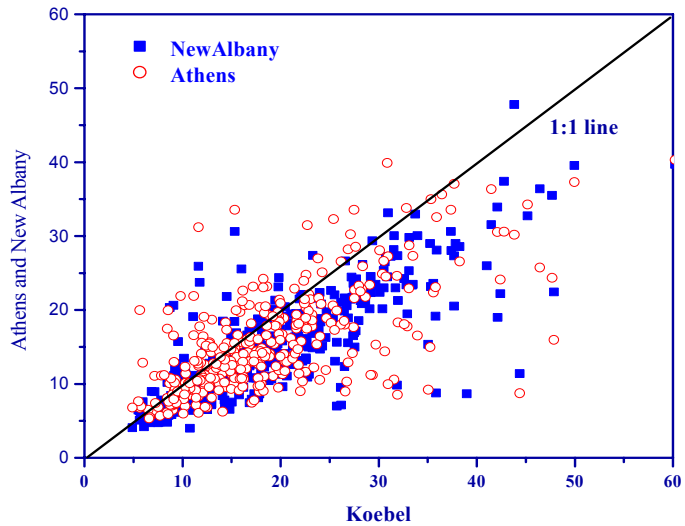


Figure II.1.10. Inter-site correlation of ambient $PM_{2.5}$. Ambient $PM_{2.5}$ concentrations measured at Athens and New Albany plotted against those measured at Koebel. A linear regression of Koebel vs. New Albany had (n=457) an R=0.80 with a slope of 0.62. A linear regression of Athens vs. Koebel (n=373) had an R=0.70 with a slope of 0.54. A linear regression of Athens vs. New Albany (n=411) had an R=0.60 with a slope of 0.58.

Table II.1.7. Correlations of ambient $PM_{2.5}$ concentrations($\mu g/m^3$) between three sites.

	Intercept	Slope	R	N	P
Warm					
Koebel vs. New Albany	3.53	0.62	0.79	281	<0.0001
Koebel vs. Athens	6.36	0.51	0.66	226	<0.0001
New Albany vs. Athens	8.52	0.49	0.51	257	<0.0001
Cold					
Koebel vs. New Albany	4.73	0.46	0.66	176	<0.0001
Koebel vs. Athens	5.34	0.48	0.60	147	<0.0001
New Albany vs. Athens	3.21	0.81	0.72	154	<0.0001

Koebel, the central urban location, had slightly higher concentrations than the other sites, which was potentially influenced by local sources. Figure II.1.11 shows a typical ambient $PM_{2.5}$ episode at the study sites. Koebel showed similar temporal patterns with the suburban site. Most strikingly, Athens, which was approximately 120 km from the two sites in Columbus, also depicted a very similar temporal profile over the entire sampling period.

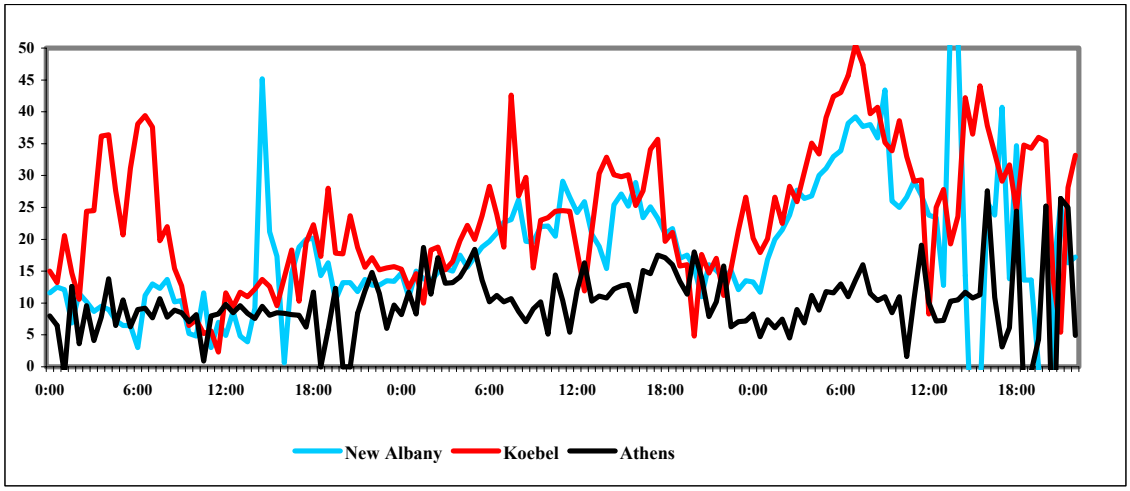


Figure II.1.11. Typical daily variations of ambient $PM_{2.5}$ at three sites. Half-hour TEOM $PM_{2.5}$ concentrations in a three 24-hr interval from May 16 to May 18, 2000.

Similar to the inter-site correlations, and comparisons of ambient $PM_{2.5}$ concentrations for the three sites in this study, sites within the region also showed strong correlations of ambient $PM_{2.5}$ concentrations as shown in Figure II.1.12.

The Advanced Technology System (ATS) monitor provides a comparable ambient $PM_{2.5}$ dataset for Athens. It resides at Gifford State Forest (39.44°N, 81.90°W) approximately 50 km northeast of Athens. Twenty-four-hr $PM_{2.5}$ mass was collected on the 47 mm Teflon filter every fifth day from June 1999 through August 2000. The ATS data depicted a mean ambient $PM_{2.5}$ concentration of 12.54 ± 6.10 μg/m^3 (N=89). While the Athens measurements, during the same periods, yielded a mean concentration of 16.01 ± 7.36 μg/m^3 (N=307). The correlation of ambient measurements at the two sites was strong with an R of 0.65 (Figure II.1.12).

For the New Albany and Koebel sites, datasets from nearby Ohio EPA monitoring sites, Maple Canyon and Woodrow, provide a comparable dataset. Maple Canyon is approximately 12 km west of New Albany and Koebel is about 1.5 km southeast of Woodrow. The mean ambient concentrations at New Albany and Maple Canyon as measured every third day from January to December 1999, were 14.86 ± 7.33 μg/m^3 and 16.90 ± 7.51 μg/m^3 respectively. The mean ambient concentrations at Koebel and Woodrow (daily measurement of 1999) were 18.51 ± 9.14 μg/m^3 and 17.38 ± 7.06 μg/m^3 respectively. Strong correlations exist between the paired ambient concentrations monitored at New Albany and Maple Canyon (R=0.73), and between Koebel and Woodrow (R=0.66) as shown in Figure II.1.12.

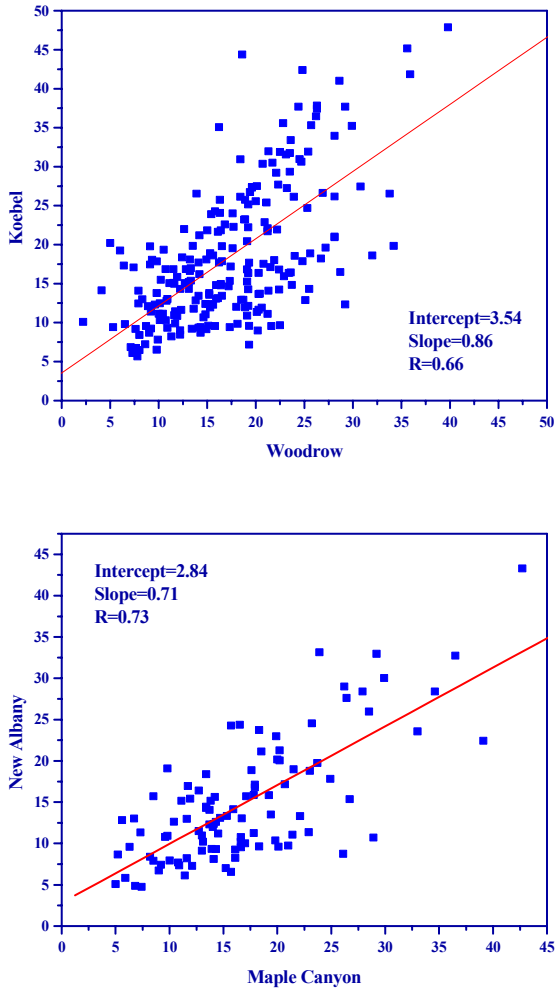


Figure II.1.12. Correlations of ambient $PM_{2.5}$ concentrations of the sites from this study and the corresponding sites within the region.

The uniform distribution of ambient $PM_{2.5}$ in this study is similar with results from other studies conducted in the U.S. and Europe.[40] These studies reported limited spatial variations of $PM_{2.5}$ and PM_{10} concentrations across multiple sites on a scale of 1-36 km with higher correlations occuring in the summer. Burton et al. reported that $PM_{2.5}$ across eight sites in Philadelphia was close to unity.[41] In the central region of Baltimore County, Williams et al. also found high correlation coefficients (R) ranging from 0.94 to 0.96.[42] In the USEPA's Particle Total Exposure Assessment Methodology (PTEAM) study, central-site $PM_{2.5}$ correlated well with $PM_{2.5}$ concentrations monitored immediately outside the participants' homes with the R-coefficients of 0.92 and 0.96 for daytime and overnight respectively.[43] Similar results were documented in the Air Pollution Exposure Distribution within adult urban populations in Europe (EXPOLIS) which showed good agreement between

$PM_{2.5}$ monitored at home outdoors and fixed site measurements.[44] The spatial homogeneity suggests that a fixed-site monitor can represent $PM_{2.5}$ concentrations throughout a large area (i.e. a metropolitan area, a town, small city, and a region).

Outdoor, Indoor, and Personal $PM_{2.5}$

$PM_{2.5}$ monitoring included outdoor (measured by the ACCU systems), indoor, and personal $PM_{2.5}$ measurements. Comparisons indicated that personal and indoor concentrations were higher than the outdoor concentrations at all sites. Comparisons between indoor and outdoor $PM_{2.5}$ mass concentration (I/O) ratios and $PM_{2.5}$ sulfate concentration I/O ratios indicated indoor $PM_{2.5}$ was greatly influenced by human activity.

In this study, measurements of indoor and personal $PM_{2.5}$ occurred when school was in session, typically from 8:00 a.m. to 3:00 p.m. From January to June 1999, the filter-based measurement (ACCU $PM_{2.5}$ concentrations) were also made from 8:00 a.m. to 3:00 p.m. Starting in September of 1999, through the completion of the study, the ambient filter-based measurements were made from 12:00 a.m. to 12:00 p.m., in order to capture sufficient mass for chemical speciation. For pairwise correlation, the 24-hr average ambient filter-based measurements were adjusted to match the 7-hr indoor and personal samples by using a weighting factor calculated from the TEOM measurements.

Comparisons Between Personal, Indoor, and Outdoor Concentrations

The results of filter-based measurements for all three sites are summarized in Table II.1.8. For all three sites, the mean indoor and personal $PM_{2.5}$ concentrations were consistently higher than the outdoor concentration. Outdoor $PM_{2.5}$ illustrated a clear seasonal trend with higher concentrations appearing during the warm months than cold months. However, personal and indoor concentrations did not demonstrate this apparent seasonal pattern as shown in Figure II.1.13. The dissimilarity of seasonal patterns between outdoor, indoor, and personal concentrations indicate the potential differences in their sources. Outdoor $PM_{2.5}$ differs from non-ambient $PM_{2.5}$ because it is influenced by regional-scale pollution emissions and meteorological conditions.[45] In comparison, nonambient $PM_{2.5}$ is highly influenced by the individual's activity-patterns and the ventilation conditions where the individual spends time.

Table II.1.8. Summary of filter-based $PM_{2.5}$ measurements ($\mu g/m^3$) for all study sites.

		Athens	Koebel	New Albany
Outdoor $PM_{2.5}$	**Mean**	13.66	13.89	12.72
	SD	8.91	9.29	8.86
	Max	61.12	77.01	69.30
	Min	0.50	0.24	0.05
	Median	11.49	11.65	10.87
	25%	8.30	8.12	7.62
	75%	17.08	16.65	15.43
	Size	332	315	327
Indoor $PM_{2.5}$				
	Mean	17.20	14.98	16.52
	SD	13.56	12.30	13.53
	Max	71.57	68.37	69.51
	Min	0.45	1.05	0.24
	Median	12.28	10.55	11.56
	25%	8.60	7.28	8.42
	75%	20.78	16.23	19.46
	Size	298	251	270
Personal $PM_{2.5}$				
	Mean	17.61	14.59	13.93
	SD	17.81	13.05	12.25
	Max	88.38	66.96	56.90
	Min	0.17	0.42	0.95
	Median	9.53	10.18	9.45
	25%	6.19	7.52	6.86
	75%	22.46	15.07	14.86
	Size	207	194	205

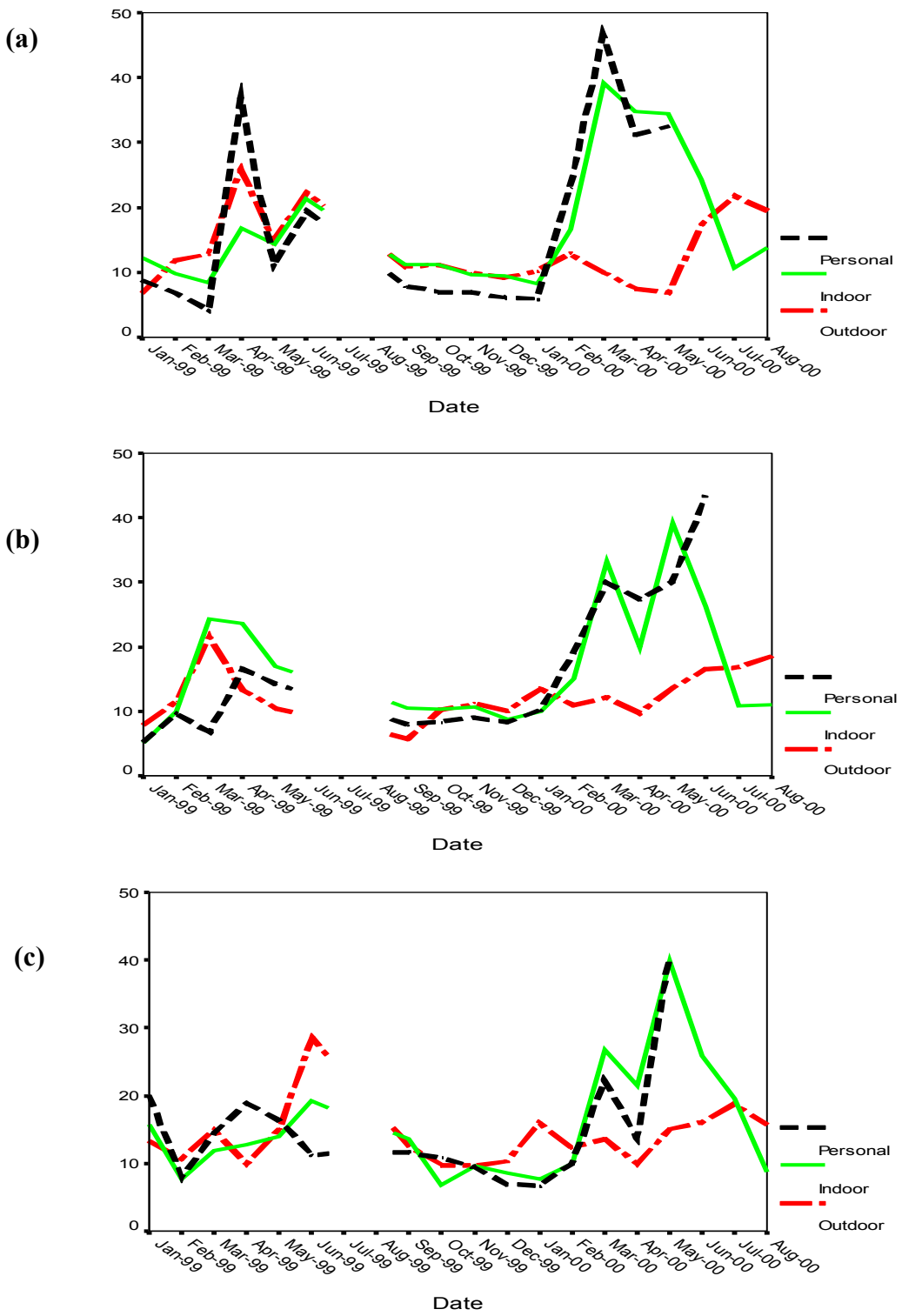


Figure II.1.13. Monthly average filter-based $PM_{2.5}$ concentrations ($\mu g/m^3$) at all sites.

Several reports have documented human activity as being responsible for high indoor and personal PM concentrations when no apparent indoor source exists.[46] Long et al. reported an increase in $PM_{2.5}$ concentration of approximately 23 ± 23 μg/m^3 and 12 ± 9.1 μg/m^3 associated with eleven dusting and fifteen vigorous walking events respectively.[47] In studying I/O ratios of PM (size range = 0.01- 2.5 μm) at Fresno, CA, Vette et al. found resuspension from activities during the day responsible for the observed diurnally I/O ratio variations for PM with size range > 1μm.[48] This study was designed to minimize the impact of indoor $PM_{2.5}$ sources including tobacco smoke and cooking activities. Consequently, the elevated indoor and personal $PM_{2.5}$ concentrations appear to be mainly related to human activity patterns. As the subjects of this study were active and spent most of their time in large groups, their activity patterns would influence resuspensions and reentrainment, resulting in elevated personal and indoor concentrations.

Comparisons Between Outdoor, Indoor, and Personal $PM_{2.5}$ by Sites

The comparison of personal, indoor, and outdoor $PM_{2.5}$ concentrations was unique for each monitoring location. Athens had the largest difference between mean personal and outdoor concentrations (3. 95 μg/m^3), followed by New Albany (1.16 μg/m^3), and Koebel (0.70 μg/m^3). Comparison of the differences between the mean personal and indoor $PM_{2.5}$ at Athens resulted in almost equivalent values (personal =17.61 μg/m^3, indoor= 17.20 μg/m^3). Athens had the highest personal and indoor $PM_{2.5}$ concentrations.

Koebel had the highest mean outdoor $PM_{2.5}$ (13.89 μg/m^3) concentrations and the lowest indoor $PM_{2.5}$ concentration (14.98 μg/m^3). The average indoor concentration exceeded the average outdoor concentrations at Koebel by 1.09 μg/m^3. While the personal concentration (14.59 μg/m^3) was similar with the indoor levels at Koebel.

New Albany, the suburban site, had the lowest average ambient $PM_{2.5}$ concentration (12.77 μg/m^3) and the lowest average personal levels (13.93 μg/m^3). The largest difference between the indoor and outdoor mean concentrations occurred at New Albany (3.75 μg/m^3), followed by Athens and Koebel. The average indoor concentrations exceeded the personal concentrations at New Albany by 2.59 μg/m^3.

Indoor and Outdoor Concentration (I/O) Ratios

The identification of indoor sources and their influence on total $PM_{2.5}$ exposures is important because the average U.S. citizen spends more time indoors than outdoors. Indoor air is influenced by human activities (i.e. cooking, cleaning, and general activities) and ventilation systems (i.e. open or closed windows and doors, air-conditioning systems). Evaluation of indoor and outdoor concentration (I/O) ratios is one method of characterizing the influence of indoor sources. In this study, two types of I/O ratios: $PM_{2.5}$ mass

concentration I/O ratios and $PM_{2.5}$ sulfate concentration I/O ratios, were evaluated. The analyses indicated that the indoor and personal $PM_{2.5}$ concentrations were highly affected by human activity. The influence of human activity on $PM_{2.5}$ levels was most prominent at New Albany and Athens.

Mass Concentration I/O Ratios

The I/O ratios were grouped into separate categories: school days and non-school days. During the school days, the mean I/O ratios ranged from 1.71 to 2.98 while during the non-school days, the mean I/O ratios ranged from 0.80 to 1.27 (Table II.1.9). As shown in Figure II.1.14, the I/O ratios dropped at all three sites when students were on vacation (starting from early June 2000). Overall, at Athens and New Albany, the I/O ratios of non-school days dropped 69% and 72% respectively compared to school days. However, Koebel only dropped 26%.

Table II.1.9. Summary data for $PM_{2.5}$ average concentrations ($\mu g/m^3$) and I/O ratios during school days and non-school days at all sites.

	School day			Non School day		
	Indoor	**Outdoor**	**I/O ratios**	**Indoor**	**Outdoor**	**I/O ratios**
Athens						
Mean	17.68	12.36	2.61	15.11	19.53	0.80
SD	14.22	8.51	5.76	10.05	8.34	0.70
Max	71.57	61.12	57.43	47.31	42.66	3.34
Min	0.45	0.50	0.17	1.01	4.95	0.10
Median	12.23	10.70	1.00	12.62	17.98	0.65
Size	242	272	235	56	60	31
Koebel						
Mean	14.44	13.44	1.71	17.46	16.04	1.27
SD	11.73	9.28	3.17	14.53	9.12	1.16
Max	68.37	77.01	31.69	55.15	48.16	4.94
Min	1.32	0.24	0.16	1.05	3.36	0.04
Median	10.54	11.30	0.98	12.85	15.22	0.96
Size	206	261	196	45	54	43
New Albany						
Mean	17.74	11.98	2.98	11.75	16.74	0.82
SD	14.47	8.59	5.47	7.27	9.09	0.60
Max	69.51	69.30	49.44	34.13	41.34	2.96
Min	0.71	0.05	0.05	0.24	3.10	0.13
Median	11.76	10.52	1.16	10.36	15.31	0.63
Size	215	273	208	55	54	54

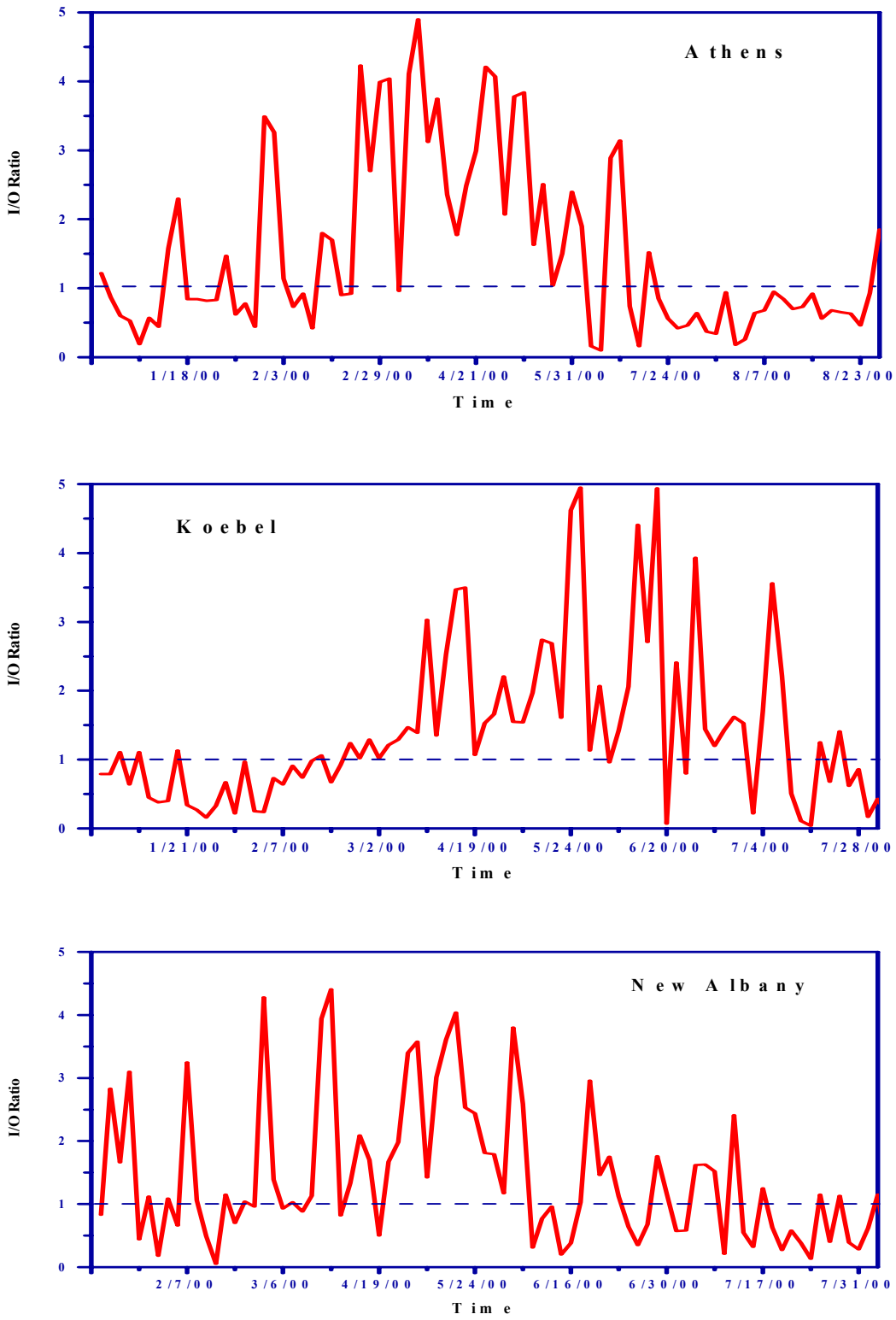


Figure II.1.14. School day I/O ratios vs. non-school day I/O ratios at three sites, 2000. I/O ratios greater than 5 are not included in the graph.

In general I/O ratios decreased when students were not present in the buildings. This is the result of reduced human activity and its impact on resuspension. However, the extent of the I/O ratio decrease varied at each site; the fluctuation pattern in the urban site, Koebel, differed from Athens and New Albany. During non-school days, I/O ratios at Athens and New Albany were less than 1, whereas Koebel's I/O ratios reduced slightly from 1.71 during school days to 1.27 during non-school days. Overall, I/O ratios at Koebel were greater than 1. The dramatic decline of indoor concentrations and I/O ratios associated with the absence of students was not experienced at Koebel. The activities of the summer school students at Koebel may contribute to the high indoor $PM_{2.5}$ concentrations.

These results are supported by several studies in which I/O relationships were highly influenced by indoor sources (i.e. human activities, ventilation conditions). This conclusion results from three observations. First, higher I/O ratios occur when human activity is high, while low I/O ratios occur when human activity is low. In nine homes in the Boston area, Long et al. reported the mean I/O ratios for $PM_{2.5}$ as 2.4 ± 14 for daytime while 0.74 ± 0.41 for nighttime. Second, high variability of indoor $PM_{2.5}$ concentrations occur during high I/O ratio time, which suggest the influence of short-term impacts of indoor source events.[49] In a fifth-grade classroom in Lindon, Utah, Patterson et al. reported prominent indoor $PM_{2.5}$ concentration peaks occurred from 9:00 a.m. to 4:00 p.m. each school day. No midday peaks existed during the weekend.[50] Third, in the absence of indoor sources, I/O ratios are less than or equal to 1. According to Wallace, an I/O ratio for $PM_{2.5}$ at homes with no apparent indoor sources was 0.65.[51]

Results similar to previous research were found in this study. First, higher I/O ratios appear during school days when human activity was high, while low I/O ratios occurred during the non-school days when human activity is minimal. Second, large variations of school day indoor $PM_{2.5}$ concentrations appeared in school days when I/O ratios were also high. Third, the I/O ratios were rarely below 1 during school days at all three sites. Since the indoor sources from smoking, cooking, and cleaning were minimized in this study, the indoor $PM_{2.5}$ was mainly generated by human activity.

$PM_{2.5}$ Sulfate Concentration I/O Ratios

Indoor $PM_{2.5}$ is the combination of ambient-origin $PM_{2.5}$ (ambient $PM_{2.5}$ that has infiltrated indoors) and indoor-generated $PM_{2.5}$. Sulfate (SO_4^{2-}) is commonly used as a marker of outdoor air in indoor environments due to its stability and absence of indoor origins. Particle sulfate results from atmospheric chemical reactions of gaseous sulfur dioxide, which is emitted from sulfur-containing fossil fuel combustion. Sulfate is not only the most homogenous pollutant in the ambient air, but also a strong marker for ambient-origin $PM_{2.5}$. Studies have reported sulfate as being the prime chemical

constituent of $PM_{2.5}$.[52] In the eastern U.S., sulfate constitutes approximately 30-40 percent of $PM_{2.5}$ compositions. Indoor aerosol sulfate arises through the resuspension of deposited outdoor sulfate tracked indoors by human activity.

In this study, two types of sulfate concentrations, indoor and outdoor, were available (refer to Section 2 Chapter 2). Similar to the $PM_{2.5}$ mass concentration I/O ratios, sulfate I/O ratios also varied between school days and non-school days. (Table II.1.10) Overall, the school sulfate I/O ratios were greater than 1.36, in contrast to the data of Lee et al. (0.81)[53], Li and Harrison (0.89).[54] During the non-school day, sulfate I/O ratios reduced to near unity (range = 0.98 ~ 1.25) at all sites. Studies suggest that for fine particles, the indoor/outdoor ratios appear lower or near unity in the absence of apparent indoor sources such as smoking, cooking and cleaning.[55] For example, Jones et al. reported sulfate I/O ratios of fine particulate matter (d_{ae} range = 1.1-2.1 μm) from 0.6 to 0.9 at twelve residences in Bringham, England.[56] The variations of sulfate I/O ratios with school day I/O ratios greater than the unity in this study, again, indicated the contributions of resuspension-related human activity to indoor $PM_{2.5}$.

Table II.1.10. Summary data for $PM_{2.5}$ sulfate concentration I/O ratios during school days and non-school days at all sites.

		Average	SD	Max	Min	Size
Athens	**School Day**	1.36	2.26	15.76	0.10	139
	Non School Day	1.25	1.25	4.69	0.16	29
Koebel						
	School Day	1.98	4.81	27.40	0.08	87
	Non School Day	0.98	1.83	10.35	0.01	39
New Albany						
	School Day	3.24	10.26	100.8	0.02	110
	Non School Day	1.06	1.34	7.88	0.10	49

The temporal patterns of sulfate I/O ratios were different at each site. At Athens and Koebel, the average indoor sulfate concentrations were lower than the average outdoor concentrations. For New Albany, the indoor sulfate was slightly higher than the outdoor concentration. While similar sulfate I/O ratios occurred at Athens (1.36) and Koebel (1.98) during school days, New Albany's sulfate I/O ratio (3.24) was significantly higher. The greatest difference between school day and non-school day sulfate I/O ratios occurred at New Albany (2.18), followed by Koebel (1.00). When the students were on vacation, the I/O ratio at New Albany reduced from 3.24 to near unity (1.06). However, only slight drop of sulfate I/O ratio values occurred at Athens (0.11). The low school day I/O ratios occurring at New Albany indicate that indoor

$PM_{2.5}$ at this site is strongly influenced by indoor sources generated by human activities.

Both Athens and New Albany have air-conditioning systems, and different patterns of I/O relationships exist in these schools. This may be the result of varying activity patterns between the student groups and of the frequency and time of open windows and open doors at each site. It may also result from the difference between the school buildings. The New Albany school was built in 1998, which is the newest building among the three school buildings, as such it will have less outdoor air infiltration. In addition, the classroom at New Albany was the only carpeted one among all three sites. Studies investigating indoor particle characters show that carpets act as long-term reservoirs for suspendable particles.[57] The variations of the I/O relationships indicate the complexity and difficulty in analyzing the influence of indoor sources, which may lead to the complexity of correlations between personal, indoor, and outdoor $PM_{2.5}$ concentrations.

Correlations between Personal, Indoor and Outdoor $PM_{2.5}$

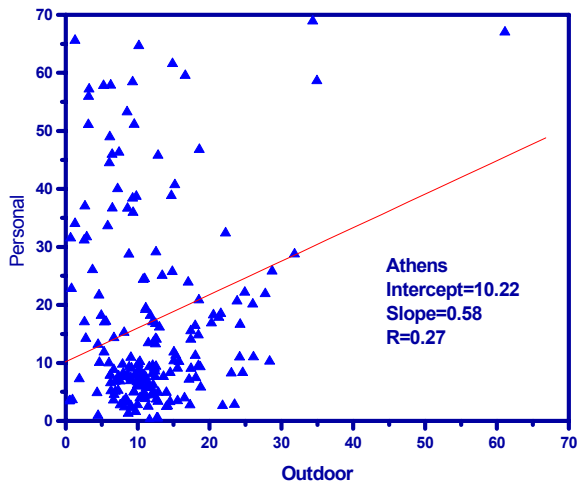
Results from regression analysis for personal, indoor, and outdoor $PM_{2.5}$ concentrations are presented in Table II.1.11 and Figure II.1.15, Figure II.1.16, and Figure II.1.17. The coefficients (R) of all pairwise comparisons were positive for all sites. Strong correlations existed between personal and indoor $PM_{2.5}$ concentrations at all three sites with R values ranging from 0.30 to 0.68. Weak to moderate correlations occurred between personal and outdoor $PM_{2.5}$ concentrations and between indoor and outdoor concentrations. The R-value ranged from 0.04 to 0.32 for personal-outdoor correlations, and from 0.13 to 0.30 for indoor-outdoor correlations.

Table II.1.11. Summary of correlations of personal, indoor, and outdoor $PM_{2.5}$ concentrations*.

	Intercept	Slope	R	N	P
Personal vs. Outdoor					
Athens	10.22	0.58	0.27	202	0.0001
Koebel	8.42	0.50	0.32	186	<0.0001
New Albany	13.37	0.05	0.04	200	0.59
Personal vs. Indoor					
Athens	2.03	0.87	0.68	196	<0.0001
Koebel	4.96	0.70	0.56	169	<0.0001
New Albany	8.19	0.32	0.30	182	<0.0001
Indoor vs. Outdoor					
Athens	14.28	0.19	0.13	292	0.03
Koebel	10.43	0.36	0.26	240	<0.0001
New Albany	10.77	0.44	0.30	265	<0.0001

* Data for personal-outdoor and personal-indoor correlation analyses are based on school day data. Indoor-outdoor correlation analysis includes both school day and non-school day data. Exclude data for non-school day yields indoor-outdoor correlations at three sites with R of 0.13, 0.32, 0.36 for Athens, Koebel, and New Albany respectively.

Correlations between personal, indoor, and outdoor $PM_{2.5}$ concentrations varied among the sites. Koebel, the urban site, had the strongest correlations for personal-outdoor and indoor-outdoor $PM_{2.5}$ concentrations. While Athens, the rural site, had the strongest personal-indoor correlation. The personal-outdoor correlations followed the pattern Koebel > Athens > New Albany. The indoor-outdoor correlations followed the pattern Koebel > New Albany > Athens. The order of personal-indoor correlations was Athens > Koebel > New Albany.

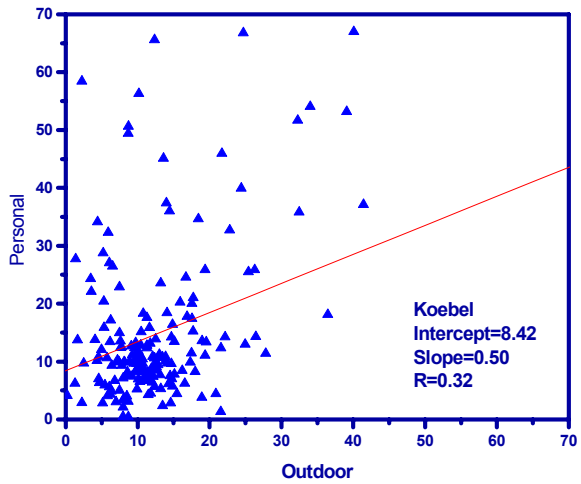


Athens

Intercept=10.22

Slope=0.58

R=0.27

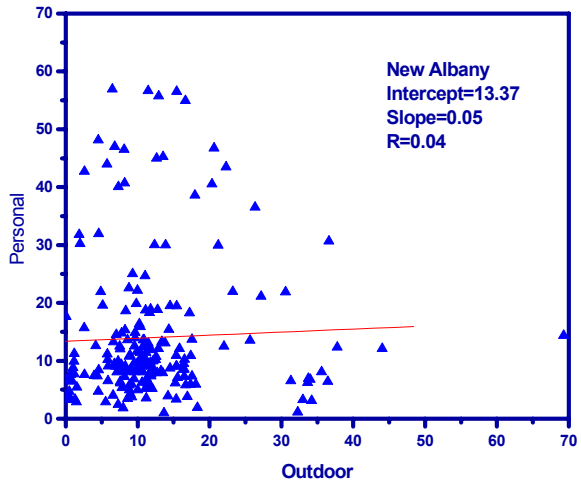


Koebel

Intercept=8.42

Slope=0.50

R=0.32



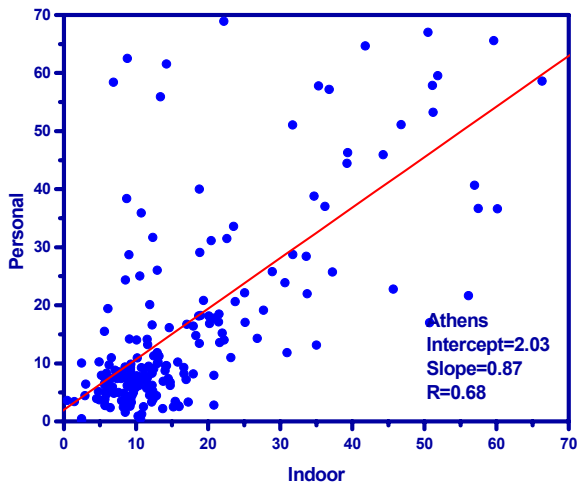
New Albany

Intercept=13.37

Slope=0.05

R=0.04

Figure II.1.15. Personal-outdoor relationships during the sampling period.

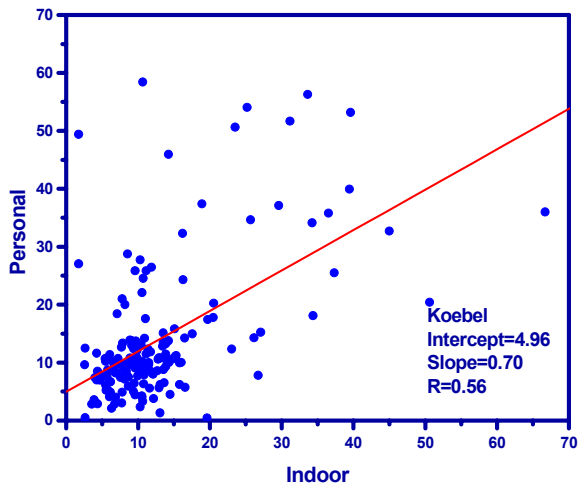


Athens

Intercept=2.03

Slope=0.87

R=0.68

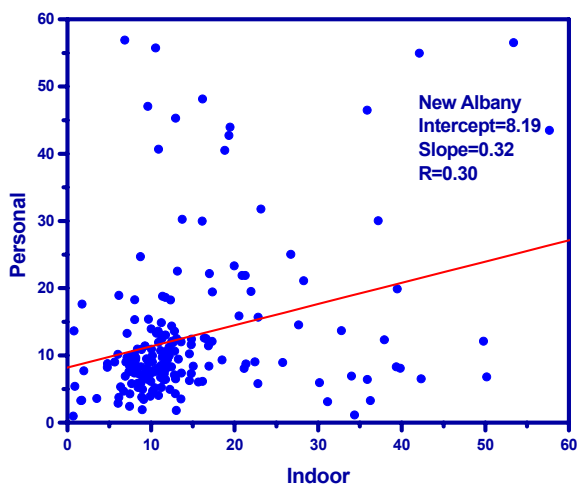


Koebel

Intercept=4.96

Slope=0.70

R=0.56



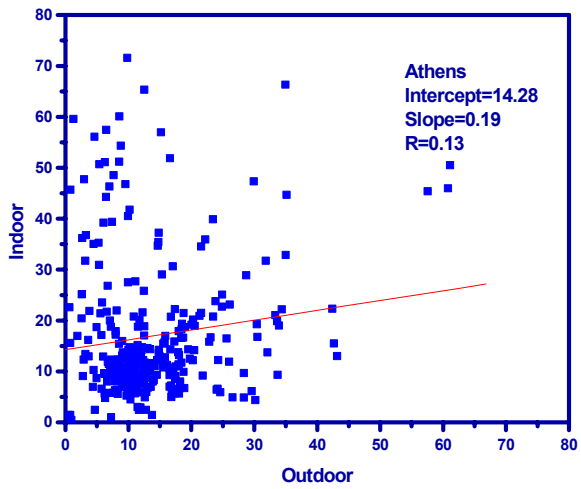
New Albany

Intercept=8.19

Slope=0.32

R=0.30

Figure II.1.16. Personal-indoor relationships during sampling period.

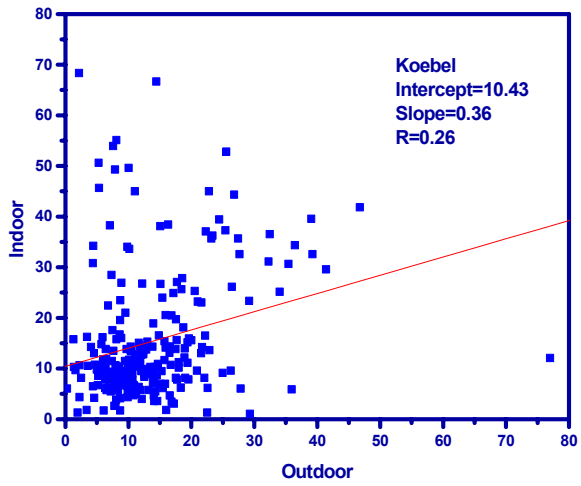


Athens

Intercept=14.28

Slope=0.19

R=0.13

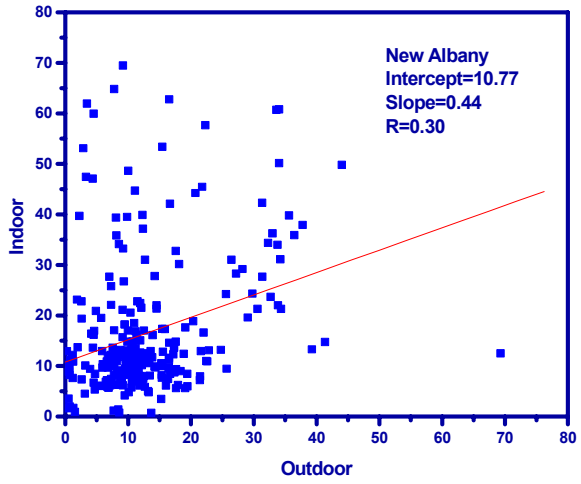


Koebel

Intercept=10.43

Slope=0.36

R=0.26



New Albany

Intercept=10.77

Slope=0.44

R=0.30

Figure II.1.17. Indoor-outdoor relationships during sampling period.

Correlations by Sampling Years and Seasons

Most PM exposure studies have been conducted during a single season, which leads to limitations in characterizing the variations of ambient concentrations, air exchange rates, and personal activities across seasons. The results of this study indicated large variations in correlations between personal, indoor, and outdoor $PM_{2.5}$ concentrations over multiple seasons. As shown in Figure II.1.18, all pairwise correlations fluctuated from month to month during the two-year study period with R-values ranging from below zero to near unity. No apparent patterns were found between different pairwise correlations. This illustrates the complexity of personal-indoor-outdoor correlations.

To examine temporal and seasonal correlation trends on personal, indoor, and outdoor $PM_{2.5}$ concentrations, data analysis of sampling years (1999 and 2000) and by seasons (warm; April to September; and cold; October to March) were examined separately. Strong and consistent correlations existed between personal and indoor $PM_{2.5}$ levels. This finding supports the hypothesis that indoor $PM_{2.5}$ is an important determinant of the total personal $PM_{2.5}$ exposure. Personal-outdoor and indoor-outdoor correlations varied during different time frames. All pairwise correlations were significant at Koebel regardless of sampling periods or seasons. More complex correlation patterns were experienced at Athens and New Albany. The results of correlations by sampling year and by season are summarized in Tables II.1.12, II.1.13, and II.1. 14.

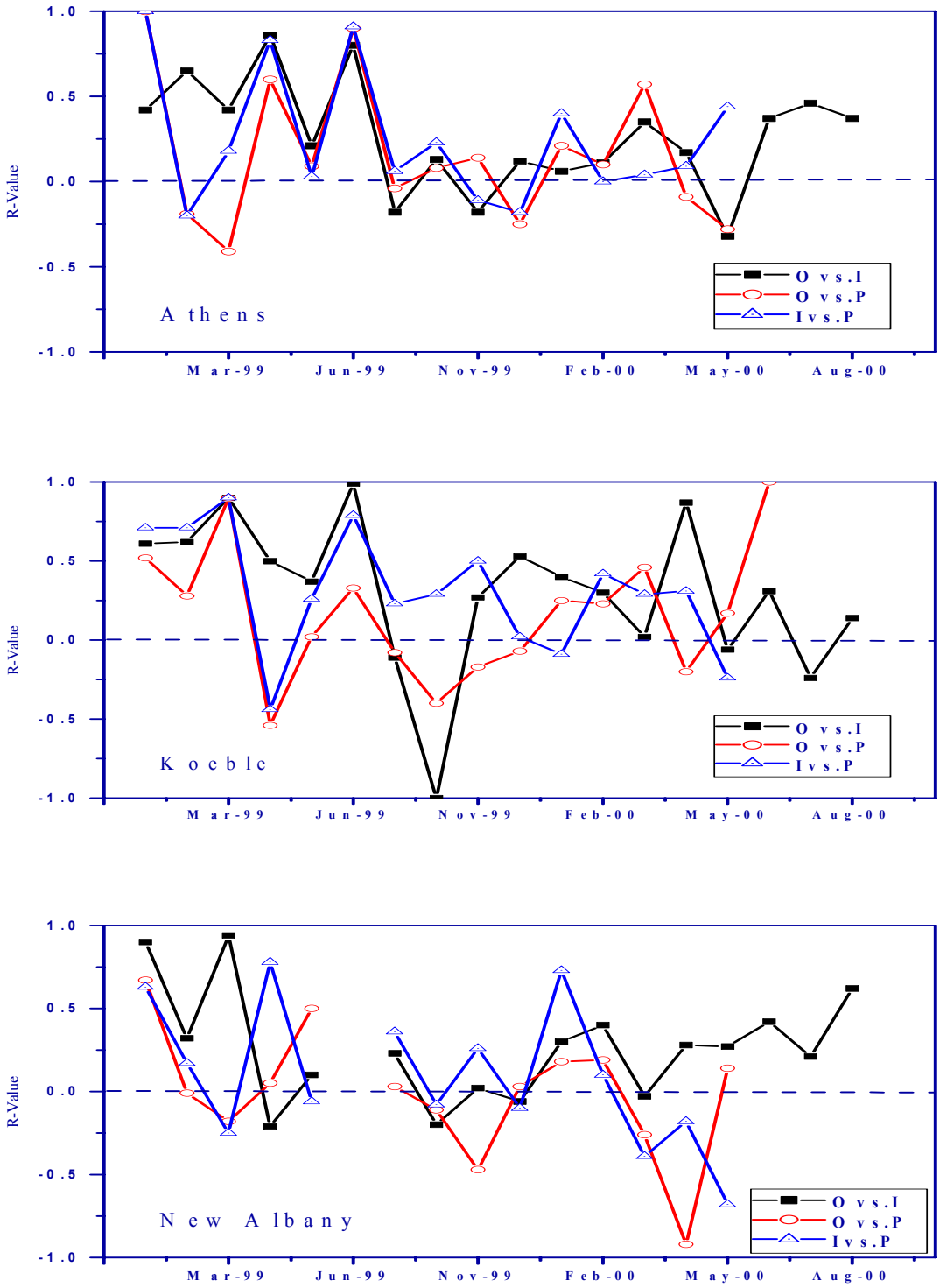


Figure II.1.18. Monthly variations of correlation coefficients of personal (P), indoor (I), and outdoor (O) concentrations at all three sites

Table II.1.12. Summary of correlations of personal and outdoor $PM_{2.5}$ concentrations ($\mu g/m^3$) by year and by season.

Personal vs. Outdoor	Intercept	Slope	R	N	P
1999					
Athens	-3.70	1.12	0.69	135	<0.0001
Koebel	6.15	0.60	0.37	139	<0.0001
New Albany	9.87	0.00	-0.01	138	0.94
2000					
Athens	28.88	-0.05	-0.02	68	0.90
Koebel	15.20	0.29	0.20	47	0.18
New Albany	22.85	0.04	0.03	62	0.83
Warm Months					
Athens	18.38	0.45	0.26	84	0.02
Koebel	14.14	0.46	0.23	65	0.07
New Albany	13.92	0.48	0.21	69	0.08
Cold Months					
Athens	9.71	0.21	0.07	119	0.48
Koebel	6.10	0.46	0.39	121	<0.0001
New Albany	11.08	0.01	0.01	131	0.89

Table II.1.13. Summary of correlations of indoor and outdoor $PM_{2.5}$ concentrations ($\mu g/m^3$) by year and by season.

Indoor vs. Outdoor	Intercept	Slope	R	N	P
1999					
Athens	3.86	0.58	0.74	156	<0.0001
Koebel	4.34	0.60	0.65	137	<0.0001
New Albany	5.45	0.77	0.54	150	<0.0001
2000					
Athens	26.78	-0.31	-0.16	136	0.05663
Koebel	19.52	0.02	0.01	103	0.88724
New Albany	16.50	0.19	0.13	115	0.17058
Warm Months					
Athens	20.09	0.03	0.02	154	0.76124
Koebel	15.54	0.28	0.16	111	0.10401
New Albany	8.31	0.53	0.43	137	<0.0001
Cold Months					
Athens	10.79	0.19	0.09	138	0.27813
Koebel	7.16	0.35	0.38	129	<0.0001
New Albany	14.40	0.29	0.16	128	0.06469

Table II.1.14. Summary of correlations of personal and indoor $PM_{2.5}$ concentrations ($\mu g/m^3$) by year and by season.

Personal vs. Indoor	Intercept	Slope	R	N	P
1999					
Athens	-3.59	1.27	0.65	131	<0.0001
Koebel	3.21	0.88	0.51	130	<0.0001
New Albany	7.47	0.17	0.27	137	0.00
2000					
Athens	10.04	0.64	0.59	65	<0.0001
Koebel	5.76	0.60	0.68	39	<0.0001
New Albany	16.46	0.31	0.25	45	0.10
Warm Months					
Athens	7.86	0.71	0.58	79	<0.0001
Koebel	12.23	0.35	0.32	54	0.02
New Albany	8.81	0.44	0.43	56	0.00
Cold Months					
Athens	-0.73	0.98	0.71	117	<0.0001
Koebel	1.03	0.99	0.69	115	<0.0001
New Albany	9.33	0.13	0.12	126	0.17

Factors Influencing Personal, Indoor, and Outdoor Correlations

Limited information is available regarding correlations between personal, indoor and outdoor $PM_{2.5}$ concentrations. Most studies focus on senior subjects and respiratory patients.[58] A few studies investigate children's $PM_{2.5}$ exposures and their relationships with indoor and outdoor levels.[59] The studies that focus on children are often conducted in homes, an environment quite different from the classroom. Therefore, making direct comparisons between this study and similar investigations is difficult. However, this study provides valuable information in examining the relationship between personal, indoor, and outdoor $PM_{2.5}$ levels. The main factors that influence the correlations are indoor $PM_{2.5}$, study design, and measurement bias.

Influ*ence of Indoor $PM_{2.5}$*

Personal $PM_{2.5}$ concentrations and their relationships to indoor and outdoor levels vary between studies, subjects, and environments. A majority of research evaluating personal, indoor, and outdoor correlations have indicated indoor $PM_{2.5}$ greatly influences personal exposures.[60] The influence of indoor $PM_{2.5}$ in these studies may result in higher indoor and/or personal concentrations than the outdoor levels, and stronger correlations for personal-indoor concentrations than personal-outdoor or/and indoor-outdoor correlations.[61]

In the PTEAM prepilot study conducted in Azusa, CA, mean 24-hr personal $PM_{2.5}$ exposure doubled the indoor (36.3 ± 2.6 μg/m^3) and the outdoor (42.6 ± 3.0 μg/m^3) concentrations.[62] For the 18 participants, pooled data showed personal concentrations were uncorrelated with outdoor levels (cross-sectional correlations). In the main PTEAM study (178 nonsmoking subjects, aged from 10-70), both indoor and personal were weakly correlated with outdoor concentrations.[63]

Study from Toronto, Canada also reported higher personal and indoor concentrations compared to ambient levels.[64] Median $PM_{2.5}$ concentrations for personal, indoor, and outdoor were 28.4, 15.4, and 13.2 μg/m^3 respectively. Pooled data for all subjects resulted in low personal-outdoor correlations (R = 0.19 to 0.27, P<0.01). However, strong agreement occurred on personal-indoor concentrations (R= 0.79, P <0.01), and the indoor-outdoor correlation was moderate (R = 0.21 to 0.33).

In EXPOLIS study conducted at Basel, Switzerland, Oglesby et al. documented higher 48-hr mean personal $PM_{2.5}$ concentration (23.7 ± 17.1μg/m^3) compared to outdoor concentration (19.0.7 ± 11.7μg/m^3).[65] Pooled data of 44 subjects (ETS and non-ETS) yielded poor personal-outdoor correlations (R = 0.07).

In Boston, Rojas-Bracho et al. found higher 12-hr mean personal (21.6 μg/m^3) and indoor (17.5μg/m^3) $PM_{2.5}$ concentrations than the outdoor levels (14.2 μg/m^3) for 17 adults.[66] The longitudinal correlation coefficients for these subjects were 0.61, 0.74, and 0.87 for personal-outdoor, indoor-outdoor, and personal-indoor correlations respectively.

This study supports much of the research described previously. Personal and indoor concentrations were higher than the outdoor levels with higher I/O ratios occurring during school days than non-school days. This study focused on 4th and 5th grade students who were generally active during the school day. Their exposures to ambient $PM_{2.5}$ were similar at each site and even similar inter-sites resulting from homogenous distribution of ambient $PM_{2.5}$. However, their indoor $PM_{2.5}$ exposures were highly variable. Personal $PM_{2.5}$ more closely correlated with indoor correlations than the outdoor levels due to the impact of indoor $PM_{2.5}$. While personal-outdoor correlations varied among sites and in different time periods, strong indoor-personal correlations occurred at all sites and all the time periods.

Influence of Study Designs

Study design is another reason for inconsistent correlations between personal, indoor, and outdoor PM concentrations. Generally, longitudinal studies result stronger personal-outdoor correlations than cross-sectional studies. In the prepilot PTEAM study, the cross-sectional personal-outdoor correlations (R^2 = 0~0.02) were lower than the longitudinal regressions in

which individual correlation was performed (R^2 = 0.01~0.58).[67] In some recent longitudinal-designed research, strong personal-outdoor correlations were found. For example, Williams et al. reported the R-value of daily average personal-outdoor correlation of 0.89 on subjects 72 to 93 years old.[68]

However, fluctuations of personal-outdoor correlations also take place in the longitudinal studies with better correlations occurring on subjects. Higher correlations in longitudinal studies are either due to choosing elderly and COPD patients who usually have low incidence of indoor sources, or to exclusion of data with high indoor source events. On the other hand, cross sectional correlations can also be strong in the absence of indoor sources. Tamura et al. found that pooled PM_{10} personal-outdoor correlations for 7 elderly adults in Japan were significant with R of 0.83.[69] These subjects were not exposed to apparent indoor sources. The data analysis also excluded days with high indoor source events (i.e. incense burning, smoking visitors). In sum, omitting indoor-generated sources from the study design and data analysis can strenghthen personal-outdoor correlations.

In general, this study was longitudinal because measurements over multiple days for the subjects were obtained. For daily personal monitoring, one subject was chosen randomly from the class. Although each subject tended to have similar activity patterns with the whole group, different personal exposure to nonambient PM sources existed due to discrepancies in individual's activity-pattern. Because of the large number of subjects involved and the length of the study, no activity diaries were maintained. This may limit the correlation analysis in differentiating the subjects from limited non-ambient $PM_{2.5}$ to those with high non-ambient $PM_{2.5}$ exposures, and result in poor to moderate personal-outdoor correlations.

Influence of Measurements

Other factors influencing correlations between personal, indoor, and outdoor $PM_{2.5}$ concentrations measurement protocols. These influences included measurement bias of sample devices used and measurement errors, including equipment malfunction and random errors. Following standard QA/QC procedures minimized measurement errors from the monitoring procedures. Refer to the *Quality Assurance Handbook* for more details on QA/QC procedures.

The possible reasons for measurement bias included the differences between monitoring devices, sampling times, sampling frequencies, and monitoring device locations. In this study, several factors minimized measurement biases. These factors include inlet type, monitoring schedule, monitor placement, inspection of the filters, and QA/QC procedures. The same inlet type was used for outdoor and indoor monitors. All sample types were monitored concurrently at each site and the monitoring devices were set up within the same building. New Albany, a special case, the outdoor $PM_{2.5}$

monitor resided on a building roof about 200 meters from the building where the indoor and personal $PM_{2.5}$ monitoring occurred). However, differences existed between monitoring devices used for personal, indoor, and outdoor measurement. More fibers or visible particles resided on personal sample filters than indoor and outdoor sample filters. It is possible the impactors, used in personal monitoring, collected some coarse particles due to low flow rate or to design capability. Moderate correlations between personal and indoor samplers and ACCU systems may contribute to the observed poor to moderate correlations.

Another common effect is the existence of "personal cloud." Personal cloud or personal-activity $PM_{2.5}$ is an increased personal exposure derived from personal measurements in comparison with a stationary monitors or a time-weighed average of indoor and outdoor concentrations. The cause of personal cloud is still unknown, however, since the chemical composition of personal cloud is similar to the indoor particles, personal cloud is related to indoor activity-generated sources. In comparing retirement centers to apartments, Rodes et al. suggested a personal cloud might be a result of "resuspended particles from carpeting, collection of body dander and clothing fibers, personal proximity to open doors and windows, and elevated PM levels in nonapartment indoor microenviroments."[70] Electrostatic effects which happen within a close vicinity of a subject to the sources may also contribute to the cloud. Although resuspension effects are more pronounced in coarse-model particles, increased $PM_{2.5}$ concentration in resuspension events (i.e. physical activity) were also recorded for small size subjects. The resuspension-related $PM_{2.5}$ increase in this study could be quite sizable due to large group (~30 subjects) involved. Studies show personal cloud as a major reason for the poor personal-outdoor correlations since the personal cloud for healthy persons could count for up to 50 $\mu g/m^3$ during their active period.

CONCLUSIONS

As part of the Air Pollution and Pediatric Health Impact Assessment (APPHIA) project, this section provides information on correlations between personal, indoor, and outdoor $PM_{2.5}$ levels and comparisons between the sites. $PM_{2.5}$ mass measurements occurred at three elementary schools in central and southeastern Ohio from January 1999 through August 2000. Outdoor, indoor, and personal $PM_{2.5}$ measurements were obtained at three locations representing a rural, urban, and suburban setting.

At all three sites, personal and indoor $PM_{2.5}$ concentrations exceeded outdoor levels. Personal $PM_{2.5}$ exposures were significantly affected by indoor $PM_{2.5}$, presumably the result of resuspension by human activity. The I/O ratios of $PM_{2.5}$ mass concentrations and of sulfate concentrations were greater than unity at all sites when school was in session. Lower I/O ratios associated with lower indoor sources were found during non-school days when the students were absent.

In addition, the personal-outdoor and indoor-outdoor correlations varied significantly throughout the study due to high variability of nonambient $PM_{2.5}$ caused by activity patterns and ventilation conditions. At all sites, indoor $PM_{2.5}$ concentrations moderately correlated with outdoor concentrations at significant levels with R ranging from 0.13 to 0.30. However, only moderate personal-outdoor correlations existed at two sites, Koebel and Athens. Weak personal-outdoor correlations occurred at New Albany. In comparison, there were strong personal-indoor correlations at all the sites.

The analysis of correlations between personal, indoor, and outdoor $PM_{2.5}$ are crucial in understanding the health effects in epidemiological studies. The central assumption of epidemiological studies is that ambient PM concentration, monitored by a fixed site, is a sufficient surrogate for personal exposure. In this study, ambient $PM_{2.5}$ distributed homogeneously throughout the study area. This indicates that ambient $PM_{2.5}$ concentrations monitored from a fixed site can represent the average ambient $PM_{2.5}$ level over a large area. However, high variations occurring with indoor and personal concentrations indicates that the ambient $PM_{2.5}$ may not be a strong indicator for indoor concentration or total personal exposures.

NOTES

1. U.S. Environmental Protection Agency, *1997 National Air Quality: Status and Trends. Six Principle Pollutants: Particular Matter (PM)* (Washington, D.C.: Office of Air & Radiation.U.S., 1998); U.S. Environmental Protection Agency. *Air Quality Criteria for Particulate Matter Chapter 1; Executive Summary. EPA/600/ P- 95/ 001aF* (Washington D.C.: Office of Research and Development, 1996); U.S. Environmental Protection Agency, *Air Quality Criteria for Particulate Matter Volume 1. EPA 600/ P- 99/ 002aB* (Washington D.C.: Office of Research and Development, 2001); J.C. Chow, & J.G. Watson, *Guideline on Speciated Particulate Monitoring. Desert Research Institute,* Prepared for Neil Frank, Jim Homolya, Office of Air Quality Planning and Standards (MD-14) (Research Triangle Park, NC: U.S. Environmental Protection Agency, 1998); J.C. Chow, J.G. Watson, E. M. Fujita, Z.Q. Lu, D.R. Lawson, & L. L. Ashbaugh, Temporal and spatial variations of $PM_{2.5}$ and PM_{10} aerosol in the Southern California air-quality study, *Atmospheric Environment* 28 (1994): 2061-2080.

2. Federal Register. 1997. 63: 38702-38752

3. D.W. Dockery, C.A. Pope, X. P. Xu, J.D. Spengler, J. H. Ware, M.E. Fay, B.G. Ferris, & F.E. Speizer, An association between air-pollution and mortality in 6 united-states cities, *New England J. of Medicine* 329 (1993): 1753-1759; J. Schwartz, D.W. Dockery, & L.M. Neas, Is daily mortality associated specifically with fine particles? *J. Air & Waste Manage. Assoc.* 46 (1996): 927-939; C.A. Pope, D.V. Bates, & M.E. Raizenne, Health-effects of particulate air-pollution- time for reassessment, *Environmental Health Perspectives* 103 (1995): 472-480; D.P. Liao, J. Creason, C. Shy, R. Williams, R. Watts, & R. Zweidinger, Daily variation of particulate air pollution and poor cardiac autonomic control in the elderly, *Environmental Health Perspectives* 107 (1999): 521-525; J.D. Spengler, P. Koutrakis, D.W. Dockery, M. Raizenne, & F.E. Speizer, Health_effects of acid aerosols on north american children: air pollution exposures, *Environmental Health Perspectives* 104 (1996): 492-499

4.Schwartz et al., Is Daily Mortality Associated with Fine Particles?

5. W.E. Wilson & H.H. Suh, Fine particles and coarse particles: concentration relationships relevant to epidemiologic studies, *J. Air & Waste Manage. Assoc.* 47(1997): 1238-1249

6. J.G. Watson, R.E. Wyzga, R.T. Burnett, J.J. Vostal, I. Romieu, J.C. Chow, J.T. Holcombe, F.W. Lipfert, D. Marrack, R.J. Thompson, & S. Vedal, Ambient particles and health: lines that divide--discussion, *J. Air & Waste Manage. Assoc.* 47 (1997): 995-1008; W.E. Wilson, D.T. Mage, & L.D. Grant, estimating separately personal exposure to ambient and nonambient particulate matter for epidemiology and risk assessment: Why and how. *J. Air & Waste Manage. Assoc.* 50 (2000): 1167-1183; W.E. Wilson & R. M. Burton, *Exposure Relationships Relevant to Particulate Matter Mortality Studies*, paper presented at A&WMA International Conference on particulate Matter: Health and Regulatory Issues (Pittsburgh PA, April 4-6, 1995); S. Vedal, Ambient Particles and health: lines that and divide. *J. Air & Waste Manage. Assoc.* 47 (1997): 551-581.

7. See U.S. EPA studies cited in note 1.

8. C. Monn, 2000, Exposure assessment of air pollutants: a review on spatial heterogeneity and indoor/outdoor/personal exposure to suspended particulate matter, nitrogen dioxide and ozone. *Atoms. Environ*. 35 (2000): 1-32; J.R. Brook, T. F. Dann, & R.T. Burnett, The relationship among TSP, PM_{10}, $PM_{2.5}$, and inorganic constituents of atmospheric particulate matter at multiple canadian locations, *J. Air & Waste Manage. Assoc.* 47(1997): 2-19; W.J. Parkhurst, R.J. Tanner, F.P. Weatherford, & R.J. Valente, Historic $PM_{2.5}/PM_{10}$ concentrations in the Southeastern United States----- potential implications of the revised particulate matter standard. *J. Air & Waste Manage. Assoc.* 4 (1999): 1060-1067; G.M. Hidy, J. M. Hales, & Scheffe, Fine particles and oxidant pollution: developing and agenda for cooperative research, *J. Air & Waste Manage. Assoc.* 50 (2000): 613-632; R.M. Burton, H.H. Suh, & P. Koutrakis, Spatial variation in particulate concentrations within metropolitan Philadelphia. *Envrion. Sci. Technol*. 30 (1996): 400-407; L. Oglesby, N. Kunzli, M. Röösli, C. Braun-Fahrlander, P. Mathys, W. Stern, M. Jantunen, & A. Kousa, Validity of ambient levels of fine particles as surrogate for personal exposure to outdoor air pollution---- results of the European EXPOLIS-EAS Study (Swiss Center Basel). *J. Air & Waste Manage. Assoc.* 50 (2000): 1251-1161; G. Buzorius, K. Hämeri, J. Pekkanen, & M. Kulmala, Spatial variation of aerosol number concentration in Helsinki City, *Atmos. Environ*. 33 (1999): 553-565; M. Röösli, C.B. Braun-Fahrläder, N. Künzli, L. Oglesby, G. Theis, M. Camenzind, P. Mathys, & J. Staehelin, Spatial variability of different fractions of particulate matter within an urban environment and between urban and rural sites, *J. Air & Waste Manage. Assoc.* 50 (2000): 1115-1124.

9. L. Wallace, Indoor particles: a review, *J. Air & Waste Manage. Assoc.* 46 (1996): 98-126; L. Wallace, Correlations of personal exposure to particles with outdoor air measurement: a review of recent studies, *Aerosol Sci. and Tech*. 32 (2000): 15-25; C. Monn, A. Fuchs, H.M. Junker, D. Kogelschatz, N. Roth, & H.U. Wanner, Particulate matter less than 10 µm (PM_{10}) and fine particles less than 2.5 µm ($PM_{2.5}$): relationships between indoor, outdoor and personal concentrations, *The Sci. of the Total Environ*. 208 (1997): 15-21.

10. T.L. Thatcher & D.W. Layton, Deposition, re-suspension and penetration of particles within a residence. *Atmos. Environ*. Sci. 29 (1995): 1487-1497; N.C. Jones, C.A. Thornton, D. Mark & R. M. Harrison, Indoor/ outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations, *Atmos. Environ*. 34 (2000): 2603-2612.

11.Wallace, Indoor particles.

12. Ibid.

13. K. Sexton, J.D. Spengler & R.D. Treotam, Personal exposure to respirable particles---- a case-study in Waterbury, Vermont. *Atmos. Environ*, 18 (1984): 1385-1398; C.E. Rodes, R.M. Kamens & R.W. Wiener, The significance and characteristics of the personal activity cloud on exposure assessment measurements for indoor contaminants. *Indoor Air*. 2 (1991): 123-145.

14. Wilson et al., Estimating separately personal exposure.

15. See note 13 for these studies.

16. Ibid.

17. Ibid.

18. Ibid

19. T. Bhadori, *Issues in Particulate Matter Exposure Assessment: Relationship between Outdoor, indoor, and Personal Measurements*. Doctoral dissertation. No. 1. MHT. 1998.4. (Boston, MA: Harvard School of Public Health, 1998).
20. See notes 1,5, and 13 for these studies.
21. Ibid.
22. See U.S. EPA studies cited at note 1 for some examples.
23. Wilson et al., Estimating separately personal exposure.
24. Ibid.
25. L. Rojas-Bracho, H.H. Suh & P. Koutrakis, *Relationships among Personal, Indoor, and Outdoor Fine and Coarse Particle Concentrations for Individuals with COPD*, *J. Expos. Anal. Environ. Epidemiol*. 10 (2000): 294-306; R. Williams, J. Suggs, R. Zweidinger, G. Evans, J. Creason, R. Kwok, C. Rodes, P. Lawless & L. Sheldon, The 1998 Baltimore particulate matter epidemiology-exposure study: part 1. comparison of ambient, residential outdoor, indoor and apartment particulate matter monitoring. *J. Expos. Anal. Environ. Epidemiol*. 10 (2000): 518-532.
26. N.A.H Janssen, G. Hoek, H. Harssema & B. Brunekreef, personal exposure to fine particles in children correlations closely with ambient fine particles, *Arch. Environ. Health*. 54 (1999): 95-101.
27. J.A. Sarnat, P. Koutrakis & H.H. Suh, Assessing the relationship between personal particulate and gaseous exposures of senior citizens living in Baltimore, MD. *J. Air & Waste Manage. Assoc.* 50 (2000): 1184-1198; L. Chang, P. Koutrakis, P.J. Catalano & H.H Suh,. Hourly personal exposure to fine particles and gaseous pollutants—results from Baltimore, Maryland. *J. Air & Waste Manage. Assoc.* 50 (2000): 1223-1235; C. M. Long, H.H. Suh & P. Koutrakis, Characterization of indoor particle sources using continuous mass and size monitors. *J. Air & Waste Manage. Assoc*. 50 (2000): 1236-1250.
28. Ibid.
29. Sarnat et al., Assessing the relationship.
30. See notes 13, and 27 for these studies
31. *Ambient Monitoring, the Upper Ohio River Valley Project (UORVP)* [on-line] <www.netl.doe.gov/coalpower/environment/air_q/am_monitor.html> (28 February 2002).
32. M. B. Meyer, H. Patashnick, J.L. Ambs, & E. Rupprecht, development of a sample equilibration system for the TEOM continuous PM monitor, *J. Air & Waste Manage. Assoc.* 50 (2000): 1345-1349.
33. Ibid.
34. R. Allen, M. Box, L.S. Liu & T.V. Larson, A cost-effective weighing chamber for particulate matter filters, *J. Air & Waste Manage. Assoc.* 51 (2001): 1650-1653.
35. Ibid.
36. S.W. Christensen, T. A. Boden, L.A. Hook & M.D. Cheng, *NARSTO Quality Systems Science Center Oak Ridge National Laboratory,* (Oak Ridge, TN: Environmental Sciences Division Publication No. 4917, Revision date: August 16, 1999).
37. See U.S. EPA studies cited at note 1 for some examples.
38. Röösli et al., Spatial variability of different fractions.
39. See U.S. EPA studies cited at note 1 for some examples.
40. See notes 1, and 8 for these studies.
41. Burton et al., Spatial variation
42. R. Williams, J. Creason, R. Zweidinger, R. Watts, L. Sheldon, & C. Shy, Indoor, outdoor, and personal exposure monitoring of particulate air pollution: the baltimore elderly epidemiology-exposure pilot study, *Atoms. Environ*. 34 (2000): 4193-4204.
43. Clayton et al., Particle total exposure assessment methodology.
44. See note 8 for these studies.
45. Wilson et al., Estimating separately personal exposure.
46. See note 9 for these studies.
47. Long et al., Characterization of indoor particle sources.
48. A.F. Vette, A.W. Rea, P.A. Lawless, C.E. Rode, G. Evans, V.R. Highsmith & L. Sheldon, Characterization of Indoor-Outdoor Aerosol Concentration Relationships during the Fresno PM Exposure Studies, *Aerosol Sci. and Tech*. 34 (2001): 118-126.

49. Long et al., Characterization of indoor particle sources.

50. E. Patterson & D.J. Eatough, Indoor/outdoor relationships for ambient $pm_{2.5}$ and associated pollutants: epidemiological implications in Lindon, Utah, *J. Air & Waste Manage. Assoc.* 50 (2000): 103-110.

51. Wallace, Indoor particles.

52. For research relating to sulfate concentration in $PM_{2.5}$ see studies at note 1 for example.

53. Lee et al., Relationship between indoor and outdoor air quality.

54. Li and Harrison, Comparison of indoor and outdoor concentrations.

55. Monn et al., Particulate matter less than 10 μm.

56. Jones et al., Indoor/Outdoor Relationships of Particulate Matter.

57. Long et al., Characterization of Indoor Particle Sources.

58. U.S. EPA, Air quality criteria for particulate matter.

59. Jansen et al., Personal exposure to fine particles in children.

60. See note 9.

61. E.D. Pellizzari, C.A. Clayton, C.E. Rodes, R.E. Mason, L.L. Piper, B. Fort, G. Pfeifer & D. Lynam, Particulate matter and manganese exposures in Toronto, Canada, *Atmos. Environ*. 33 (1999): 721-734; R. Williams, J. Suggs, J. Creason, C. Rodes, P. Lawless, R. Kwok, R. Zweidinger & L. Sheldon, The 1998 Baltimore particulate matter epidemiology-exposure study: part 2. personal exposure assessment associated with an elderly study population. *J. Expos. Anal. Environ. Epidemiol*. 10 (2000): 533-543; K. Tamura, M. Ando, M. Sagai & Y. Matsumoto, Estimation of levels of personal exposure to suspended particulate matter and nitrogen dioxide in Tokyo. *Environ. Sci. (Tokyo)*. 4 (1996): 37-51; D. Mage, W. Wilson, V. Hasselblad & L. Grant, Assessment of human exposure to ambient particle matter, *J. Air & Waste Manage. Assoc.* 49 (1999): 1280-1291; C.E. Rodes, P.A. Lawless, G.F. Evans, L.S. Sheldon, R.W. Williams, A.F. Vette, J.P. Creason & D. Walsh, The relationships between personal PM exposures for elderly populations and indoor and outdoor concentrations for three retirement center scenarios, *J. Exposure Anal. Environ. Epidemiol.* 11 (2001): 103-115; C. Howard-Reed, A.W. Rea, M.J. Zufall, J.M. Burke, R.W. Williams, J.C. Suggs, L.S. Sheldon, D. Walsh & R. Kwok, Use of continuous neophelometer to measure personal exposure to particles during the U.S. Environmental Protection Agency Baltimore and Fresno Panel Studies, *J. Air & Waste Manage. Assoc.* 50 (2000): 1125-1132.

62. Wallace, Indoor Particles.

63. H. Ozkaynak, J. Xue, J. Spengler, L. Wallace, E. Pellizzari & P. Jenkins, Personal exposure to airborne particles and metals: results from the particle team study in Riverside, California, *J. Expos. Anal. Environ. Epidemiol*. 6 (1996): 57-78.

64. Pellizzari et al., Particulate matter and manganese exposure.

65. Oglesby et al., Validity of ambient levels.

66. Rojas–Bracho et al., Relationships among personal, indoor, and outdoor fine and coarse particle concentrations.

67. Wallace, Indoor Particles.

68. Williams, et al., The 1998 Baltimore particulate matter epidemiology–exposure study.

69. Tamura et al., Estimation of levels of personal exposure.

70. Rodes et al., The relationships between personal PM exposures.

Section 2, Chapter 2
CHARACTERIZATION OF $PM_{2.5}$ IN CENTRAL AND SOUTHEAST OHIO

INTRODUCTION

The research presented in this section was conducted to provide a comprehensive study of the chemical and transport characteristics of $PM_{2.5}$ in urban, suburban, and rural areas of Central and Southeastern Ohio. The main objectives of this research study are:

- To determine the levels of $PM_{2.5}$ in the three counties representing urban, suburban, and rural areas of Central and Southeastern Ohio;
- To chemically characterize $PM_{2.5}$ in the study areas;
- To study indoor and outdoor $PM_{2.5}$ characteristics in the study areas;
- To study the relationship of $PM_{2.5}$ with ozone and various meteorological parameters;
- To study the transport characteristics of $PM_{2.5}$ in these areas.

Measurements in several urban atmospheric environments have shown an increasing trend in the concentration of highly dispersed fine aerosols (i.e. aerosols with particle diameters less than 2 μm), and a decrease in the concentration of coarse particles (diameter less than 10 μm).[1] Total emissions from transportation, and fuel combustion, etc. make up most of the anthropogenic fine aerosols (size under 2μm) in the ambient atmosphere. The coarse particulates in industrial emissions are efficiently separated by air cleaning equipments. Fine aerosols can be dispersed in the atmosphere homogeneously, can be transported for long distances, and, because of their relatively high residence times in the atmosphere, can accumulate there.

Fine aerosol particles are formed by condensation of hot vapors during the combustion process and from gas-to-particle conversion in the atmosphere. Because of the small size of $PM_{2.5}$, they can penetrate deeply into the lungs and result in adverse human health effects. Several studies indicate that increases in human mortality and morbidity are associated with levels of air particulate significantly lower than previously thought.[2]

In July 1997, the USEPA made changes to the PM National Ambient Air Quality Standards (NAAQS) by adding two new primary $PM_{2.5}$ standards set at 15 $\mu g/m^3$ (annual arithmetic mean) and 65 $\mu g/m^3$ (24-hour average). This change was to provide increased protection against PM-related health effects. Areas will be in compliance with the new annual $PM_{2.5}$ standard when the 3-year average of the annual arithmetic mean $PM_{2.5}$ concentrations, from single or multiple community-oriented monitors, is less than or equal to 15 $\mu g/m^3$. For the new 24-hour $PM_{2.5}$ standard, the form is based on the 98th percentile of $PM_{2.5}$ concentrations in one year (averaged over 3 years), at the population-oriented monitoring site with the highest measured values in an area.[3]

$PM_{2.5}$ Monitoring

Ambient air monitoring was conducted at the three locations noted in Chapter 1 of this section. A teacher was trained to operate and collect the samples, and calibrate the personal sampling pumps at each of the sites. The School of Health Sciences at Ohio University was in charge of training the teachers as well as measuring the mass of the filters before and after sampling. Ohio University was also responsible for the maintenance and flow calibrations of the monitors.

CHEMICAL CHARACTERIZATION

This section provides background information about the chemical characterization of $PM_{2.5}$ and the methodology used in the characterization. It documents information about the analytical equipment used for the chemical characterization and the quality assurance and quality control procedures utilized in this study.

Chemical Analysis

The ambient and indoor $PM_{2.5}$ samples collected on teflon filters were analyzed using X-Ray Fluorescence (XRF) and Ion Chromatography (IC) techniques. Elemental analysis was conducted on the filter samples using a Kevex 771-EDX Spectrometer (Energy Dispersive X-ray Fluorescence) instrument. The $PM_{2.5}$ mass was analyzed for Silicon, Phosphorus, Sulfur, Chlorine, Potassium, Calcium, Titanium, Vanadium, Chromium, Mangenese, Iron, Cobalt, Nickel, Copper, Zinc, Arsenic, Cadmium and Tin. The filters were subsquently extracted with deionized water by ultrasonic treatment, and

the anions (F^-, Cl^-, NO_3^-, SO_4^{-2}, PO_4^{-3}) and cations (LI^+, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}) present were determined using the Dionex DX-500 IC (ion chromatography) system.

Analytical Equipments and Methodology

Continuous ambient $PM_{2.5}$ measurements were carried out using TEOM Series 1400a monitors manufactured by Ruprecht and Patashnick Co. Inc. The TEOMs were set to run 24–hours, seven days a week. Filter-based ambient $PM_{2.5}$ measurements were made with an Automatic Cartridge Collection Unit (ACCU) System, which was connected to the TEOMs. The 24-hour averaged filter samples were collected daily during weekdays.

Indoor monitors were operated at 10 L/min using flow-controlled indoor sampling pumps (Model 3000-02Q, URG). Measurements of indoor $PM_{2.5}$ concentrations were made using 2.5 µm cyclones (URG-2000-30EH). Indoor monitors were timed to run from 8:00 a.m. to 3:00 p.m. Monday through Friday throughout the school year. The ambient outdoor and indoor $PM_{2.5}$ measurements and monitoring scheme is discussed in detail earlier in this report.

The indoor and outdoor samples were collected on 37 mm and 47 mm Whatman Teflon filters (2-µm pores size), respectively. After the sampling, the filters were placed in Petri dishes, double bagged and kept at 4°C until analysis. Samples were then sent to the Department of Environmental Engineering at Texas A & M University - Kingsville to perform chemical speciation and analysis.

The analysis of trace elements was performed using the Kevex 771-EDX Spectrometer (Energy Dispersive X-ray Fluorescence) instrument. X-Ray Fluorescence is a non-destructive technique that can analyze elements from Fluorine to Uranium in the periodic table. The instrument consists of a spectrometer, secondary targets, Rhodium target x-ray tube and high resolution Si(Li) solid state x-ray detector.[4] All filters were run with Germanium as the secondary target with the tube voltage set to 50 kV and the tube current to 2.9 mA. Air was used in the chamber and the counting time was set to 100 seconds. Elements found in the samples included Silicon, Phosphorus, Sulfur, Chlorine, Potassium, Calcium, Titanium, Vanadium, Cromium, Mangenese, Iron, Cobalt, Nickel, Copper, Zinc, Arsenic, Cadmium and Tin.

The particles sampled on the filters were then extracted with deionized water for 10 minutes using the Fisher Scientific FS9 ultrasonic, and the anions (F^-, Cl^-, NO_3^-, SO_4^{-2}, PO_4^{-3}) and the cations (Li^+, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}) present were determined using the Dionex DX-500 IC (ion chromatography) system. The system included an electrochemical detector, chromatography oven, gradient pump, and an autosampler. This method of analysis is

destructive in nature as the filter samples are dissolved in deionized water and hence lost. The anion guard, column and suppressor assembly is used for the anion analysis and cation guard, column and a suppressor is used to measure the cation concentration in the filter samples. Peaknet 5.0 software is used for the calibration curve generation, post-run data processing, and the report generation.[5]

Quality Assurance

Quality control (QC) and quality auditing establish the precision, accuracy, and validity of measured values. Quality assurance integrates quality control, quality auditing, measurement method validation, and sample validation into the measurement process. The results of quality assurance are data values with specified precision, accuracy, and validity.[6]

Quality control is intended to prevent, identify, correct, and define the consequences of difficulties that might affect the precision and accuracy, and or validity of measurements.[7] QC activities for Texas A&M- University Kingsville included modifying standard operating procedures followed during ambient sampling/ source sampling, chemical analysis, data processing, and quality auditing.

The quality auditing function consisted of systems and performance audits. The systems audit included a review of the operational and QC procedures to assess whether they were adequate to assure valid data that they met the specified levels of accuracy and precision. It also examined all phases of the measurement activity to determine that procedures were followed and that operators were properly trained. Performance audits established whether the predetermined specifications were achieved in practice. Both system and performance audits were performed at Texas A&M University – Kingsville and Ohio University on an annual basis to assure data quality. In addition, proper maintenance procedures were followed for the equipments in this study for sampling and chemical analysis.

AMBIENT OUTDOOR ANALYSIS

The chemical speciation and analysis of the filter samples was performed at Department of Environmental Engineering at Texas A & M University – Kingsville. The results of ambient outdoor analysis are assembled in this section. First, the data tables provide $PM_{2.5}$ mass and chemical composition measurements. Then, data is validated and spatial variations of the $PM_{2.5}$ concentrations and temporal variations of $PM_{2.5}$ sulfate concentrations are examined.

$PM_{2.5}$ Mass and Chemical Composition Data Summary

Tables II.2.1 to II.2.3 depict the $PM_{2.5}$ mass and chemical composition data summary for the three outdoor sites in Ohio for the study period from February 1999 to August 2000. The average $PM_{2.5}$ mass concentrations considered here are the arithmetic averages of the filter mass collected at each site during the entire period of study.

Sulfate ion was the largest component present in the samples. The average sulfate concentrations were highest at Koebel and lowest at New Albany. Other abundant components present in the samples were silicon, chlorine ion, and sodium ion. The concentrations of these components varied from site to site.

Data Validation

The data acquired from field monitoring and laboratory analysis were compared for consistency. The data was validated by checking the sum of the chemical species concentrations against the total $PM_{2.5}$ mass. Regression plots were run to examine the relationships between parameters such as the chemical the species concentration and sum of chemical species. Outliers were reexamined to determine the cause of discrepancy. Results from the data validation for the period of May through August 2000 are presented in Figures II.2.1 to II.2.3.

Sum of Chemical Species Versus $PM_{2.5}$ Mass Concentrations

The measured and monitored mass data were compared by plotting the scatter graphs for the sum of species against mass concentrations. Correlation between these two parameters was studied by plotting the mass concentration (independent variable X) against the sum of species (dependent Y).

Many of the species remain unidentified in the chemical analysis and hence the sum of the species should always be less than or equal to the gravimetrically measured mass.[8] In order to avoid the double counting, total sulfur (S), soluble potassium (K^+) and chloride (Cl^-) were excluded from the sum of species.

Figures II.2.1 to II.2.3 show a relationship between the measured mass concentration and the sum of chemically analyzed species. Also, it is clear that the sum of species is always less than the gravimetrically measured $PM_{2.5}$ mass concentrations.

Table II.2.1. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Athens (February 1999-August 2000)

Species ($\mu g/m^3$)	Average	Standard Deviation	Median	Range	
				Minimum	Maximum
PM2.5 Mass	13.66	8.91	11.494	0.50	61.12
Si	0.1124	0.1979	0.0473	0.0005	1.5285
P	0.0018	0.0012	0.0015	0.0001	0.0050
S	0.7130	1.2759	0.3278	0.0022	10.9926
Cl	0.0116	0.0202	0.0046	0.0001	0.1675
K	0.0180	0.0099	0.0161	0.0002	0.0399
Ca	0.0100	0.0215	0.0047	0.0000	0.2529
Ti	0.0010	0.0022	0.0003	0.0000	0.0209
V	0.0002	0.0003	0.0001	0.0000	0.0031
Cr	0.0015	0.0011	0.0010	0.0001	0.0046
Mn	0.0006	0.0009	0.0002	0.0000	0.0041
Fe	0.0062	0.0128	0.0032	0.0000	0.1190
Co	0.0016	0.0014	0.0012	0.0001	0.0050
Ni	0.0007	0.0005	0.0006	0.0001	0.0022
Cu	0.0008	0.0021	0.0001	0.0000	0.0139
Zn	0.0012	0.0023	0.0005	0.0000	0.0209
As	0.0037	0.0026	0.0029	0.0003	0.0118
Cd	0.0001	0.0001	0.0001	0.0000	0.0002
Sn	0.0010	0.0008	0.0008	0.0001	0.0035
Li^+	0.0016	0.0018	0.0005	0.0001	0.0053
Na^+	0.1569	0.3045	0.0631	0.0010	2.7660
$NH4^+$	0.4824	0.6069	0.1473	0.0000	2.4876
K^+	0.1755	0.2302	0.0562	0.0024	0.9903
Mg^{+2}	0.0765	0.1171	0.0191	0.0012	0.4721
Ca^{+2}	0.1074	0.2369	0.0436	0.0001	1.2395
F^-	0.0071	0.0033	0.0053	0.0040	0.0146
Cl^-	0.1399	0.1702	0.0438	0.0030	0.7112
NO^{3-}	0.5618	0.6207	0.1911	0.0059	2.2013
PO_4^{-3}	-	-	-	-	-
SO_4^{-2}	2.5831	2.2836	1.8627	0.0207	9.3761
Sum of Species	5.1777	6.1288	2.8454	0.0421	33.4600
Unidentified	7.7035	2.0095	8.4288	0.4294	27.6557

Table II.2.2. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at New Albany (February 1999-August 2000)

Species ($\mu g/m^3$)	Average	Standard Deviation	Median	Range	
				Minimum	Maximum
PM2.5 Mass	12.72	8.86	10.87	0.05	69.30
Si	0.1123	0.1373	0.0580	0.0000	0.6516
P	0.0028	0.0017	0.0024	0.0006	0.0080
S	0.5749	0.6495	0.3639	0.0000	4.3732
Cl	0.0142	0.0236	0.0053	0.0000	0.1662
K	0.0139	0.0112	0.0104	0.0012	0.0551
Ca	0.0118	0.0138	0.0074	0.0000	0.0821
Ti	0.0016	0.0023	0.0010	0.0000	0.0205
V	0.0004	0.0008	0.0001	0.0000	0.0048
Cr	0.0020	0.0013	0.0016	0.0005	0.0078
Mn	0.0014	0.0021	0.0007	0.0000	0.0182
Fe	0.0105	0.0218	0.0046	0.0000	0.2064
Co	0.0011	0.0007	0.0009	0.0001	0.0034
Ni	0.0011	0.0008	0.0009	0.0003	0.0037
Cu	0.0019	0.0046	0.0007	0.0000	0.0450
Zn	0.0041	0.0109	0.0004	0.0000	0.0605
As	0.0049	0.0060	0.0029	0.0001	0.0455
Cd	0.0001	0.0001	0.0001	0.0000	0.0007
Sn	0.0020	0.0014	0.0018	0.0002	0.0063
Li^+	0.0013	0.0014	0.0004	0.0000	0.0048
Na^+	0.2091	0.3923	0.0739	0.0044	2.8390
$NH4^+$	0.5162	0.5930	0.2472	0.0012	2.6985
K^+	0.1336	0.2113	0.0432	0.0001	1.4805
Mg^{+2}	0.0260	0.0356	0.0231	0.0004	0.3135
Ca^{+2}	0.0818	0.1438	0.0309	0.0001	1.1321
F^-	0.0047	0.0010	0.0048	0.0037	0.0059
Cl^-	0.2237	0.2607	0.1893	0.0028	1.6247
NO^{3-}	0.2020	0.2772	0.0893	0.0048	1.3209
PO_4^{-3}	0.2265	0.1735	0.1686	0.0340	0.5688
SO_4^{-2}	2.1201	2.0044	1.5139	0.0092	13.7594
Sum of Species	4.5060	4.9841	2.8479	0.0637	31.5071
Unidentified	8.6687	3.4865	8.5798	-0.0115	29.8298

Table II.2.3. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Koebel (February 1999-August 2000)

Species ($\mu g/m^3$)	Average	Standard Deviation	Median	Range	
				Minimum	Maximum
PM2.5 Mass	13.89	9.29	11.65	0.24	77.01
Si	0.1085	0.1219	0.0594	0.0020	0.6060
P	0.0038	0.0024	0.0033	0.0006	0.0117
S	0.8140	1.5949	0.4204	0.0045	18.2467
Cl	0.0145	0.0221	0.0065	0.0000	0.1549
K	0.0313	0.0320	0.0220	0.0035	0.2350
Ca	0.0188	0.0217	0.0129	0.0002	0.1377
Ti	0.0022	0.0027	0.0014	0.0001	0.0169
V	0.0003	0.0005	0.0002	0.0000	0.0046
Cr	0.0024	0.0015	0.0021	0.0003	0.0095
Mn	0.0016	0.0017	0.0011	0.0000	0.0095
Fe	0.0160	0.0171	0.0106	0.0001	0.0950
Co	0.0009	0.0007	0.0007	0.0000	0.0040
Ni	0.0011	0.0008	0.0008	0.0001	0.0041
Cu	0.0016	0.0070	0.0004	0.0000	0.0856
Zn	0.0042	0.0080	0.0012	0.0000	0.0611
As	0.0045	0.0038	0.0035	0.0005	0.0226
Cd	0.0001	0.0001	0.0001	0.0000	0.0003
Sn	0.0027	0.0020	0.0025	0.0001	0.0106
Li^{+}	0.0051	0.0185	0.0017	0.0001	0.1289
Na^{+}	0.2560	0.3940	0.0926	0.0015	1.5527
$NH4^{+}$	0.5264	0.5332	0.3113	0.0003	2.5725
K^{+}	0.0997	0.1201	0.0643	0.0006	0.8591
Mg^{+2}	0.0313	0.0850	0.0177	0.0003	0.7842
Ca^{+2}	0.1237	0.1255	0.0794	0.0004	0.6981
F^{-}	0.0518	0.0760	0.0184	0.0044	0.2000
Cl^{-}	0.2401	0.2560	0.2118	0.0104	1.9171
NO^{3-}	0.2591	0.3284	0.0965	0.0080	1.4070
PO_4^{-3}	0.3252	0.4785	0.0928	0.0332	1.6907
SO_4^{-2}	2.7139	2.4591	2.0275	0.0152	13.7931
Sum of Species	5.6608	6.7151	3.5630	0.0864	45.3192
Unidentified	7.8843	1.2591	7.9480	1.4237	13.9203

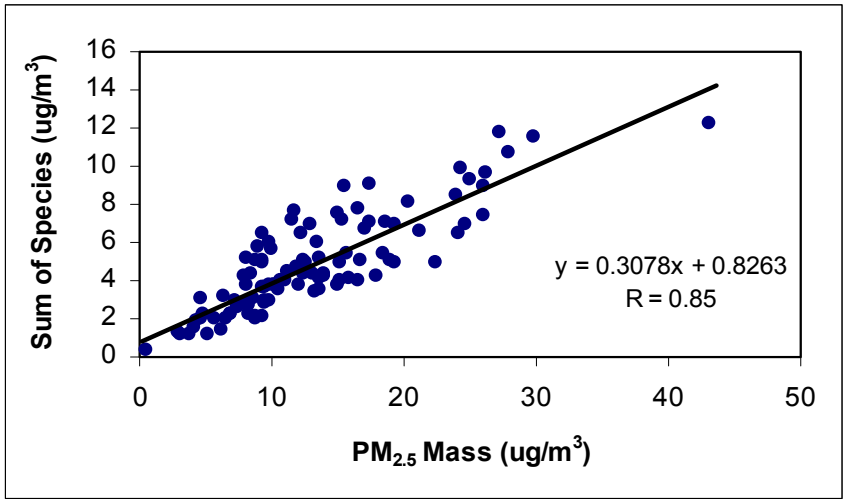


Figure II.2.1. Scatter plot of sum of species versus mass outdoor concentrations for Athens (May- August 2000)

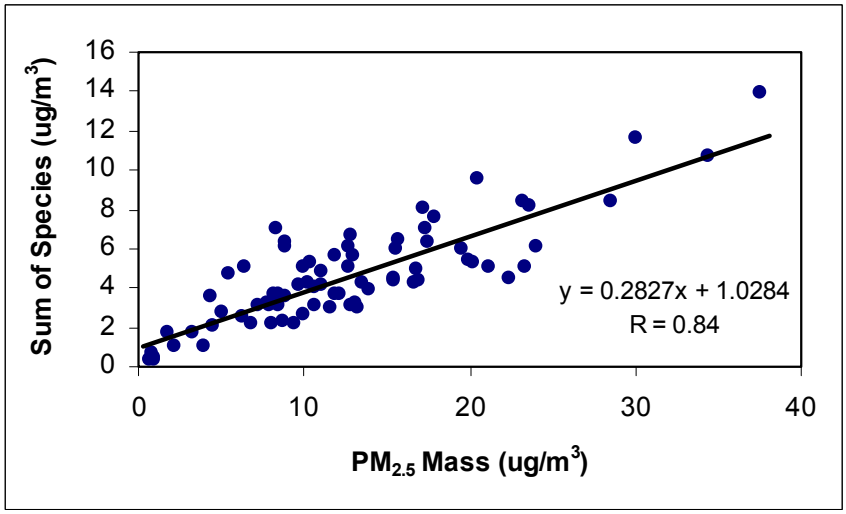


Figure II.2.2. Scatter plot of sum of species versus mass outdoor concentrations for New Albany (May-August 2000)

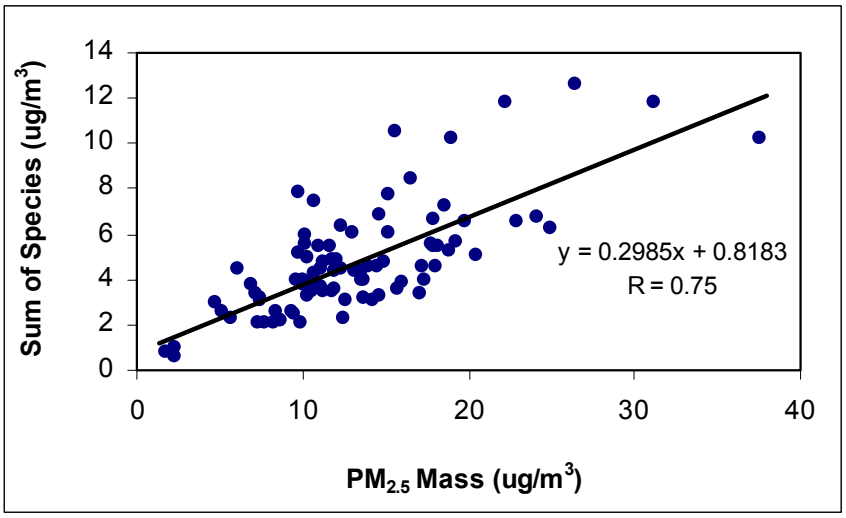


Figure II.2.3. Scatter plot of sum of species versus mass outdoor concentrations for Koebel (May-August 2000)

Sulfate versus Total Sulfur

Sulfate (SO_4^{-2}) ion concentration was obtained by ion chromatography (IC) analysis and the total sulfur (S) concentration was obtained from x-ray fluorescence (XRF) analysis on Teflon-membrane filters. Figures II.2.4 to II. 2.6 show scatter plots of sulfate versus sulfur of the $PM_{2.5}$ measurements. The ratio of sulfate to sulfur should equal three if all of the sulfur were present as soluble sulfate. A reasonably good correlation (R = 0.69, 0.71, and 0.79 at Koebel, New Albany and Athens respectively) and a good average ratio of 2.2 was found for these measurements, which indicates that the most of the $PM_{2.5}$ sulfur was present as sulfate.[9]

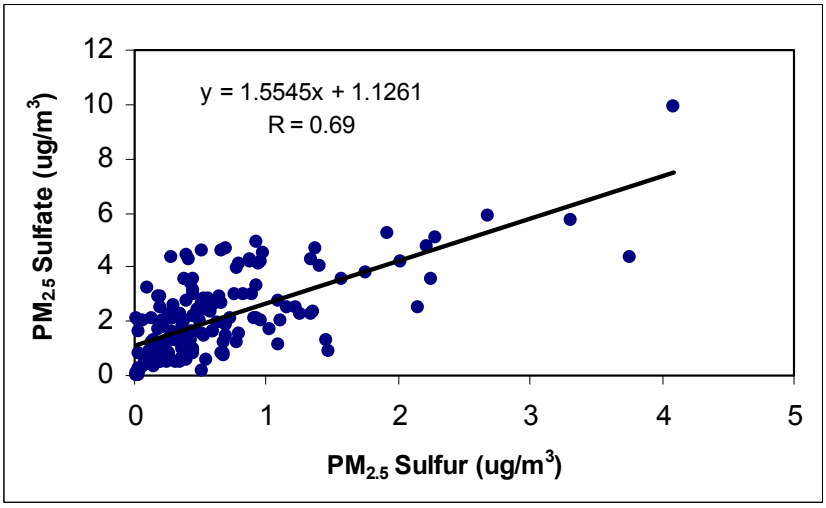


Figure II.2.3. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Koebel outdoor samples (May-August 2000)

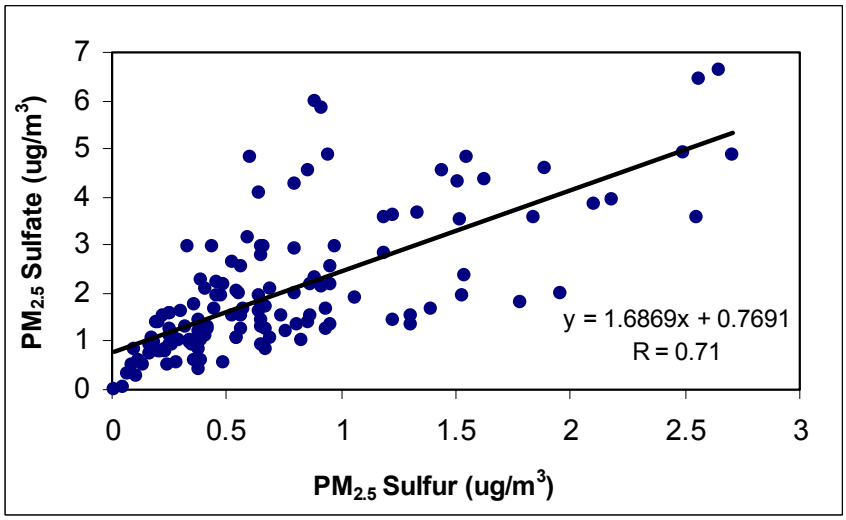


Figure II.2.5. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for New Albany outdoor samples (May-August 2000)

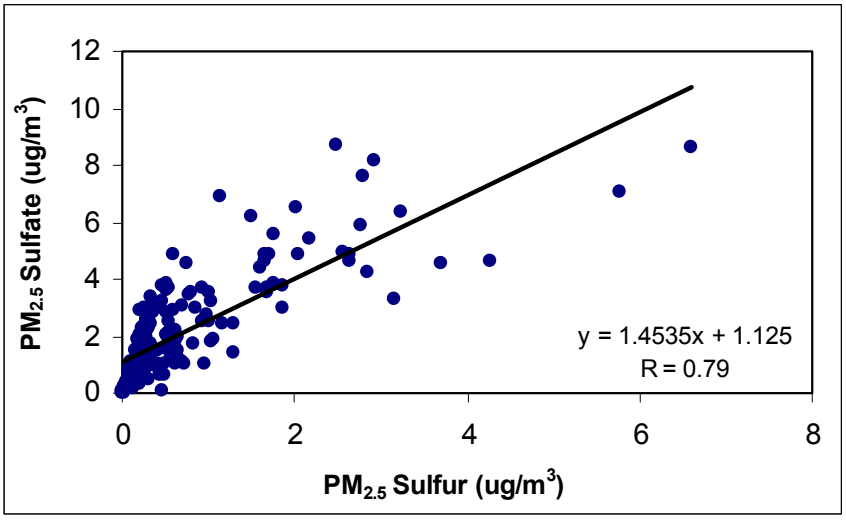


Figure II.2.6. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Athens outdoor samples (May-August 2000)

Anion and Cation Balance

Ion chromatography was used to determine the concentrations of various ions present in the filter samples. Samples were analyzed for cations, lithium, sodium, ammonium, potassium, magnesium and calcium and anions, fluoride, chloride, nitrate, phosphate and sulfate. The anion and cation concentrations of the $PM_{2.5}$ samples were obtained and correlated.

Regression plots for anion and cation (Figures II.2.7 to II.2.9) clearly show that these ionic measurements are highly correlated with regression coefficients of 0.88, 0.87, and 0.86 for Athens, New Albany, and Koebel outdoor sites, respectively.

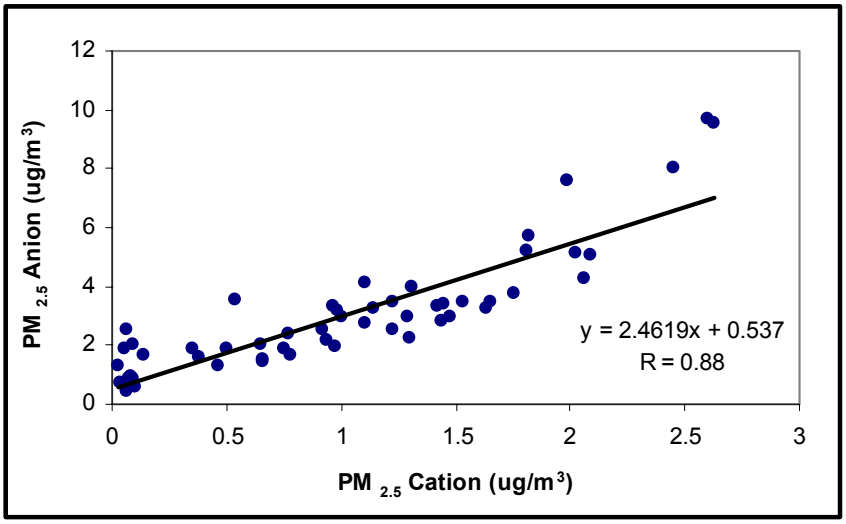


Figure II.2.7. Scatter plot of cation and anion balance for Athens outdoor samples (May-August 2000)

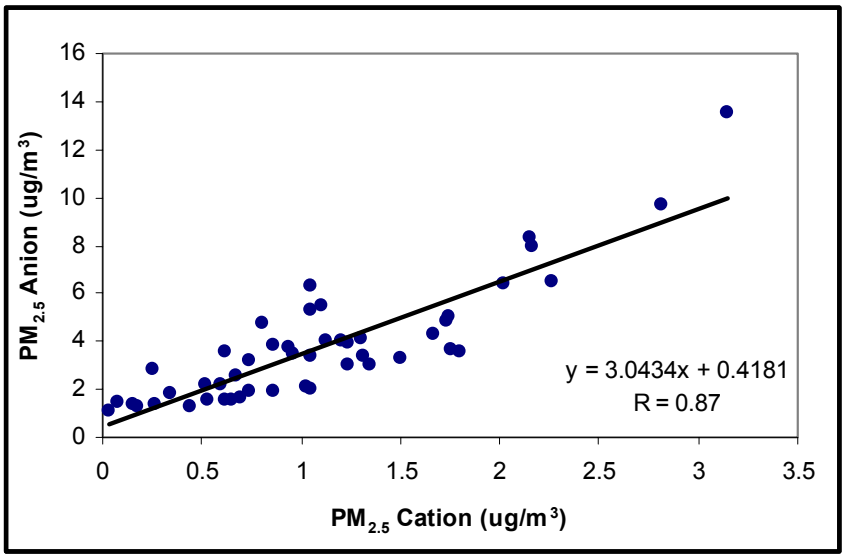


Figure II.2.8. Scatter plot of cation and anion balance for New Albany outdoor samples (May-August 2000)

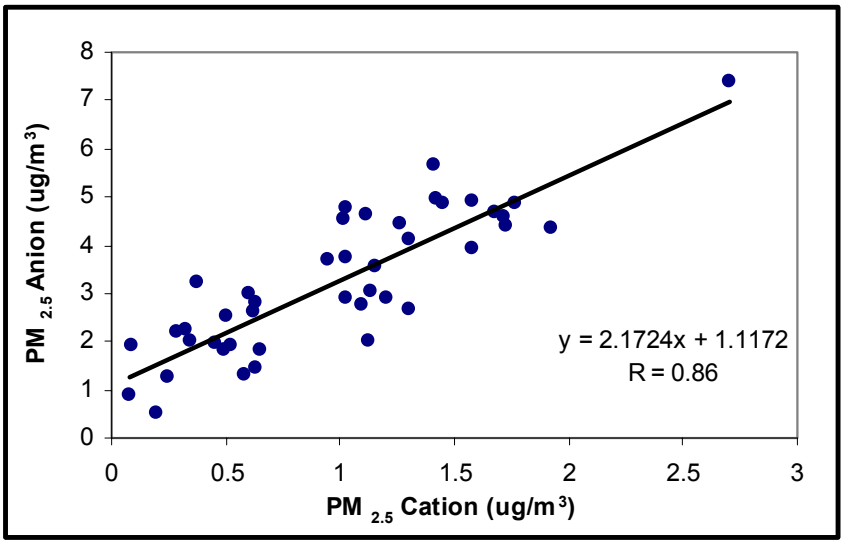


Figure II.2.9. Scatter plot of cation and anion balance for Koebel outdoor samples (May-August 2000)

RESULTS AND DISCUSSION

$PM_{2.5}$ Chemical Species Concentrations

Chemical analysis of samples collected from February 1999 through August 2000 at the three monitoring sites were analyzed with ion chromatography and X-ray fluorescence techniques. Daily values of each component were obtained at all the sites. The results were statistically analyzed using Statistica software[10] and box plots were obtained. The box plots show the median value along with the minimum and maximum concentrations for each component (Figures II.2.10 to II.2.12).

Concentrations of Cl^-, NO_3^-, SO_4^{-2}, PO_4^{-3}, Li^+, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}, Si, P, S, Cl, K, Ca, Ti, V, Cr, Co, Ni, Mn, Fe, Cu, Zn, As, Cd and Sn are shown in the figures below. They were determined for each site and then compared. The result shows that sulfate is the major component present in all $PM_{2.5}$ samples. Other abundant components included nitrate and ammonium ions and silicon.

The anion and cation average concentrations most of the times followed the pattern $SO_4^{-2} > NO_3 > PO4^{-3} > Cl^-$ and $Na^+ > NH_4^+ > Ca^{+2} > K^+ > Mg^{+2}$. Heavy metals such as titanium, vanadium, manganese, iron, copper, and zinc were found in all the samples, and iron was the most abundant species.

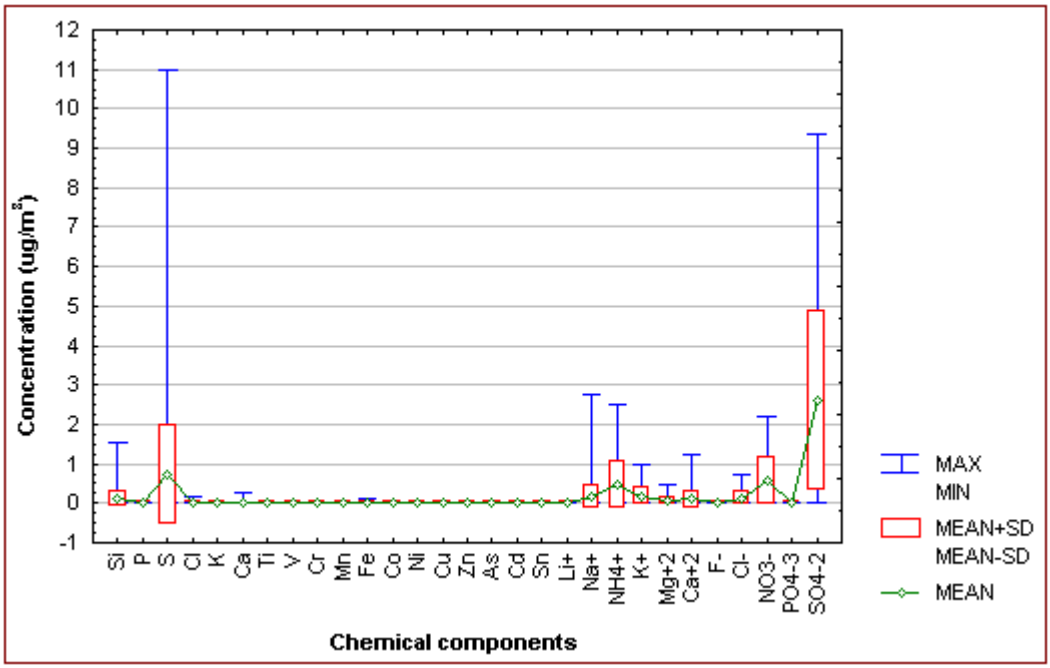


Figure II.2.10. Concentrations of the chemical components present in the samples at the Athens outdoor site (February 1999-August 2000)

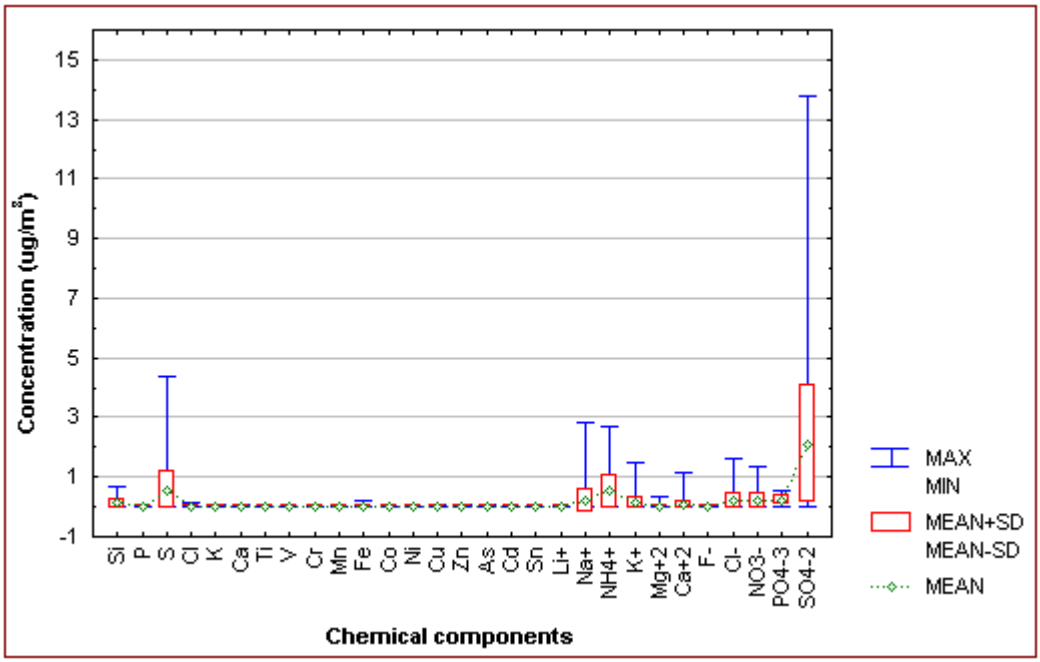


Figure II.2.11. Concentrations of the chemical components present in the samples at the New Albany outdoor site (February 1999-August 2000)

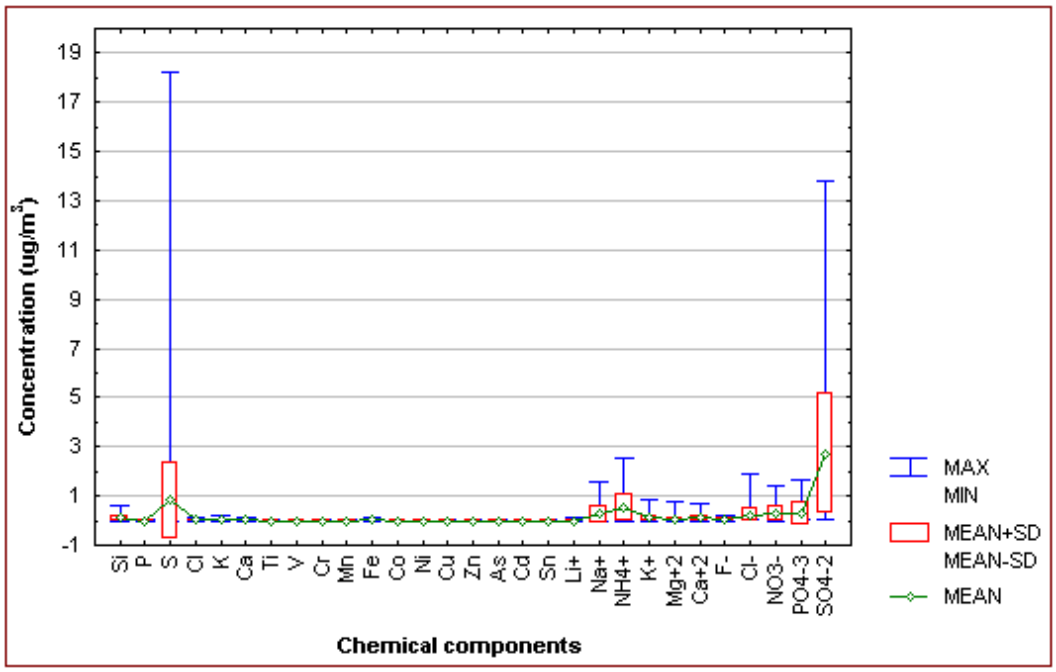


Figure II.2.12. Concentrations of the chemical components present in the samples at the Koebel outdoor site (February 1999-August 2000)

Major Chemical Components of $PM_{2.5}$

Most fine sulfates are the results of oxidation of sulfur dioxide gas to sulfate particles. In humid atmospheres, oxidation typically occurs in clouds where sulfuric acid is formed within water droplets. If there is inadequate ammonia in the atmosphere to fully neutralize the sulfuric acid, then the resulting aerosols are acidic. The mass associated with dry ammonium sulfate can be estimated from independent measurements of sulfate and ammonium ions.[11] For this study, it is assumed that all particulate sulfur is ammonium sulfate and equation 3 below is used to calculate the mass of the ammonium sulfate ion. Also, assuming that the collected nitrate ion is associated with fully neutralized nitrate aerosol, (NH4NO3), the ammonium nitrate mass is estimated from the nitrate ion mass concentration by using a multiplication factor of 1.29 as shown in equation 4 below.[12]

Soil mass concentration is estimated by summing the elements predominantly associated with soil, plus oxygen for the common compounds (SiO_2, CaO, FeO, Fe_2O_3, TiO_2).[13] Figures II.2.13 to II.2.15 show pie charts of various chemical components of collected particulates for each site and are calculated using following equations:

1. Unidentified = measured mass – sum of 2,3,4,5,6 and 7
2. Soil = 1.62(Ca) + 2.42(Fe) + 1.94 (Ti) + **2.49** (Si)
3. Ammonium sulfate = 1.37 (soluble sulfate)
4. Nitrate = 1.29 (soluble nitrate)
5. Phosphates = Phosphates
6. Salt = 1.65 (Cl), XRF
7. Trace elements = sum of XRF measured species – (Si + Ca + Fe + S + Cl + Ti)

It was assumed that the ammonium nitrate is the main form of secondary nitrates. However, since the hydrogen content in NH_4NO_3 is not well retained on the teflon filters, only the measured mass of soluble nitrate is included in the reconstructed chemical composition and will subsequently be referred to as nitrate.[14]

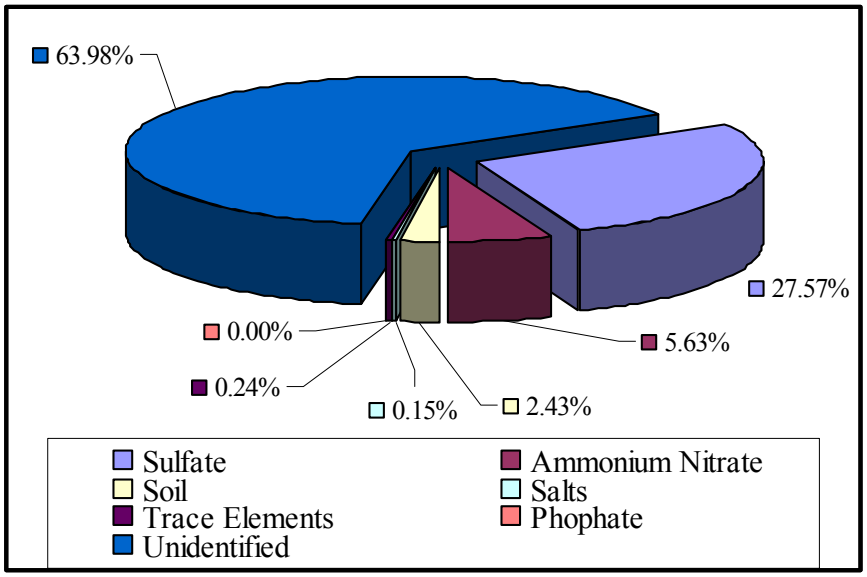


Figure II.2.13. $PM_{2.5}$ components of outdoor ambient air (February 1999–August 2000) at Athens

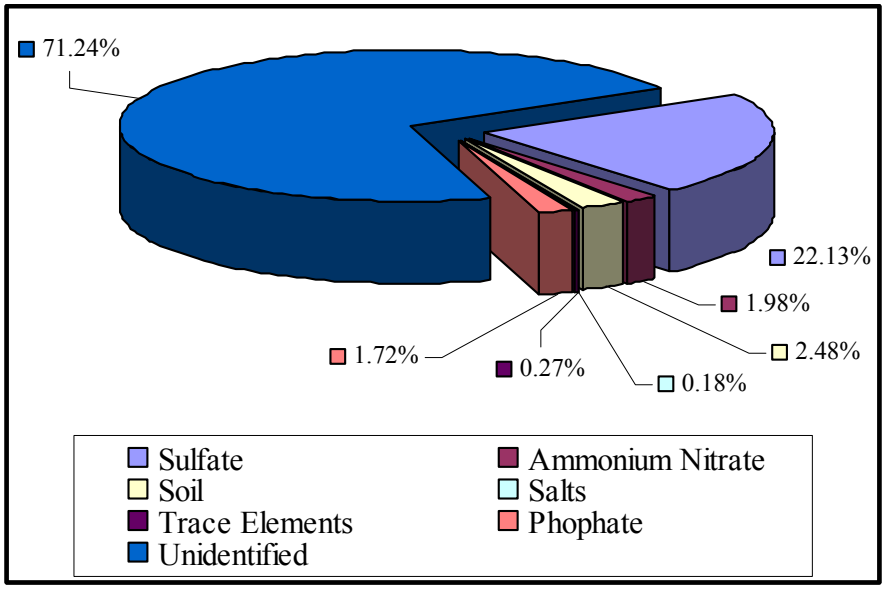


Figure II.2.14. $PM_{2.5}$ components for outdoor ambient air (February 1999–August 2000) at New Albany

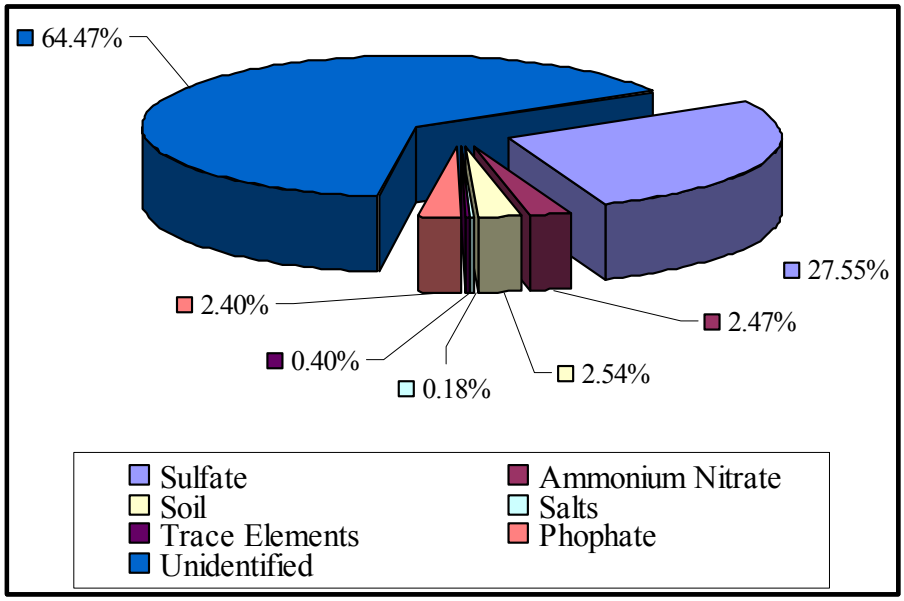


Figure II.2.15. $PM_{2.5}$ components for outdoor ambient air (February 1999–August 2000) at Koebel

The figures above show that an average 35 percent of the total particulate ($PM_{2.5}$) mass was successfully analyzed at the outdoor sites. Ammonium sulfate percentage ranged from 22 to 28 percent of the total particulate matter mass. Sulfate was highest at Athens. The percentage range of soil was in the range of 2 to 2.5 percent with Koebel showing the highest. The rural site, Athens, showed higher percentage (~ 6 percent) of nitrates than the other two sites. Organic matter and elemental carbon were not analyzed as a part of this study.

Monthly Variations in Sulfate Concentration

Levels of sulfate and ammonium ions present in samples give an insight into the acidity of the fine particulate fraction. Investigators have generally assumed that sulfate is present in tropospheric aerosol particles as ammonium salts and sulfuric acid.[15] Figures II.2.16 to II.2.18 show variations in monthly sulfate ion levels for outdoor sites during the entire period of study. As the figures show, sulfate concentrations increased from winter to summer at all three sites.

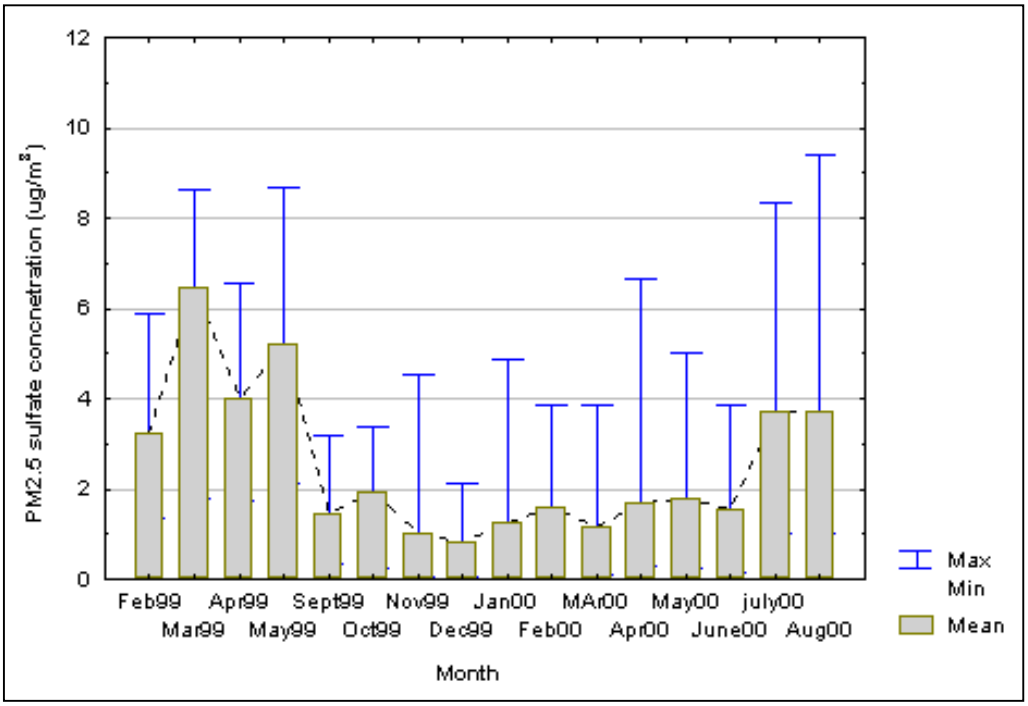


Figure II.2.16. Temporal variations in sulfate concentrations for Athens outdoor samples for the study period (February 1999-August 2000)

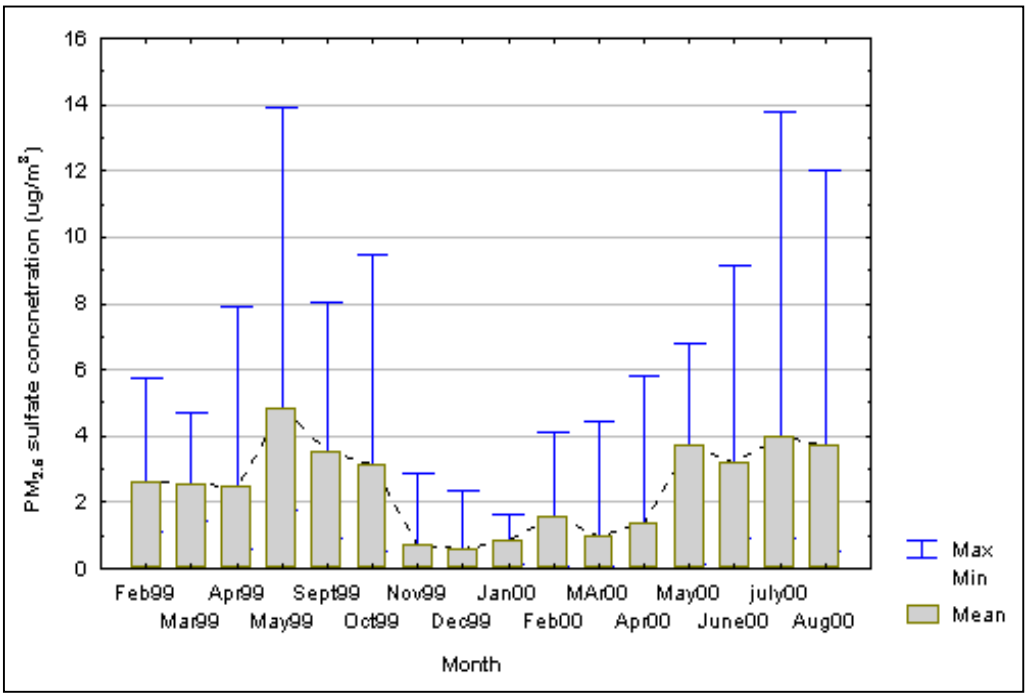


Figure II.2.17. Temporal variations in sulfate concentrations for New Albany outdoor samples (February 1999-August 2000)

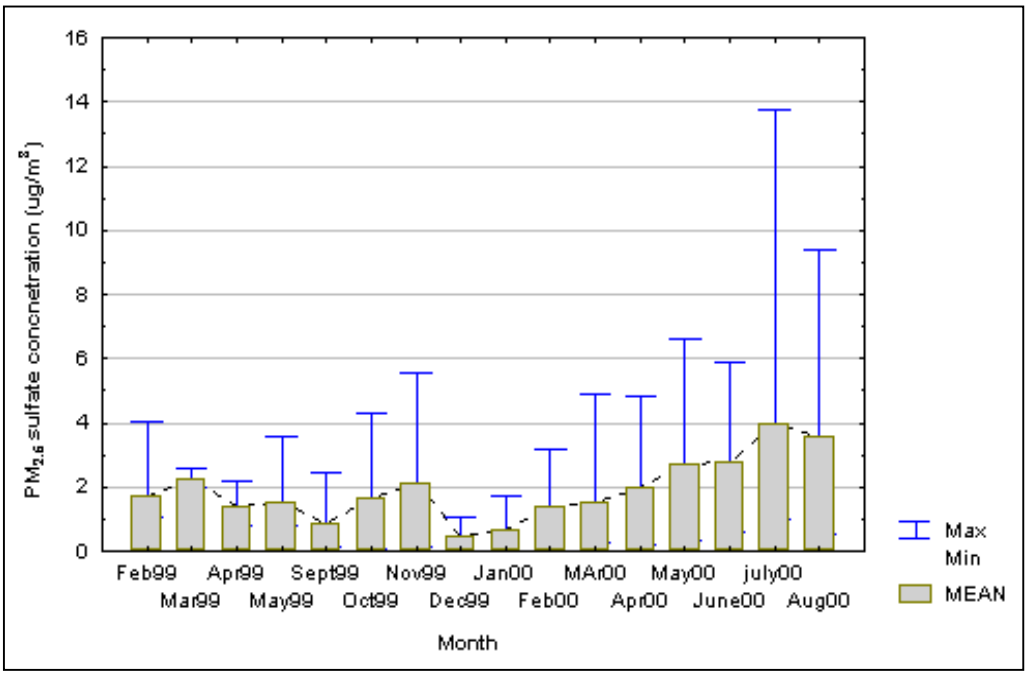


Figure II.2.18 Temporal variations in sulfate concentrations for Koebel outdoor samples (February 1999-August 2000)

$PM2_{.5}$ and Meteorological Parameters

For evaluating strategies to control PM concentrations, it is important to determine the meteorological factors that influence PM level. Correlations between $PM_{2.5}$ and weather components, such as temperature, wind speed, wind direction, and relative humidity, at New Albany, Koebel, and Athens are plotted in Figures II.2.19 through Figure II.2.24. The correlation plot between $PM_{2.5}$ and wind speed shows that PM concentrations decrease with increasing wind speed and vice versa. At the suburban site the $PM_{2.5}$ concentration was highest when the winds were blowing from the southeast despite the low frequency of occurrence of this particular wind direction. A similar pattern was observed at the urban site in Columbus. The rural site exhibits a different pattern in that the $PM_{2.5}$ concentration was highest when the winds were blowing from the south and the southeast directions.

Temperature, another important meteorological parameter, significantly affects the $PM_{2.5}$ concentration and this fact is shown in the correlation plot between $PM_{2.5}$ and temperature. Although temperature is related to $PM_{2.5}$ at New Albany and Koebel, correlation was weak at the Athens. High $PM_{2.5}$ concentration levels were generally observed when wind speed was lower than 8 mph and temperature was higher than 70°F. No significant relation was found between $PM_{2.5}$ and relative humidity.

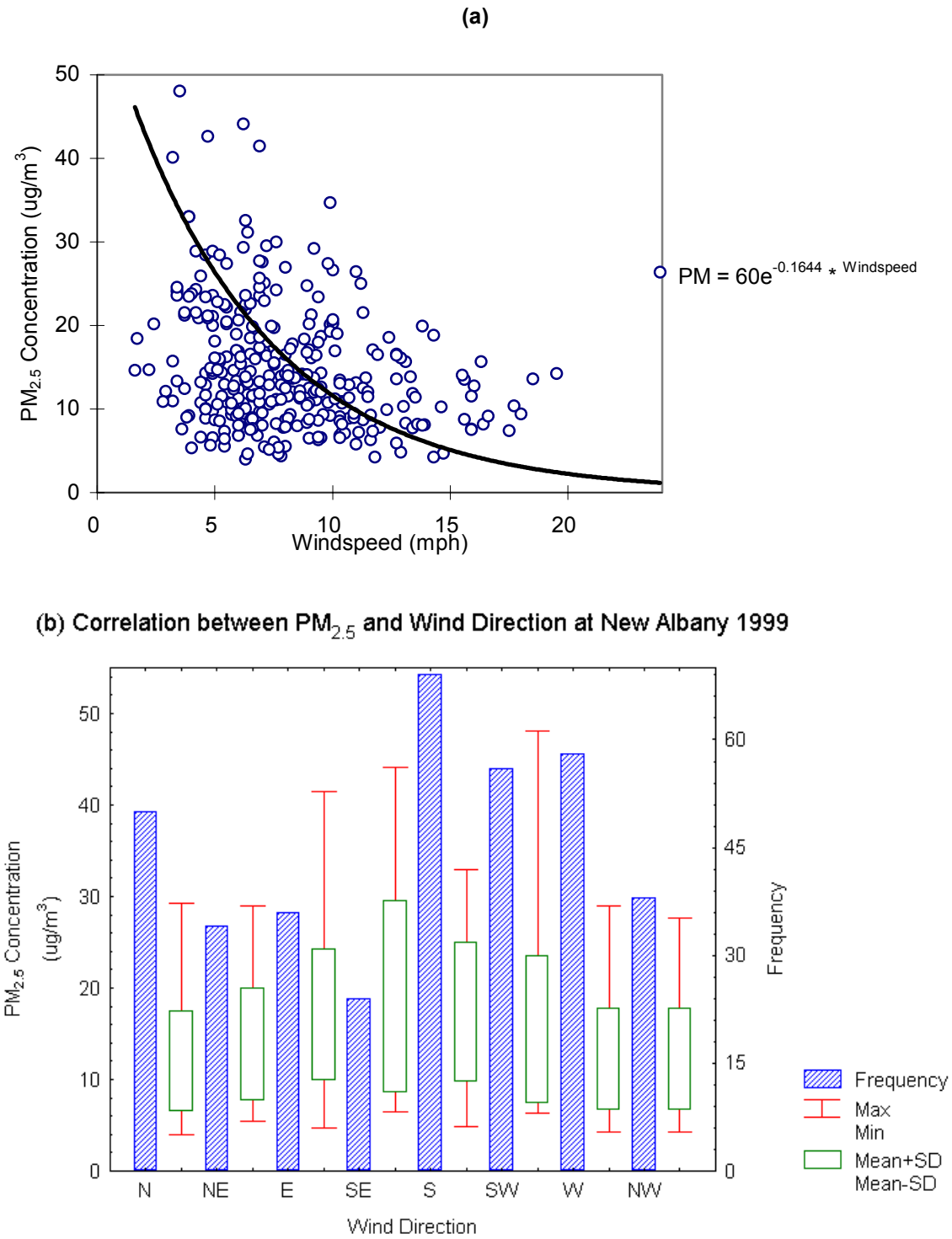


Figure II.2.19. Correlations between $PM_{2.5}$ and weather components at New Albany, Ohio in 1999: (a) $PM_{2.5}$ vs. wind speed and (b) $PM_{2.5}$ vs. wind direction

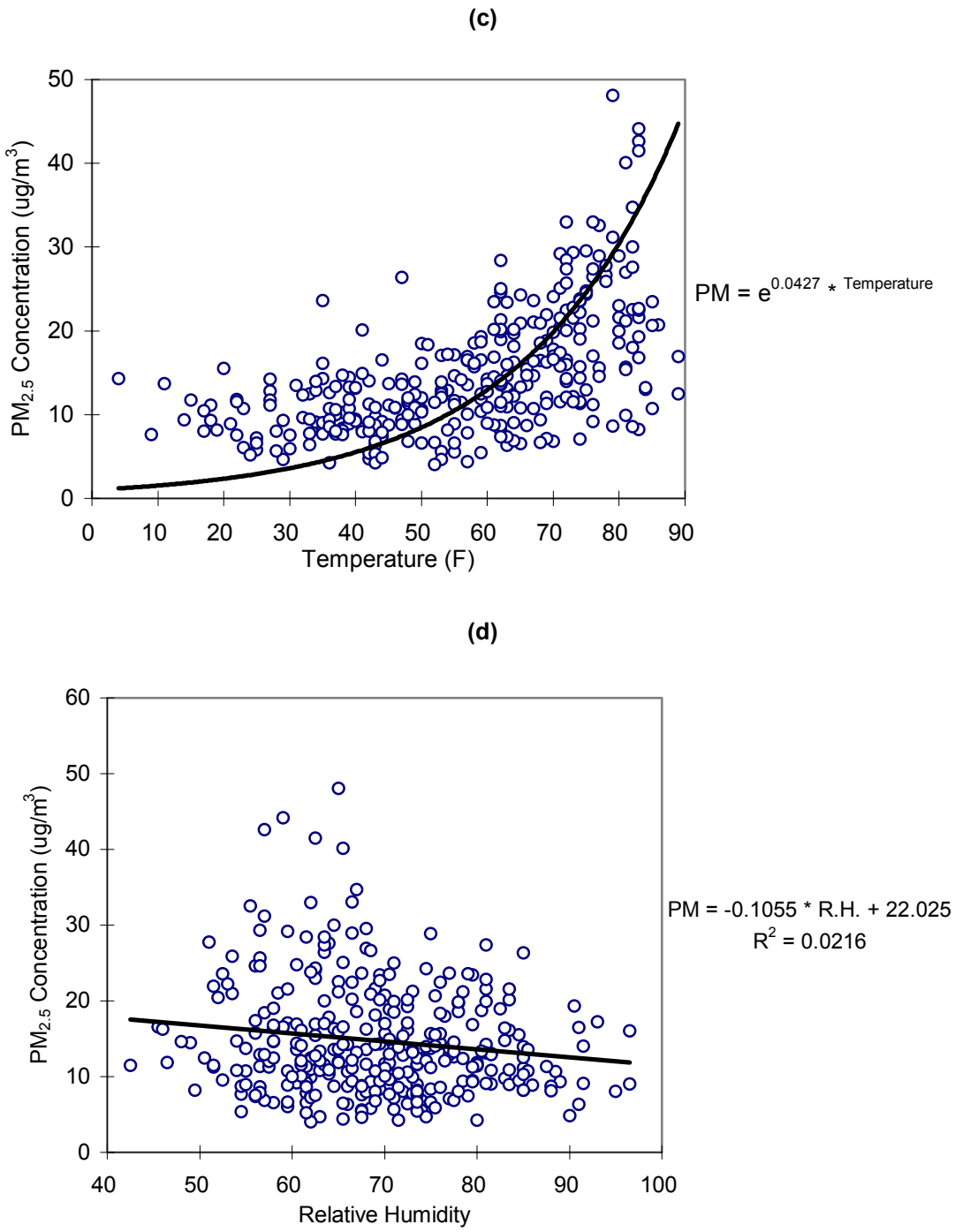


Figure II.2.20. Correlations between $PM_{2.5}$ and weather components at New Albany, Ohio in 1999: (c) $PM_{2.5}$ vs. temperature and (d) $PM_{2.5}$ vs. relative humidity

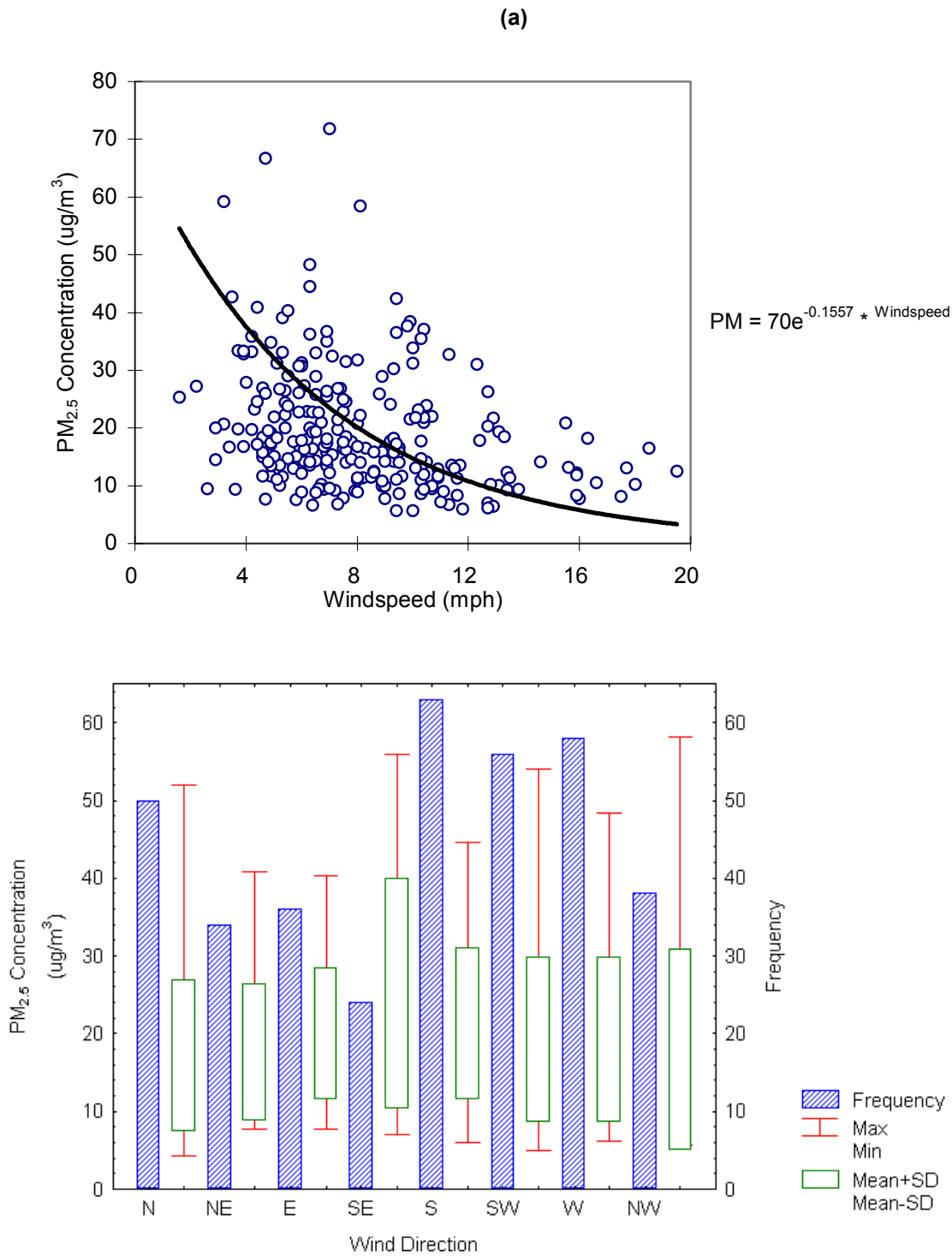


Figure II.2.21. Correlations between $PM_{2.5}$ and weather components at Koebel, Columbus, Ohio in 1999: (a) $PM_{2.5}$ vs. wind speed and (b) $PM_{2.5}$ vs. wind direction

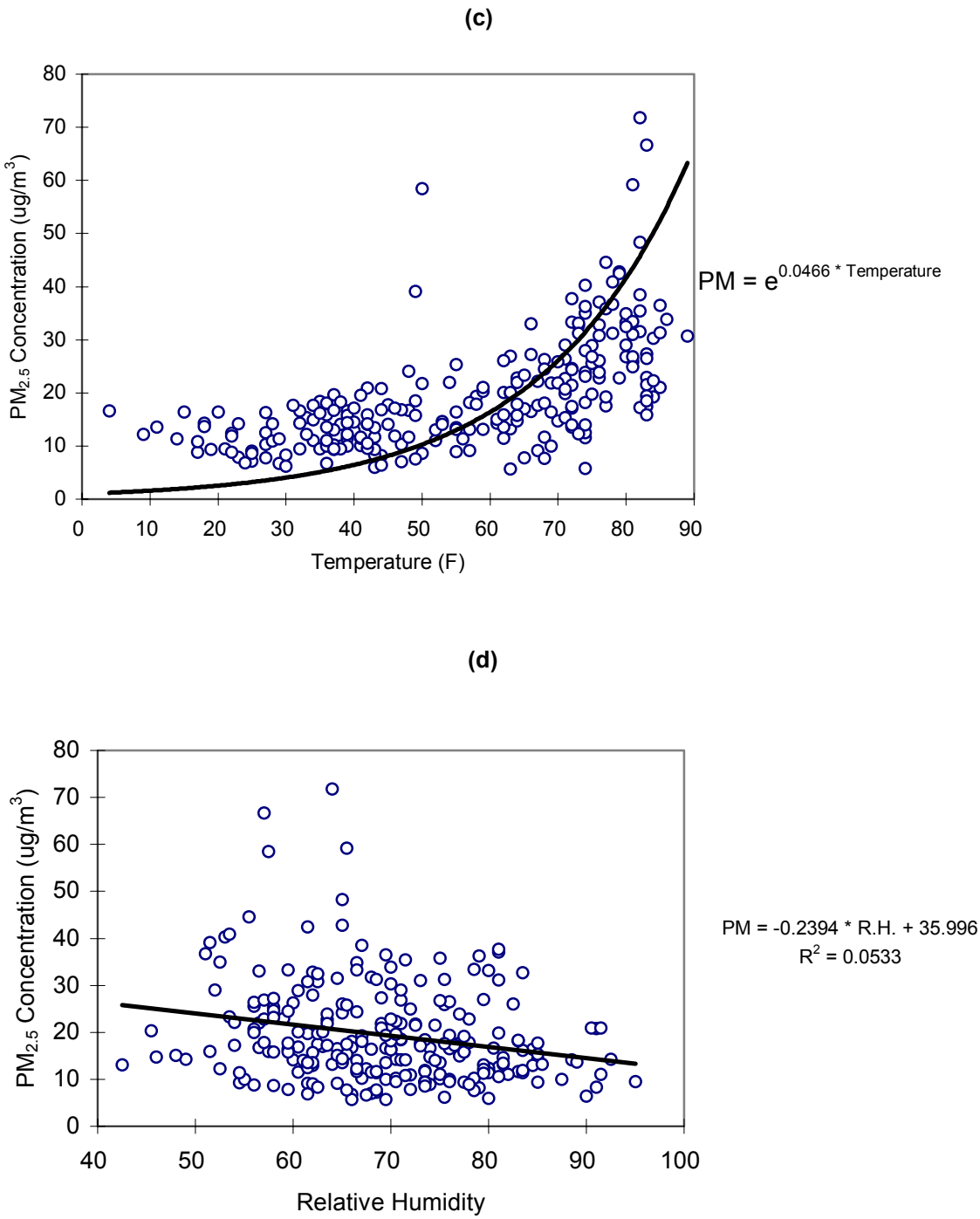


Figure II.2.22. Correlations between $PM_{2.5}$ and weather components at Koebel, Columbus, Ohio in 1999: (c) $PM_{2.5}$ vs. temperature and (d) $PM_{2.5}$ vs. relative humidity

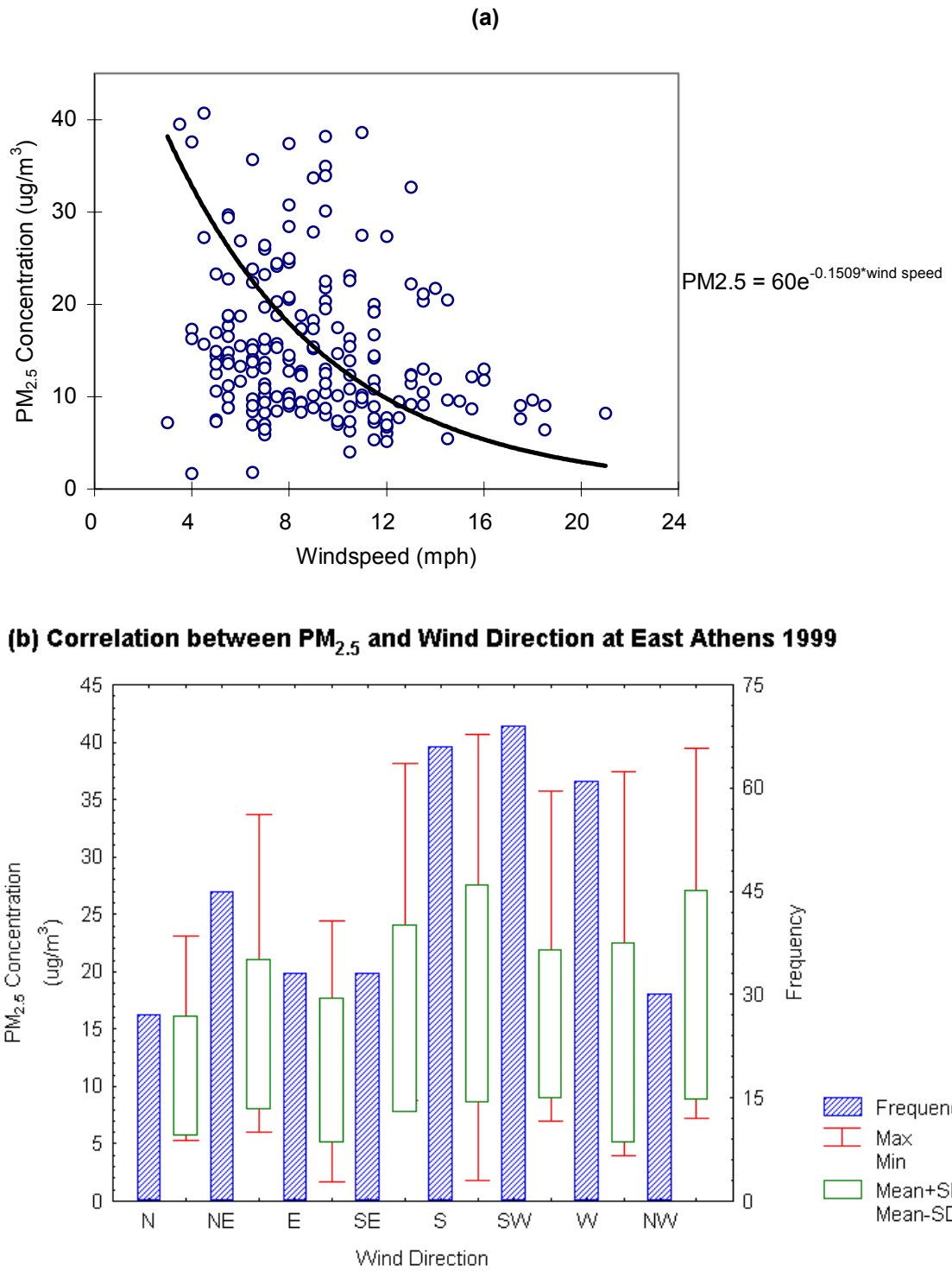


Figure II.2.23. Correlations between $PM_{2.5}$ and weather components at Athens in 1999: (a) $PM_{2.5}$ vs. wind speed and (b) $PM_{2.5}$ vs. wind direction

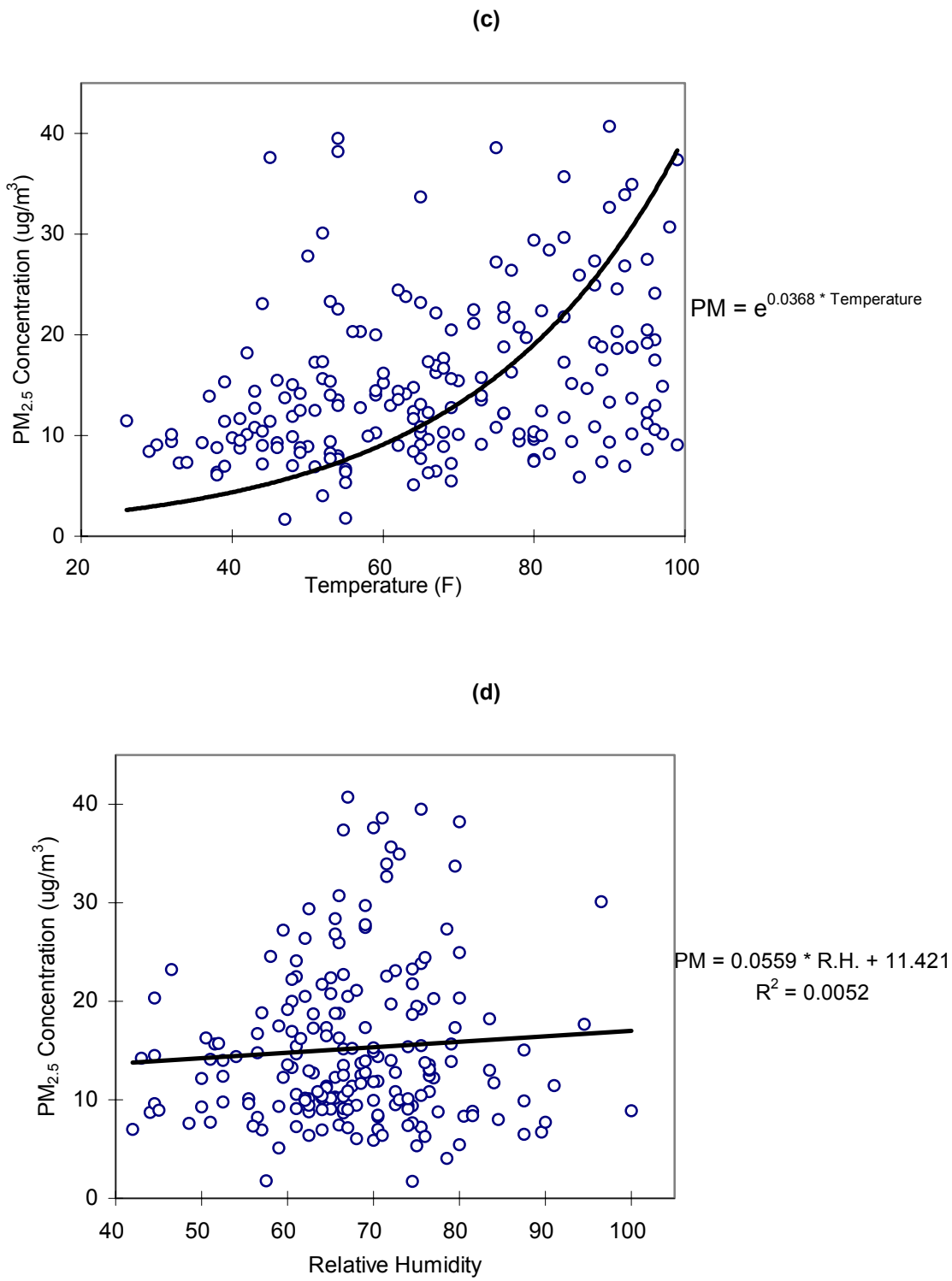


Figure II.2.24. Correlations between $PM_{2.5}$ and weather components at Athens in 1999: (c) $PM_{2.5}$ vs. temperature and (d) $PM_{2.5}$ vs. relative humidity

LONG-RANGE TRANSPORT ON FINE $PM_{2.5}$ DISTRIBUTION IN CENTRAL OHIO

Air quality problems related to fine particulate matter ($PM_{2.5}$) in Ohio is associated with both local emission sources and pollutants transported from great distances. Industrial and urban activities in Ohio contribute to the local and regional air pollution problems. Most of the major industrial sources of fine particulate matter are located along the Ohio River valley. Significant PM sources in the neighboring states surrounding Ohio also contribute to the air quality problems in the state. Favorable meteorological situations have a major impact on the formation and transport of $PM_{2.5}$ from within and outside of Ohio. A detailed understanding of the sources of pollutants and meteorological conditions affecting air quality is therefore required for any meaningful air quality planning in Ohio. The characteristics of fine particulate matter distribution are evaluated for the three monitoring sites. Particular emphasis is placed on the study of long-range transport characteristics of $PM_{2.5}$ and its precursors into the central Ohio region.

The meteorological dynamics that cause air to rise or fall, and that determine its path can affect air quality by carrying air pollutants many miles from their sources.[16] Therefore, the trajectory analysis technique is useful to study the movement of air parcels carrying pollutants from sources situated long distances. Cluster analysis, another technique used in this study is a multivariate statistical approach. Recent studies have used cluster analysis for various purposes. Dorling et al. applied cluster analysis of trajectories to find out the relationships between large-scale surface pressure patterns and the pollution climatology of a site.[17] Also, they used cluster analysis as a tool for examining the influence of synoptic weather patterns on air and precipitation chemistry.[18] Brankov et al. examined the relationship between synoptic-scale atmospheric transport patterns and concentration levels of several toxic trace elements with cluster analysis.[19] Another study by Rao et al. addressed the influence of a finite number of synoptic patterns associated with pollutant transport from a different source region.[20]

This section presents the results of detailed analyses of the air quality issues pertaining to fine particulate matter affecting the urban, suburban and rural areas in Ohio from data monitored by the School of Health Sciences at Ohio University during 1999-2000.

Trajectory and Cluster Analysis

Trajectories are used to aid in complex decisions regarding atmospheric transport pathways.[21] This study applied the hybrid single-particle lagrangian integrated trajectory (HYSPLIT4) model from National Oceanic and Atmospheric Administration (NOAA)'s Air Resource Laboratory (ARL) to

estimate backward trajectories.[22] The HYSPLIT4 model is used for atmospheric emergencies, diagnostic case studies, or climatological analyses. 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. For this study, 24-hour back trajectories at 500 meter, which is generally in the middle of the mixed layer, on high PM days with values over 30 $\mu g/m^3$ were computed. This study adapted a start time of 16 UTC, same as noon in local time, corresponding to high PM values.

Cluster analysis of backward trajectories allows for the identification of the regional source of pollutants. This analysis consists of splitting a data set into several dominant groups that are homogeneous and peculiarly different from each other as possible. In this study, the clustering approach proposed by Dorling et al.[23] was chosen and modified. For each one-day (24-hour) back trajectory 6 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 and assigned each of the three-day real trajectories to the seed that is closest in terms of the distance between their corresponding six-hourly coordinates. Then the seed or average trajectory of each cluster is recalculated with each real trajectory and the number of clusters is reduced by the same process that merges the two clusters whose average trajectories are closest.[24] This algorithm, however, was modified in this study. Each trajectory was assigned to several clusters in terms of directions of original source regions that are x-y coordinates of starting points of 24-hour back trajectory. Main clusters in this study were divided into eight directional components, which were North, Northwest, West, Southwest, South, Southeast, East, and Northeast. In addition, an additional cluster category called "Close" was 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 treated a small region and this projection was more convenient to plot clusters than polar stereographic projection.

Back trajectories can show the impact of upstream emissions and integrate different information including winds in the upstream layer over time, moving distances, and source location. For the study period between 1999 and 2000, 24-hour back trajectories at 500 meters for high PM days with values over 30 $\mu g/m^3$ were applied using the HYSPLIT4 model from NOAA's Air Resource Laboratory (ARL) and are presented in Figures II.2.25 a-c. The three plots of these trajectories show that the air parcel came from all around Ohio during high PM days with very few trajectories from the east. These back trajectories for the high PM days reveal that major air parcels came from the west to south direction during the study period.

Meteorological analysis can be performed using local surface wind and computed back trajectories for each area. For a detailed analysis of the $PM_{2.5}$ distribution, the path of the air parcel causing the high concentration is more important than the hourly local surface wind directions that do not account for the effect of long-range movement in the upper atmosphere. Back trajectories can show the impact of upstream emissions and integrate different information including winds in the upstream layer over time, moving distances, and source location.

Cluster analysis is an advanced method from trajectory analysis as it segregates and merges each trajectory based on its direction and/or similarity. It is a useful method to trace the original regional source of the pollutant. The clusters, their percentiles, their frequencies, and their average concentrations for the three monitoring sites during 1999-2000 are presented in Figures II.2.26 through II.2.28.

At New Albany the highest frequency of high PM days, was associated with the southwest cluster. Also the second and third highest frequencies of high PM days were observed in the south cluster and the southeast cluster passing over the Ohio River valley. The highest average PM concentration was noted along the west cluster. For Koebel the highest frequency of high PM days occurred with the southwest cluster. Other frequent high PM days were associated with clusters from the north, northwest, and south. The highest average PM concentration occurred with the north cluster, which also had the second highest frequency of high PM days. For Athens, high PM days occurred more frequently when the trajectories were from the southwest. The highest average PM concentration appeared along the west cluster.

In summary these results reveal that high PM days occurred most often along the southwest cluster, but the highest average PM concentrations appeared along the west or north clusters. Most clusters' source regions correspond with major cities in neighboring states and major cities in Ohio. This suggests that local industrial complexes and adjoining urban areas affect PM levels in most cities in Ohio. Also, since a large amount of clusters pass over the Ohio River valley, the analysis indicate that the Ohio River valley acts as one of the main source regions of PM precursors in Ohio.

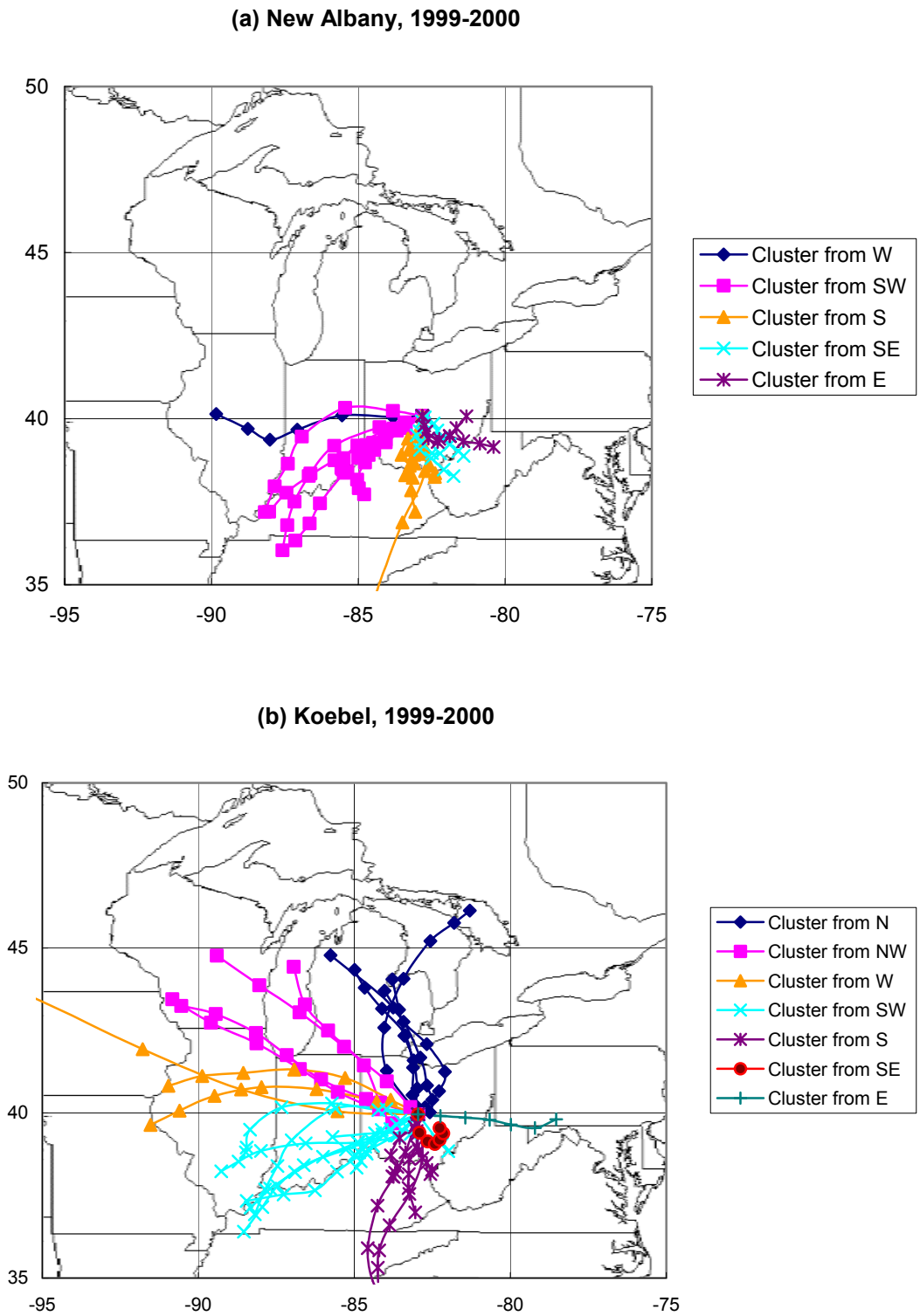


Figure II.2.25. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1999-2000: (a) New Albany and (b) Koebel

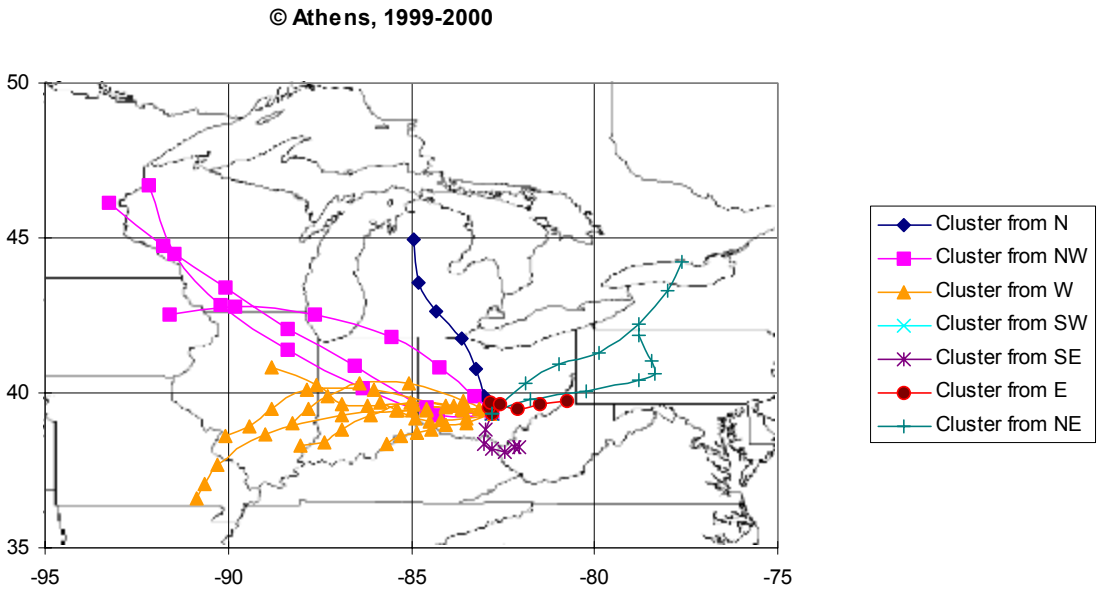


Figure II.2.25 (contd). Back trajectories for high PM days at the monitoring sites selected in Ohio, 1999-2000: (c) Athens

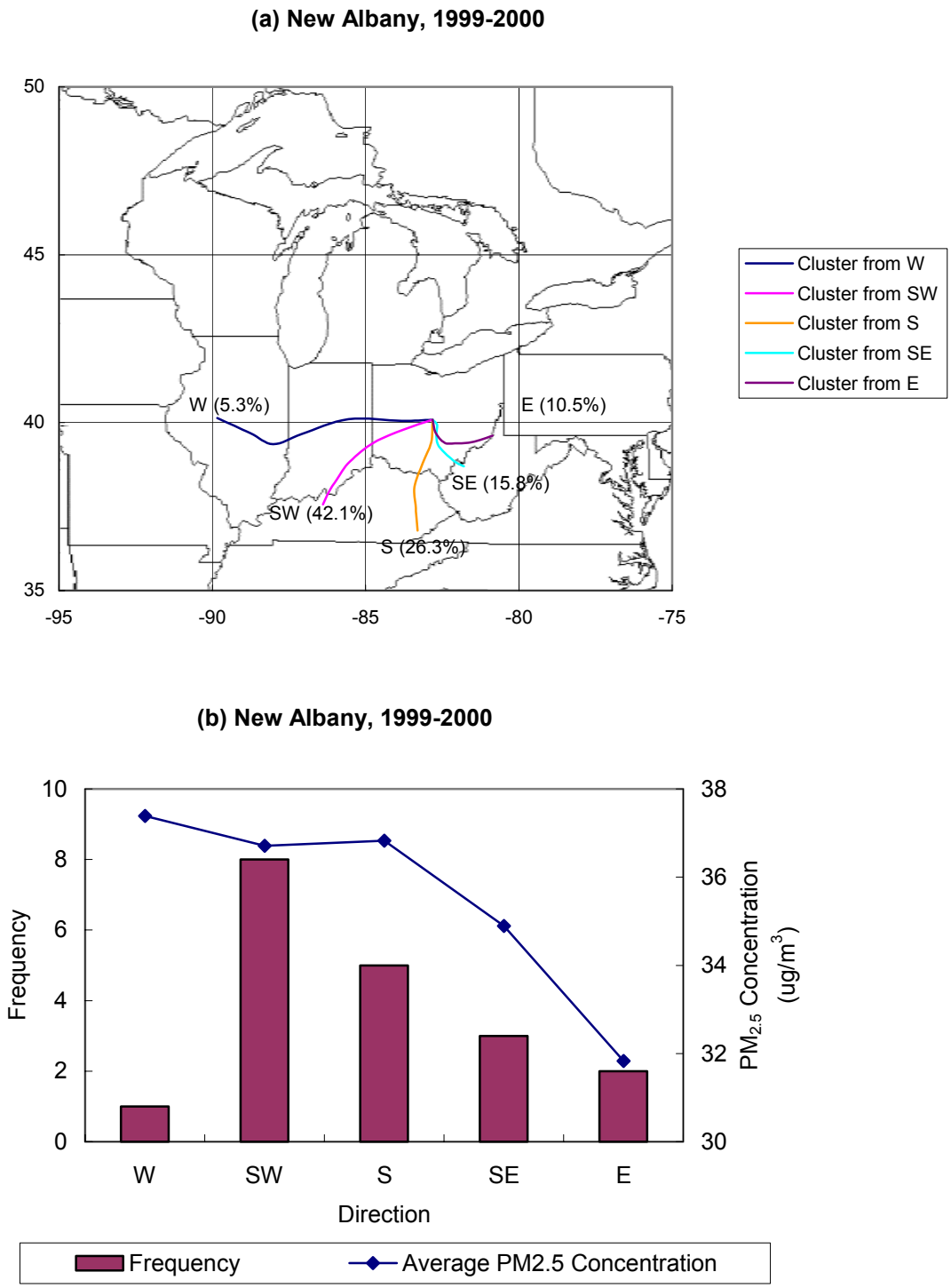


Figure II.2.26. (a) Cluster plot at New Albany, 1999-2000 (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at New Albany, 1999-2000

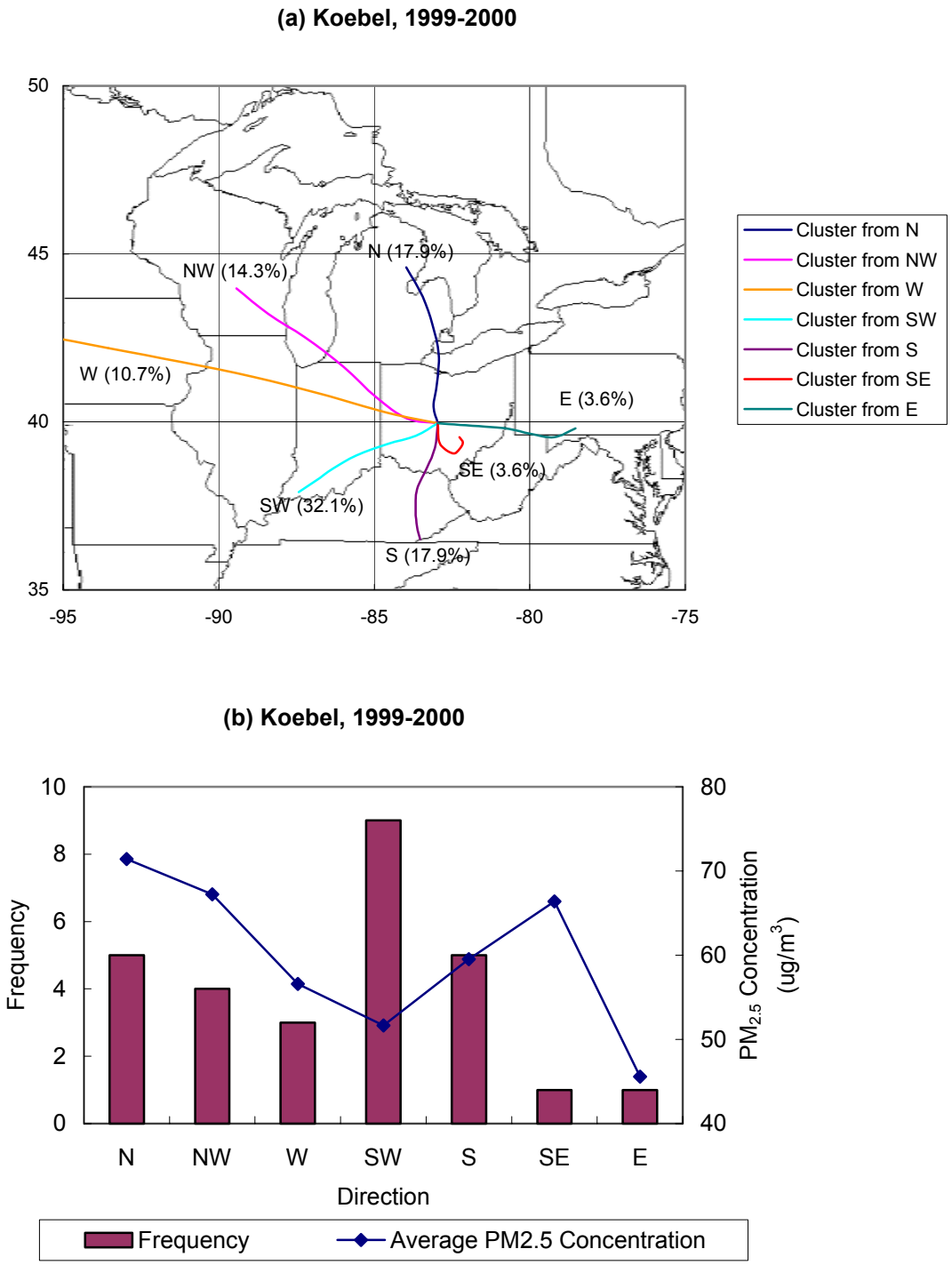


Figure II.2.27. (a) Cluster plot at Koebel, 1999-2000 (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at Koebel, 1999-2000

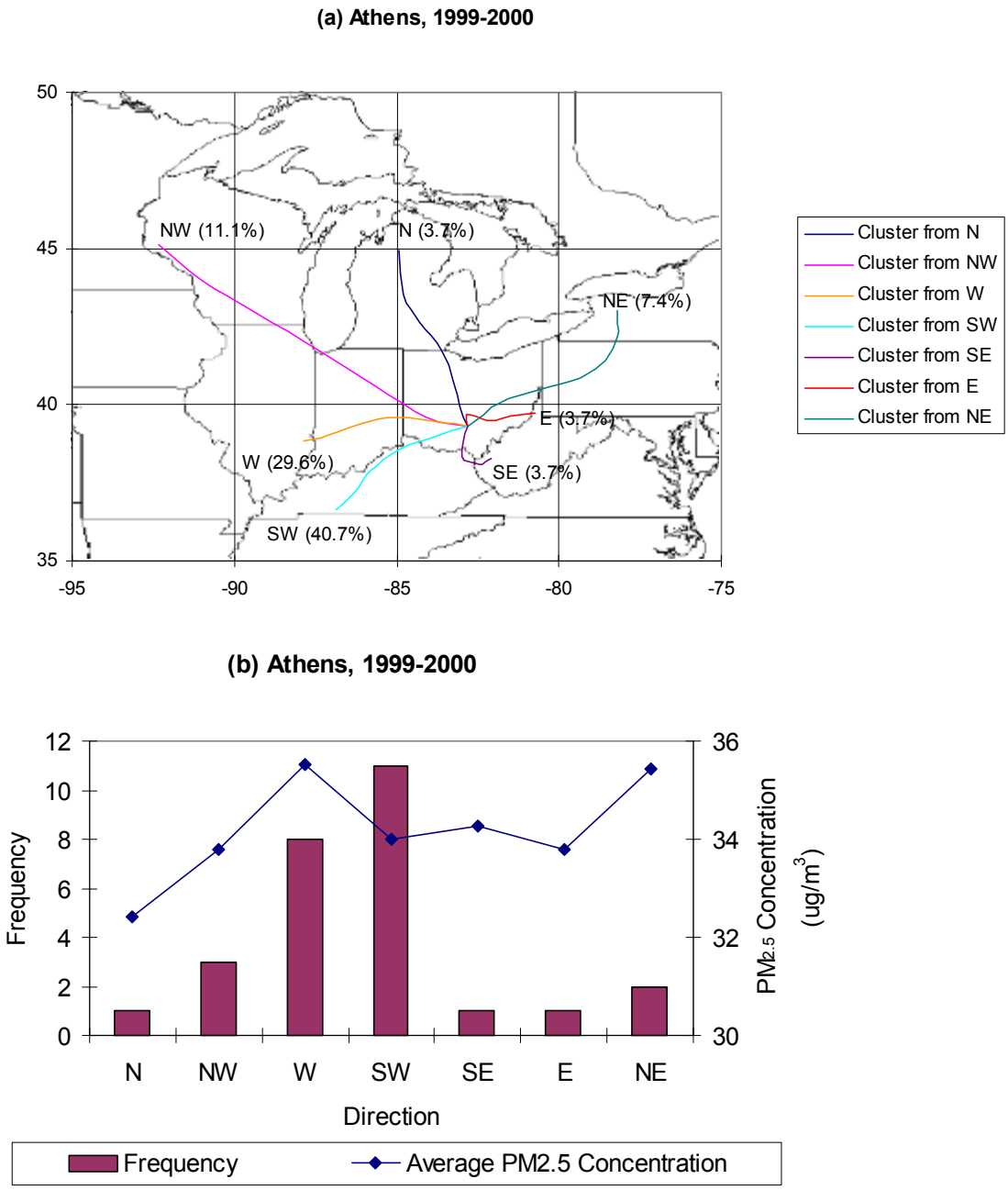


Figure II.2.28. (a) Cluster plot at Athens, 1999-2000 (b) Frequencies and average $PM_{2.5}$ concentrations by cluster at Athens, 1999-2000

RELATIONSHIP BETWEEN $PM_{2.5}$ AND OZONE

The correlation between $PM_{2.5}$ and ozone at New Albany and Koebel is plotted in Figure II.2.29. Data for ozone concentrations was obtained from the Ohio EPA monitoring site located at Maple Canyon, Columbus OH. This plot between $PM_{2.5}$ and ozone concentration shows no significant relation between them.

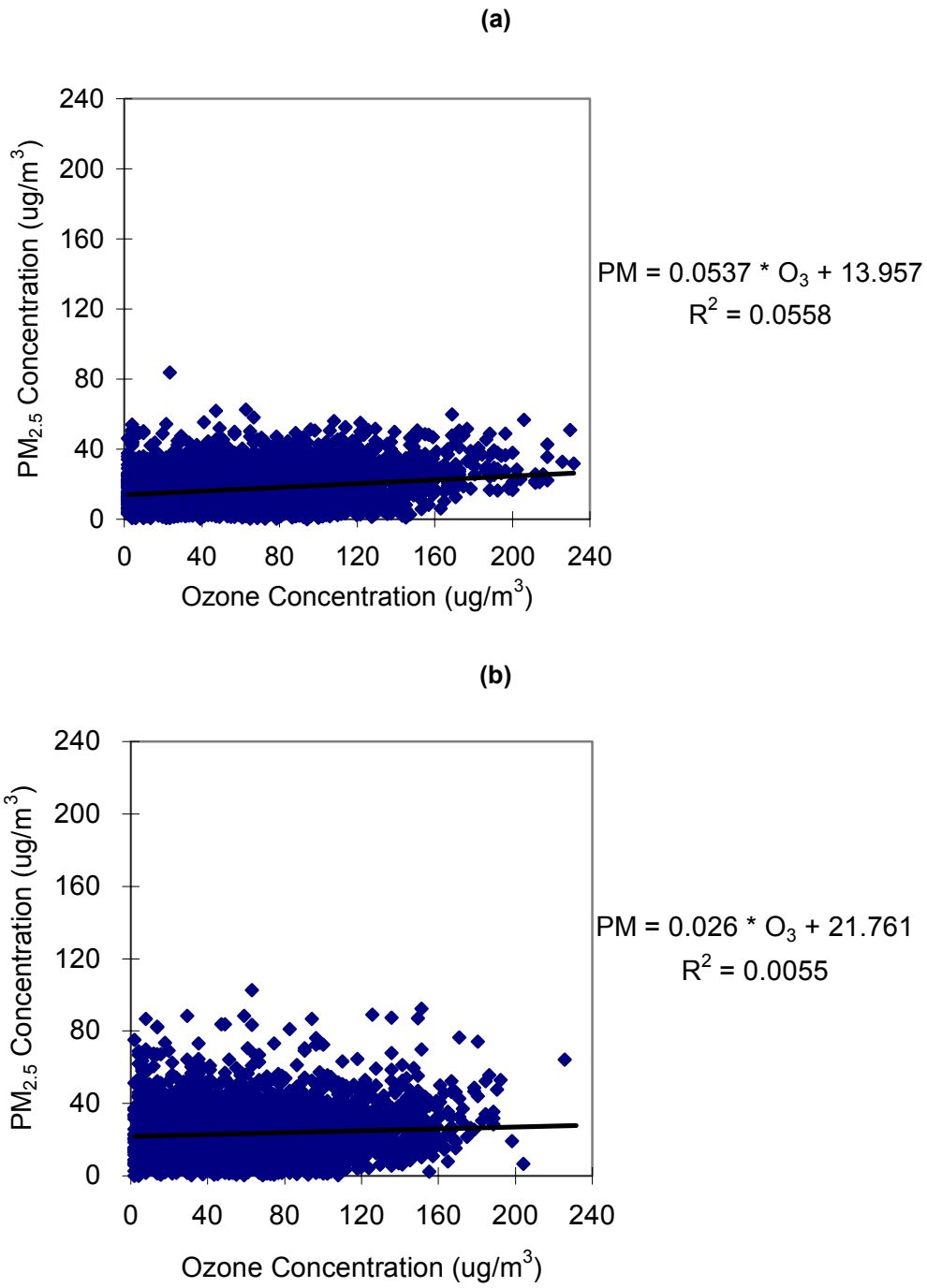


Figure II.2.29. Correlations between $PM_{2.5}$ and ozone in 1999: (a) New Albany and (b) Koebel

EFFECT OF WEATHER ON SULFATE AND SULFUR

Sulfate is formed from an atmospheric reaction of SO_2 and can be transported far from the sources of the SO_2. To evaluate strategies to control sulfate concentrations, it is important to determine the meteorological factors that influence sulfate levels. Correlations between sulfate and weather components, such as temperature, wind speed, wind direction, and relative humidity at New Albany, Koebel, and Athens are plotted in Figures II.2.30 to II.2.34 for the period from February 1999 to December 1999.

Correlation plots between sulfate and wind speed show that sulfate concentrations decrease with increasing wind speed suggesting significant influence of wind speed on sulfate concentrations. Correlation of wind direction with sulfate reveals that the sulfate concentrations at all three sites were highest when the winds were blowing from the southeast. This indicates that there are sources of SO_2 southeast of all the three sites.

Temperature, one of the important meteorological parameters, significantly affects the sulfate concentration and this is emphasized in the correlation plot between sulfate and temperature. This correlation pattern is noted at all the three sites. High sulfate concentration levels were generally observed when the wind speed was lower than 8 mph and temperature was higher than 70°F. No significant relation could be found between sulfate and relative humidity.

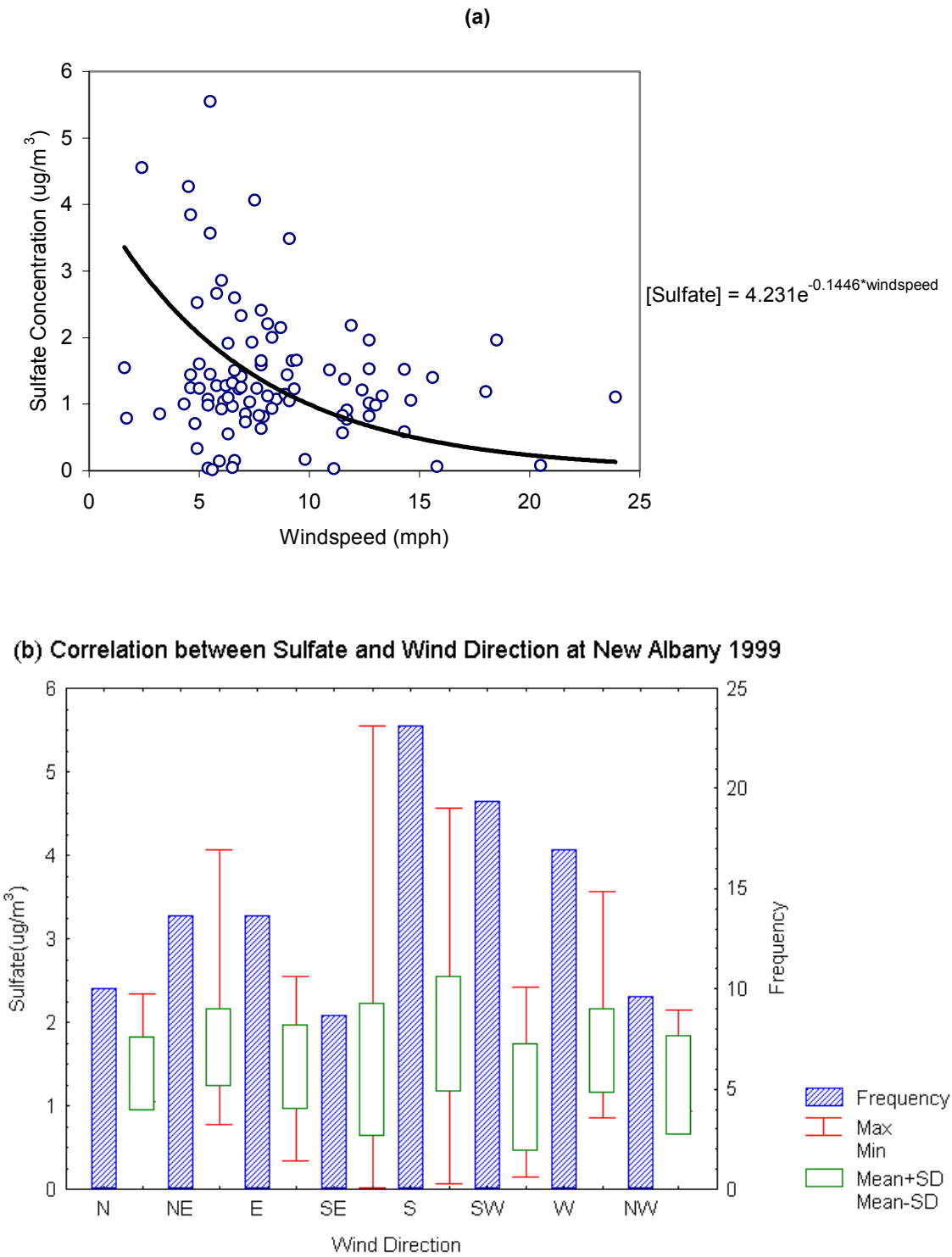


Figure II.2.30. Correlations between sulfate and weather at New Albany in 1999: (a) sulfate vs. wind speed and (b) sulfate vs. wind direction

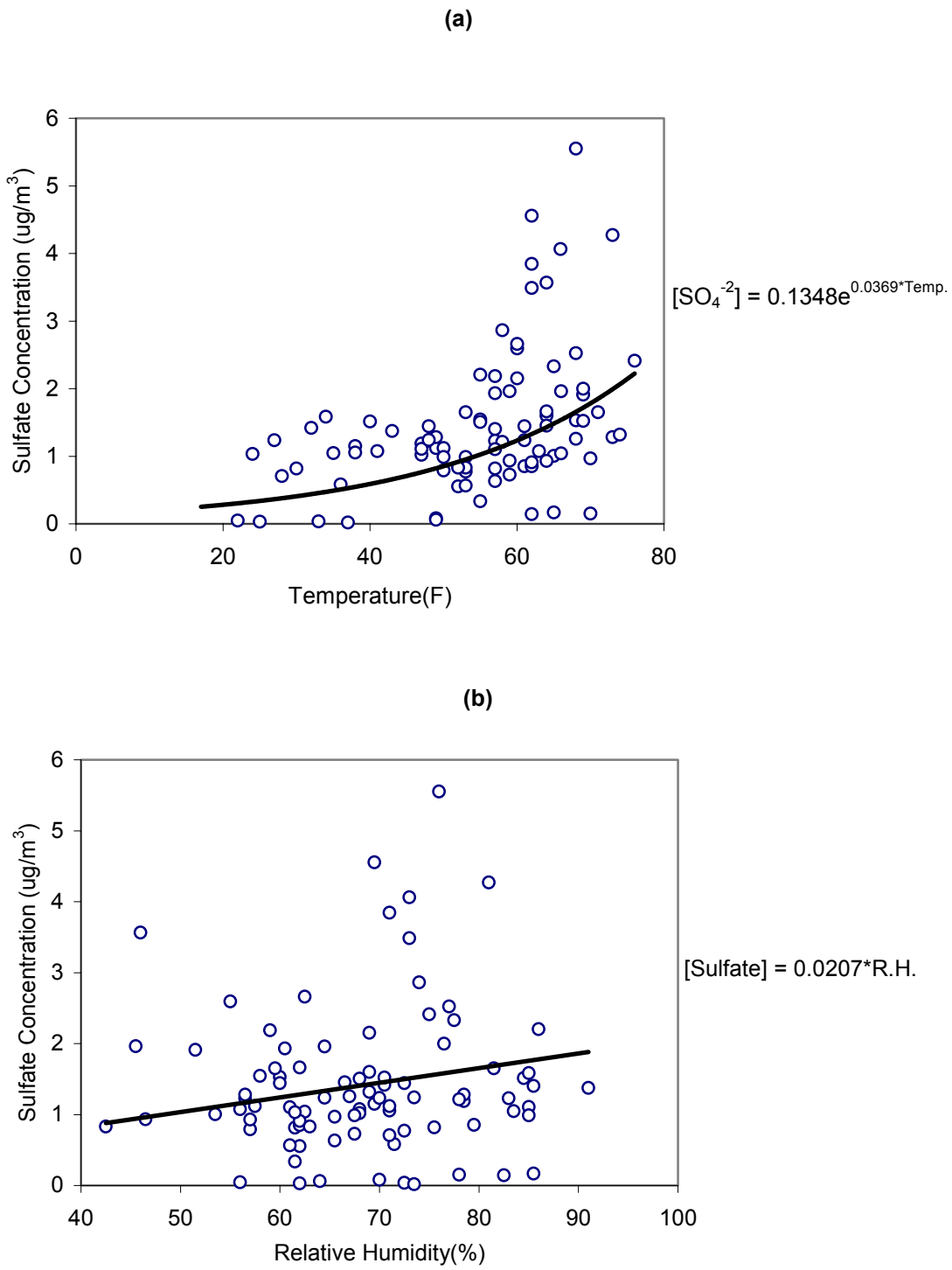


Figure II.2.31. Correlations between Sulfate and weather at New Albany in 1999: (a) sulfate vs. temperature and (b) sulfate vs. relative humidity

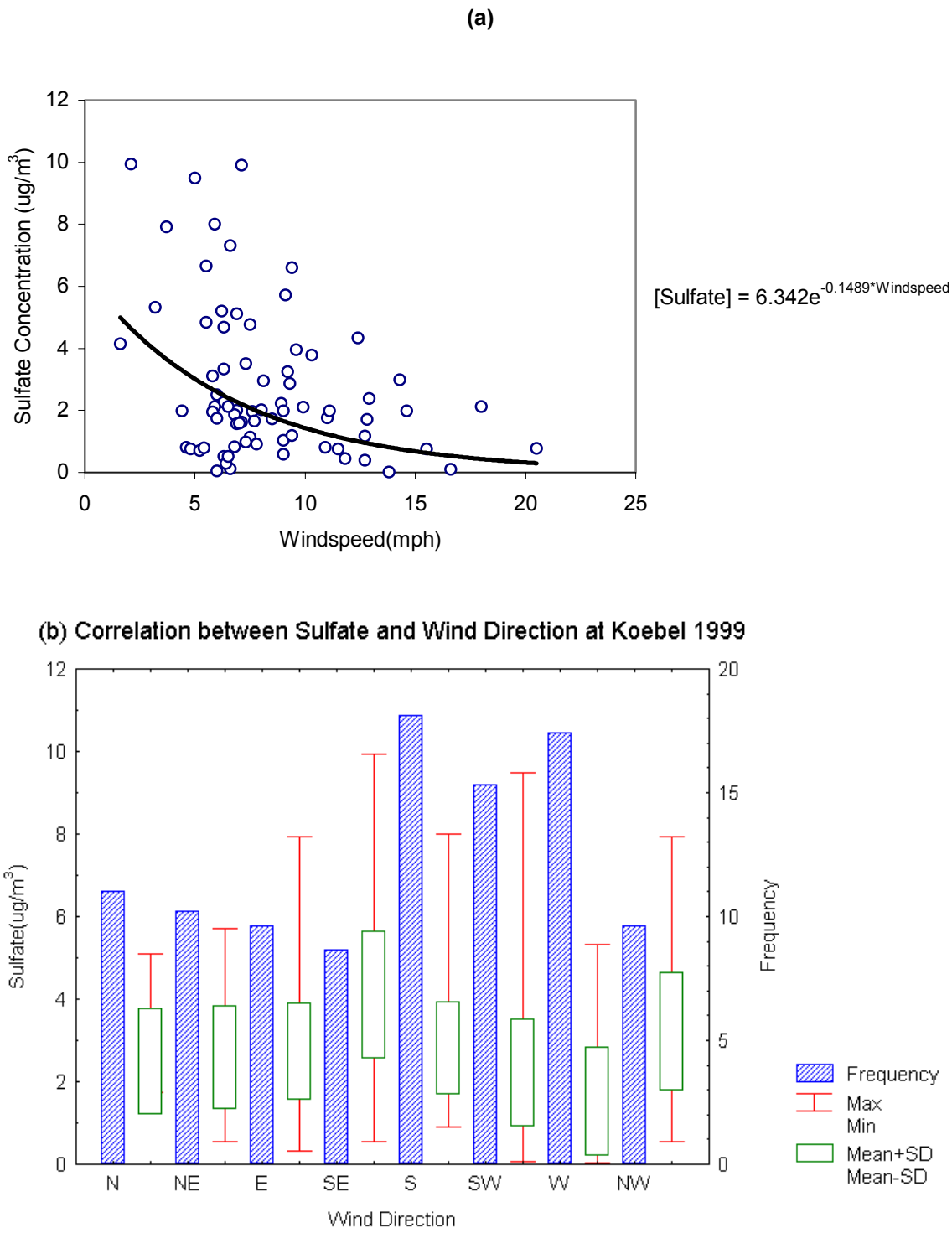
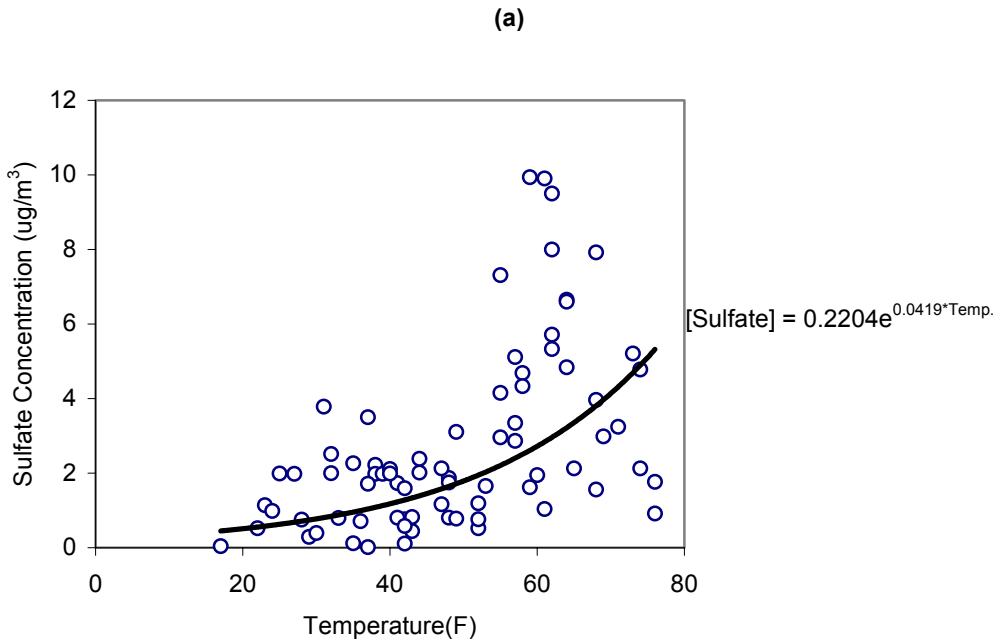


Figure II.2.32. Correlations between sulfate and weather at Koebel in 1999: (a) sulfate vs. wind speed and (b) sulfate vs. wind direction



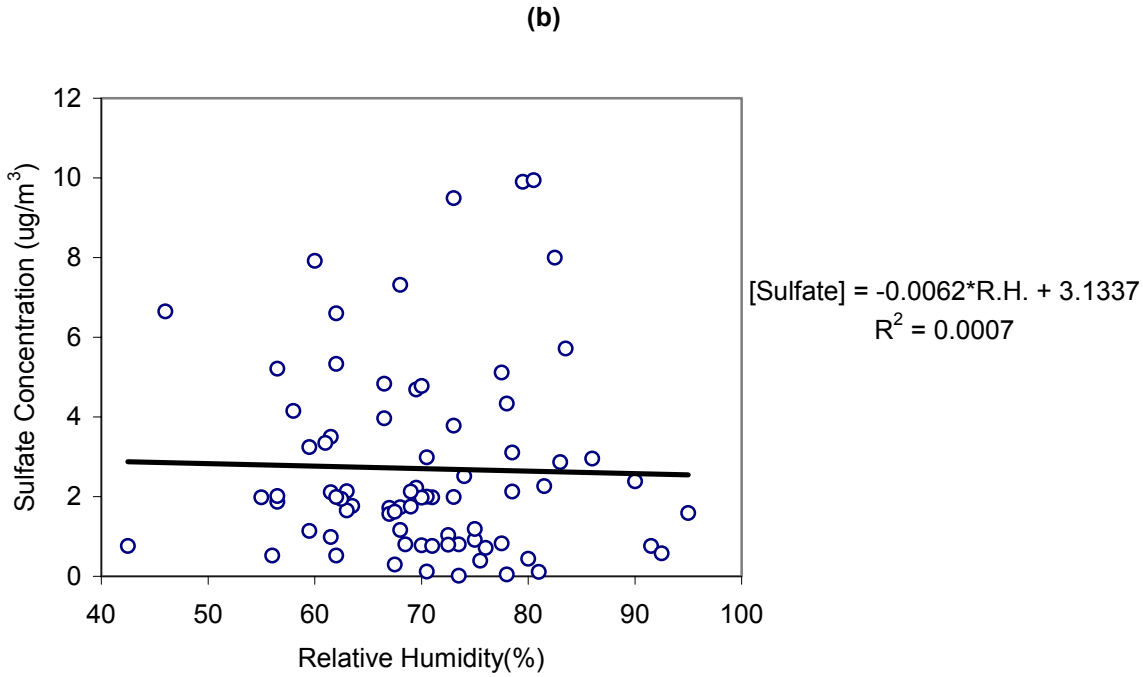


Figure II.2.33. Correlations between sulfate and weather at Koebel in 1999: (a) sulfate vs. temperature and (b) sulfate vs. relative humidity

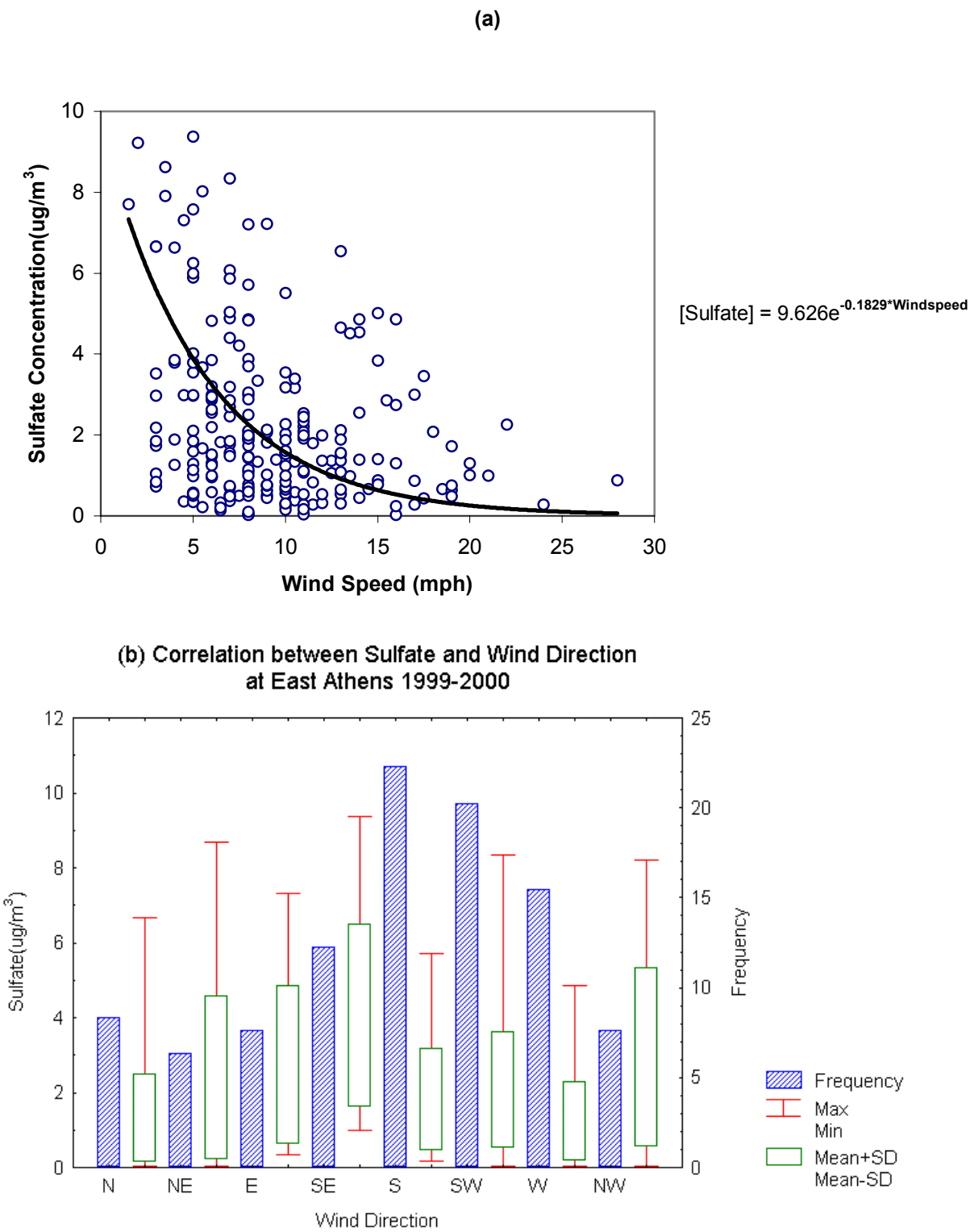
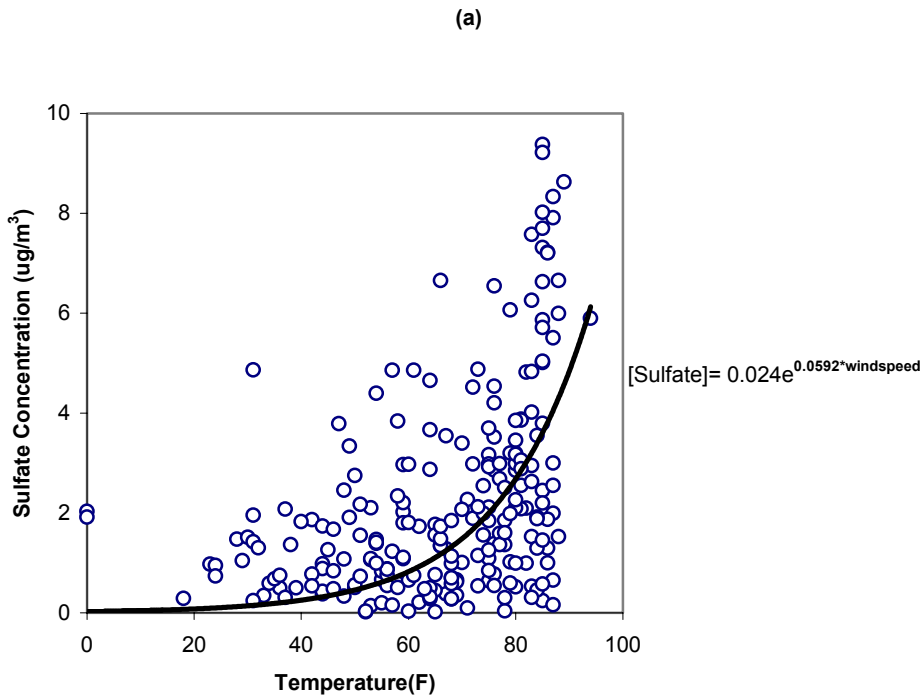


Figure II.2.34. Correlations between sulfate and weather at Athens in 1999-2000: (a) sulfate vs. wind speed and (b) sulfate vs. wind direction



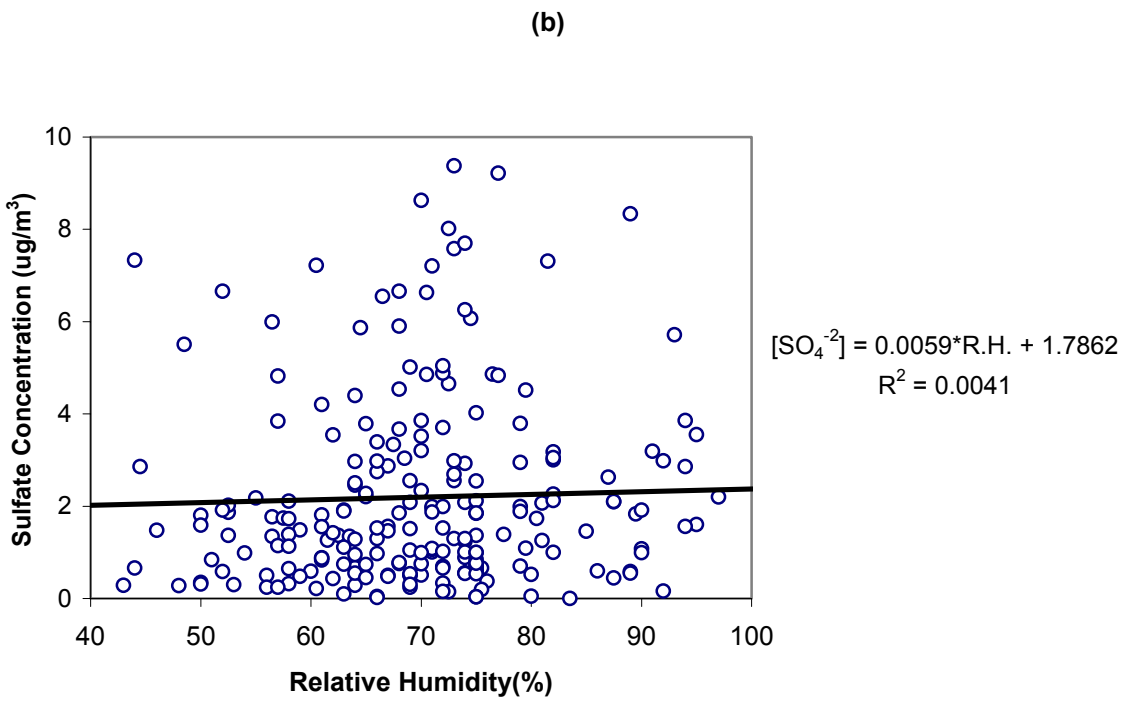


Figure II.2.35. Correlations between sulfate and weather at Athens in 1999: (c) sulfate vs. temperature and (d) sulfate vs. relative humidity

INDOOR ANALYSIS

The results of indoor analysis are assembled and presented here in the same order as the ambient outdoor results. The data tables provide $PM_{2.5}$ mass and chemical composition measurements. The results are validated and spatial variations of the $PM_{2.5}$ concentrations and temporal variations of $PM_{2.5}$ sulfate concentrations are discussed.

$PM_{2.5}$ Mass and Chemical Composition Data Summary

Tables II.2.8 to II.2.10 depict the $PM_{2.5}$ mass and chemical composition data summary for the three indoor sites from February 1999 to August 2000. The average $PM_{2.5}$ concentrations considered here are the arithmetic averages of the filter mass collected at each site during the period of study.

Similar to the results of ambient outdoor analysis, sulfate ion was found to be the greatest component present in the indoor filter samples. The average sulfate concentrations were highest at Koebel and lowest at New Albany. Other important components present in the samples were silicon, chlorine ion, and sodium ion. The concentrations of these components varied from site to site. Compared to concentrations at outdoor sites, very low or no concentrations of phosphates were found.

Table II.2.4. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Athens (February 1999-August 2000)

Species ($\mu g/m^3$)	Average	Standard Deviation	Median	Range	
				Minimum	Maximum
$PM_{2.5}$ Mass	17.20	13.56	12.28	0.45	71.57
Si	0.4237	0.3982	0.3113	0.0056	2.0793
P	0.0045	0.0068	0.0013	0.0001	0.0311
S	0.6840	1.0651	0.3050	0.0076	10.4034
Cl	0.0434	0.0695	0.0208	0.0002	0.5698
K	0.0288	0.0448	0.0139	0.0015	0.2473
Ca	0.1827	0.3034	0.0745	0.0009	2.6217
Ti	0.0122	0.0174	0.0059	0.0001	0.1420
V	0.0045	0.0057	0.0024	0.0003	0.0419
Cr	0.0049	0.0083	0.0015	0.0001	0.0375
Mn	0.0046	0.0068	0.0023	0.0001	0.0557
Fe	0.0843	0.1443	0.0329	0.0001	1.4240
Co	0.0022	0.0026	0.0013	0.0000	0.0140
Ni	0.0057	0.0128	0.0004	0.0000	0.0535
Cu	0.0041	0.0081	0.0015	0.0000	0.0667
Zn	0.0095	0.0152	0.0048	0.0000	0.1558
As	0.0128	0.0232	0.0028	0.0003	0.1223
Cd	0.0053	0.0190	0.0002	0.0000	0.1379
Sn	0.0037	0.0070	0.0007	0.0001	0.0397
Li^+	0.0351	0.0482	0.0037	0.0001	0.1047
Na^+	0.5664	0.7126	0.2975	0.0159	4.7524
$NH4^+$	0.7834	0.6504	0.6793	0.0024	3.8057
K^+	0.1302	0.1181	0.0940	0.0040	0.5535
Mg^{+2}	0.1551	0.2601	0.0450	0.0101	1.0034
Ca^{+2}	0.3068	0.4422	0.0633	0.0007	2.9486
F^-	0.1836	0.1111	0.1318	0.0138	0.3867
Cl^-	0.4237	0.7091	0.1689	0.0118	3.5760
NO^{3-}	0.4594	0.6223	0.1599	0.0249	2.8292
PO_4^{-3}	-	-	-	-	-
SO_4^{-2}	2.3260	2.1373	1.5875	0.0761	11.1147
Sum of Species	6.8907	7.9695	4.0141	0.1768	49.3184
Unidentified	9.2942	4.7509	7.7098	0.8287	17.0025

Table II.2.5. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at New Albany (February 1999-August 2000)

Species ($\mu g/m^3$)	Average	Standard Deviation	Median	Range	
				Minimum	Maximum
$PM_{2.5}$ Mass	16.52	13.53	11.56	0.24	69.51
Si	0.3016	0.2165	0.2635	0.0013	0.9989
P	0.0083	0.0169	0.0020	0.0000	0.0881
S	0.6186	1.0972	0.1908	0.0009	7.1519
Cl	0.0362	0.0451	0.0215	0.0000	0.2367
K	0.0187	0.0347	0.0068	0.0001	0.2011
Ca	0.1484	0.1908	0.0799	0.0000	1.1637
Ti	0.0080	0.0109	0.0038	0.0000	0.0614
V	0.0036	0.0036	0.0024	0.0001	0.0199
Cr	0.0011	0.0011	0.0008	0.0000	0.0045
Mn	0.0042	0.0095	0.0013	0.0000	0.0632
Fe	0.0556	0.0732	0.0257	0.0001	0.4207
Co	0.0028	0.0052	0.0009	0.0000	0.0275
Ni	0.0031	0.0065	0.0006	0.0000	0.0302
Cu	0.0051	0.0096	0.0016	0.0000	0.0564
Zn	0.0075	0.0136	0.0025	0.0000	0.1108
As	0.0139	0.0266	0.0020	0.0001	0.1127
Cd	0.0003	0.0005	0.0001	0.0000	0.0028
Sn	0.0060	0.0105	0.0010	0.0000	0.0382
Li^+	0.0010	0.0005	0.0009	0.0001	0.0035
Na^+	0.3299	0.4721	0.1597	0.0072	3.3339
$NH4^+$	0.7067	0.5624	0.7085	0.0002	2.7191
K^+	0.3594	0.7186	0.1107	0.0018	4.5500
Mg^{+2}	0.0471	0.0310	0.0355	0.0077	0.1554
Ca^{+2}	0.3655	0.5549	0.0880	0.0009	2.8095
F^-	0.1245	0.0737	0.1103	0.0176	0.3042
Cl^-	0.2522	0.4167	0.1251	0.0005	4.3577
NO^{3-}	0.4817	0.5089	0.2553	0.0242	4.2353
PO_4^{-3}	-	-	-	-	-
SO_4^{-2}	1.9735	2.5875	1.1675	0.0649	16.5942
Sum of Species	5.8844	7.6984	3.3687	0.1280	49.8513
Unidentified	11.4110	6.5307	8.3718	0.1120	19.6551

Table II.2.6. Statistical summary of $PM_{2.5}$ mass and its chemical compositions at Koebel (February 1999-August 2000)

Species ($\mu g/m^3$)	Average	Standard Deviation	Median	Range	
				Minimum	Maximum
$PM_{2.5}$ Mass	14.98	12.30	10.55	1.05	68.37
Si	0.2430	0.1822	0.1927	0.0099	0.9120
P	0.0161	0.0237	0.0047	0.0001	0.1043
S	0.6314	0.9926	0.2743	0.0044	8.3289
Cl	0.0407	0.0843	0.0188	0.0000	1.0251
K	0.0838	0.1707	0.0106	0.0002	0.8871
Ca	0.1264	0.2367	0.0567	0.0009	2.1264
Ti	0.0082	0.0233	0.0032	0.0001	0.2560
V	0.0030	0.0057	0.0016	0.0003	0.0431
Cr	0.0121	0.0184	0.0065	0.0002	0.1151
Mn	0.0042	0.0076	0.0013	0.0001	0.0477
Fe	0.0465	0.1019	0.0202	0.0005	1.1142
Co	0.0025	0.0038	0.0009	0.0000	0.0170
Ni	0.0054	0.0090	0.0013	0.0000	0.0431
Cu	0.0032	0.0059	0.0008	0.0001	0.0382
Zn	0.0067	0.0173	0.0038	0.0000	0.2421
As	0.0050	0.0087	0.0015	0.0000	0.0480
Cd	0.0005	0.0011	0.0001	0.0000	0.0067
Sn	0.0138	0.0253	0.0034	0.0000	0.1208
Li^+	0.0054	0.0132	0.0035	0.0001	0.0576
Na^+	0.6358	1.1494	0.2176	0.0126	7.7851
$NH4^+$	0.6819	0.5772	0.6878	0.0008	2.7389
K^+	0.4823	1.2061	0.1018	0.0002	7.1066
Mg^{+2}	0.0890	0.1603	0.0271	0.0055	1.0088
Ca^{+2}	0.3701	0.5113	0.1403	0.0049	4.2503
F^-	0.3094	0.5963	0.2431	0.1183	4.6465
Cl^-	0.5002	1.0616	0.1372	0.0267	6.5299
NO^{3-}	0.7232	0.6995	0.3732	0.0282	3.9965
PO_4^{-3}	0.3235	-	0.3235	0.3235	0.3235
SO_4^{-2}	2.3522	3.1596	1.3140	0.0418	24.5160
Sum of Species	7.7258	11.0526	4.1715	0.5797	78.4355
Unidentified	7.8318	2.0887	6.6805	0.4726	-10.0267

Data Validation

Similar to the outdoor data validation, the indoor data validation was conducted for (1) sum of chemical species versus $PM_{2.5}$ mass concentrations, and (2) sulfate versus total sulfur, and (3) anion and cation balance.

Sum of Chemical Species Versus $PM_{2.5}$ Mass Concentrations

Measured and monitored mass data were compared by plotting the scatter graphs for the sum of species against mass concentrations shown in Figures II.2.36 to II.2.38. The relationship between these two parameters was examined by plotting the mass concentration (independent variable X) against the sum of species (dependent Y).

Many of the species remain unidentified in the chemical analysis; hence, the sum of the species should always be less than or equal to the gravimetrically measured mass.[25] In order to avoid double count, total sulfur (S), soluble potassium (K^+) and chloride (Cl^-) were excluded from the sum of species.

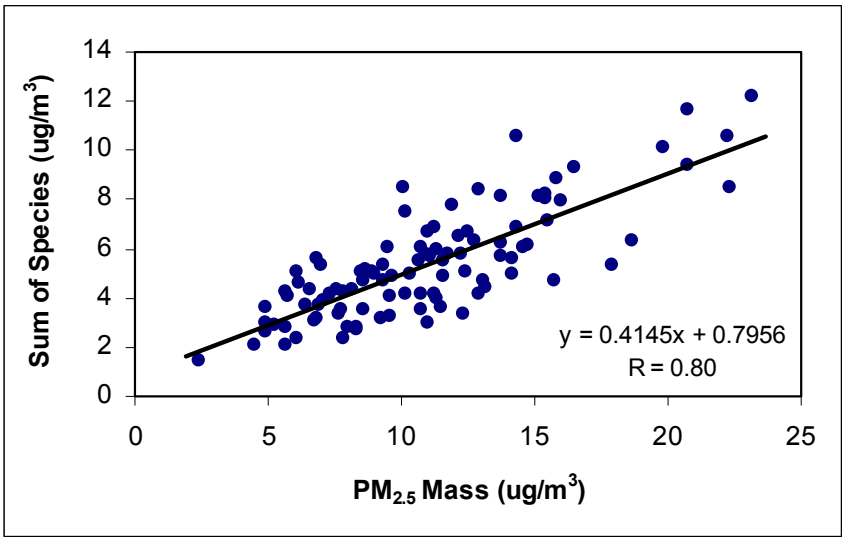


Figure II.2.36. Scatter plot of sum of species versus mass concentrations at Athens indoor samples (May-August 2000)

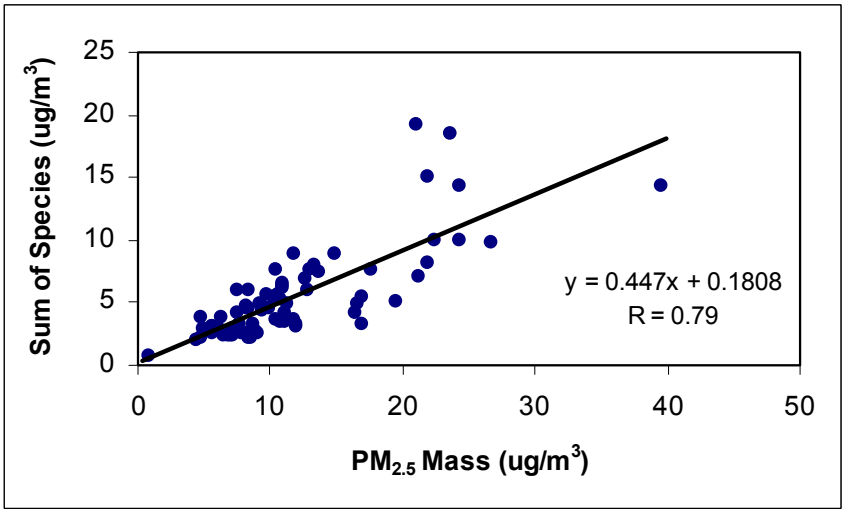


Figure II.2.37. Scatter plot of sum of species versus mass concentrations at New Albany indoor samples for May to August 2000

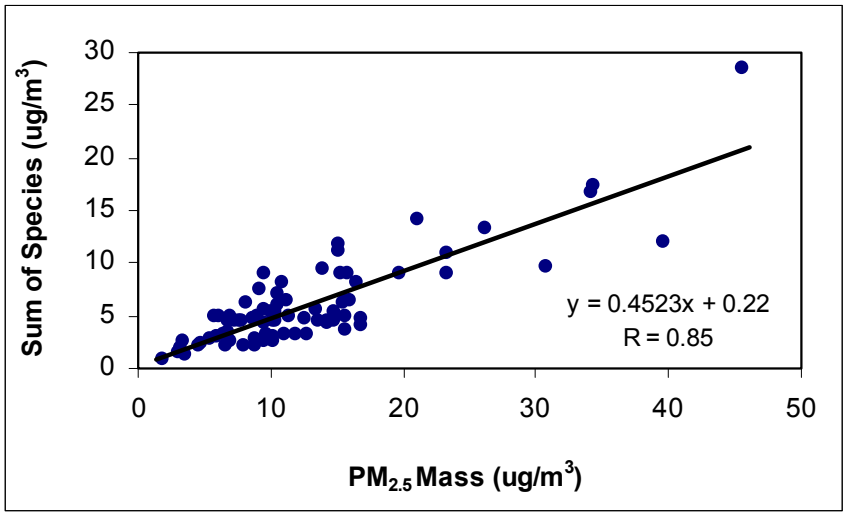


Figure II.2.38. Scatter plot of sum of species versus mass concentrations at Koebel indoor samples for May to August 2000

As the previous figures show, there is a relationship between the measured mass concentration and the sum of chemically analyzed species. Also, it is clear that the sum of species is always less than the gravimetrically measured $PM_{2.5}$ mass concentrations.

Sulfate versus Total Sulfur

Sulfate (SO_4^{-2}) ion concentration was obtained by ion chromatography (IC) analysis and the total sulfur (S) concentration was obtained from x-ray fluorescence (XRF) analysis on Teflon-membrane filters. Figures II.2.39 to II.2.41 are scatter plots of sulfate versus sulfur of the $PM_{2.5}$ measurements.

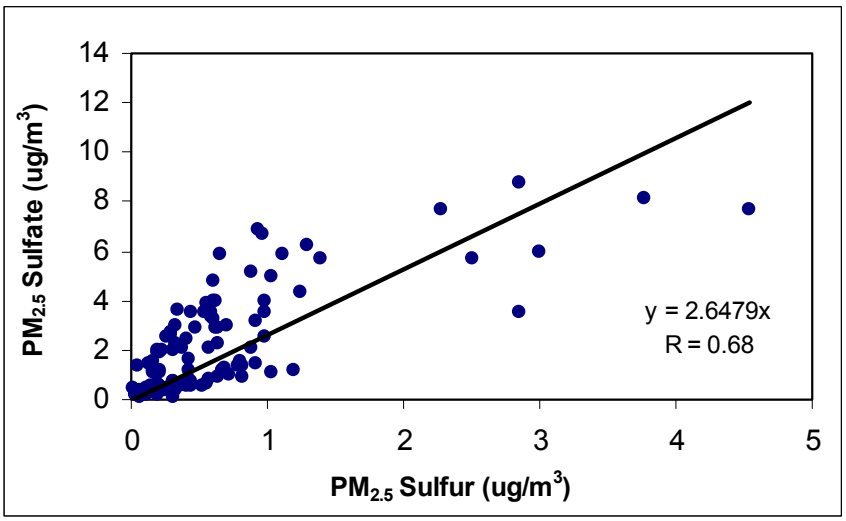


Figure II.2.39. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Athens indoor samples (May to August 2000)

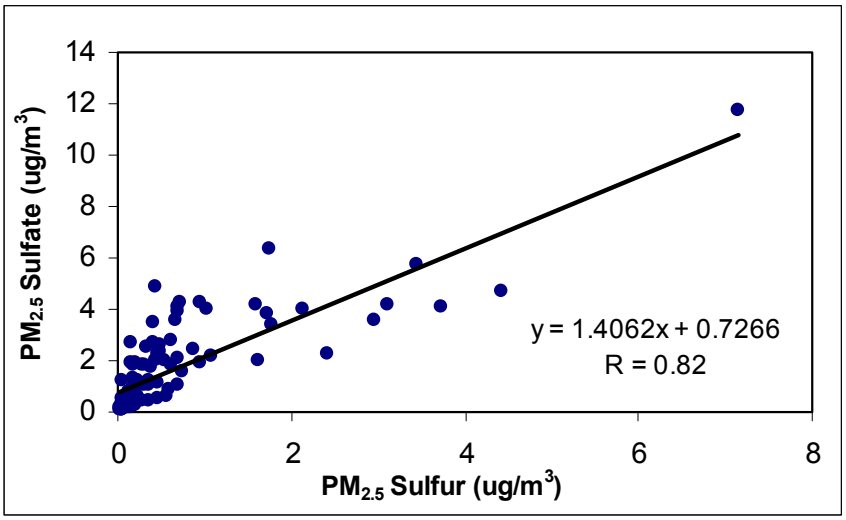


Figure II.2.40. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for New Albany indoor samples (May to August 2000)

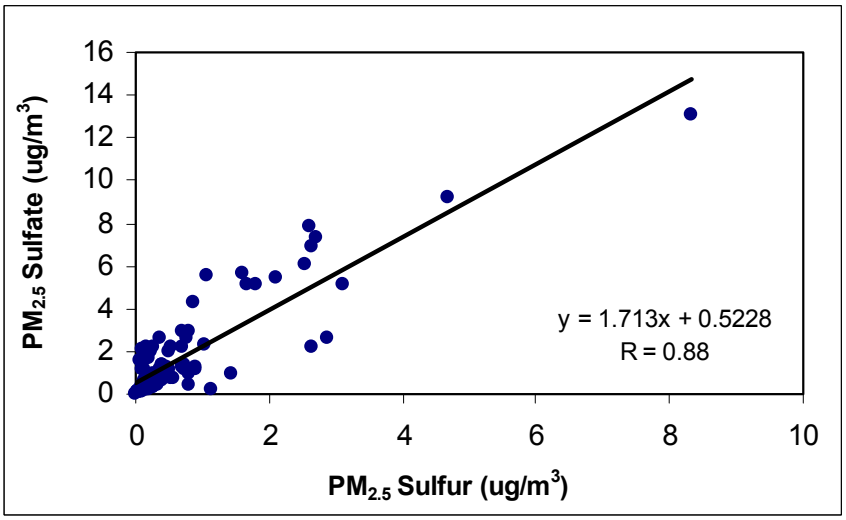


Figure II.2.41. Scatter plot of sulfate (SO_4^{-2}) versus total sulfur (S) for Koebel indoor samples (May to August 2000)

A strong correlation (R = 0.68, 0.82, 0.88 for Athens, New Albany and Koebel respectively) were found for these measurements, which indicates that the majority of the $PM_{2.5}$ sulfur was present as sulfate.[26]

Anion and Cation balance

Ion chromatography was used to determine the concentrations of various ions present in the filter samples. Samples were analyzed for cations, lithium, sodium, ammonium, potassium, magnesium and calcium and anions, fluoride, chloride, nitrate, phosphate and sulfate. The anion and cation concentration of the $PM_{2.5}$ indoor samples were obtained and correlated.

The regression plots used for anion and cation balance, shown below in Figures II.2.42 to II.2.44, clearly show that these ionic measurements are highly correlated, with the regression coefficients of 0.69, 0.83, 0.80 for Athens, New Albany and Koebel indoor sites, respectively.

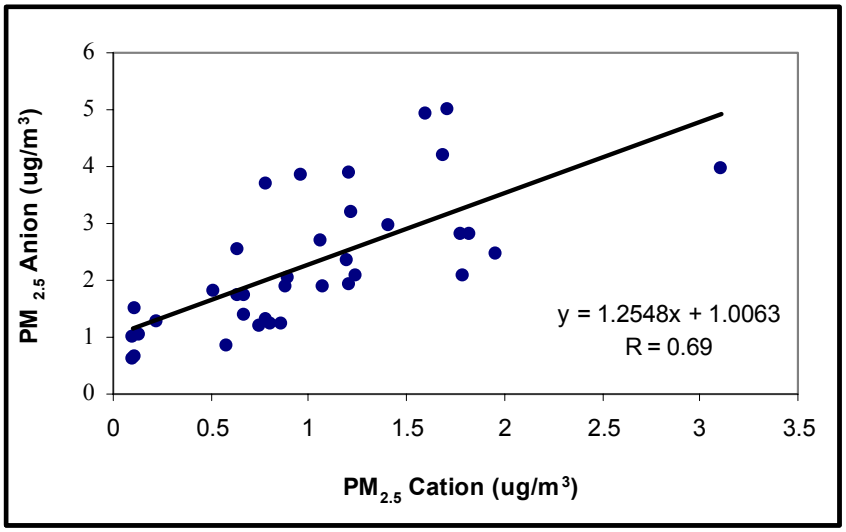


Figure II.2.42. Scatter plot of cation and anion balance for Athens indoor samples (May to August 2000)

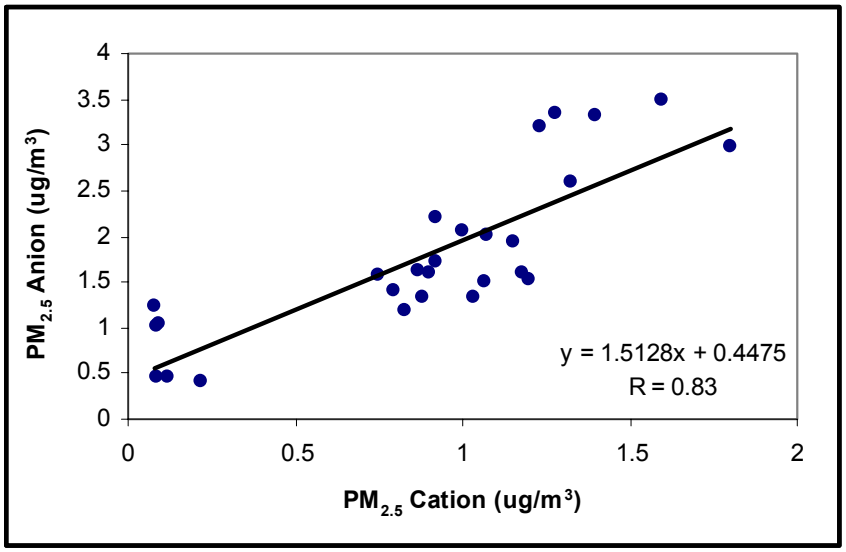


Figure II.2.43. Scatter plot of cation and anion balance for New Albany indoor samples (May to August 2000)

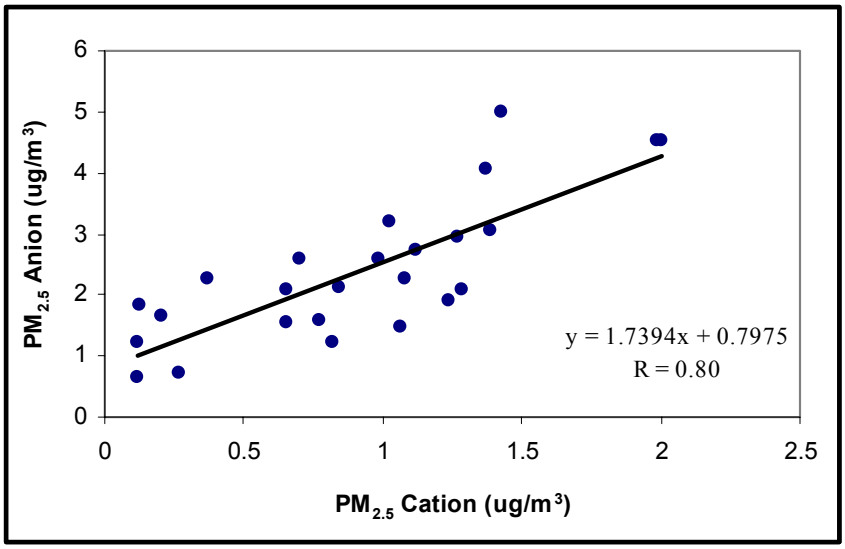


Figure II.2.44. Scatter plot of cation and anion balance for Koebel indoor samples (May to August 2000)

Results and Discussion

$PM_{2.5}$ Chemical Species Concentration

The indoor filter samples collected from February 1999–August 2000 at the three monitoring sites in Ohio were analyzed with the ion chromatography and X-ray fluorescence techniques. Daily values of each of the components were obtained at all the sites. The results were statistically analyzed using Statistica software and box plots were obtained. The box plots show the median value along with the minimum and maximum concentrations for each of the components (Figures II.2.45 to II.2.247).

Concentrations of Cl^-, NO_3^-, SO_4^{-2}, PO_4^{-3}, Li^+, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}, Si, P, S, Cl, K, Ca, Ti, V, Cr, Co, Ni, Mn, Fe, Cu, Zn, As, Cd and Sn are shown in Figure II.2.45. They were determined for each site and then compared. The results show that sulfates are the major component present in all of the $PM_{2.5}$ samples. Other abundant components included nitrate ion, ammonium ion, and silicon. High concentrations of silica were found in the indoor samples compared to the outdoor samples. Significant levels of sodium, chloride and potassium were found in the rural (Athens) samples as compared to the urban (Koebel) samples. The concentrations of each of these components varied from site to site during the period of February 1999 to August 2000.

The anion and cation average concentrations generally followed the pattern $SO_4^{-2} > NO_3 > Cl^-$ and $Na^+ > NH_4^+ > Ca^{+2} > K^+ > Mg^{+2}$. Heavy metals such as titanium, vanadium, manganese, iron, copper, and zinc were found in all the samples, and iron was the most abundant species.

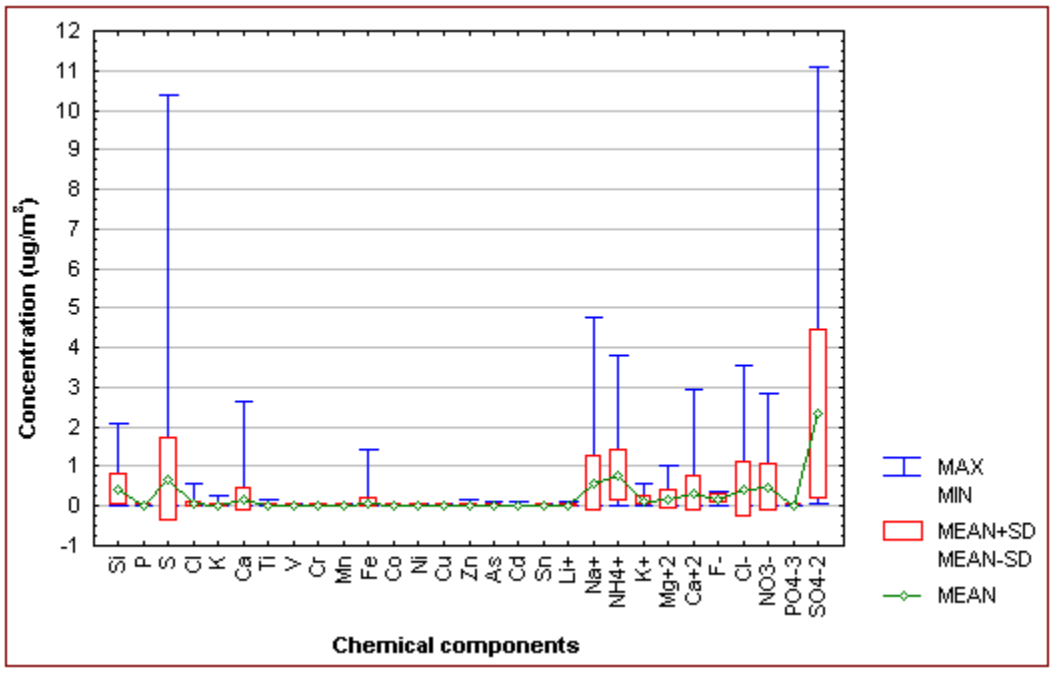


Figure II.2.45. Concentrations of the chemical components present in the indoor samples at Athens for February 1999 to August 2000

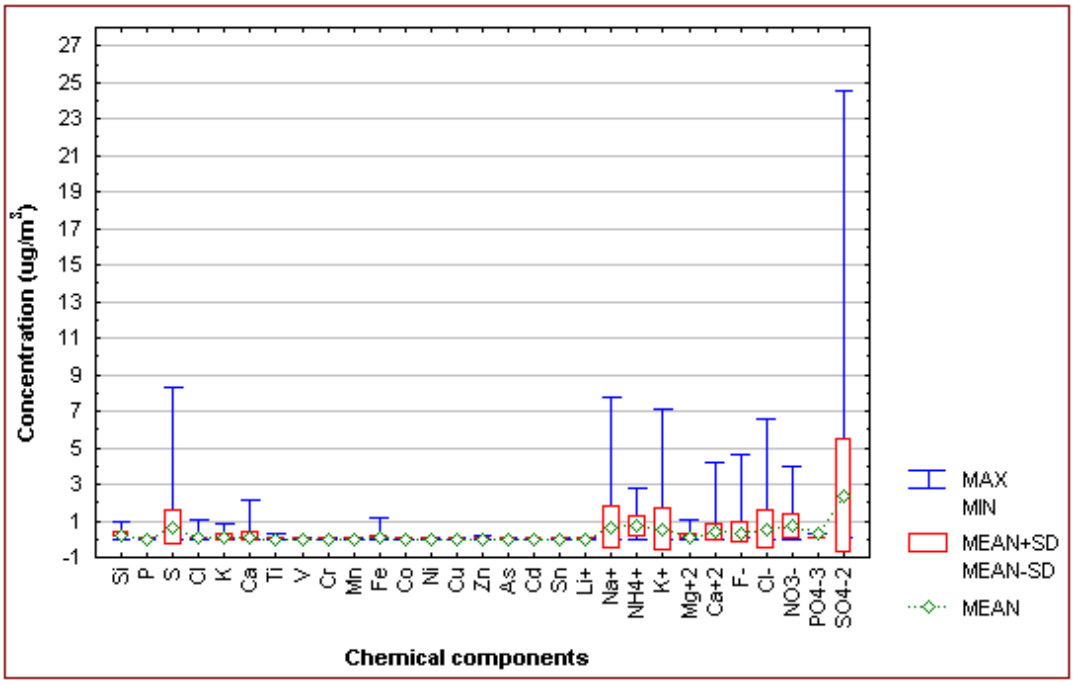


Figure II.2.46. Concentrations of the chemical components present in the indoor samples at New Albany for February 1999 to August 2000

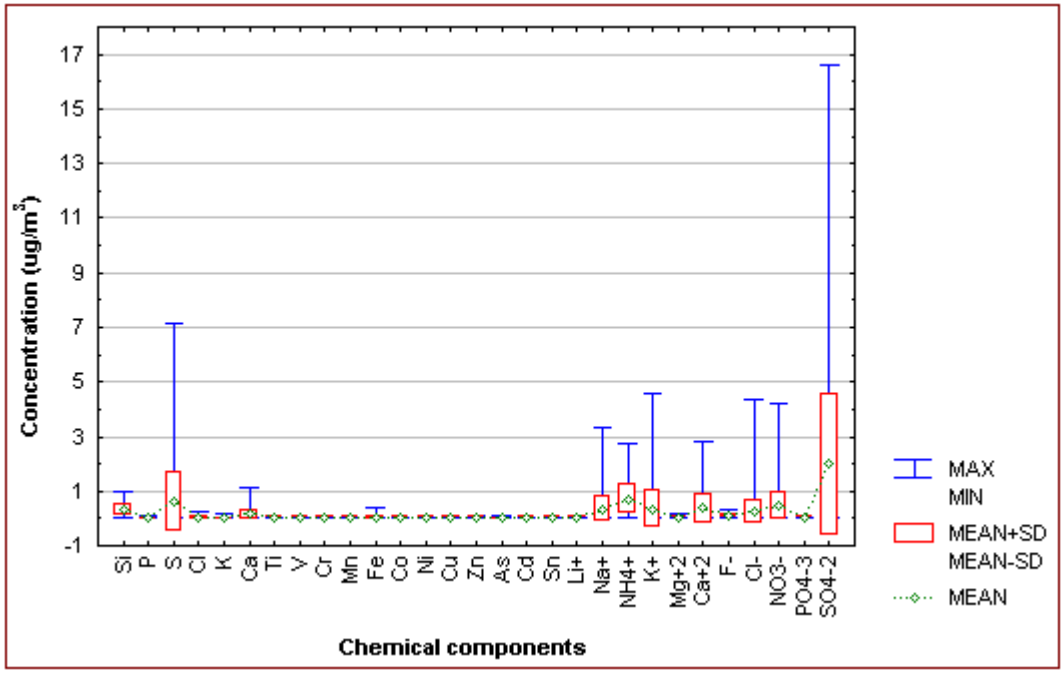


Figure II.2.47. Concentrations of the chemical components present in the indoor samples at Koebel for February 1999 to August 2000

Major Chemical Components of PM $_{2.5}$

Similar to the previous discussion about major components of outdoor $PM_{2.5}$ samples, the figures below show various chemical components of collected particulates for each site and are calculated using following equations.

1. Unidentified = measured mass – sum of 2,3,4,5,6 and 7
2. Soil = 1.62(Ca) + 2.42(Fe) + 1.94 (Ti) + 2.49 (Si)
3. Ammonium Sulfate = 1.37 (soluble sulfate)
4. Nitrate = 1.29 (soluble nitrate)
5. Phosphates = Phosphates
6. Salt = 1.65 (Cl), XRF
7. Trace elements = sum of XRF measured species – (Si + Ca + Fe + S + Cl + Ti)

It was assumed that all particulate sulfur is ammonium sulfate. Ammonium nitrate is the main form of secondary nitrates.

Figures II.2.48 to II.2.50 show that the soil concentration at all indoor sites was higher than the outdoor soil concentrations. The soil percentage ranged from 6 percent to 10 percent at the Koebel and the Athens indoor site, respectively. Sulfate concentration was highest at Koebel and ranged from 16 percent to 21 percent of the total particulate matter mass. There was little or no phosphate found at the indoor sites. Organic matter and elemental carbon were not analyzed as a part of this study.

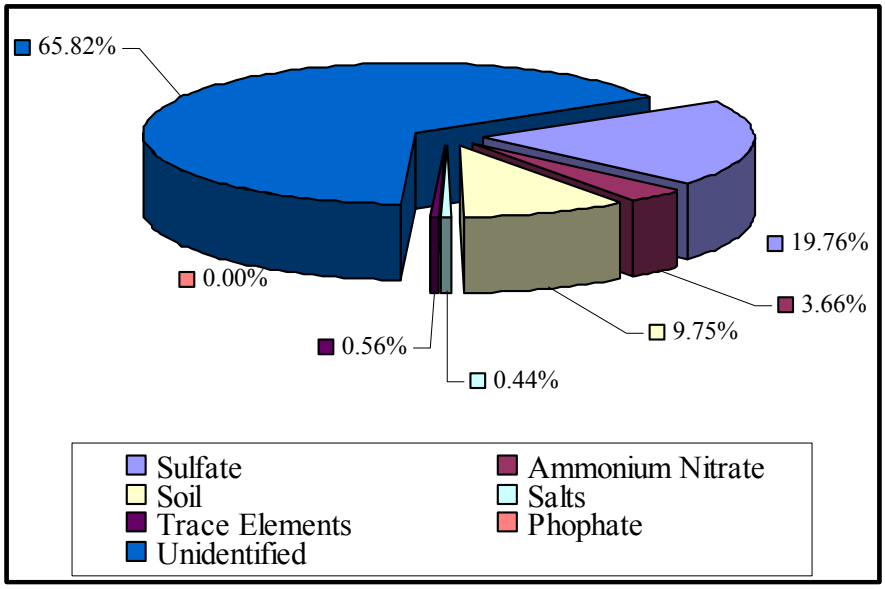


Figure II.2.48. Indoor $PM_{2.5}$ chemical composition for Athens during February 1999 – August 2000

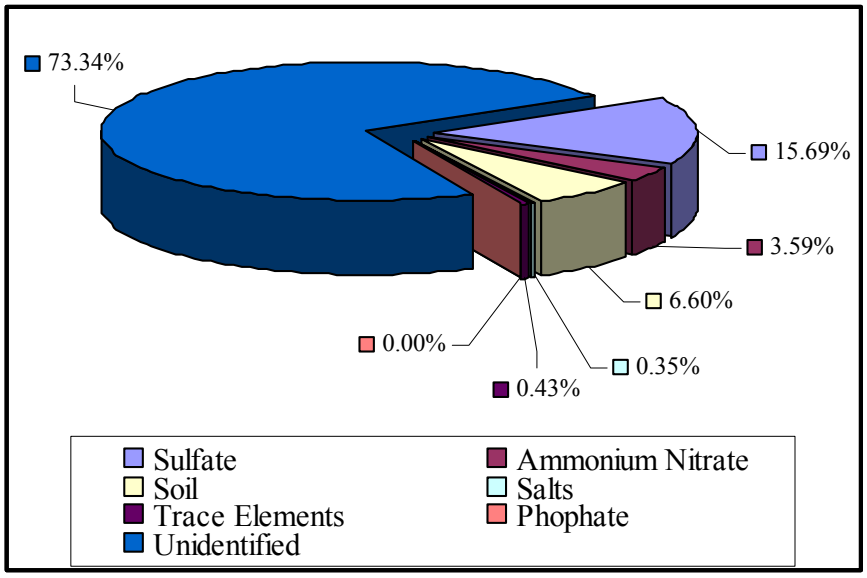


Figure II.2.49. Indoor $PM_{2.5}$ chemical composition for New Albany (February 1999–August 2000)

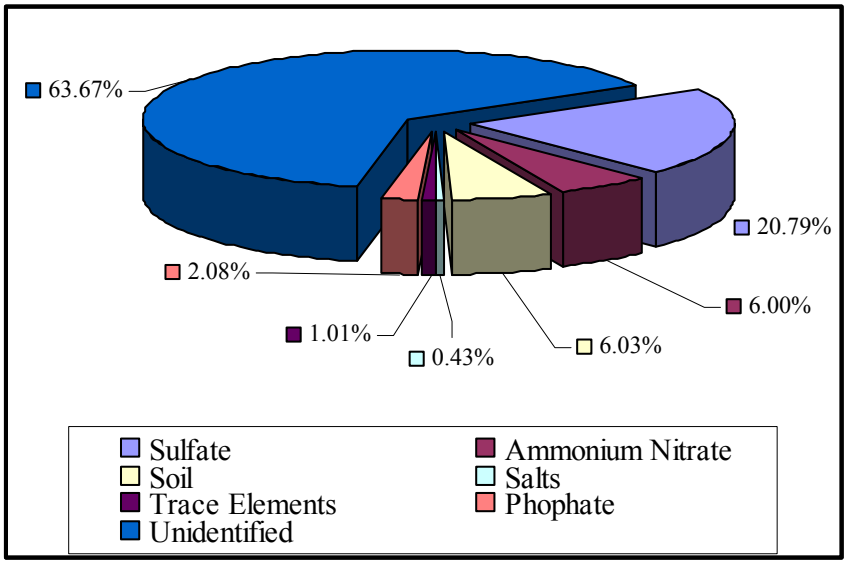


Figure II.2.50. Indoor $PM_{2.5}$ chemical composition for Koebel (February 1999–August 2000)

Monthly Variations in Sulfate Concentration

The values of sulfate and ammonium ion found from the analyzed samples give an insight into acidity of the fine particulate fraction. Investigators have generally assumed that sulfate is present in tropospheric aerosol particles as ammonium salts and sulfuric acid.[27] Figures II.2.51 to II.2.53 show the monthly sulfate ion variations for indoor sites during the period of study.

The figures show that the sulfate concentrations increased from the winter to summer at Athens. Koebel and New Albany also followed the same trend. Sulfate concentrations in general were higher in summer 1999 than the summer 2000. Indoor sites in general show a decrease in sulfate concentrations during period between months of October to March and high concentrations in summer. The average $PM_{2.5}$ sulfate concentration for Athens, Koebel and New Albany for the period of study were 2.32, 1.97, 2.35 $\mu g/m^3$, respectively. The average sulfate concentrations were highest at Koebel followed by Athens and with the lowest at New Albany.

The concentrations of water-soluble ions could be lower at Texas A&M University- Kingsville than the actual concentrations at the monitoring stations in Ohio due to the volatilization of the nitrates and sulfates from the Teflon filters.

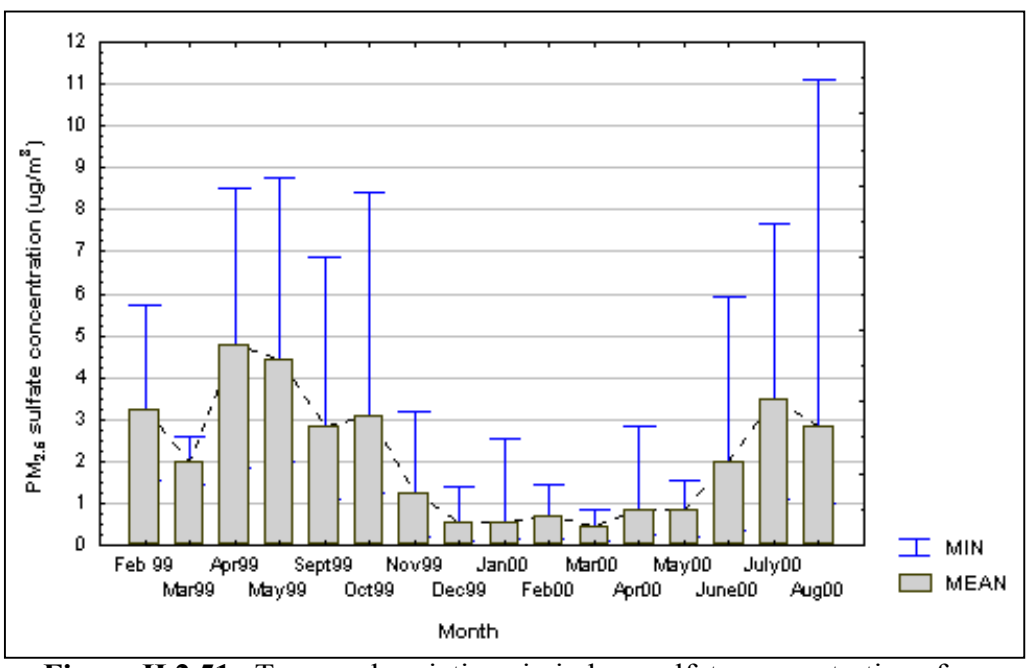


Figure II.2.51. Temporal variations in indoor sulfate concentrations for Athens samples from February 1999 to August 2000

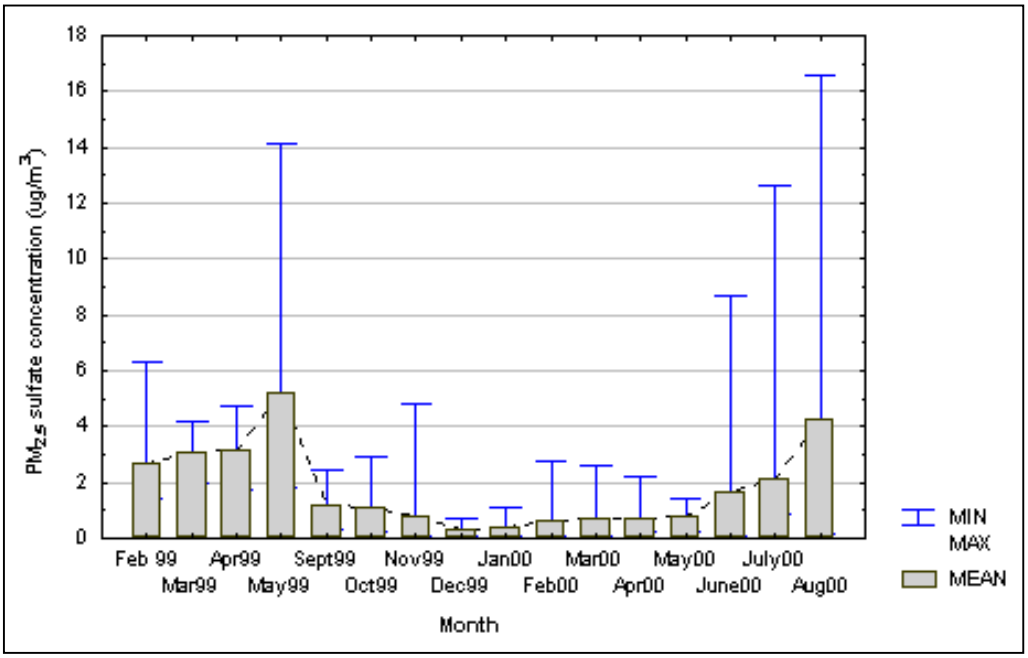


Figure II.2.52. Temporal variations in indoor sulfate concentrations for New Albany samples from February 1999 to August 2000

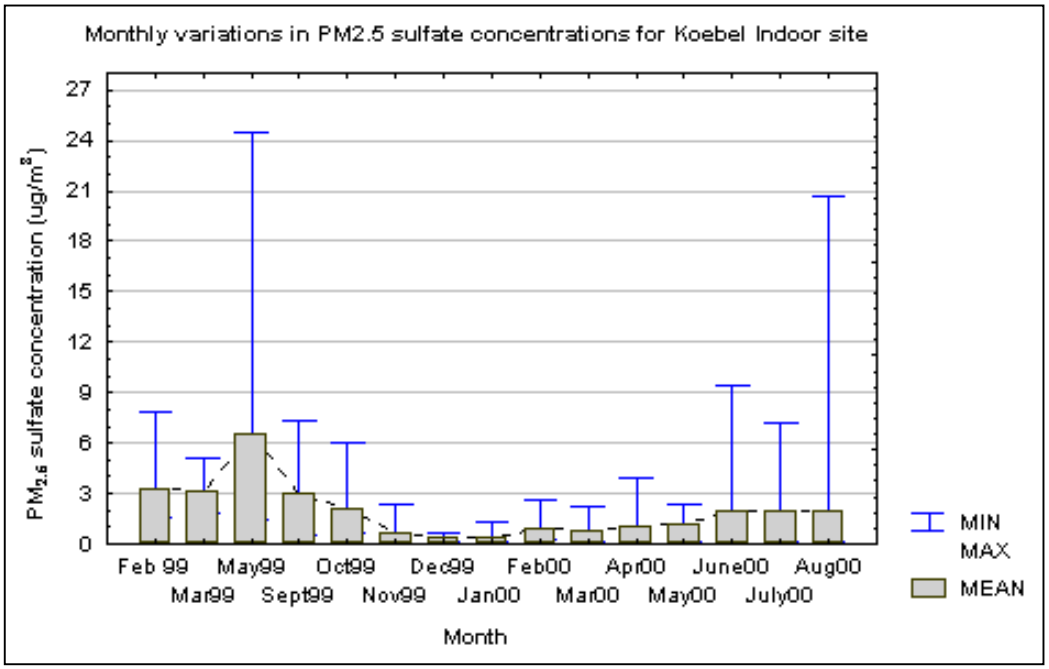


Figure II.2.53. Temporal variations in indoor sulfate concentrations for Koebel samples from February 1999 to August 2000

COMPARISON OF INDOOR AND OUTDOOR ANALYSIS

The results of the $PM_{2.5}$ monitoring and the outdoor and indoor analysis for each of the chemical components were statistically analyzed and the average, standard deviation, minimum and maximum values were determined using the Statistica software.

The box-whisker distribution of concentration for the parameters, ammonium, sulfate and nitrate for the entire period of study is shown in II.2.54 to II.2.56, respectively.

Figure II.2.54 shows the plot for ammonium ion concentration at the three sites in Ohio during the entire period of study. Ammonium ions are generally present in nature in the compound form as ammonium nitrate, ammonium chloride, and ammonium sulfate. The Athens indoor and the New Albany outdoor sites showed the highest average concentrations of ammonium ions during the period of this study.

Box-whisker plots for the anions as NO_3^- and SO_4^{-2} are shown in Figures II.2.55 and II.2.56. Figure II.2.55 represents nitrate ion distribution where the overall average concentration at the Athens outdoor and the Koebel indoor site was the highest. The main sources for increased levels of nitrate ion in the ambient air are from combustion sources. Figure II.2.57 shows sulfate ion variation among all the sites during the period of study. The average concentration was highest at the Athens indoor site and the average sulfate concentration for outdoor air was almost equal at all the three sites. The sources of sulfate ion concentration in $PM_{2.5}$ are mainly from SO_2 emissions from coal-fired plants, vehicular emissions and other combustion sources.

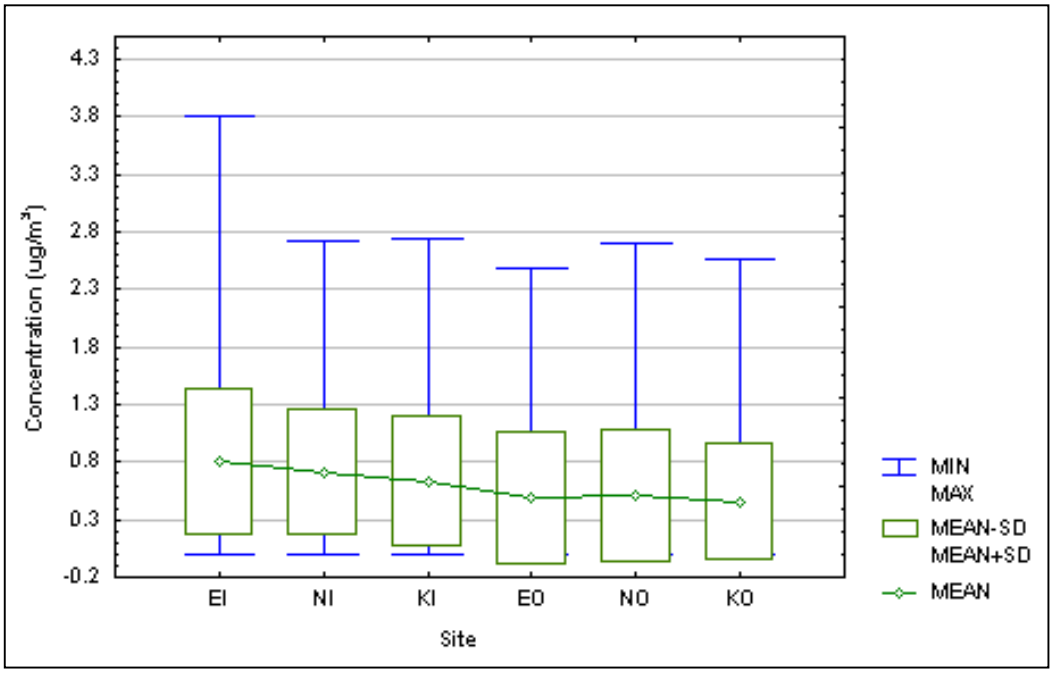


Figure II.2.54. Ammonium ion distribution in Ohio (Feb. 1999 – Aug. 2000)

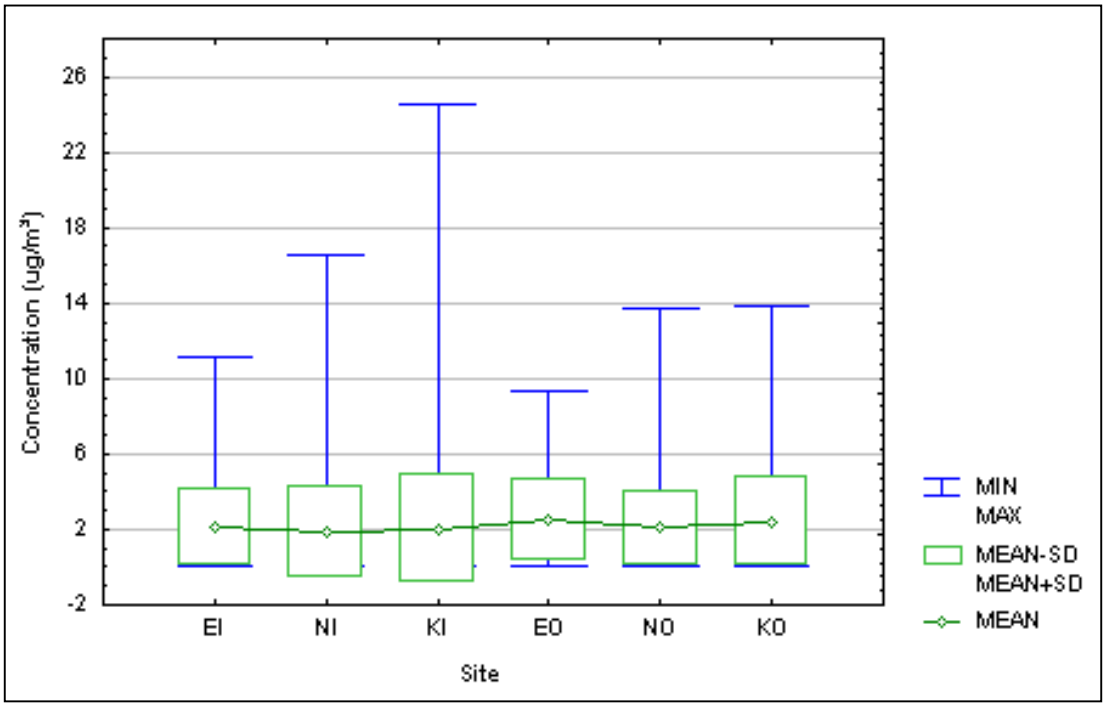


Figure II.2.55. Sulfate ion distribution in Ohio (Feb. 1999 – Aug. 2000)

* EO = Athens Outdoor; NO = New Albany Outdoor; KO = Koebel Outdoor; EI = Athens Indoor; NI = New Albany Indoor; and KI = Koebel Indoor.

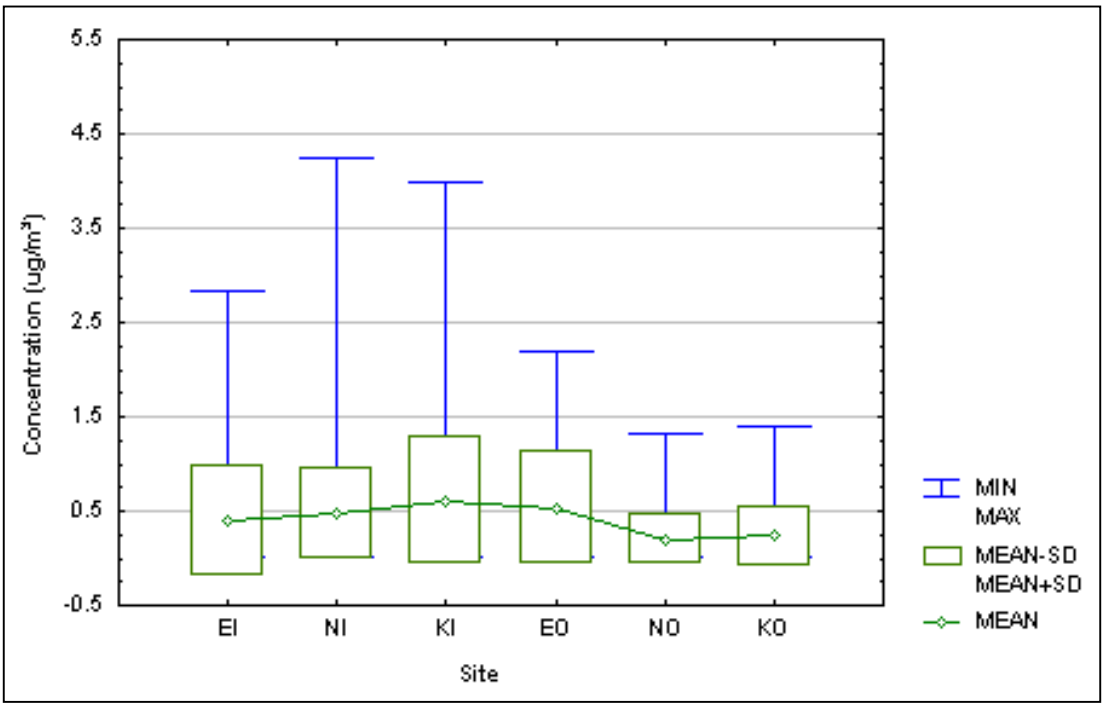


Figure II.2.56. Nitrate ion distribution in Ohio (Feb. 1999 – Aug. 2000)

SUMMARY

The monitoring of fine particulate matter was carried out at three elementary schools (Koebel, New Albany and Athens) typifying an urban, suburban and rural location in Ohio from February 1999 through August 2000. Indoor and outdoor air samples were collected at each site.

On an average, 35 percent of the total particulate ($PM_{2.5}$) mass was successfully analyzed at the indoor and outdoor sites. The components determined by the chemical analysis included: F^-, Cl^-, NO_3^-, SO_4^{-2}, PO_4^{-3}, Li^+, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}, Si, P, S, Cl, K, Ca, Ti, Co, Ni, V, Cr, Mn, Fe, Cu, Zn, As and Cd. The greatest percentage in the samples was sulfate. Other abundant components included phosphate, nitrate, ammonium, chloride, sodium, calcium, silicon, and iron. Soil concentrations at the indoor sites were found to be higher compared to the outdoor sites soil concentrations. The soil percentage ranged from 7 percent to 10 percent at the New Albany and the Athens indoor site respectively.

Correlation analysis between $PM_{2.5}$ and weather components showed that the $PM_{2.5}$ concentrations tended to increase with rising temperatures, and decreased with increasing wind speeds. In general, $PM_{2.5}$ concentration was

highest when the winds were blowing from the south and the southeast direction at all three three sites.

NOTES

1. Spurny, K. R. 2000 and D. Hochrainer, eds. 2000. *Aerosol Chemical Processes in the Environment*. Boca Raton, FL: Lewis Publishers.

2. Painuly P. 2001. *An Evaluation of Fine Particulate Matter in Ohio: Chemical and Transport Characteristics,* Master's thesis, Texas A&M University-Kingsville; Arya, S.P. 1999. *Air Pollution Meteorology and Dispersión*. New York: Oxford University Press.

3. Alvarado M. 2000. *Chemical Characterization of Fine Particulate Matter in Ohio*, Master's thesis, Texas A&M University-Kingsville.

4. Kevex Instruments, Inc, 1999. *Kevex 771-EDX Spectrometer User's Guide and Tutorial*.

5. Dionex Corp., 1996. *Introduction to the Dionex DX 500 Chromatography Systems*.

6. Tropp, R.J., S.D. Kohl, J.C. Chow, and C.A. Frazier. 1998. *Final Report for the Texas $PM_{2.5}$ Sampling and Analysis Study*. DRI Document No. 6570-685-7770.1F. Prepared for the City of Houston, Bureau of Air Quality Control, Houston, TX, by Desert Research Institute, Reno, NV, and TRC Environmental Corp., Chapel Hill, NC. December 15, 1998.

7. Ibid

8. Ibid

9. Ibid

10. Statistica Software, Version 5.1, StatSoft, 2300 East 14^4 Street, Tulsa, OK 74104

11. Malm, W. C., M. L. Pitchford, M. Scruggs, J. F. Sisler, R. Ames, S. Copeland, K. A. Gebhart, and D. E. Day. 2000. *Spatial and Seasonal patterns and temporal varabilty of haze and it's constituents in United States: Report III*. Fort Collins, CO: Cooperative Institute for Research in the Atmosphere.

12. Ibid

13. Tropp et al., *Final Report.*

14. Painuly, *An Evaluation of Fine Particulate Matter*; Hays, S.M., R. V.Gobbell, and N. R. Ganick. 1995. *Indoor Air Quality.* New York: McGraw-Hill; Air & Waste Management Association. 2002. *Indoor Air—A Fact Sheet for Homeowners.* [cited 5 November 2002]. Available from World Wide Web: <www.awma.org/resources/education/indoorair.htm >; Plog, B.A., J. Niland, and P. J. Quinlan. 1999. *Fundamentals of Industrial Hygiene*. Chicago, IL: National Safety Council; Environmental Protection Agency. 1997. *Revised Particulate Matter Standards.* [cited 5 November 2002]. Available from World Wide Web: <http://www.epa.gov/ttn/caaa/t1/fact_sheets/pmfact.pdf >; Iiabaca, M., I. Oleata, E. Campos, J. Villaire, M. Tellez-Rojo, and I. Romieu.1999. Association between Levels of Fine Particulate and Emergency Visits for Pneumonia and other Respiratory Illnesses among Children in Santiago, Chile. *J. Air & Waste Manage. Assoc.* 49: 154-163; National Energy Technology Laboratory: U.S. Department of Energy. 2001. *Ambient Monitoring Upper Ohio River Valley Project*. [cited 5 November 2002]. Available from World Wide Web: <www.netl.doe.gov/coalpower/environment/air_q/index.html>.

15. Alavarado, Chemical Characterization of Fine Particulate Matter.

16. TNRCC Web Page. [cited 5 November 2002]. Available from World Wide Web: http://www.tnrcc.state.tx.us/updated/air/monops/data/trajectories/maintraj.html /maintraj.html.

17. Dorling, S.R., T.D. Davies, and C.E. Pierce. 1992. Cluster analysis: a technique for estimating the synoptic meteorological controls on air and precipitation chemistry. *Atmospheric Environment.* 26A(14): 2583-2602.

18. Ibid.

19. Brankov, E., S.T. Rao, and P.S. Porter, P.S. 1999. Identifying pollution source regions using multiply censored data. *Environmental Science and Technology.* 33(13): 2273-2277.

20 Rao, S.T., E.B. Brankov, and P.S. Porter. 1998. A trajectory-clustering-correlation methodology for examining the long-range transport of air pollutants. *Atmospheric Environment*. 32(9), 1525-1534.

21. Draxler, R. R. 1996. *Trajectory Optimization for Balloon Flight Planning*. *Weather and Forecasting.* 11: 111-114.

22. Draxler, R.R. and G.D. Hess. 1997. *Description of the HYSPLIT4 Modeling System*. [cited 5 November 2002]. Available from World Wide Web: <http://www.arl.noaa.gov/data/models/hysplit4/win95/arl-224.pdf>.

23. Dorling et al., Cluster analysis.

24. Dorling et al., Cluster analysis; Rao et al., A trajectory-clustering-correlation methodology .

25. Tropp et al., *Final Report.*

26. Ibid.

27. Ibid.

Section 2, Chapter 3
HEALTH STATUS EVALUATION

The prospective pediatric health study was conducted from 1998 through June 2000. The first phase of data collection was completed from January 1999 through May 1999. The second data collection phase included the 1999-2000 academic year and averaged 40 weeks from September through August.

METHODOLOGY

Longitudinal studies were conducted in three different areas (see Chapter 1 of this section). A rural site was represented by East Elementary School located in Athens, which is in Southeastern Ohio. Koebel Elementary School located in South Central side of Columbus represented the urban testing center. A suburban site was located in New Albany and was represented by New Albany school. Conducting health assessments in different locations provided an opportunity to assess different patterns of exposures to air pollutants. All students enrolled in 4th and 5th grades were considered eligible for the study.

Participant Consent

Participation in the project was on a volunteer basis. Consent forms were obtained from the students, parents, and principals of the participating schools. Each consent form included: 1) the purpose of the research, and 2) an outline of proposed student activities. Student responsibilities included: completion of peak flow measurements, monitoring for pulmonary symptoms, and recording of daily attendance.

Consent forms clearly articulated the anonymous character of the study. Parental consent forms also contained information on how parents could contact project personnel. The signed consent forms were collected and kept by project personnel at Ohio University. Child consent forms were designed to introduce students to the project goals and activities. Students choosing to participate in the project were required to obtain permission from their parents. Parental and student consent forms were accompanied by a letter from the school principals and classroom teachers stating the willingness of the school administration to participate in the Study.[1]

Since the project involved studying human subjects, in particular minors, it was subject to review by the Ohio University Institutional Review Board (IRB). Required IRB documents were submitted to the Ohio University IRB including: 1) OU IRB Project Outline Forms, 2) parental and student consent forms, 3) project description, 4) project time line, 5) a copy of Child Health Questionnaire (CHQ), and 6) CHQ FAQs. The primary investigator presented the project proposal to OU IRB. The project proposal was reviewed and received approval.

Media Attention

As Table II.3.1 shows, the project received wide publicity. Participating schools were the center of media attention throughout the length of the project. Communication with persons outside the study, including the mass media, regarding study design and results was primarily managed and conducted by Dr. Kevin Crist (see Appendix for publication clippings).

Table II. 3.1. Summary of Media Attention

Newspaper	Headline(s)	Date
New Albany News	"4th graders part of scientific air pollution study"	12/9/98
This Week (local weekly neighborhood newspaper in Columbus)	"Researchers studying air breathed by fourth graders" "Students Help Study Air Quality"	1999
Columbus Dispatch	"Schools, Pupils Wired for Air Pollution Study: OU Scientists are Interested in Soot"	1/20/99

[1] Consent forms and other questionnaire information is on file at Ohio University.

Project Management

For the prospective study, faculty from College of Health and Human Services (CHHS) designed and implemented the overall management of the project. A medical evaluation team was comprised of faculty and medical students at the Ohio University College of Osteopathic Medicine (OUCOM). Graduate research assistants served as liaisons between schools, hospitals, and project management. Their responsibilities included primary and secondary research, data collection and management, review of previous studies, management of medical evaluations and quality control.

During the initial stage, general guidelines outlining the primary responsibilities and operating procedures for project participants were developed. Principles guiding the development of these operating procedures included data collection, documentation, data analysis, and quality control issues. Also, they specified duties for project coordinators and teachers involved in the project.

To ensure data quality, the project group developed a quality assurance strategy to help sustain student motivation. The strategy included providing a detailed description of peak flow measurement procedures to teachers and students. It also included constant communication with the research personnel through social events such as pizza parties and cross-cultural classes. Other incentives included discount coupons redeemable at local restaurants.

Research personnel updated participants and other project members on progress and intermediate results. This strategy resulted in minimizing dropouts and enhancing data collection. Regularly scheduled meetings of project personnel improved follow-up, facilitated updating of site-visiting procedures, and helped maintain quality control.

Teachers, students, and project coordinators met on regular basis, usually on the day when the research data were collected from the schools. Initially, project coordinators visited sites once a week to provide training and address quality control issues. Once students and teachers developed substantial expertise in using peak flow meters, reporting absenteeism, and daily health status, project coordinators typically visited schools twice a month.

HEALTH STATUS DATA

Components of the prospective pediatric study included: 1) emergency room visits 2) daily monitoring of pulmonary function, 3) daily school and class absenteeism, and 4) a cross-sectional health survey.

Emergency Room Visits

Emergency room (ER) clinic records were obtained from Riverside, Mt Carmel East and Mt Carmel West in Columbus Ohio and Obleness in Athens Ohio. These hospitals were choosen based on the proximity to the sampling sites. Prior to releasing admission data for 1999 and 2000, the institutional review boards for the hospitals verified confidentiality protection. The records included date, principal and additional diagnoses as International Classification of Diseases (ICD-9), age, sex and zip code of the patient's residence.

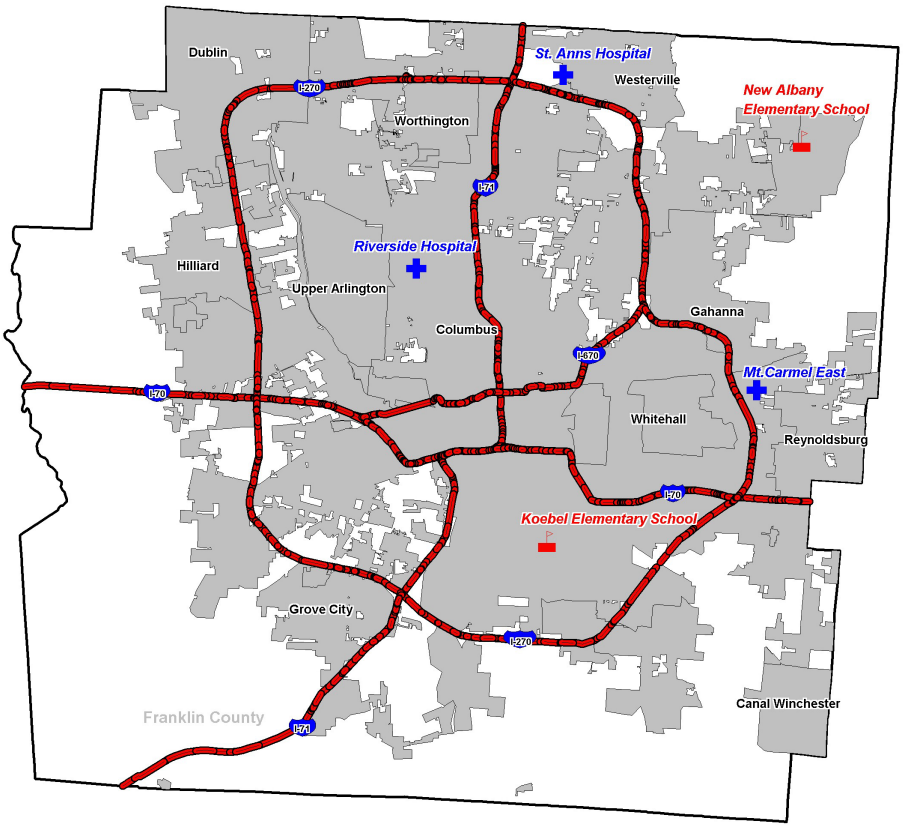


Figure II.3.1. Location of Hospitals in Columbus Ohio where Emergency room data was obtained for 1999 through August of 2000

The daily admissions from all the ERs were aggregated for each sampling site (Koebel, New Albany, and Athens). The admissions were aggregated by utilizing a 20- mile radius from each sampling site as defined by the zip code of the patient's residence. The daily counts were sorted by ICD-9 codes for acute respiratory infections, pneumonias, COPD and asthma. Table II.3.2 provides a listing of the ICD-9 codes corresponding to the respiratory categories used.

Table II.3.2 ER DIAGNOSIS CATEGORIES AND ICD-9 CODES

Diagnosis	**ICD-9 Code**
Acute infections	464, 466
Pneumonias	480-486
COPD	490-492, 496
Asthma	493

Daily monitoring of pulmonary function

The study involved daily monitoring of pulmonary function. Previous studies have used spirometers to assess the response of the pulmonary system to air pollution. Although spirometry is a sensitive method to measure lung function, its operation requires specially trained personnel. Considering the long-term nature of the study and its design that required measuring of lung capacity on daily basis, peak flow meters (PFM) were employed. PFM are easy to use, inexpensive and widely used among patients with pulmonary illnesses in an outpatient environment.

The full range PFMs (60- 880L/min) were purchased from HealthScan Products Inc., a division of Healthdyne Technologies. The ASSESS Peak Flow meter package consisted of a peak flow meter, two plastic mouthpieces, and instructions.

PFMs were distributed to each project participant at the beginning of each school year. During the project study period the PFMs were kept in classrooms and regularly inspected by teachers to ensure their safety and function. Any broken equipment was immediately replaced. To ensure and monitor hygiene standards, the research team developed PFM cleaning logs. School principals or classroom teachers cleaned the mouthpieces of the PMFs using appropriate cleansing solutions and washing equipment.

Three PFM measurements were performed on a daily basis Monday through Friday (weekends and holidays excluded). Each school performed measurements at the time assigned by the investigators. Koebel and Athens completed measurements at 12:00 – 12:30 p.m., while New Albany ran measurements between 8:00 and 9:00 a.m.

Assessment of lung capacity of the elementary school children was performed in two stages. The first stage was from January through May 1999; the second stage during the 1999-2000 academic year. At the beginning of each stage, the project coordinators made a presentation at the three schools. The presentation included general information about the project, its design, methodology, and expected outcomes. Another purpose of the presentation was to educate the community about PFM use. Teachers received handouts on PFM measurement process guidelines, the master peak flow data sheet, and PFM cleaning logs.

To standardize data collection procedures, project personnel designed a form to transcribe the daily PFM data and the highest of three measurements was used for data analysis. Peak flow data sheets were collected from each test center twice a month. Ohio University served as the official repository for all study documents. To ensure anonymity, all data sheets were coded prior to being imputed into the database. Research assistants updated the database on a regular basis.

PFM data was correlated with air pollution monitoring data. Peak flow data was temporally analyzed with absenteeism to identify seasonal variations and provide descriptive characteristic of PFM measurements. Furthermore, for each participating student, daily PFM measures served as the dependent variable in an autoregressive hierarchical linear regression analysis. The independent variables for this regression analysis are various air pollution measures obtained from the school sites. The analysis was hierarchical because it proceeded in two steps. First, items were added to the regression model to represent potential confounding factors, which might be related to both the dependent and predictor variables. These included time-related terms to model whatever trends or cyclical patterns in the data. Second, the air pollution variables were added to the data analysis. Untransformed predictors and the predictors that lagged one or more weeks were evaluated as. At both steps of the analysis, standard procedures were performed including the examination of residual and autocorrelation plots.

Active Surveillance of Daily Absences

An important component of daily health status monitoring was screening for the presence of respiratory symptoms. The required information included the number of students absent due to respiratory conditions (retrospectively according to notes from parents), and number of students present in class with such respiratory symptoms (such as a runny nose, cough, etc).

School absenteeism data were collected from the three participating sites. School secretaries compiled the information on the monthly absentee log

forms. Athens and Koebel[2] were represented by one 4th or 5th grade class; New Albany was represented by two 5th grade classes. Absenteeism data was collected for the second semester of 1998-1999 and the entire1999-2000 school year. Total enrollment in all elementary schools and classes involved in the project was relatively constant during the study period.

Data at Koebel and Athens were incomplete due to teacher workload associated with regular responsibilities and personal health problems. Collection of daily absentee data and recording of respiratory symptoms from the New Albany site was more consistent. Data collection was enhanced due to the fact that the teacher at New Albany participated in the study for its entire period and was highly motivated. This allowed for further analysis of the data from this school site.

To standardize the collection procedure, special forms were designed to monitor class and overall school attendance and were reviewed monthly. Similarly, to monitor class attendance, daily absentee logs included information on the total number of students enrolled and absent in each class. Teachers were responsible for collecting data to complete the absentee form daily. These data included day, date, total number of children enrolled in the class, and the number of students absent (reasons for absenteeism were specified after the explanation notes were received).

Cross Sectional Health Survey

Pediatric health assessment was performed in two cohorts of the project. The first group was surveyed in March - April 1999; the sample is hereafter referred to as the "1998-99 data." For this survey, an 18-page questionnaire was designed by combining two questionnaires: 1) modified *Parent Form 28 Child Health Questionnaire* (CHQ- PF 28) and 2) the *American Thoracic Association Questionnaire* (see Appendix A for samples). Questionnaires were distributed to 4th and 5th grade students. All 4th and 5th graders of three participating schools represented the target group.

The response rates for the 1998-99 survey was 70 percent for all students and 99 percent for the PFM children. Total number of surveyed PFM children was 73 rural, 74 urban, and 160 suburban at the three school sites. The survey results were compared with data for General U.S. Population Sample presented in CHQ Manual.

The second survey was initiated in the Fall of 1999; hereafter referred to as the "1999-00 data." The short form of the questionnaire contained questions

[2] Unfortunately, due to issues related to the administrative structure, some data from Koebel Elementary school are presented as the aggregate monthly data (September, October, and May).

adapted from the *American Thoracic Association Questionnaire.* Only students participating in PFM measurements participated in the survey. In both years, the questionnaire was self-administered and completed by parents of 4th and 5th graders voluntarily. In 1999-2000, 23 rural students responded, 25 urban and 44 suburban students responded to the questionnaire, for a response rate of approximately 99 percent.

The questionnaire assessed: child's global health, overall physical and psychological health, general and pulmonary medical history, child's respiratory status, living conditions, and parents' demographic information.

Meteorology

A meteorological monitoring station was located at each elementary school. The weather stations recorded wind direction, wind speed, precipitation, barometric pressure, and solar radiation (refer Chapter 1 of this section for a complete description of the meteorological monitoring). This data was augmented with data from the National Climatic Data Center (NCDC). Daily values for average and maximum temperature, average relative humidity, total precipitation, average barometric pressure, and average wind speed were used for the statistical analysis.

Air Quality Data

Indoor and outdoor monitoring for $PM_{2.5}$ was conducted at all three elementary schools participating in this study Koebel, New Albany, and Athens. A detailed description of the sampling sites, and the monitoring, and analytical methods is described in Section 2 Chapter 1 of this report. For evaluating the relationship between respiratory health and air quality the monitoring data was limited to $PM_{2.5}$ mass outdoors and indoors, Sulfate (as a component of the $PM_{2.5}$) indoor and outdoor and, personal $PM_{2.5}$ mass obtained at the elementary schools participating in this study.

A 24-hour average mass concentration for the outdoor monitoring was used. The indoor, personal, and outdoor particulate matter sulfate concentrations were seven hour averages (8am -3pm) tagged to the school day. During the second phase of this study the filter based ambient monitoring, ($PM_{2.5}$ sulfate concentrations) was extended to 23 hours to increase the limit of detection. For consistency an estimate of the seven hour average (8am-3pm) was calculated by using the ratio of the 8am-3pm to the 23 hour mass averaged concentration obtained from the TEOM.

The indoor, outdoor and personal monitoring data was used to evaluate the relationship between air quality and respiratory illness for the 4rd and 5th graders participating in this study. The ambient measurements, TEOM mass data and sulfate concentrations, were used to evaluate the relationship between

air quality and respiratory illness for the adjacent community (Emergency room data sorted within a 20 mile radius).

RESULTS AND DISCUSSION

Statistical Analyses

The relationship between respiratory health and air quality may be confounded by other variables, such as meteorological indices, that are related to both. In the analyses that follow, we controlled for a long-term trend by including a linear effect of time. We controlled for seasonal variation in respiratory health by including dummy variables for study months and days of the week.

In analyzing the relationship between emergency room visits as a function of the 24-hour TEOM average, we included a dummy variable for each month of the study, e.g., one dummy variable to represent January of 1999, and so on. In every other analysis, we included a dummy variable for each pair of months in the study, e.g., one dummy variable to represent January and February of 1999, another to represent March and April of 1999, and so on. This was necessary because of the amount of missing data in the dataset, which was primarily due to weekends, holidays, and vacations, when many of the outcome and explanatory measures could not be collected. In all analyses, we included a dummy variable for each day of the week.

For most of the analyses, this set did not include dummy variables representing Saturday and Sunday because data was not collected on these days. We also controlled for a variety of meteorological variables, including linear effects for average temperature, average wind speed, average relative humidity, average barometric pressure, and the occurrence of precipitation. Although many researchers have argued that the relationship between weather, particularly temperature, and respiratory health should be modeled using more complex curvilinear effects, we chose to model it using linear effects primarily because of the size of these datasets.

In any analysis of time series data, the possibility that the residuals exhibit autocorrelation must be considered. Preliminary analyses were conducted with only the seasonal and weather variables in the models. Analyses of the residuals indicated the presence of autocorrelation. A first-order autocorrelation structure was as effective as any of the more complex structures examined for modeling the autocorrelation present in the data.

Separate analyses were conducted for each pollutant. Analyses were also conducted for each pollutant lagged one day. Because data were generally not available on the weekends, holidays, and vacations, for most outcome measures, a lag of one day reduced the available data by more than 20%. A lag

of two days would have reduced the number of days by more than 40%. For this reason, only a one-day lag of the pollution variables was examined.

For the peak flow measures, we used linear regression models with a first-order autoregressive structure. For the emergency room data, we used poisson regression models based on the generalized estimating equations approach developed by Liang and Zeger (1986a, 1986b) with a first-order autoregressive structure

Meteorology

Table II.3.3. summarizes meteorological variables at all three locations. Considering that all three sites area within relatively close proximity to each other, it is not unexpected to find similar levels of precipitation, relative humidity, barometric pressure, and temperature. The one notable meteorological difference is found in wind speed; New Albany is the windiest location of the three.

Table II.3.3. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables

	N	M	SD	Min	25th	Mdn	75th	Max
			Athens					
Average wind speed[3]	601	2.2	1.6	0.0	1.0	1.8	3.0	11.3
Average relative humidity[4]	601	71.2	13.0	32.5	62.6	71.1	80.2	100.0
Precipitation	609	0.1	0.3	0.0	0.0	0.0	0.0	2.7
Barometric pressure[5]	601	30.1	0.2	29.4	30.0	30.1	30.2	30.7
Average daily temp[6]	601	56.8	16.6	10.0	43.8	59.7	70.8	87.3
			Koebel					
Average wind speed	603	6.72	3.51	1.38	4.08	6.10	8.60	23.90
Average relative humidity	602	70.71	11.46	40.85	62.50	70.00	78.59	100.0
Precipitation	609	0.95	0.28	0.00	0.00	0.00	0.05	2.67
Barometric pressure	603	29.43	0.39	28.63	29.13	29.30	29.79	30.54
Average daily temp	603	55.34	18.43	4.00	40.69	58.00	71.33	89.00
			New Albany					
Average wind speed	603	7.08	3.34	1.38	4.69	6.50	8.90	23.90
Average relative humidity	603	71.78	11.86	40.85	62.58	71	80.00	100
Precipitation	609	0.095	0.28	0.00	0.00	0.00	0.05	2.67
Barometric pressure	603	29.35	0.33	28.63	29.12	29.28	29.51	30.54
Average daily temp	603	55.11	18.27	4.00	40.69	58.00	71.00	89.00

[3] Miles/hour
[4] Percent
[5] In Hg^0 (inches of mercury
[6] ^oF

Air Quality

Descriptive statistics relating to air quality measurements are shown in Table II.3.4. As this table shows, Athens recorded the highest average values for personal and indoor $PM_{2.5}$; however, average ambient levels of $PM_{2.5}$ were highest at the Koebel site in Columbus. The Koebel site also recorded the highest level of indoor SO_4, with a recorded maximum value of 24.52. Even so, the levels for SO_4 across the three sites are not notably different.

Table II.3.4. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables (micrograms/cubic meter)

	N	M	SD	Min	25th	Mdn	75th	Max
			Athens					
$PM_{2.5}$ Personal	207	17.6	17.8	0.2	6.2	9.5	22.8	88.4
$PM_{2.5}$ Indoor	298	17.2	13.6	0.5	8.6	12.3	20.8	71.6
Weight – Outdoor	296	13.7	9.0	0.5	8.3	11.8	17.2	61.1
SO_4 – Indoor	216	2.3	2.1	0.1	0.6	1.6	3.5	11.1
SO_4 – Ambient	243	2.6	2.3	0.0	0.8	1.9	3.5	9.4
$PM_{2.5}$ Ambient	438	15.3	7.2	4.5	10.1	13.4	18.8	41.0
			Koebel					
$PM_{2.5}$ Personal	194	14.59	13.05	0.42	7.49	10.18	15.14	66.97
$PM_{2.5}$ Indoor	251	14.98	12.30	1.05	7.22	10.55	16.26	68.36
Weight – Outdoor	303	13.83	8.81	0.24	8.69	11.65	16.29	61.29
SO_4 – Indoor	191	2.35	3.16	0.04	0.54	1.31	2.63	24.52
SO_4 – Ambient	199	2.71	2.46	0.02	0.98	2.03	3.62	13.79
$PM_{2.5}$ Ambient	491	18.47	8.64	4.89	12.26	16.61	22.44	60.22
			New Albany					
$PM_{2.5}$ Personal	205	13.93	12.25	0.95	6.82	9.45	15.09	56.90
$PM_{2.5}$ Indoor	270	16.52	13.52	0.24	8.40	11.56	19.52	69.51
Weight – Outdoor	297	12.79	8.53	0.05	8.04	10.95	15.45	61.34
SO_4 – Indoor	208	1.97	2.59	0.06	0.40	1.17	2.42	16.59
SO_4 – Ambient	222	2.12	2.00	0.01	0.94	1.51	2.80	13.76
$PM_{2.5}$ Ambient	552	14.72	7.08	4.00	9.62	13.07	18.51	47.81

Emergency Room Visits and Peak Flow Meters

Peak flow readings are an imperfect indicator of a child's respiratory health. Children are capable of producing spuriously low or high readings. Therefore, before conducting any analyses, unusually high and low peak flow readings were identified and deleted from the dataset; fewer than 1% of these data were deleted. Table II.3.5. provides a summary of health data that includes emergency room data and results of the peak flow meter measurements.

Table II.3.5. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Respiratory Measures

	N	M	SD	Min	25th	Mdn	75th	Max
Athens								
Mean Peak Flow – 1999	87	0.01	0.02	-0.05	-0.01	0.01	0.02	0.06
Mean Peak Flow – 1999 (Ill)	83	0.04	0.04	-0.05	0.02	0.04	0.07	0.14
Number Attending – 1999 (Ill)	87	8.9	1.3	4.0	9.0	9.0	10.0	10.0
Mean Peak Flow – 2000	124	0.00	0.02	-0.08	-0.01	0.00	0.01	0.05
Proportion Absent – 2000	168	0.03	0.02	0.00	0.03	0.04	0.04	0.09
Total - Respiratory Illness	545	1.0	1.1	0.0	0.0	1.0	1.0	7.0
Children – Asthma	545	0.1	0.0	0.0	0.0	0.0	0.0	2.0
Elderly – COPD	545	0.1	0.3	0.0	0.0	0.0	0.0	2.0
Koebel								
Mean Peak Flow – 1999	90	0.00	0.43	-0.06	-0.02	0.00	0.01	0.16
Mean Peak Flow – 2000	145	0.00	0.04	-0.09	-0.02	0.00	0.02	0.09
Mean Peak Flow – 2000 (I11)	145	0.00	0.05	-0.12	-0.03	0.00	0.02	0.16
Number Attending – 2000 (I11)	149	9.74	1.58	2.00	9.00	10.00	11.00	12.00
Proportion Absent – 2000	138	0.07	0.04	0.02	0.05	0.06	0.07	0.31
Total - Respiratory Illness	547	35.29	13.46	12.00	27.00	32.00	40.00	89.00
Children – Asthma	547	1.28	1.26	0.00	0.00	1.00	2.00	6.00
Elderly – COPD	547	3.86	2.12	0.00	2.00	4.00	5.00	11.00
New Albany								
Mean Peak Flow – 1999	95	-0.00	0.02	-0.08	-0.01	0.00	0.01	0.07
Mean Peak Flow – 1999(Ill)	95	0.00	0.06	-0.16	-0.04	0.00	0.05	0.16
Number Attending -1999(Ill)	95	5.37	0.83	3.00	5.00	6.00	6.00	6.00
Mean Peak Flow – 2000	168	0.00	0.02	-0.05	-0.02	0.00	0.02	0.06
Mean Peak Flow – 2000 (Ill)	168	0.00	0.03	-0.07	-0.02	0.00	-0.02	0.09
Number Attending –2000(Ill)	168	13.29	1.31	8.00	12.00	13.00	14.00	15.00
Proportion Absent – 2000	175	0.04	0.02	0.01	0.02	0.04	0.04	0.09
Total - Respiratory Illness	547	36.44	13.82	13.00	28.00	33.00	41.00	90.00
Children – Asthma	547	1.31	1.29	0.00	0.00	1.00	2.00	6.00
Elderly – COPD	547	3.99	2.20	0.00	2.00	4.00	5.00	12.00

An aggregate daily peak flow measure was computed for each school. First, each child's daily peak flow reading was standardized. A child's mean peak flow reading for the year was subtracted from each of the child's daily peak flow recordings. These differences were then divided by the child's mean peak flow reading for the year. Second, the daily standardized peak flow readings were aggregated by averaging them across all of the children in each school. Separate analyses were performed for each of the three schools and for each of the two years in the study.

At the start of each school year, parents completed the Child Health Questionnaire. In completing this questionnaire, parents reported whether their children had ever been diagnosed with a respiratory illness. Separate daily mean standardized peak flow measures were computed for children whose parents had reported that their children had been diagnosed with a respiratory

illness. This was done for New Albany (6 children) and Athens (10 children) in 1998-1999 and for New Albany (15 children) and Koebel (13 children) in 1999-2000.

Health Status Questionnaire

Survey results indicate that children living in the urban study area are most likely to live in a home in which there are smoking adults. On the other hand, urban children are less likely than rural and suburban children to own pets and to have air conditioning in their homes.

The general health status of the children participating in the study is depicted in Figures II.3.2 and II.3.3. As these figures show, the perceived health status of students in the urban area is worse than those students who are in both the rural and suburban districts.

In both study years, only about 20 percent of the urban students stated that they were in "excellent" health. Contrast this with the more than 50 percent of rural students in both years who state they are in excellent health. In terms of the suburban sample, almost 60 percent of the respondents indicated that they were in excellent health during the 1998-99 school year, and almost 48 percent assessed their health as excellent in the 1999-00 school year.

Reported respiratory symptoms from the 1998-99 survey are summarized in Figures II.3.5 and II.3.6. As these figures show, the urban children are more likely to say that they have experienced chronic cough, wheezing and asthma.

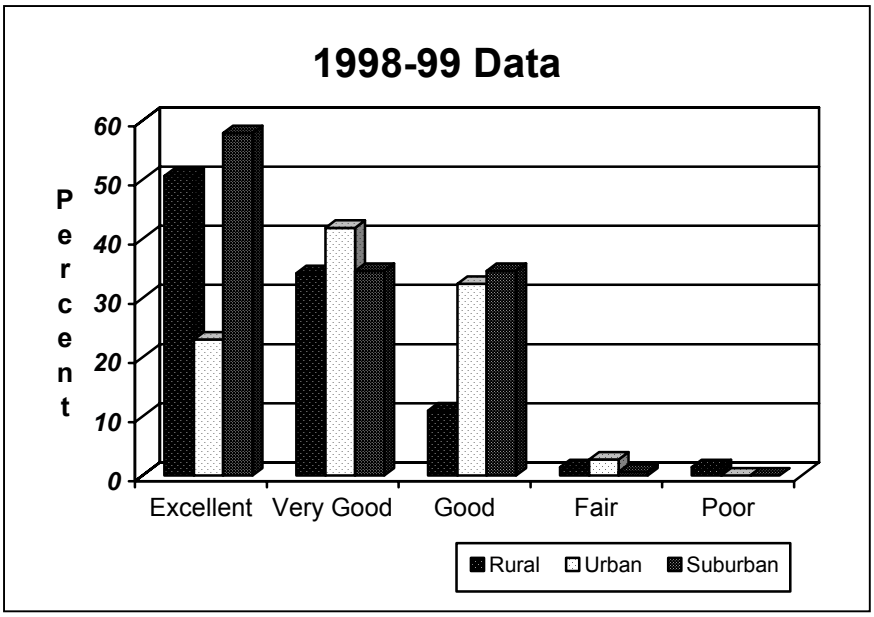


Figure II.3.2. General Health Status, 98-99 Sample

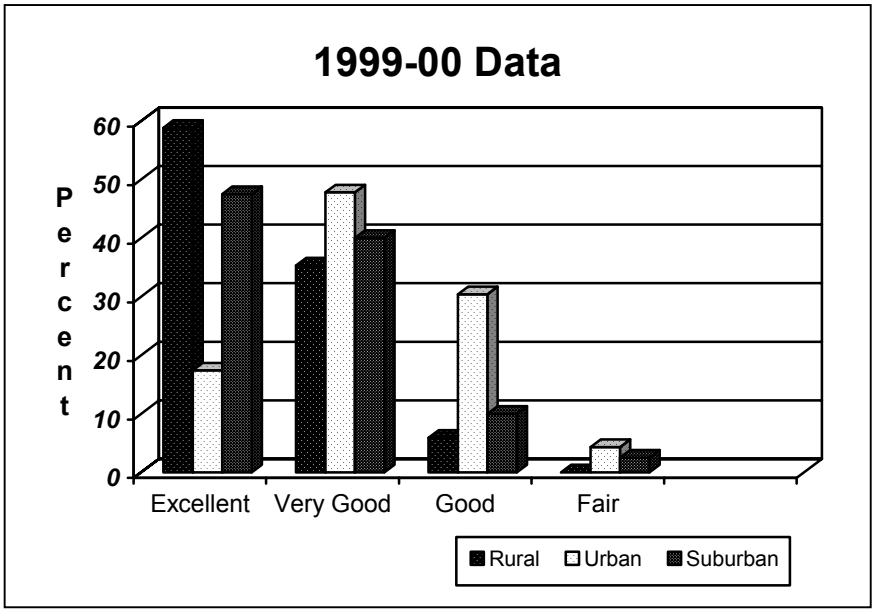


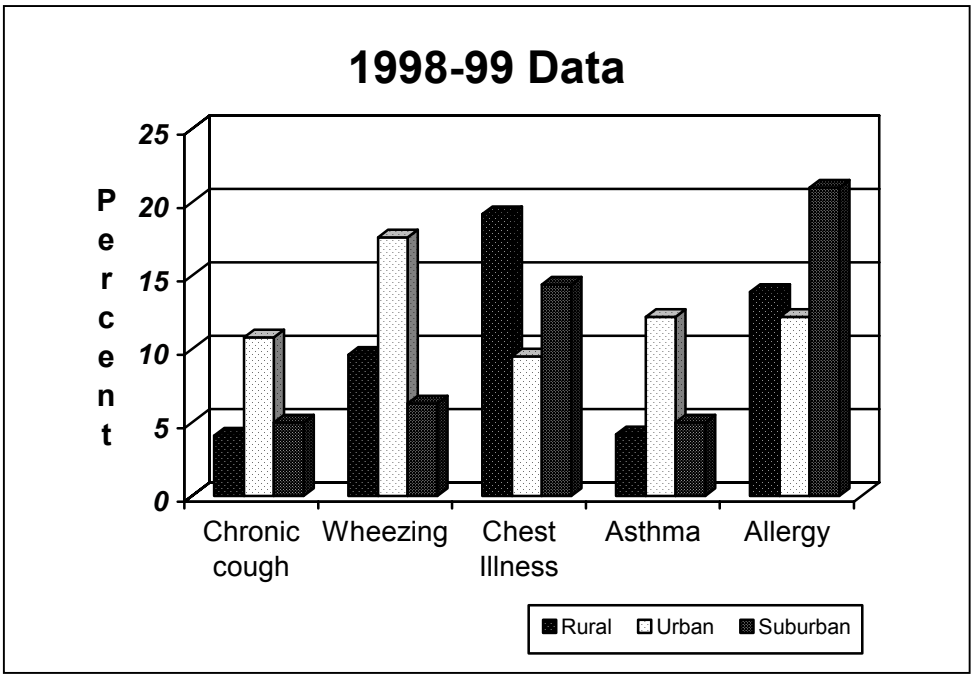
Figure II.3.3. General Health Status, 99-00 Sample

Rural children indicated that they have experienced chest illness more often than children in urban and suburban area. An interesting finding is that suburban children report the highest percentage of allergies. This may be due to the fact that these children are most likely to have access to medical care. Reported respiratory symptoms from the 1999-2000 survey are summarized in Figures II.3.4 and II.3.5. The results from this survey should be interpreted with caution because of the low number of respondents, especially in the urban cohort.

Parents were asked to identify several other illnesses that their children have had. These illnesses included: measles, sinus trouble, bronchiolitis, bronchitis, asthmatic bronchitis, pneumonia, whooping cough, croup and cystic fibrosis. Figures II.3.6. and II.3.7. summarize the results from the two survey years.

For the 1998-99 survey period, rural parents reported the highest percentage of incidence of measles, bronchitis, and pneumonia. Suburban children had the highest percentage of sinus trouble and croup. Urban children reported the highest incidence of whooping cough.

During the 1999-2000 survey period, urban children reported the highest percentage of measles. Suburban children reported the highest percentage of sinus trouble, bronchitis, pneumonia, and croup. Rural children had the highest percentage of whooping cough. Complete results for the health status questionnaires can be found in Appendix B.



II.3.4. Reported Respiratory Symptoms, 98-99 Sample

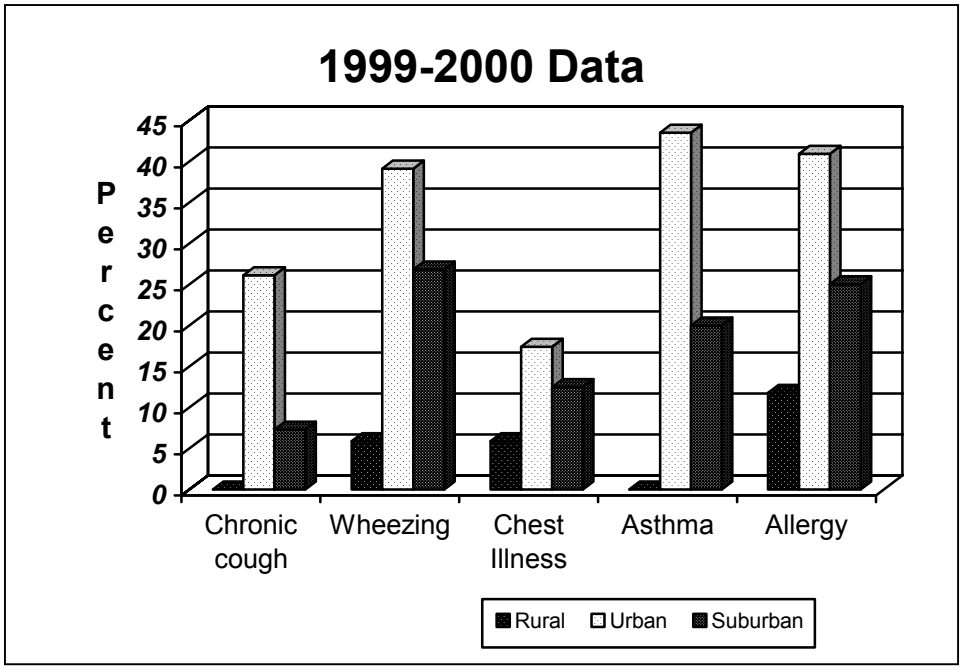
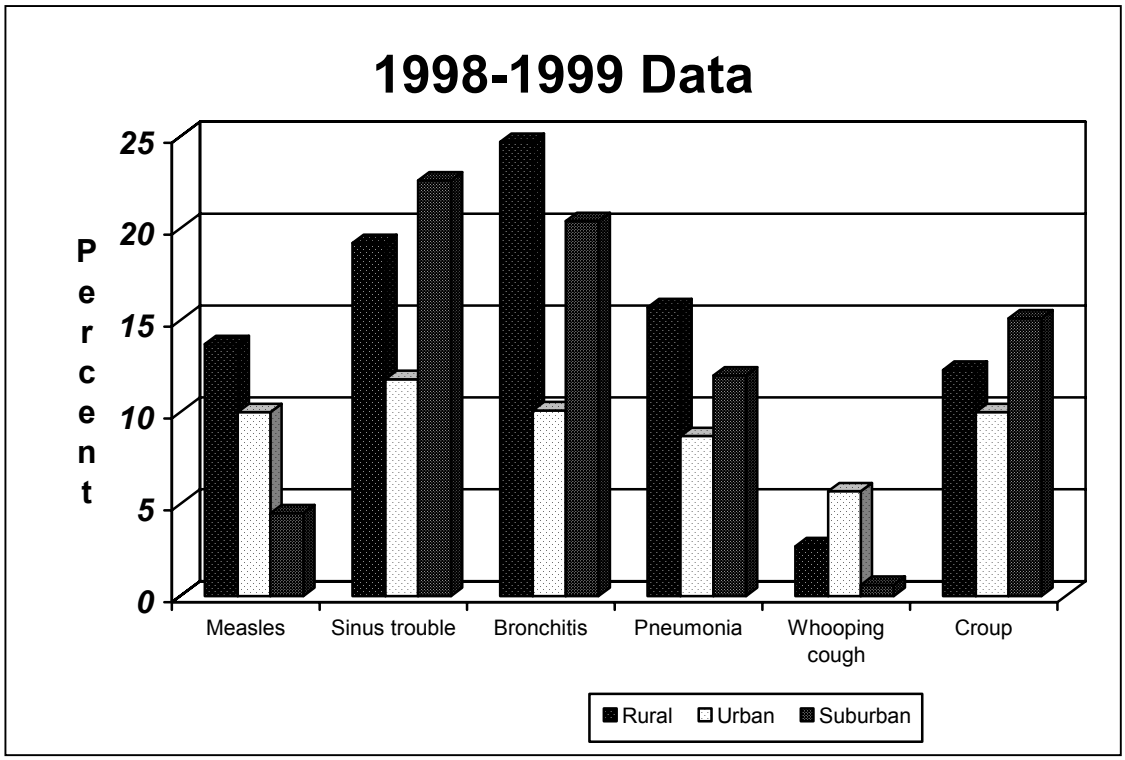


Figure II.3.5. Reported Respiratory Symptoms, 99-00 Sample



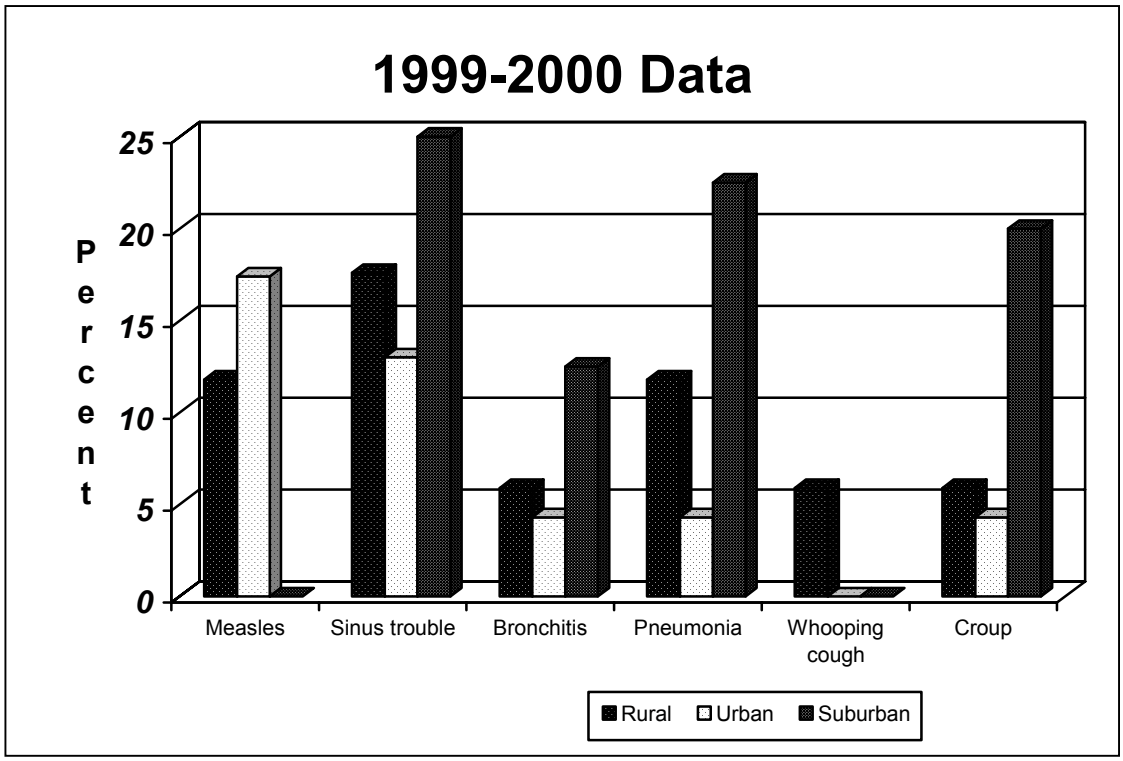


Figure II.3.6. and II.3.7. Responses from Parents Relative to Child's Respiratory Status

Respiratory health and air pollution

Tables II.3.6 through II.3.8 contains zero-order correlations between the respiratory measures and the air quality measures. Table II.3.7 contains summaries of the statistical analyses conducted to examine the relationship between the respiratory measures and the air quality measures while controlling for seasonality and weather.

Table II.3.6. Correlation Matrix (and Significance Levels) for Daily Respiratory Measures with the Air Quality Variables at Athens

	$PM_{2.5}$ Personal	$PM_{2.5}$ Indoor	SO_4 – Indoor	SO_4 – Ambient	$PM_{2.5}$ Ambient
Mean Peak Flow – 1999	.148 (.258)	.087 (.442)	.179 (.208)	.112 (.390)	.175 (.143)
Mean Peak Flow – 1999 (Ill)	-.041 (.760)	.004 (.970)	.100 (.501)	.169 (.210)	-.175 (.149)
Number Attending – 1999 (Ill)	.076 (.564)	.131 (.242)	.144 (.314)	.034 (.795)	-.071 (.554)
Mean Peak Flow – 2000	.210 (.033)	.161 (.095)	-.139 (.212)	.044 (.663)	.090 (.455)
Proportion Absent – 2000	.189 (.033)	.262 (.002)	-.169 (.089)	.020 (.830)	-.041 (.697)
Total - Respiratory Illness				.142 (.038)	-.151 (.003)
Children – Asthma				.077 (.263)	-.006 (.906)
Elderly – COPD				.032 (.644)	.041 (.429)

Table II.3.7. Correlation Matrix (and Significance Levels) for Daily Respiratory Measures with the Air Quality Variables at Koebel

	$PM_{2.5}$ Personal	$PM_{2.5}$ Indoor	SO_4 – Indoor	SO_4 – Ambient	$PM_{2.5}$ Ambient
Mean Peak Flow – 1999	.125 (.260)	.114 (.298)	.321 (.030)	.160 (.283)	-.062 (.596)
Mean Peak Flow – 2000	.296 (.003)	.271 (.007)	-.242 (.024)	-.062 (.602)	.057 (.566)
Mean Peak Flow – 2000 (I11)	.102 (.324)	.009 (.927)	.001 (.991)	.036 (.763)	-.051 (.607)
Number Attending – 2000 (I11)	-.152 (.132)	-.052 (.606)	.029 (.784)	-.218 (.057)	-.100 (.305)
Proportion Absent – 2000	-.155 (.147)	-.161 (.135)	-.118 (.315)	-.017 (.890)	-.113 (.284)
Total - Respiratory Illness				-.090 (.250)	-.278 (.000)
Children – Asthma				.142 (.070)	-.071 (.141)
Elderly – COPD				-.040 (.615)	-.083 (.083)

Table II.3.8. Correlation Matrix (and Significance Levels) for Daily Respiratory Measures with the Air Quality Variables at New Albany

	$PM_{2.5}$ Personal	$PM_{2.5}$ Indoor	SO_4 – Indoor	SO_4 – Ambient	$PM_{2.5}$ Ambient
Mean Peak Flow – 1999	.260 (.025)	.180 (.103)	.069 (.634)	-.124 (.386)	.083 (.430)
Mean Peak Flow – 1999(Ill)	.044 (.712)	-.300 (.006)	.024 (.867)	-.066 (.645)	-.064 (.544)
Number Attending - 1999(Ill)	.055 (.644)	.077 (.490)	-.156 (.281)	.067 (.639)	.019 (.854)
Mean Peak Flow – 2000	.372 (.000)	.441 (.000)	-.057 (.565)	.198 (.040)	.321 (.000)
Mean Peak Flow – 2000 (Ill)	.120 (.178)	.302 (.001)	-.070 (.478)	.100 (.302)	.253 (.002)
Number Attending –2000(Ill)	.340 (.000)	.410 (.000)	-.056 .572	.080 (.413)	.139 (.098)
Proportion Absent – 2000	.024 (.784)	-.054 (.551)	-.178 (.070)	-.122 (.209)	-.134 (.103)
Total - Respiratory Illness				-.036 (.630)	-.224 (.000)
Children – Asthma				-.054 (.470)	.006 (.894)
Elderly – COPD				.027 (.716)	.002 (.963)

There were few consistent relationships between the respiratory measures and the air quality measures, after controlling for seasonality and weather. At two of the three sites (Koebel, New Albany), indoor filter weights with a one-day lag were negatively related to the attendance of students who had a prior history of respiratory illness. At New Albany, outdoor filter weights were negatively related to mean standardized peak flow, but only significantly so for all students in 2000, but not for just those with a history of respiratory illness, and for all students with a history of respiratory illness in 1999, but not for all students. Although negative correlations between mean standardized peak flow and outdoor filter weights were also observed at the other two sites in 2000, none were statistically significant. Additional correlation tables can be found in Appendix C.

Limitations

The failure to detect expected relationships between the respiratory measures and the air quality measures, after controlling for seasonality and weather, may be due to several possible causes. First, relatively little data were available for analyses. Because students do not attend school on weekends, on holidays, or during the summer, there were only approximately 100 observations available for each of the analyses. Second, this problem was probably aggravated by the relatively conservative approach that was taken in conducting the statistical analyses. To adequately control for seasonality and weather, more covariates were entered into the model than was desirable, given the number of observations. This suggests that the analyses probably had relatively little power.

Section 3, Chapter 1
A RETROSPECTIVE ANALYSIS OF THE AIR QUALITY DATA FROM OHIO

INTRODUCTION

There has been increased attention on the health impacts of air pollutants such as ozone, particulate matter, carbon dioxide, sulfur dioxide and nitrogen dioxide. The sources and potential health effects of exposure to these air pollutants are summarized in Table III.1.1. Since the 1980s, the State of Ohio has been involved in continuous efforts to reduce major air pollutant levels to comply with national ambient air quality standards (NAAQS).

In 1997, the USEPA announced new NAAQS for ground-level ozone, the primary constituent of smog, replacing the previous 1-hour primary ozone standard with a new 8-hour standard to protect against longer exposure periods.[1] If the new eight-hour ozone standard is applied, thirty counties in Ohio will be designated as "non-attainment."[2] In establishing the 8-hour standard, USEPA set the standard at 0.08 parts per million (ppm) and defines the new standard as a "concentration-based" form, specifically the 3-year average of the annual 4th-highest daily maximum 8-hour ozone concentration. The USEPA will retain the previous 1-hour primary ozone standard if a certain area achieves 3 consecutive years of air quality data over 125 ppb for the 1-hour ozone.

Table III.1.1. Summary of Air Pollution Effects and Trends in Ohio

Pollutant	Sources	Potential Health Effects	Reduction in Ohio (1981-2000)[3]
Ozone	The reaction of VOCs, NOx, heat, and sunlight.	Respiratory diseases and increasing respiratory symptoms	Steady decline
Particulate Matter	Fuel combustion or formed as secondary aerosols	Aggravation of respiratory conditions, respiratory disease, and a decrease of lung function	22% (annual average) 27% (24hr average)
CO	Incomplete burning of carbon-based fuels	Reduces the blood's ability to deliver oxygen to vital tissues	62%(1hr average) 62%(8hr average)
SO_2	Fuel containing sulfur (mainly coal and oil) burned	Breathing, respiratory illness, alterations in pulmonary defenses	58%(24hr average) 60%(annual average)
NO_2	High-temperature combustion processes	Changes in airway responsiveness and lung function	15%(annual average)

Ambient ozone is still the most widespread air quality problem in Ohio despite several generations air quality legislation. Ohio has thirty counties designated as non-attainment areas for the 8-hour ozone standard. Both USEPA Region 5 and Ohio have their own control strategies to reduce ground ozone levels in order to remain in attainment.[4] However, regional ozone control along with this local level strategy must be in place for an improvement in the air quality within Ohio

The USEPA added two new primary $PM_{2.5}$ standards in 1997. Ohio began monitoring for $PM_{2.5}$ in 1999 and has not included results in the most recent air quality trends reports. However, Ohio has been in compliance for the NAAQS for PM_{10} since 1989. The standard for PM_{10} is 50 $\mu g/m^3$ for annual arithmetic mean and 150 $\mu g/m^3$ for 24-hour average. In July 1997, to improve protection

against PM-related health effects, USEPA set new $PM_{2.5}$ standards at 15 $\mu g/m^3$ for annual arithmetic mean and 65 $\mu g/m^3$ for 24-hour average. Areas will be in compliance with the new annual $PM_{2.5}$ standard when the 3-year average of the annual arithmetic mean $PM_{2.5}$ concentration is less than or equal to 15 $\mu g/m^3$.[5]

The standard for CO was set by USEPA as a 1-hour averaged concentration and 8-hour averaged concentration not to exceed 9.0 ppm (10 mg/m^3) and 35.0 ppm (40 mg/m^3) more than once per year. National average CO concentrations have decreased 37 percent while CO emissions decreased 16 percent. Long-term data indicate that reductions in CO occurred despite a 31 percent increase in vehicle miles traveled in the U.S. during the past 10 years. Today's passenger cars are capable of emitting 90 percent less carbon monoxide than their uncontrolled counterparts of the 1960s. As a result, ambient carbon monoxide levels have dropped, despite large increases in the number of vehicles on the road and miles traveled.

Globally, SO_2 is considered to be a major pollution problem. There are two primary NAAQS for sulfur dioxide. The first is a long-term, one-year arithmetic average not to exceed 0.03 ppm. The second is a short-term, 24-hour average where concentrations are not to exceed 0.14 ppm more than once per year. The current secondary NAAQS for SO_2, is a 3-hour average concentration of 0.5 ppm not to be exceeded more than once per year.

Nitrogen oxides contribute to ozone formation and can have adverse effects on both terrestrial and aquatic ecosystems. USEPA's health-based national air quality standard for NO_2 is 0.053 ppm (measured as an annual arithmetic mean concentration).

Air quality problems in Ohio are associated both with local emission sources and pollutants transported over great distances. Industrial and urban activities in Ohio contribute to local and regional air pollution problems. Most of the major industrial sources of air pollutant precursors are located along the Ohio River valley. In addition, meteorological conditions contribute to the formation and transport of ozone within Ohio. A detailed understanding of long-term trends, the sources of pollutants and meteorological conditions affecting air quality is required for any meaningful air quality planning in Ohio.

The main objectives of this study were:

- To analyze time series and long-term trends of the air pollutants;
- To characterize meteorological parameters that affect air pollutant levels in Ohio; and
- To identify atmospheric patterns associated with the transport of air pollutants to and from Ohio.

AIR QUALITY AND METEOROLOGICAL DATA

Air quality data from monitoring sites located in Cincinnati, Dayton, Toledo, Columbus (two sites), Cleveland, Akron, Marietta and Steubenville for the period of 1992-2000 were utilized in this study. The data was obtained from USEPA's Aerometric Informational Retrieval System (AIRS) through Ohio EPA. The air pollution measurements used in this study were O_3, PM_{10}, SO_2, NO_2, and CO. Table III.1.2 and Figure III.1.1 show detailed information of the air monitoring sites used in this study. A central ozone monitor in each city was utilized with the exception of Columbus in which two sites were used. Additional pollutant monitoring data, if available, were obtained at the ozone monitoring site or at the nearest location within the city

Meteorological data were obtained from the National Climatic Data Center (NCDC). Daily values for average and maximum temperature, average relative humidity, total precipitation, average barometric pressure, and average wind speed were retrieved from the NCDC data sets for each city represented in this study.

Table III.1.2. Geographic location of selected air monitoring sites for ozone

City	Site Name	Latitude, N	Longitude, W
Akron	Patterson Park	41.1061	-81.5039
Cincinnati	Central	39.1286	-84.5042
Cleveland	District	41.5547	-81.5750
Columbus	Maple Canyon	40.0878	-82.9597
Columbus	Chesapeake	39.9928	-83.0414
Dayton	Northridge	39.8139	-84.1950
Toledo	Friendship Park	41.7194	-83.4750
Marietta	Marietta	39.4317	-81.4603
Steubenville	Steuben	40.3628	-80.6156

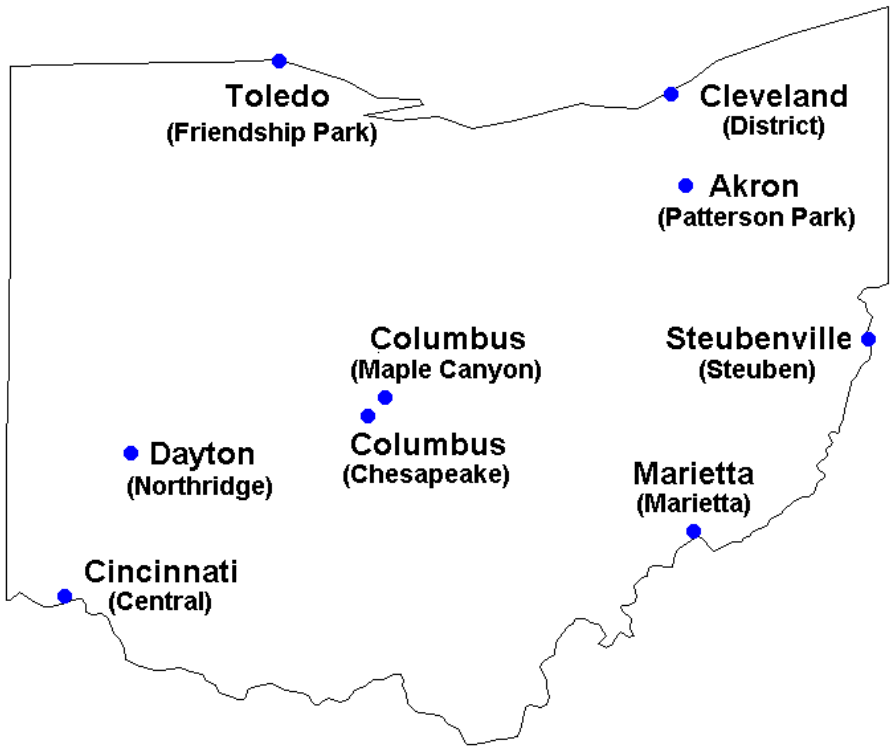


Figure III.1.1. Geographic location of selected air monitoring sites for ozone; City and site name.

Table III.1.3. summarizes data gathered from the sampling locations. For PM_{10}, 24- hour averaged values were obtained for each site. The typical sampling frequency was one in six days, the exception being Steubenville, which was sampled every day. For O_3, SO_2, NO_2, and CO 1-hour averages were obtained. From these values the 1-hour and 8-hour average daily maximum values were computed. With the exception of ozone, which is monitored from April 1 through the end of October, data were available for the entire year.

Table III.1.3. Summary of Data Sampling Protocols and Locations

Pollutant	Location	Sampling protocol	Time period
PM_{10}	Columbus (Maple Canyon, Chesapeake)	24 hour, averaged Approx 1- in 6 days	1992-2000
	Cleveland		
	Steubenville		
	Cincinnati		1992-1999
CO	Cincinnati	1-hour average	1992-2000
	Dayton		
	Columbus (Chesapeake)		
	Cleveland		
	Akron		
	Steubenville		
	Columbus (Maple Canyon)		1993-2000
SO_2	Cincinnati	1-hour average	1992-2000
	Dayton		
	Columbus (Chesapeake)		
	Cleveland		
	Akron		
	Steubenville		
NO_2	Steubenville	1-hour average	1992-2000
	Cincinnati		
	Cleveland		1992-1999

STATISTICAL ANALYSIS OF AIR POLLUTANTS IN OHIO

This study applied a time series and a correlation analysis to evaluate the characteristics of air pollutants for each of the selected air monitoring sites in Ohio (Table III.1.2). The time series analysis was adopted to develop monthly and weekly distributions of the air pollutant concentrations. Also, this study applied correlation analysis to analyze the effects of weather components, such as temperature, wind speed, and wind direction.

Some key details of the analysis are listed below:

- General characterization of ozone, particulate matter, CO, SO_2 and NO_2 was performed using time-series analysis for high pollution

days. Time-series values used for this analysis included: the 1-hour and 8-hour averaged concentration values for ozone and CO; 1-hour and 24-hour averaged concentration values for particulate matter; and annual and 24-hour averaged concentration for SO_2, NO_2.

- Air pollution data were analyzed to identify exceedances during the entire monitoring period. High concentration episodes occurring during the study period were also identified and analyzed.
- Monthly, weekly, and diurnal distributions of air pollution concentrations were analyzed.
- The Kolmogorov-Zurbenko (KZ) filter analysis was employed on the monitoring data to evaluate trends, variance, and long-term, short-term, and seasonal components of the air pollutants.
- Air pollution data were analyzed using correlation techniques to identify spatial relationship between the selected sites.
- Correlation analysis between the 1-hour and 8-hour average concentrations of ozone and CO were used to evaluate and estimate the climatological equivalencies between these concentrations.
- Regional high ozone levels were studied from the historical dataset to evaluate high ozone episodes for selected urban sites in Ohio.

General Characterization

Ozone

The design value, the three-year average of the fourth highest 8-hour ozone value, is a component of the episode selection process used by USEPA. This value is useful in evaluating and contrasting exceedances for each site and for comparing each site's design value and the highest exceedance value for each day in a particular episode. The design values for ozone from the nine monitoring sites were analyzed to evaluate the exceedances from 1992 to 2000.

The number of exceedance days for the 1-hour ozone NAAQS is shown in Table III.1.4. As can be seen from the table, the number of exceedance days for the one-hour ozone NAAQS in three consecutive years did not violate the standard during the period from 1992 to 2000 with one exception: Marietta.

Table III.1.4. Number of exceedance days for 1-hour NAAQS ozone standard.

	92-94	93-95	94-96	95-97	96-98	97-99	98-00
Cincinnati	0	1	1	1	0	0	0
Dayton	1	1	0	1	1	2	2
Columbus (Maple Canyon)	0	0	0	0	0	0	0
Columbus (Chesapeake)	1	1	1	1	0	0	
Akron	0	0	0	0	0	1	1
Marietta	4	2	1	0	1	1	1
Toledo	1	2	1	1	0	0	0
Steubenville	1	1	1	0	0	0	0

The trend of the ozone design value is illustrated in Figures III.1.2. through III.1.9. As these figures show, all sites did not attain the 8-hour NAAQS for ozone except Cleveland and Steubenville. The Cleveland site has consistently monitored ozone below the 8-hour averaged NAAQS for ozone. Toledo, Marietta, Cincinnati, Dayton, Maple Canyon, Akron, and the Marietta site have had measurements consistently above the 8-hour average NAAQS for ozone. Annual maximum 1-hour and 8-hour average ozone values from 1992 to 2000 are presented in the Appendix D.

The ozone season in Ohio starts in April and ends in October and the Ohio EPA monitors ozone during this season. In this study, the threshold ozone values for the exceedance analysis employed 125 ppb for the 1-hour ozone standard value and 85 ppb for the 8-hour ozone standard value. The total number of days exceeding eight-hour threshold level, grouped by month, is shown in Table III.1.5.

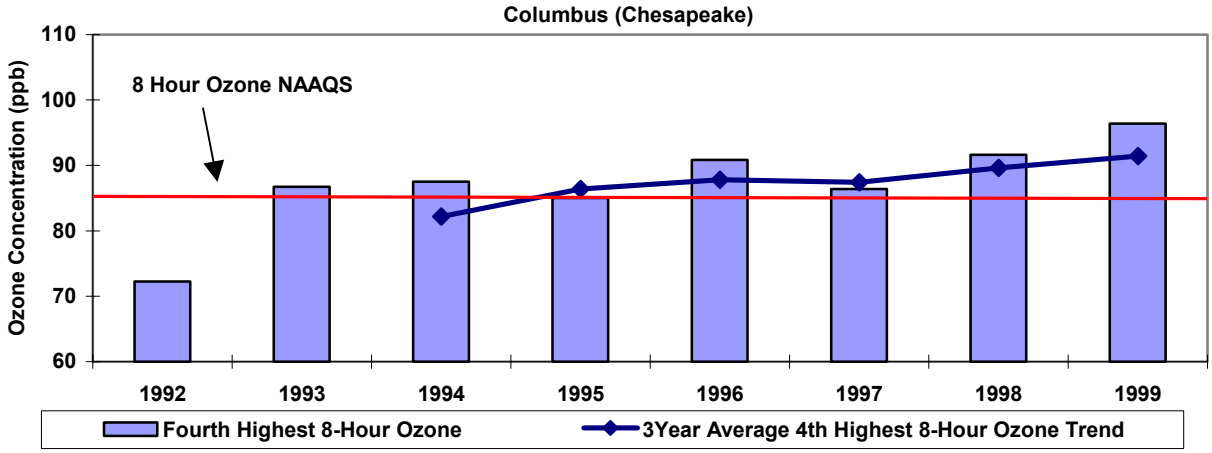


Figure III.1.2. Fourth Highest 8-hour Averaged Ozone Concentration, Columbus (Chesapeake)

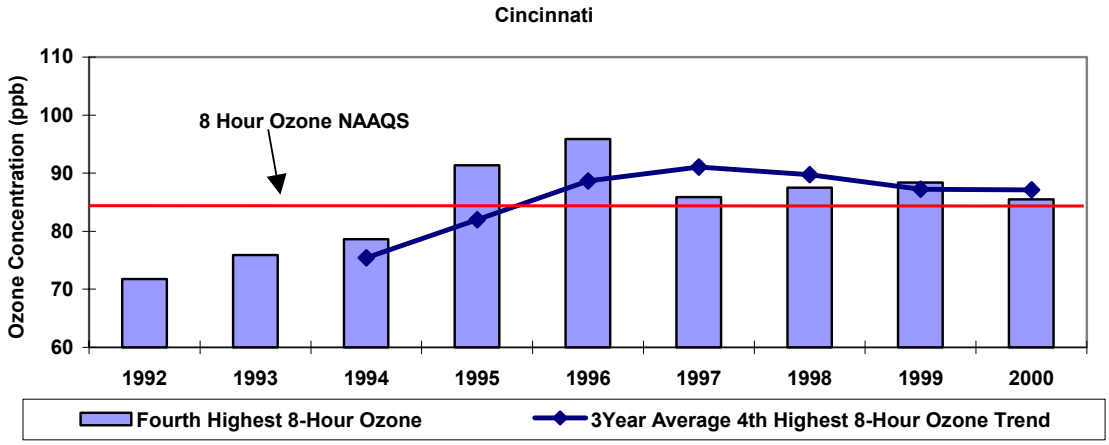


Figure III.1.3. Fourth Highest 8-hour Averaged Ozone Concentration, Cincinnati

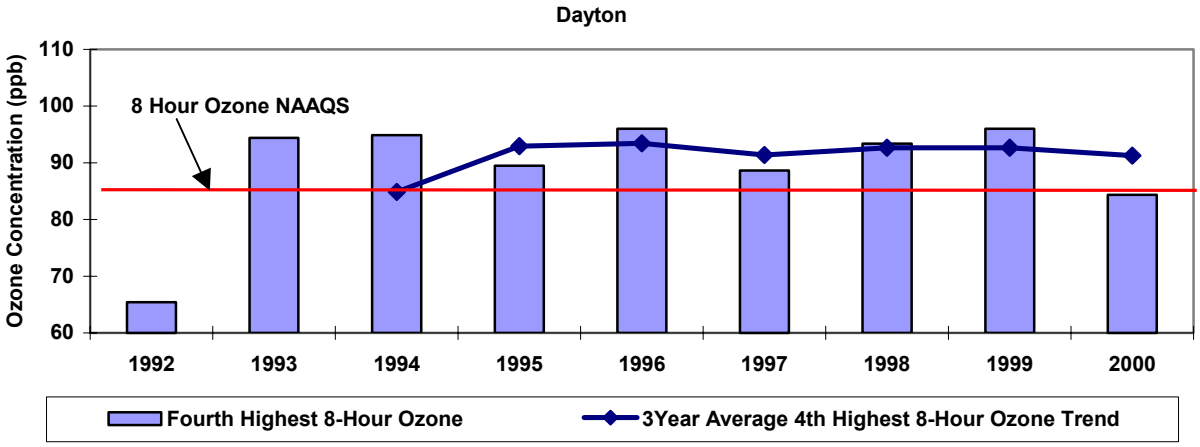


Figure III.1.4. Fourth Highest 8-hour Averaged Ozone Concentration, Dayton

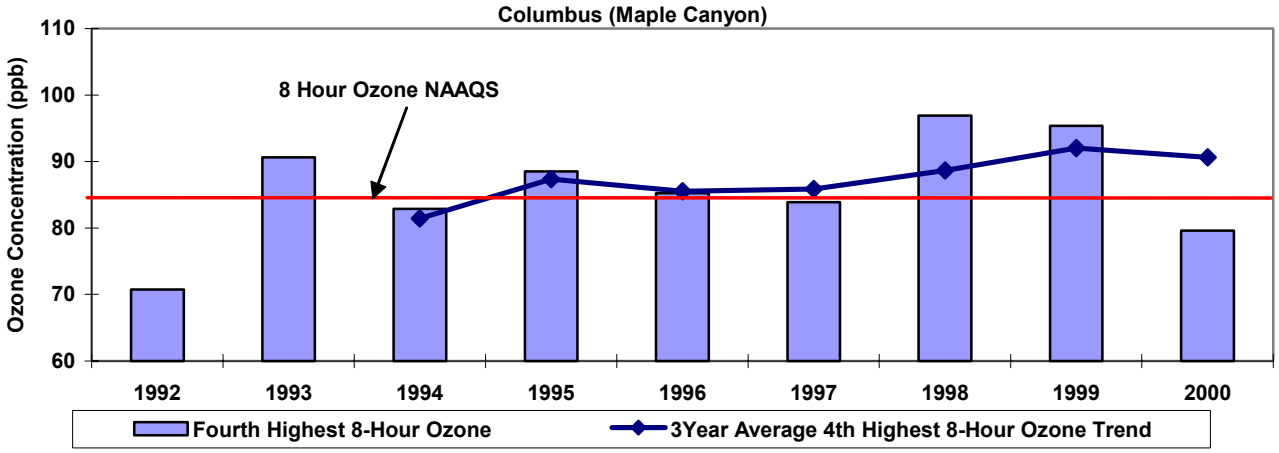


Figure III.1.5. Fourth Highest 8-hour Averaged Ozone Concentration, Columbus (Maple Canyon)

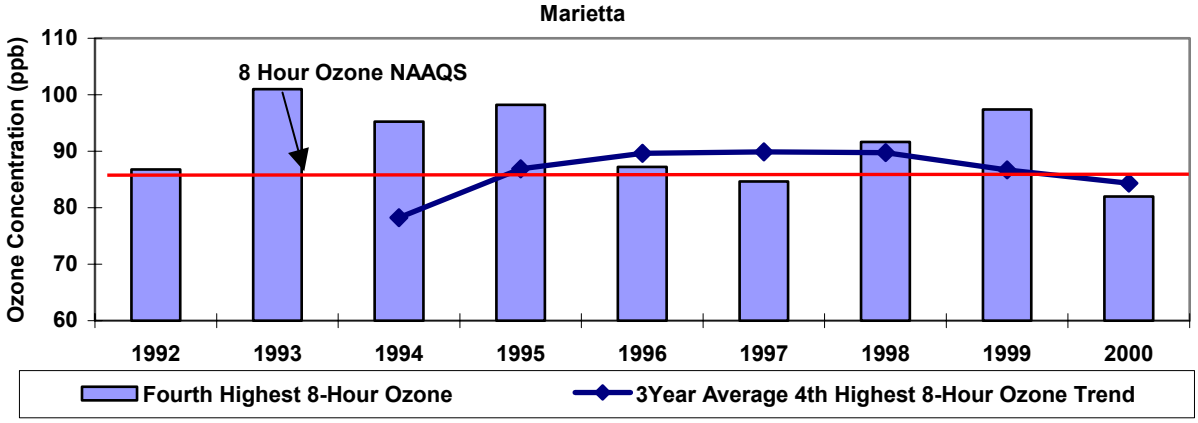


Figure III.1.6. Fourth Highest 8-hour Averaged Ozone Concentration, Marietta

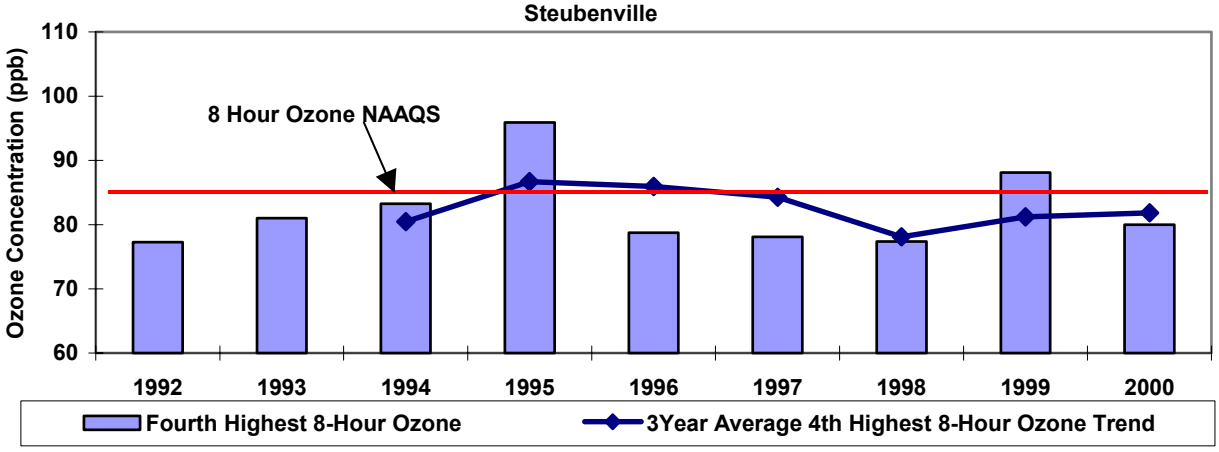


Figure III.1.7. Fourth Highest 8-hour Averaged Ozone Concentration, Steubenville

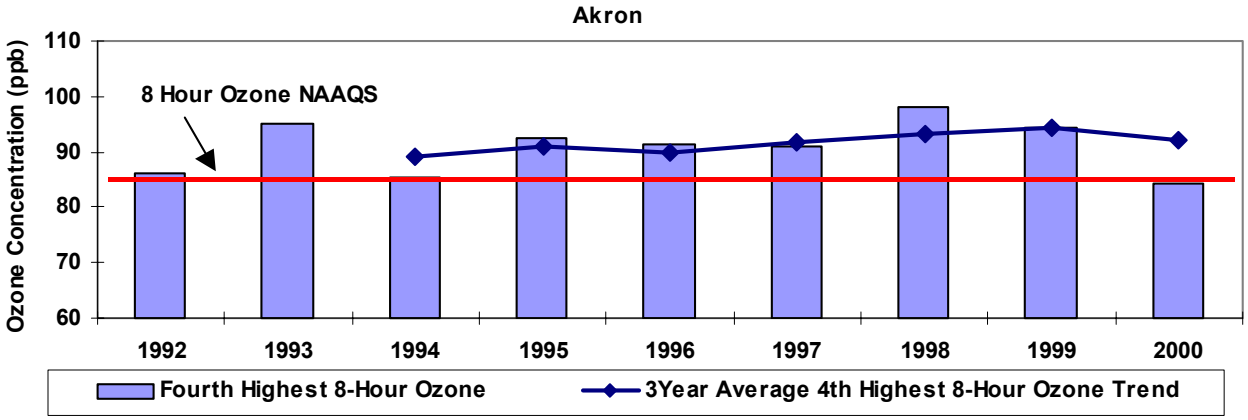


Figure III.1.8. Fourth Highest 8-hour Averaged Ozone Concentration, Akron

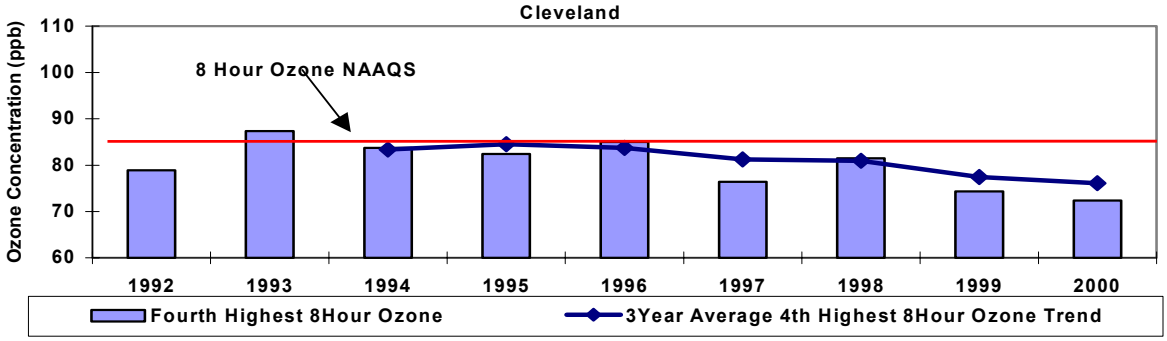


Figure III.1.9. Fourth Highest 8-hour Averaged Ozone Concentration, Cleveland

Table III.1.5 shows that the highest number of the 8-hour ozone exceedances occurs during the months of June and July and it appears that the ozone season typically begins in May and lasts for five months until September. The highest frequency of high 8-hour ozone in Cleveland occurs in July. Marietta has the highest frequency of exceedances during June and August. The frequency of days exceeding the 1-hour threshold level is plotted in Figure D.1. in Appendix D. One-hour ozone exceedances are very rare when compared to the 8-hour ozone exceedances shown in Table III.1.5.

Table III.1.5. High ozone days exceeding 8-hour threshold level, 1992-2000

	April	May	June	July	August	Sept.	Oct.
Cincinnati	0	2	15	10	5	1	0
Dayton	0	8	23	21	13	1	0
Columbus (Maple Canyon)	0	5	17	11	10	2	0
Columbus (Chesapeake)	0	6	20	13	16	5	0
Akron	0	9	28	17	16	3	0
Cleveland	0	1	4	9	6	0	0
Marietta	0	15	24	9	24	3	1
Toledo	0	3	14	10	7	5	0
Steubenville	0	0	11	11	7	0	0

Particulate Matter (PM_{10})

Annual averaged PM_{10} values are shown in Figure III.1.10. None of the five sites violate the NAAQS PM_{10} standard of 50 µg/m^3. All sites except Columbus (Chesapeake) showed decreasing trends during 2000. The NAAQS PM_{10} standard considers 24-hour averaged PM values. Twenty-four-hour averaged PM_{10} values at the five sites during 1992-2000 are shown in Figure D.2 in Appendix D.

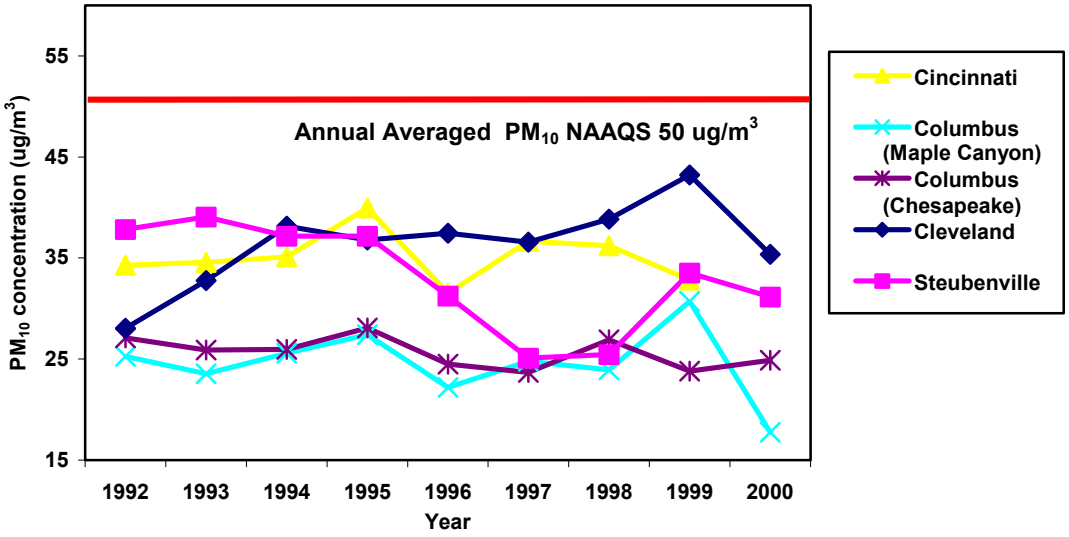


Figure III.1.10. Annual Averaged PM_{10} in 1992-2000

Carbon Monoxide

Figure III.1.11 shows the trend lines of the 8-hour averaged CO concentration during 1992-2000. Significant reductions in the ambient CO concentrations are observed at all sites in Ohio. The annual second highest values were used to determine the trend line. None of the six sites violated the CO NAAQS of 9 ppm. Furthermore, Cincinnati, Dayton, Akron and Cleveland showed decreasing trends through 2000. Eight-hour averaged CO levels of Cincinnati, Dayton, Columbus (Chesapeake), Akron and Cleveland were reduced by over 44%, 28%, 37%, 50% and 46%, respectively since 1992. Trend lines of the one-hour averaged CO concentrations are shown in Figure D.3, Appendix D.

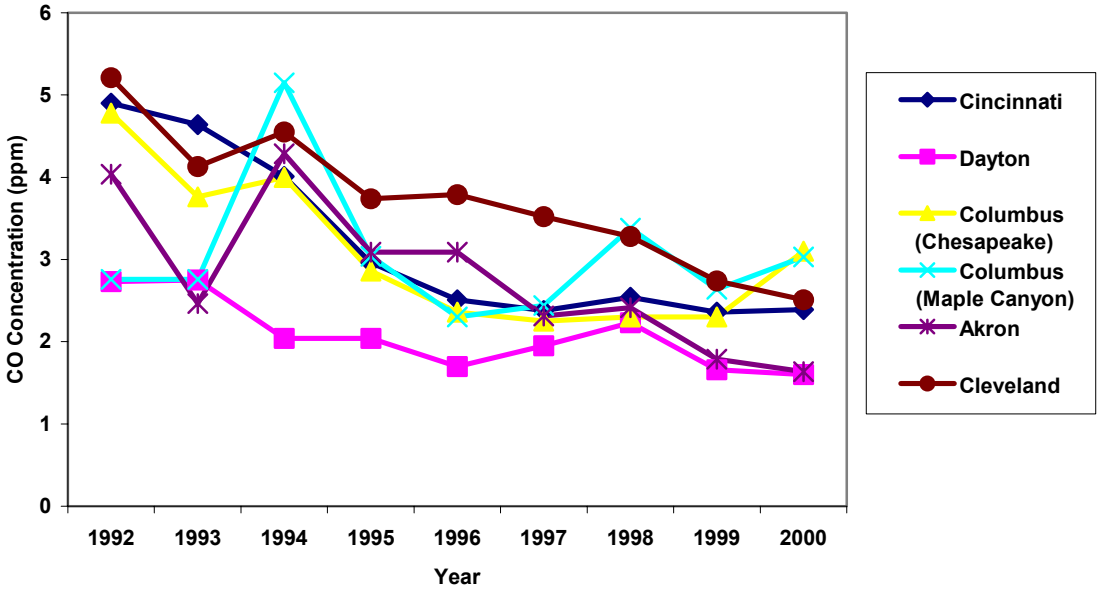


Figure III.1.11. Second Highest 8-hour Averaged CO in 1992-2000

Sulfur Dioxide

The trend lines of the annual mean SO_2 concentration during the period 1992-2000 are shown in Figure III.1.12. Significant reductions in the ambient SO_2 levels were noted at all sites in Ohio. None of the six sites violated the NAAQS of 30 ppb for an annual mean. The SO_2 levels of Cleveland and Steubenville showed significant decreasing trends during the selected period and other sites show comparably decreasing trends between 1993 and 1995. Since 1992, there have been substantial reductions in measured annual mean SO_2 concentrations for Cincinnati (-58%), Dayton (-43%), Columbus (Chesapeake) (-65%), Cleveland (-37%), Akron (-52%) and Steubenville (-16%).

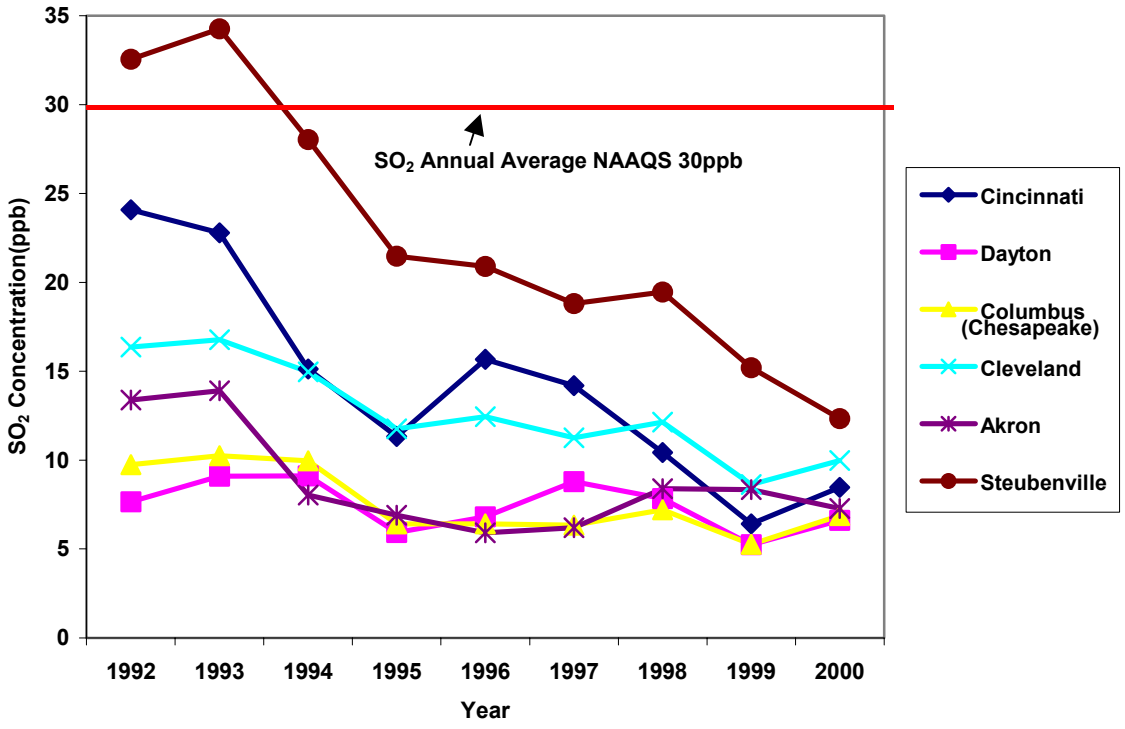


Figure III.1.12. Annual Averaged SO_2 in 1992-2000

Nitrogen Dioxide

Figure III.1.13. shows the trend lines of the eight-hour averaged NO_2 concentrations during 1992-1998. There were slight increasing trends in NO_2 levels for Cincinnati. Cleveland experienced a slight decrease during the study period with the exception of 1997 and 1998. Steubenville experienced relatively constant concentrations with the exception of 1992 and 1997. It was noted that NO_2 concentrations at the Steubenville site are relatively lower than other two sites.

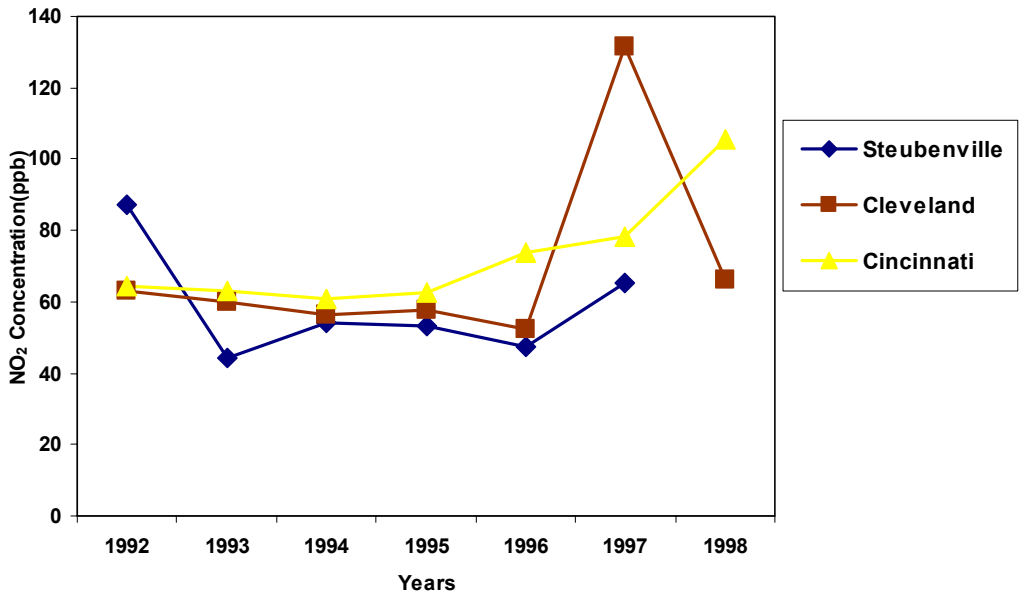


Figure III.1.13. Second Highest 8-hour Averaged NO_2 in 1992-2000

Monthly Analysis

$PM_{10,}$ CO, SO_2 and NO_2 percentile distributions representing monthly maximum, minimum, mean, and mean plus and minus standard deviation values at the five sites are illustrated in Figures III.1.14. through III.1.16. These monthly PM_{10} distributions show that the mean PM concentrations were high during the summer months and low during the winter months. Monthly 8-hour average CO distribution in Figures III.1.17. through Figures III.1.19. show that the 8-hour average CO concentrations were high during the winter months and low during the summer months. The 8-hour average SO_2 and NO_2 concentrations were high during the winter months and low during the summer months as shown in Figures III.1.20. and III.1.24.

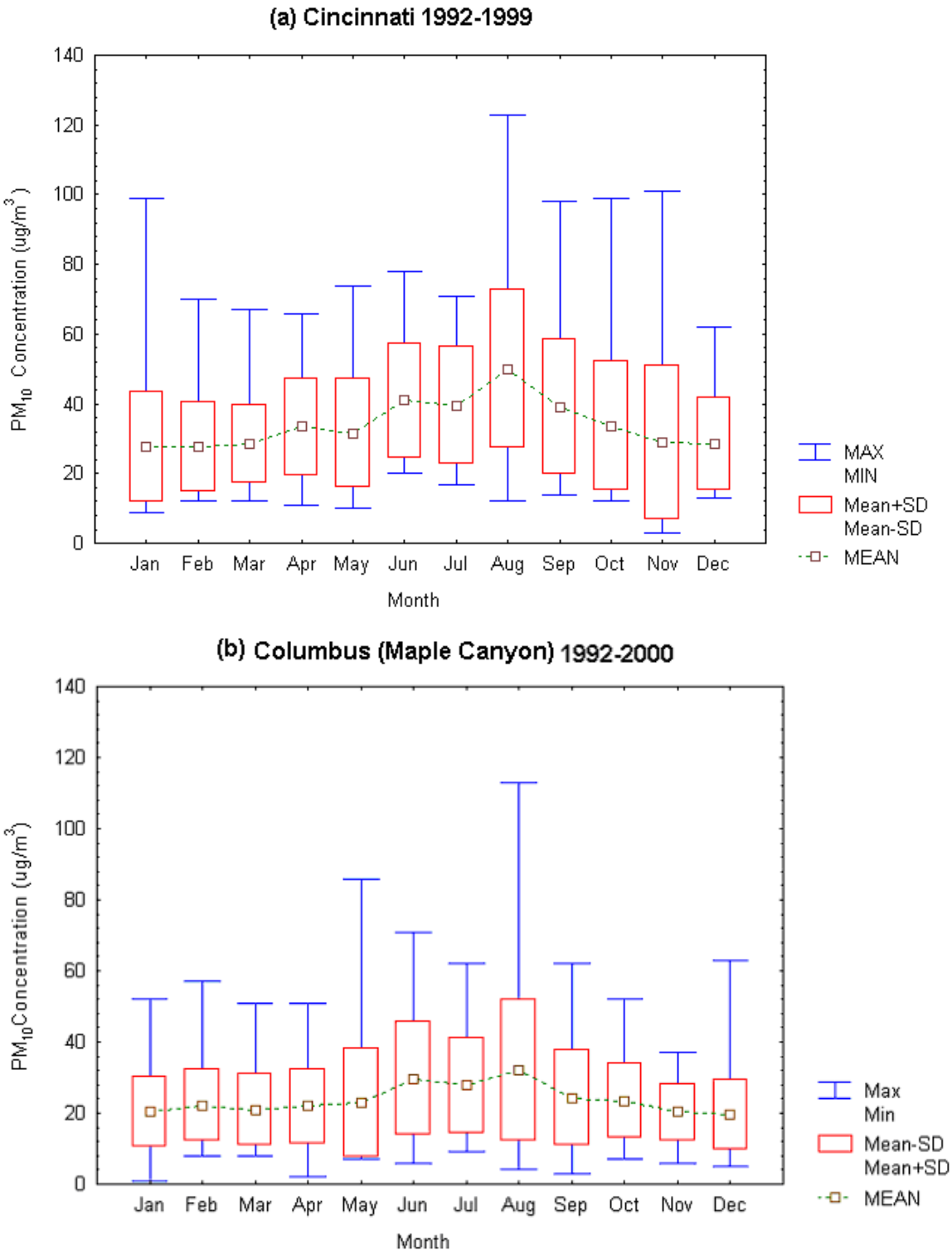
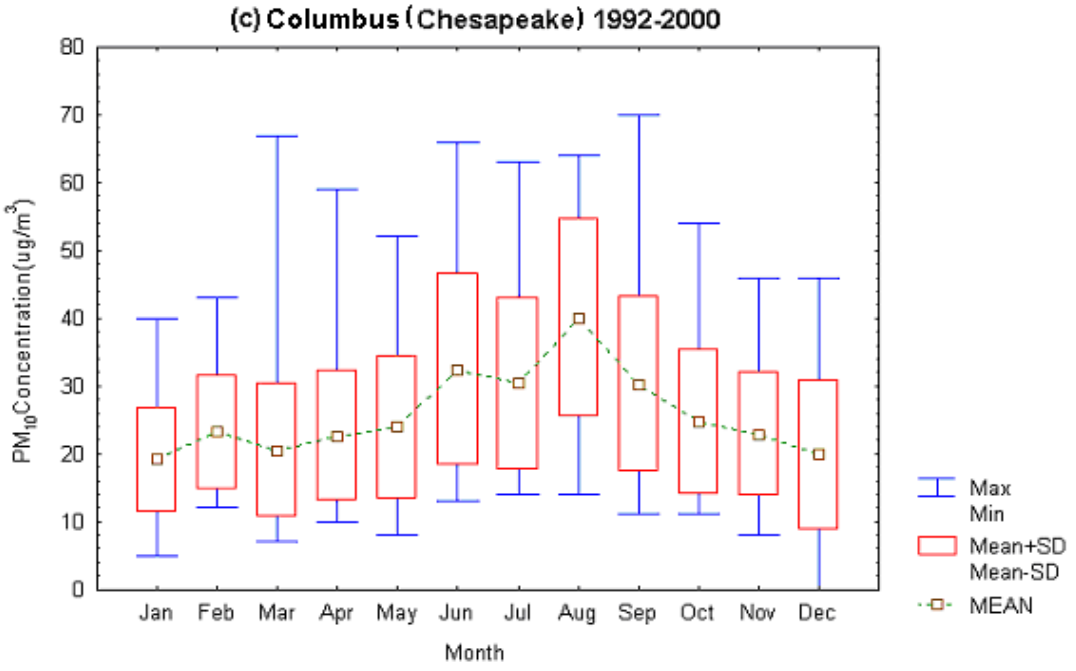


Figure III.3.14. Monthly PM_{10} distribution in: (a) Cincinnati, 1992-1999 and (b) Columbus (Maple Canyon), 1992-2000



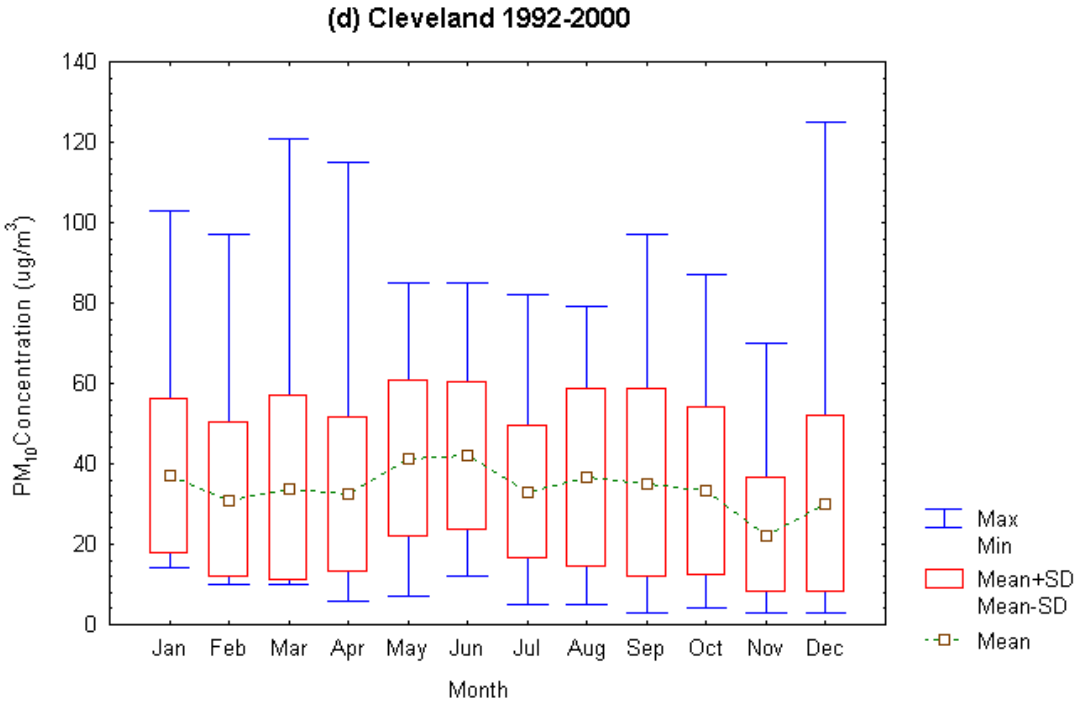


Figure III.1.15. Monthly PM_{10} distribution in 1992-2000: (c) Columbus (Chesapeake) and (d) Cleveland

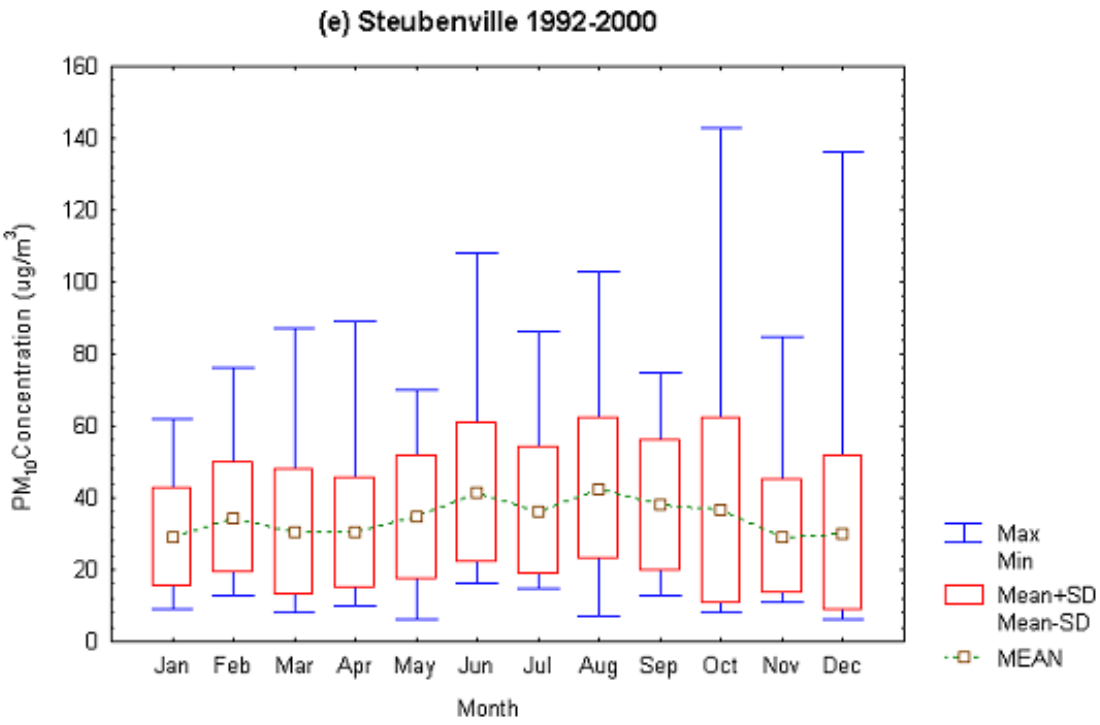


Figure III.1.16. Monthly PM_{10} distribution in 1992-2000: (e) Steubenville

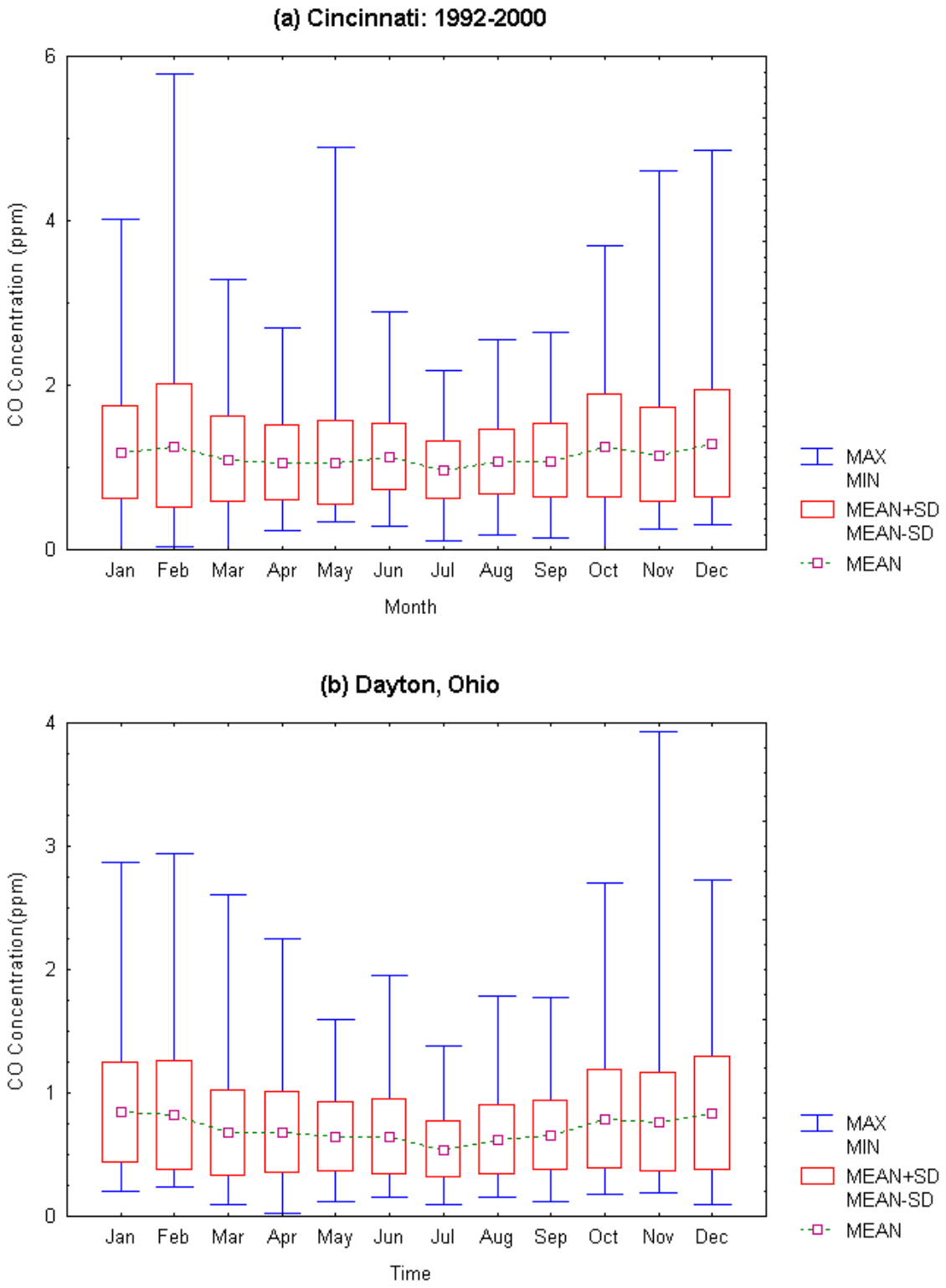
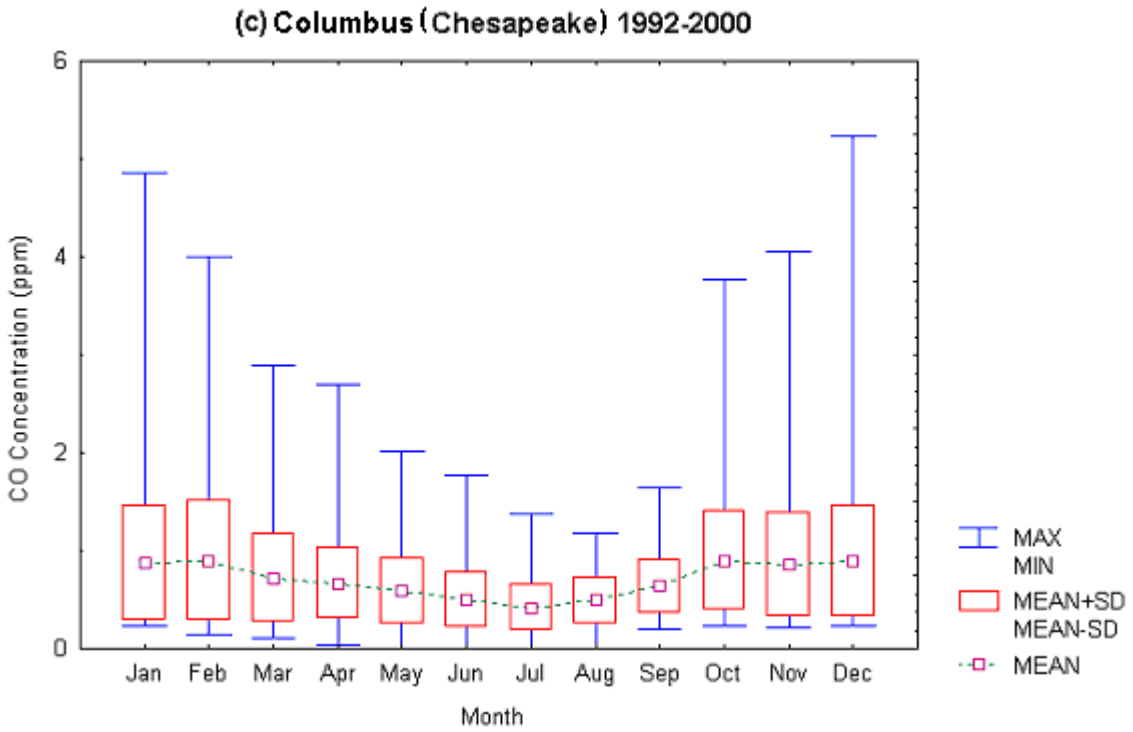


Figure III.1.17. Monthly 8-hour average CO distribution in 1992-2000: (a) Cincinnati and (b) Dayton



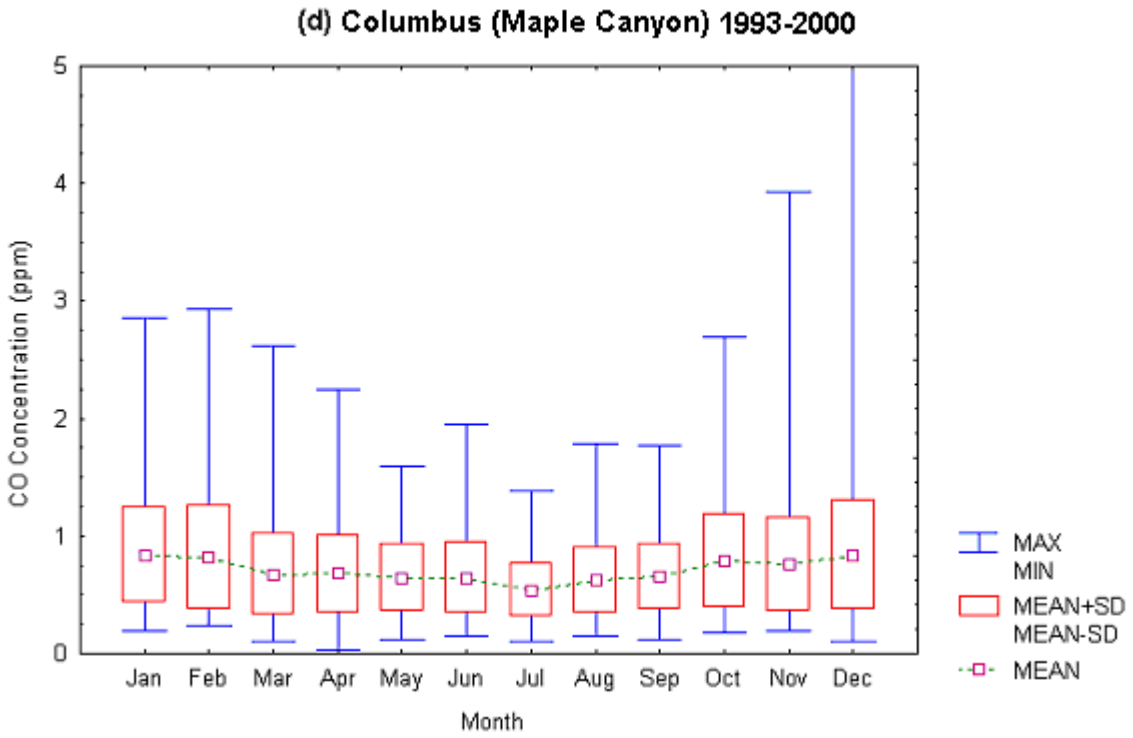


Figure III.1.18. Monthly 8-hour average CO distribution in: (c) Columbus (Chesapeake), 1992-2000 and (d) Columbus (Maple Canyon), 1993-2000

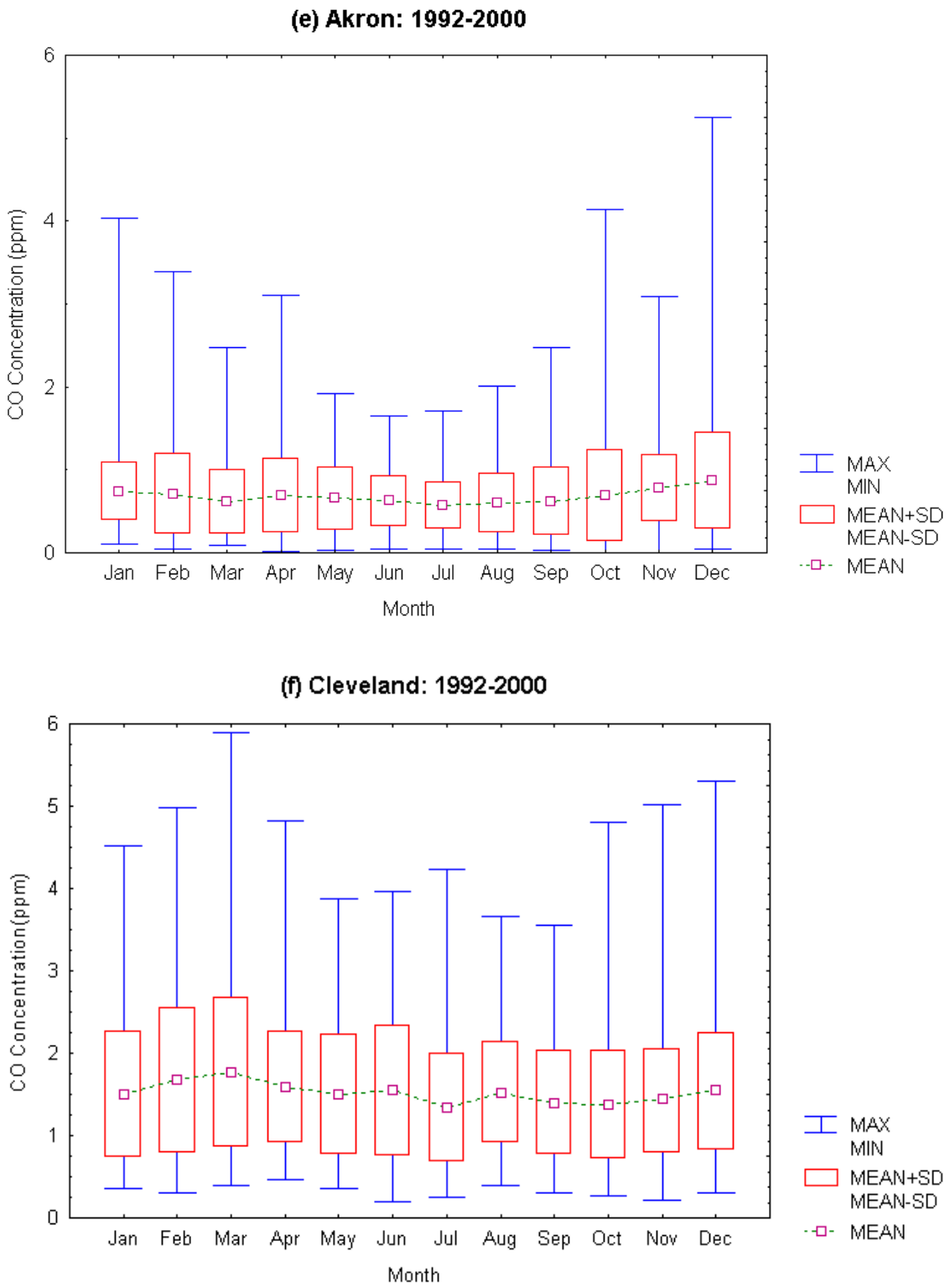


Figure III.1.19. Monthly 8-hour average CO distribution in 1992-2000: (e) Akron and (f) Cleveland

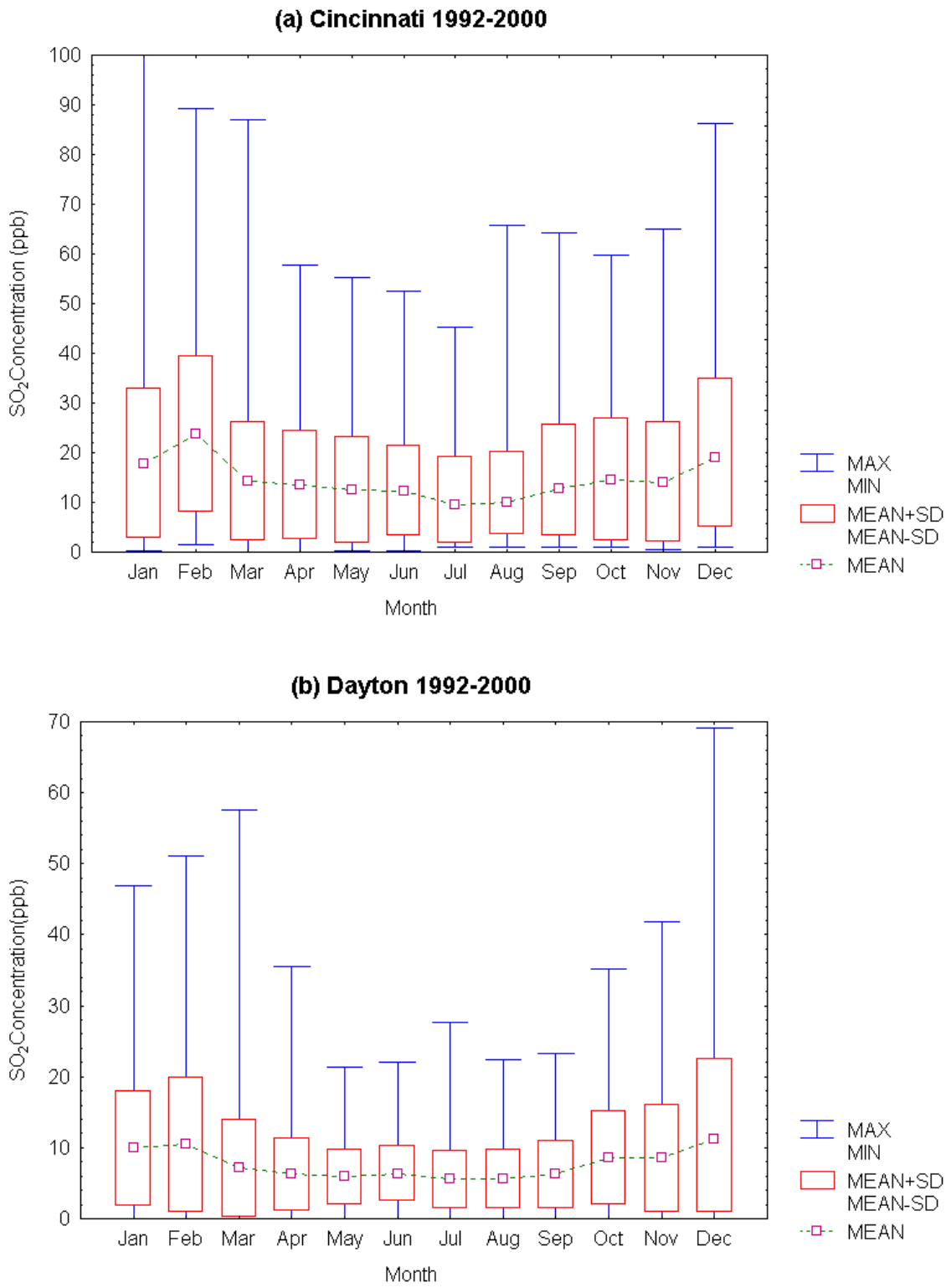
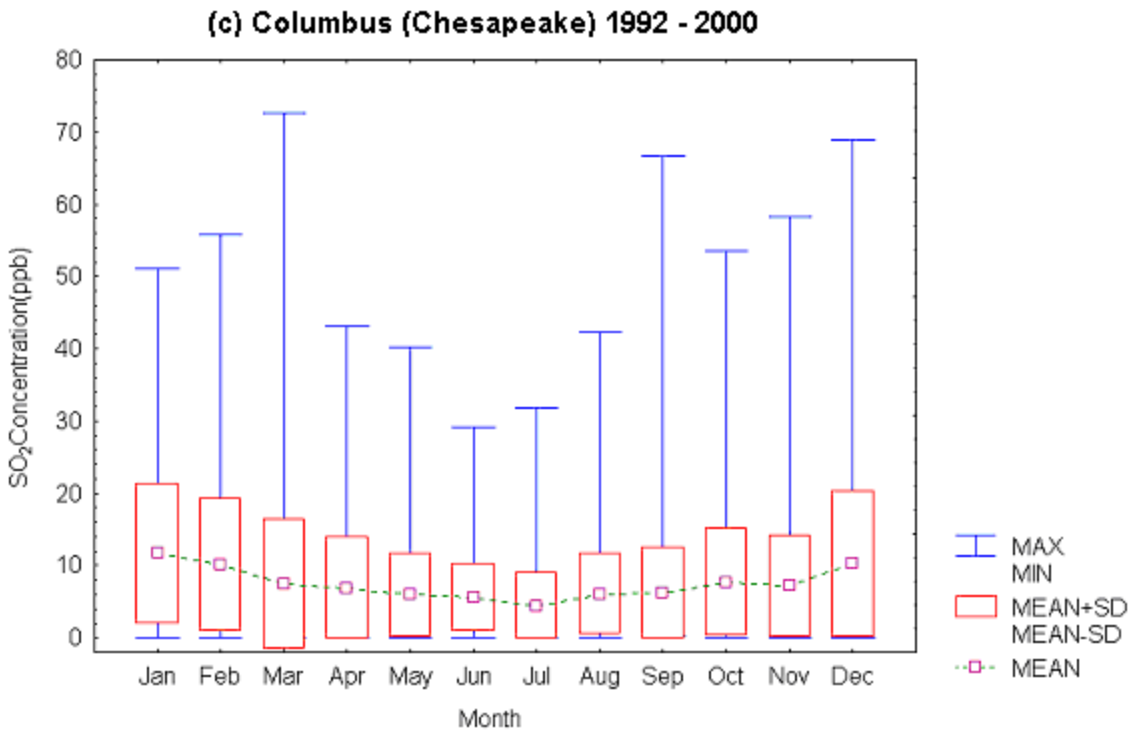


Figure III.1.20. Monthly 8-hour average SO_2 distribution in 1992-2000: (a) Cincinnati and (b) Dayton



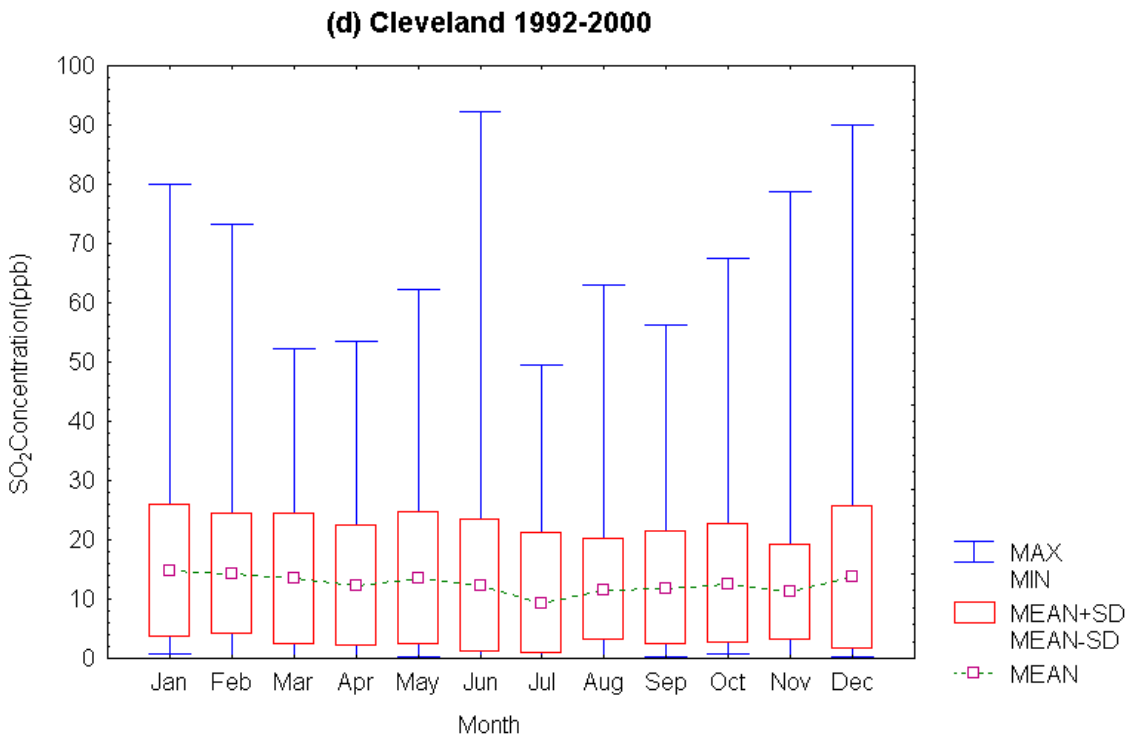


Figure III.1.21. Monthly 8-hour average SO_2 distribution in 1992-2000: (c) Columbus (Chesapeake) and (d) Cleveland

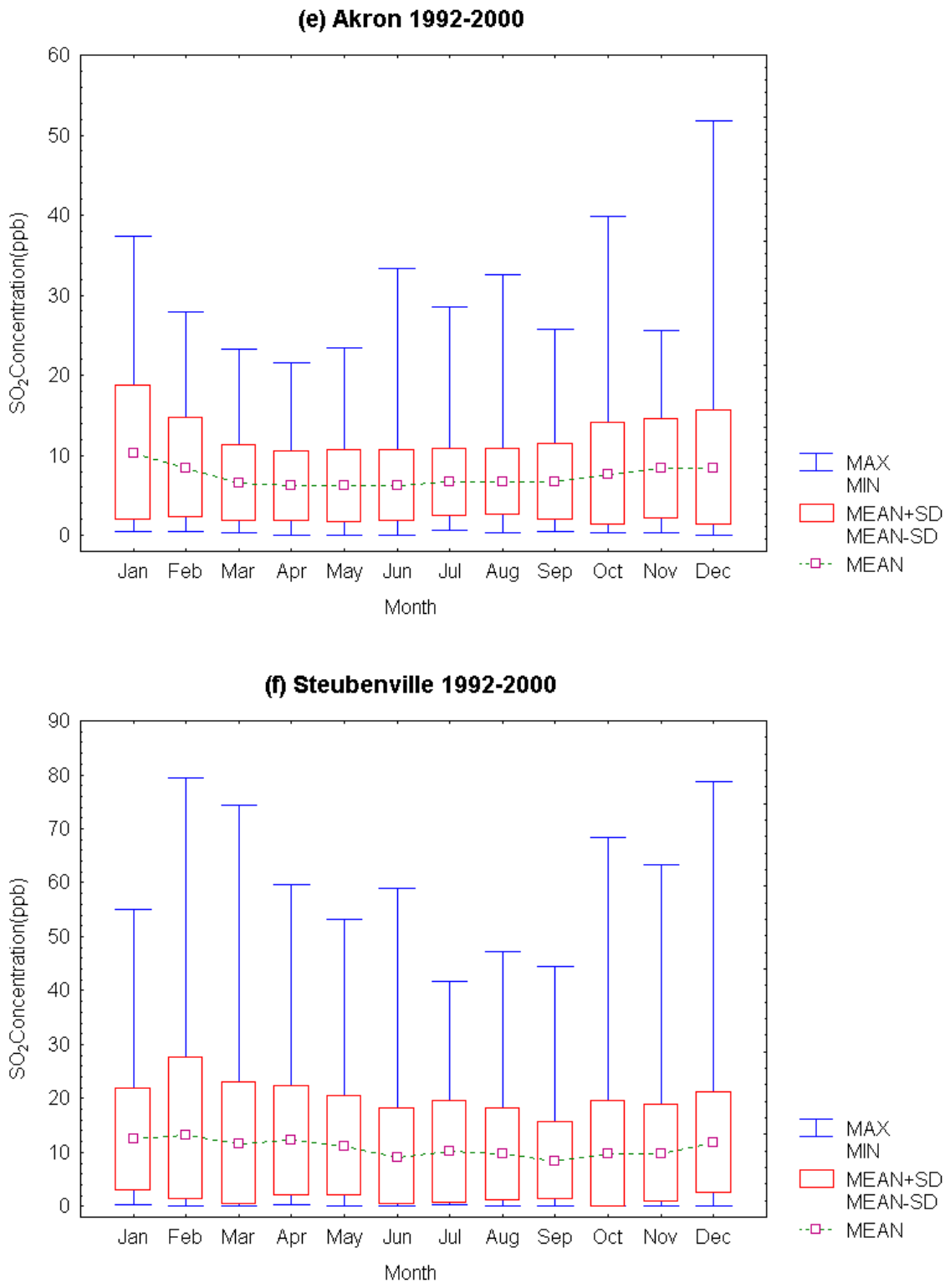


Figure III.1.22. Monthly 8-hour average SO_2 distribution in 1992-2000: (e) Akron and (f) Steubenville

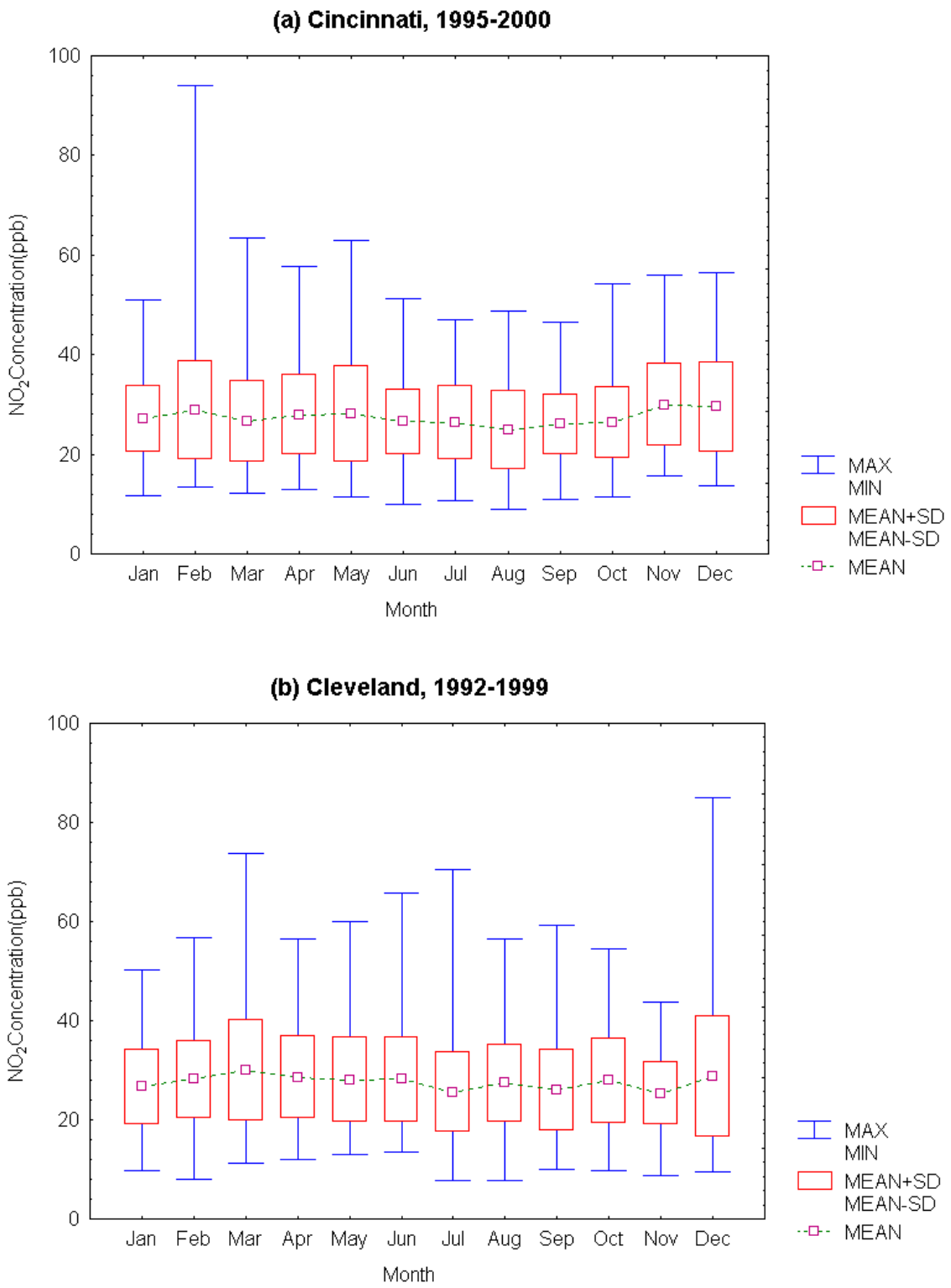


Figure III.1.23. Monthly 8-hour average NO_2 distribution in: (a) Cincinnati 1992-2000 and (b) Cleveland, 1992-1999

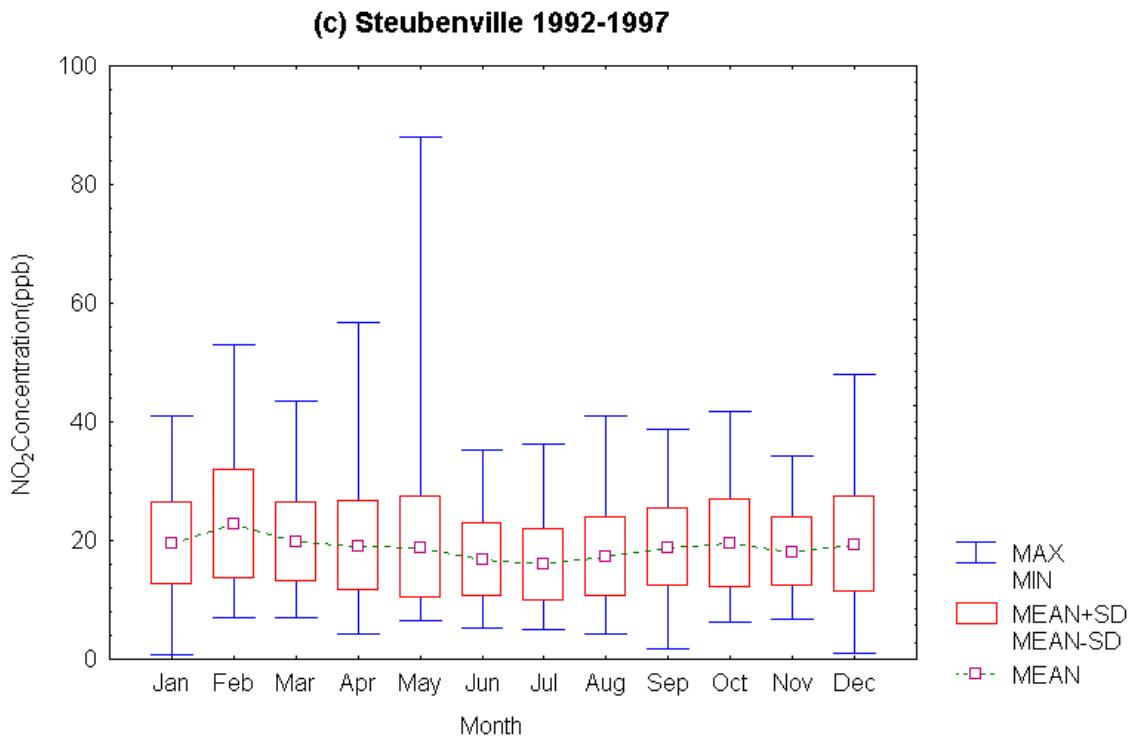


Figure III.1.24. Monthly 8-hour average NO_2 distribution in: (c) Steubenville, 1992-1997

Weekly Distribution

Ozone

The percentage of occurrences, or frequency, of ozone levels exceeding the 8-hour NAAQS by day of the week is presented in Figures III.1.25. through III.1.29. The frequency of exceedances by day of the week varies with each site. The highest frequency of exceedances was observed during weekend days rather than weekdays. Cincinnati showed the lowest frequency of exceedances on Tuesday and Wednesday and the highest occurring on Thursday through Sunday.

The Dayton site showed the lowest frequency of exceedances on Tuesday and the highest on Friday. Data recorded in Dayton indicate that a high frequency of exceedances occur on Monday and then fluctuate throughout the week. The Columbus (Maple Canyon) shows a moderate level early in the week and the highest frequency of exceedances on the two weekend days. However, this site showed a low frequency on Friday, which makes Columbus (Maple Canyon) stand out among the sites.

The Columbus (Chesapeake) site has a lower frequency of exceedances earlier in the week with the number of exceedances increasing during the weekend. The highest frequency of exceedances at this site occurs on Sunday. The Cleveland site does not show any exceedance on Wednesday and it has three high frequency days on Thursday, Saturday, and Sunday. Also, this site had a lower frequency of exceedances on Friday as compared to Thursday, showing a similar trend noted at Columbus (Maple Canyon). The Toledo site posts the highest frequency of exceedances on Monday with lower frequencies during Tuesday through Thursday. A higher frequency of exceedances was also observed during the weekend days at Toledo.

The Akron site showed the lowest frequency on Monday and Wednesday and the highest frequency on Saturday. The Marietta site shows a very similar pattern to the Columbus (Chesapeake) site with lower frequency of exceedances on the weekdays with an increase through the weekend. The highest frequency level at this site also occurs on Sunday. The Steubenville site showed few exceedances on Monday and Sunday and the highest frequency occurred on Friday.

Particulate Matter (PM_{10})

The weekly PM_{10} distributions is shown in Figures III.1.30. through III.1.32. It is notable that the PM concentration during the weekend is lower than weekdays and that Mondays and Tuesdays typically have high PM concentrations that decrease gradually through the remainder of the weekdays. The exception was Steubenville in which the PM concentration gradually increased from Monday through Friday and then decreased through the weekend.

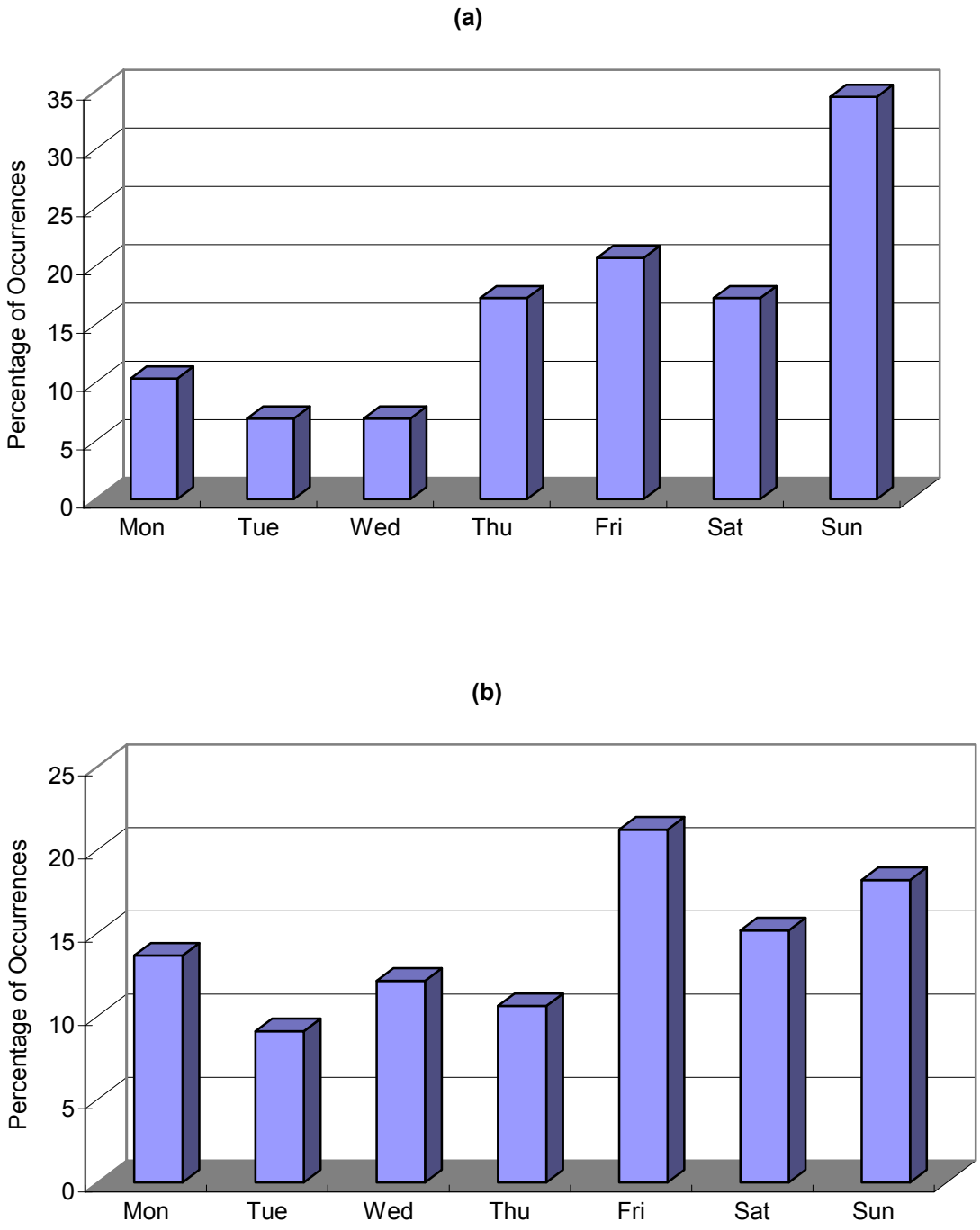


Figure III.1.25. High ozone occurrences by day of the week, 1992-2000: (a) Cincinnati and (b) Dayton

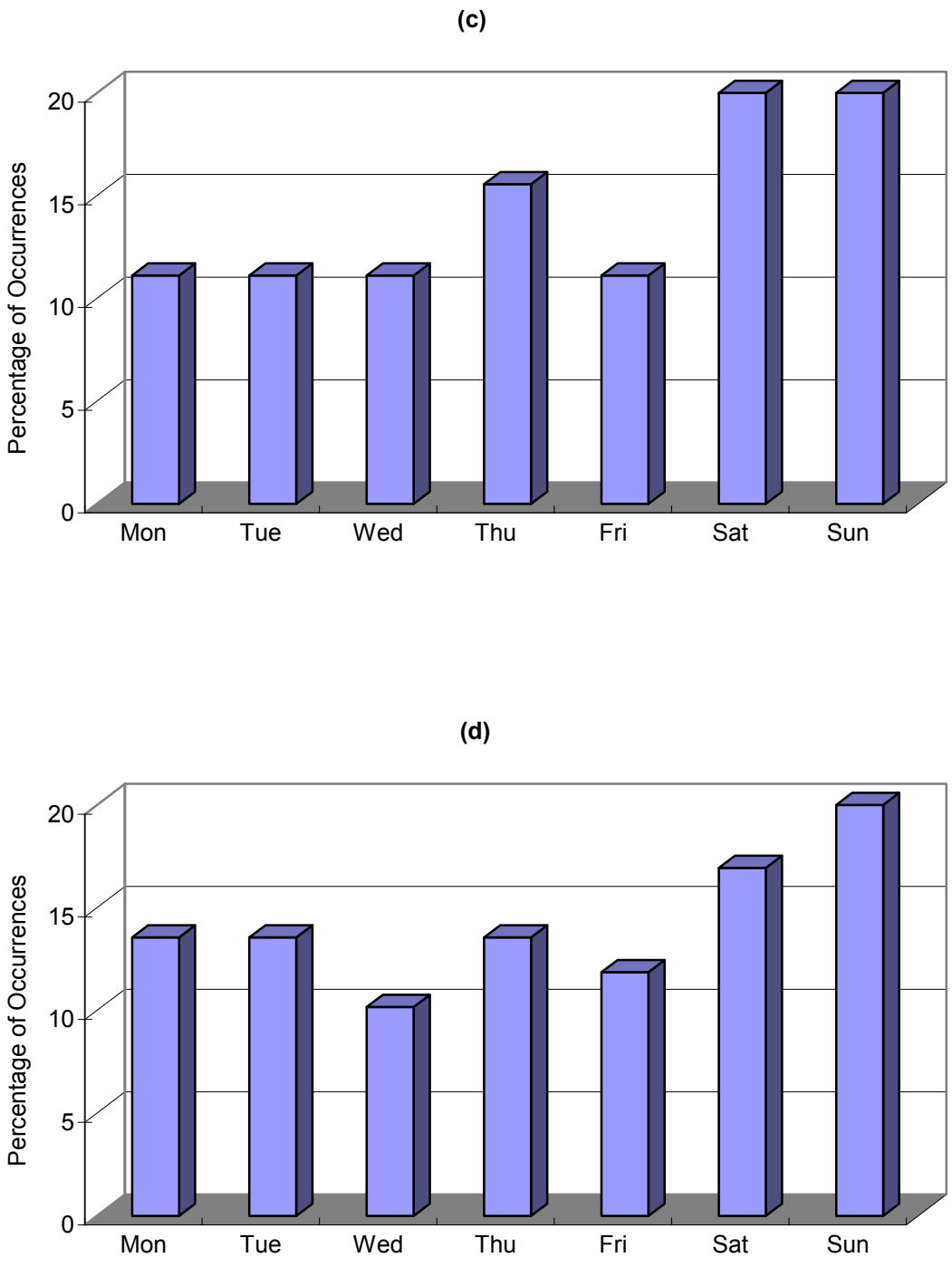


Figure III.1.26. High ozone occurrences by day of the week (c) Columbus (Maple Canyon), 1999-2000 and (d) Columbus (Chesapeake), 1992-1999

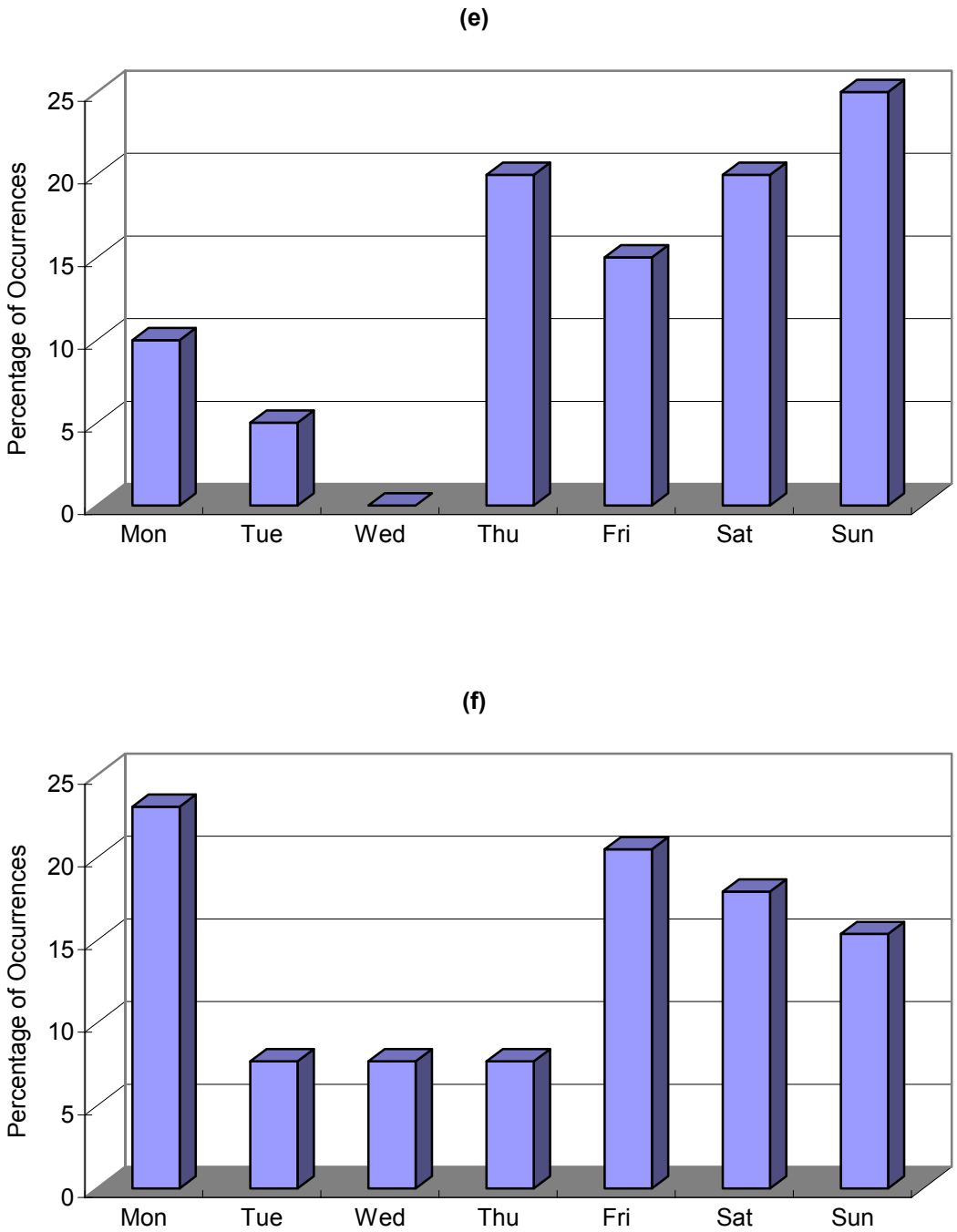


Figure III.1.27. High ozone occurrences by day of the week, 1992-2000: (e) Cleveland and (f) Toledo

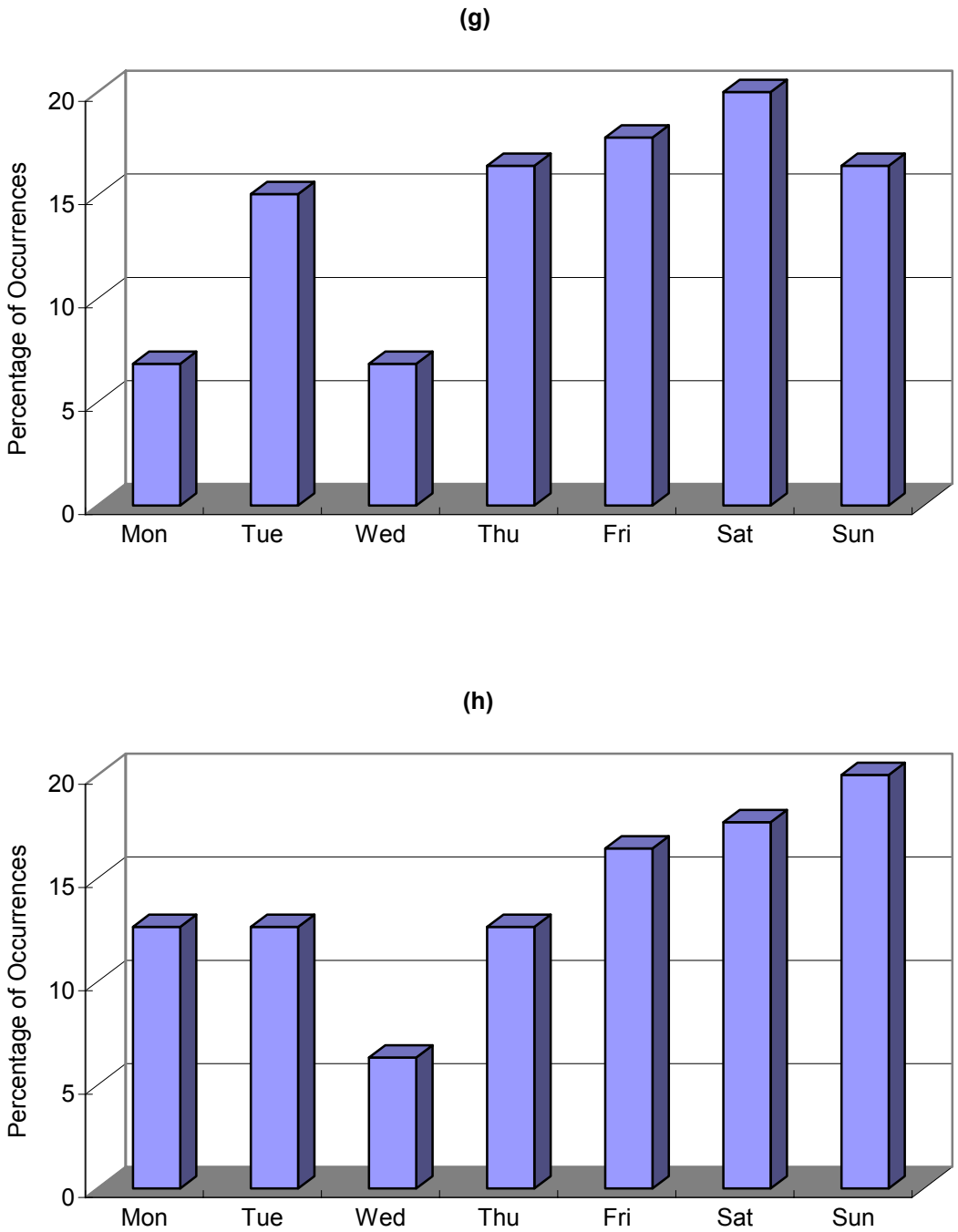


Figure III.1.28. High ozone occurrences by day of the week, 1992-2000 (g) Akron and (h) Marietta

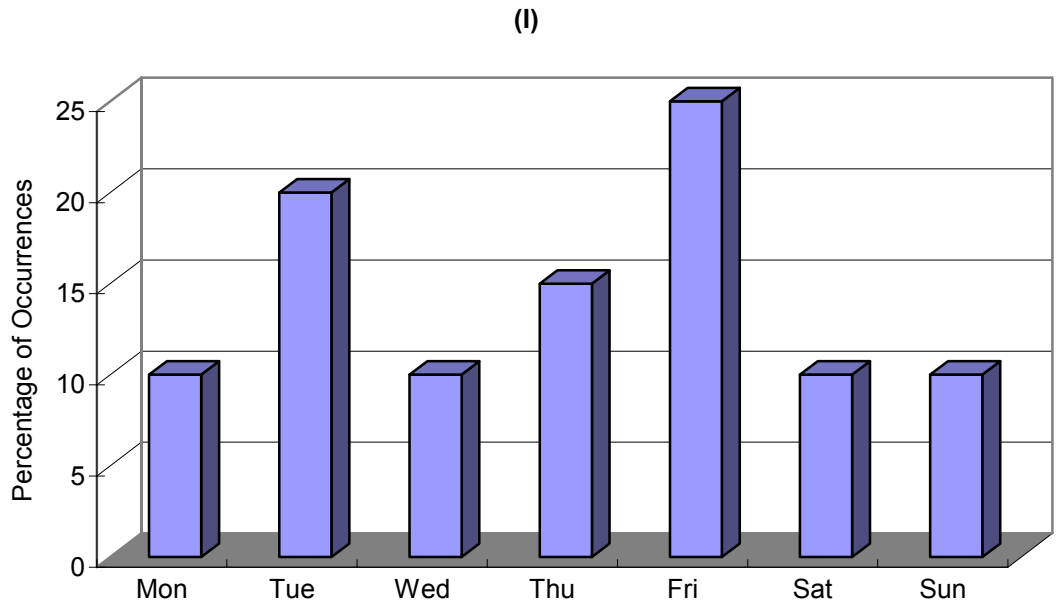


Figure III.1.29. High ozone occurrences by day of the week, (i) Steubenville, 1992-2000

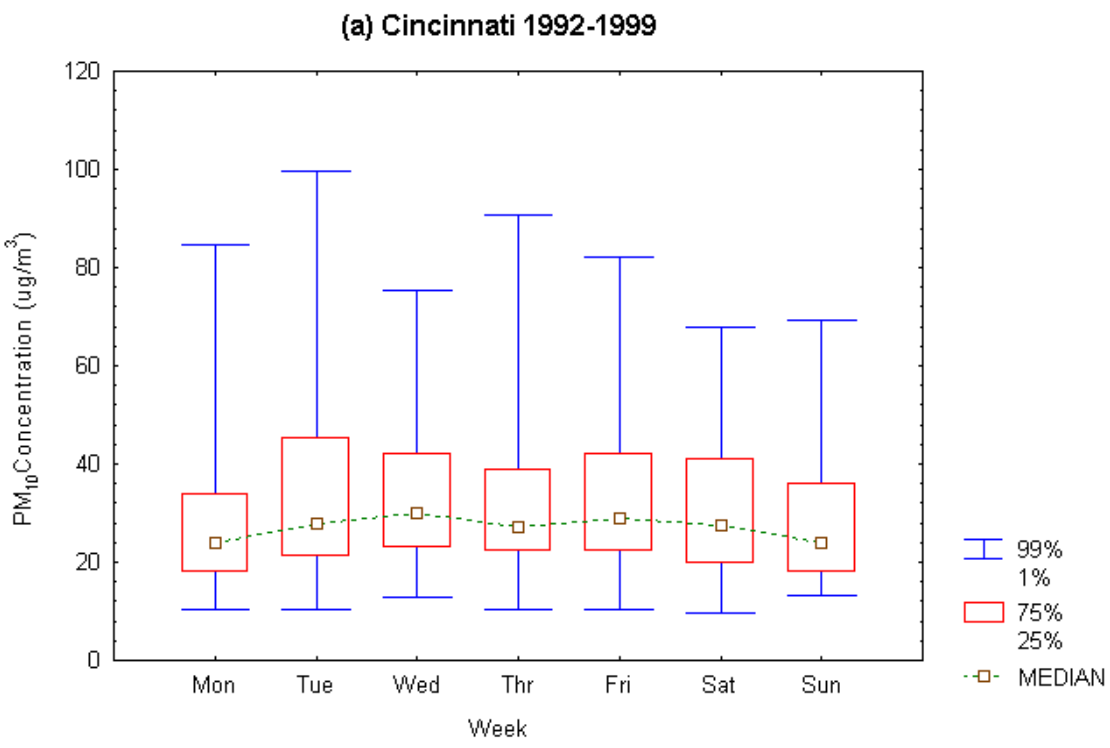


Figure III.1.30. Weekly PM_{10} distribution in 1992-1999: (a) Cincinnati

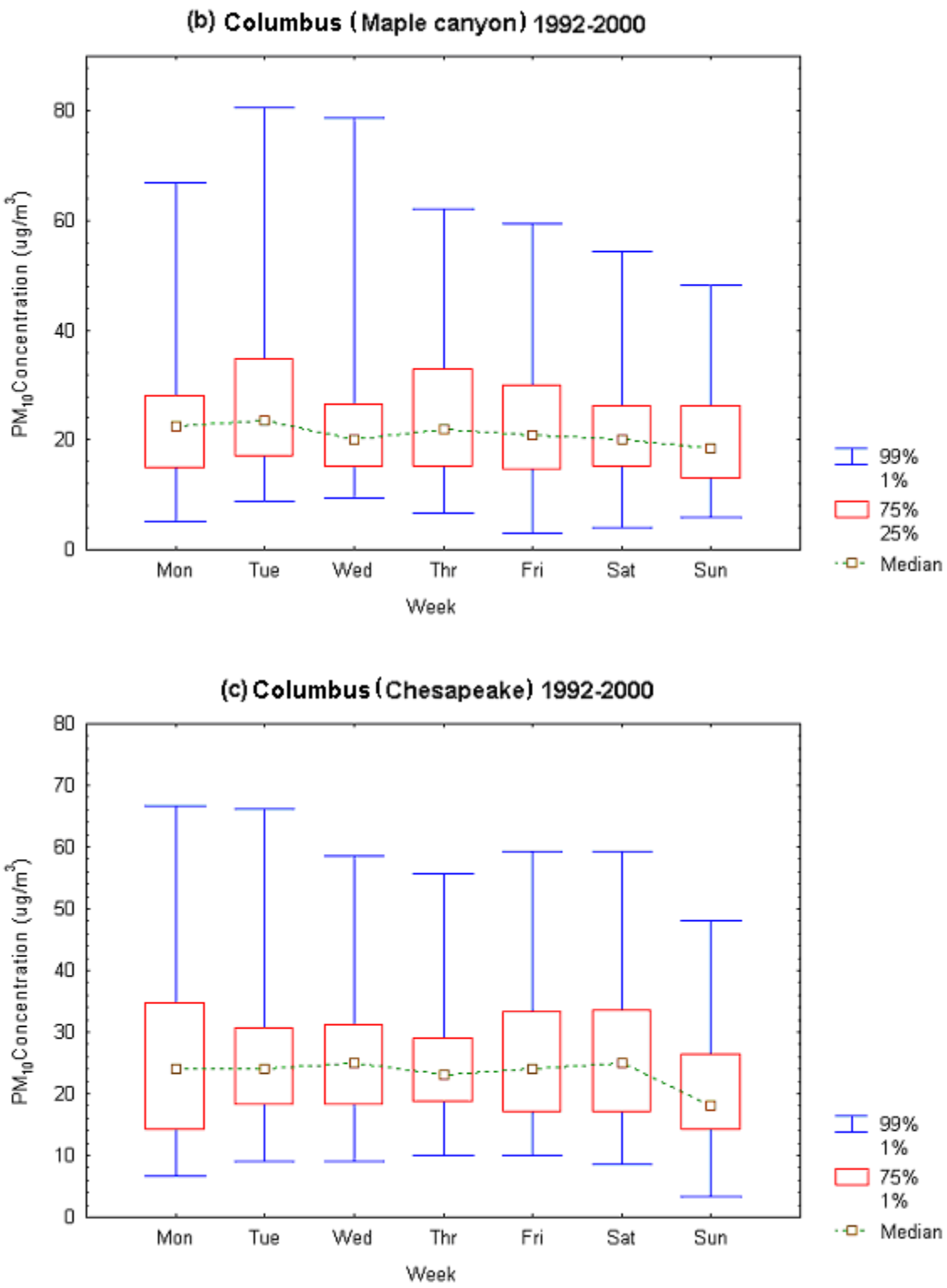
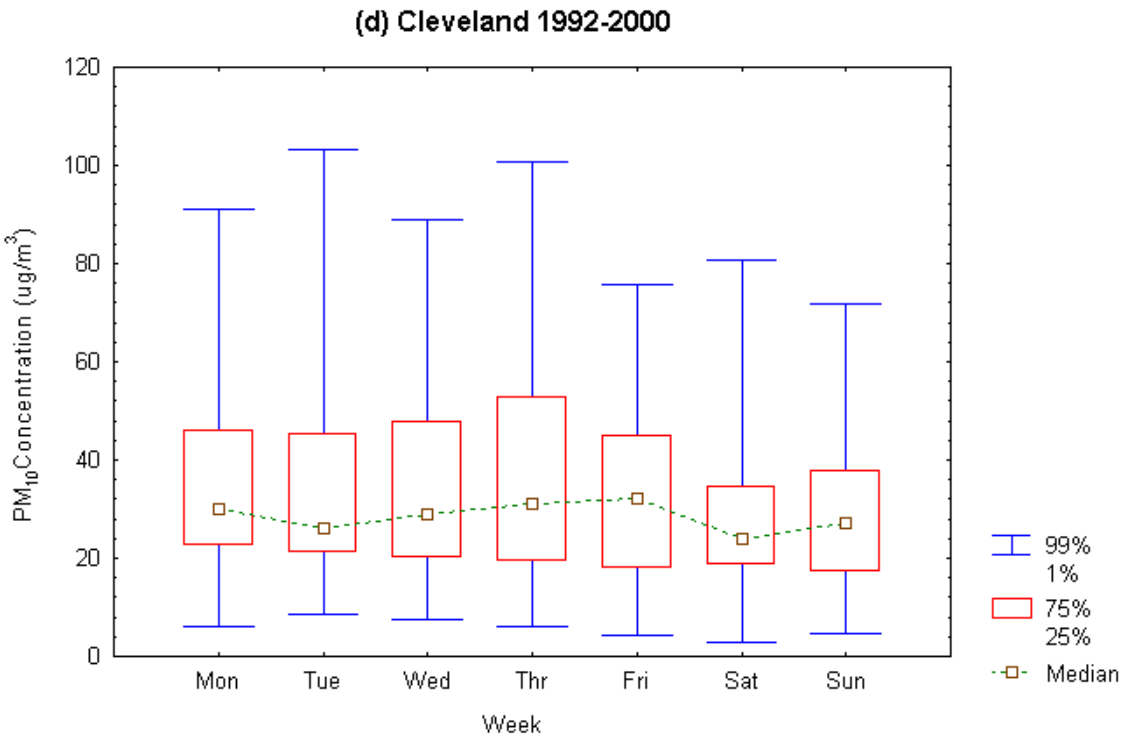


Figure III.1.31. Weekly PM_{10} distribution in 1992-2000: (b) Columbus (Maple Canyon) and (c) Columbus (Chesapeake)



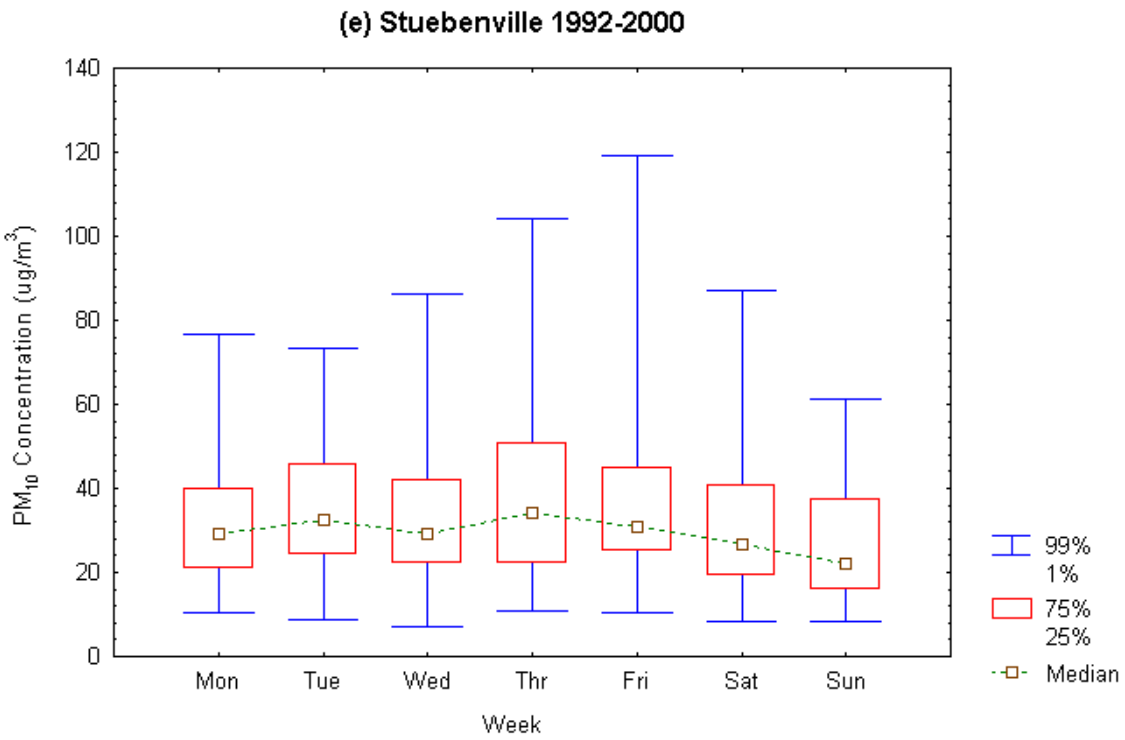


Figure III.1.32. Weekly PM_{10} distribution in 1992-2000: (d) Cleveland and (e) Steubenville

Time Series Analysis using KZ Filter

The Kolmogorov-Zurbenko (KZ) filter is a sound method to decompose time series into fluctuations of the desired time scales because of its powerful separation characteristics, simplicity, and the ability to handle missing data. [6] The KZ filter is based on an iterative moving average that removes high frequency (with respect to the window size) variations from the data. The moving average is computed by

$$y_i = \frac{1}{2q+1} \sum_{j=-q}^{q} x_{i+j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where 2q+1 is the length of the filter window, y_i becomes the input for the second pass.

By modifying the window length and the number of iterations, the filtering of different scales of motion can be controlled. To filter all periods of less than P days, the following criterion is used

$$D \times N^{\frac{1}{2}} \leq P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where D (D=2q+1) is the window size in days and N is the number iterations.[7]

To study the long-term ozone trend in Ohio, we decomposed the daily maximum ozone concentration time series into three components as follows:

$$X = E + S + W = \text{Baseline} + W \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where X is the original time series,
E = long-term trend component,
S = seasonal variation,
W = the short-term variation (white noise).

The KZ filter was applied to the 8-hour averaged data for O_3, SO_2, and NO_2, and the 24-hour averaged PM_{10} concentrations. The results for O_3 are shown in Figures III.1.33a and III.1.33b. The 8-hour average ozone concentrations in Cincinnati and Columbus (Chesapeake) increased by 18% and 16% respectively, since 1992, while ozone concentrations in Cleveland decreased by 12%. In Dayton, the long-term trend of ozone fluctuates during the study period even though the end point is a little higher than the beginning.

For PM_{10}, Figure III.1.34, concentrations at all sites except Steubenville are relatively constant during the study period. PM_{10} concentrations at Steubenville decreased by 6% since 1992. PM_{10} concentrations at Cincinnati and Steubenville were relatively higher than those of other sites.

Measured levels of CO and SO_2 show a significant decreasing trend during the study period (Figures III.1.35. and III.1.36.). CO concentrations at Cincinnati, Dayton, Columbus (Chesapeake) and Cleveland decreased by approximately 200%, 66%, 10% and 100% respectively since 1992. SO_2 concentrations also decreased by 41%, 11%, 33% and 20%, respectively at the same sites.

In contrast to the decreasing trends of CO and SO_2, NO_2 has increased at the study sites with the exception of Cincinnati which experienced a slight decrease (Figure III.1.37.). The NO_2 concentration at Cleveland and Steubenville increased by 8% and 3% respectively. NO_2 levels at Cincinnati decreased by 3% during the study period. The seasonal components and the white noise of all the pollutants are shown in Appendix D.

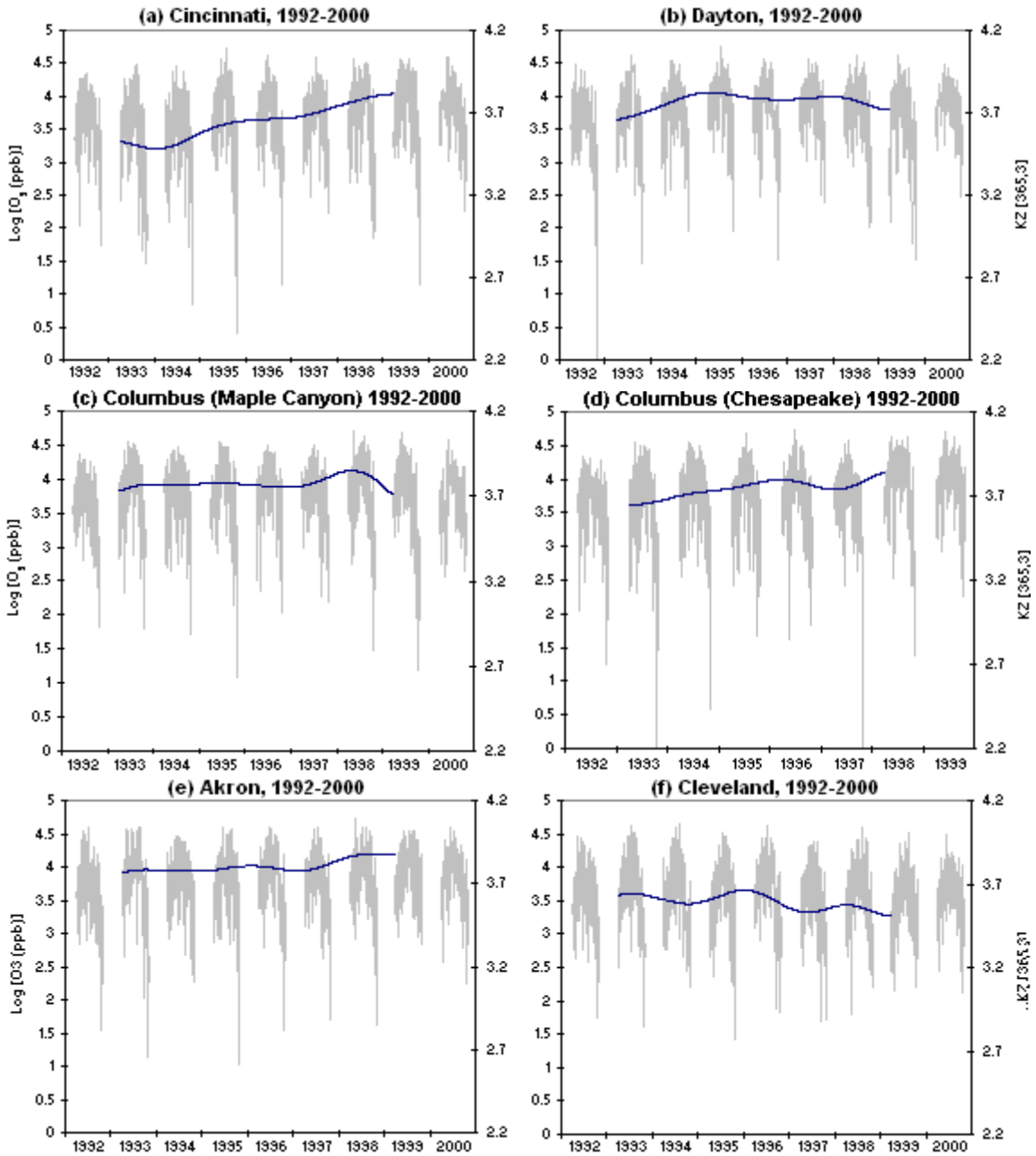


Figure III.1.33a. KZ[365,3] of O_3 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]

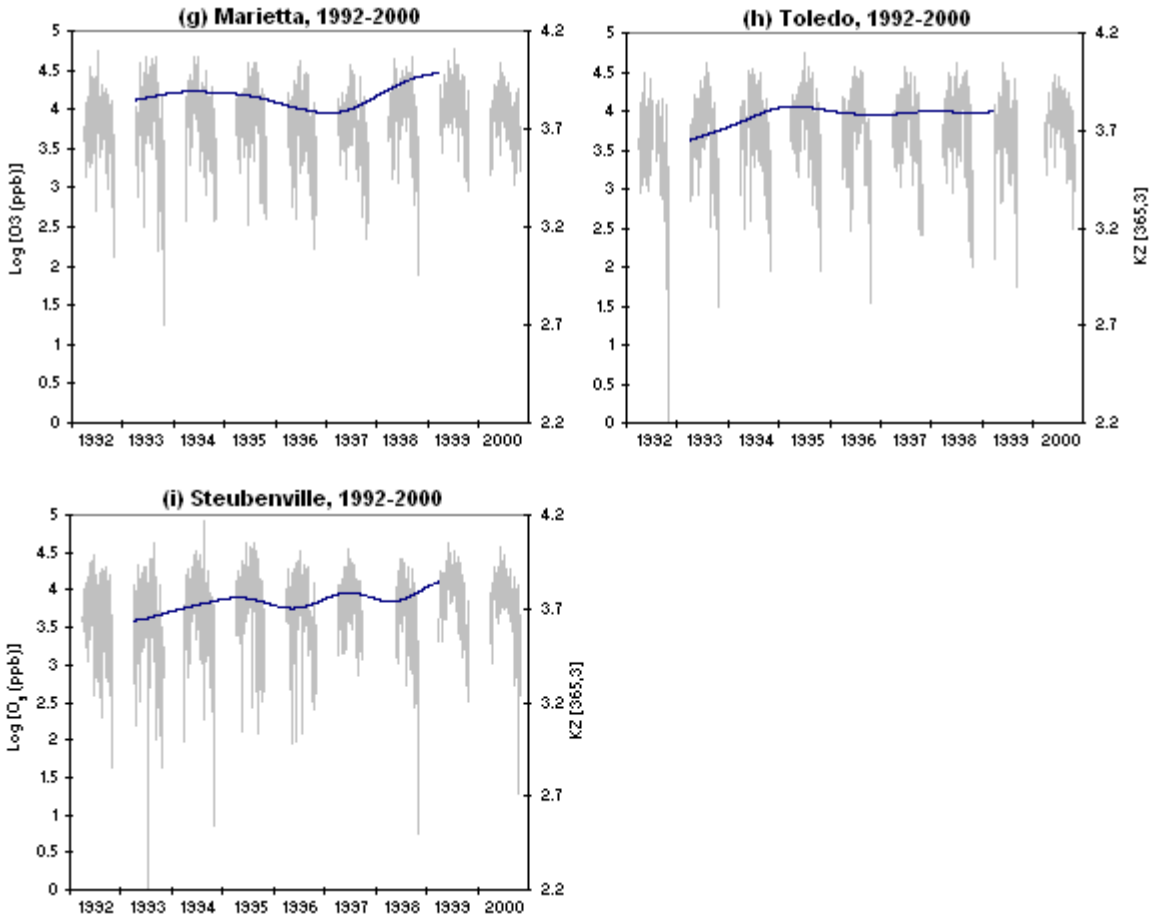


Figure III.1.33b. KZ[365,3] of O_3 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]

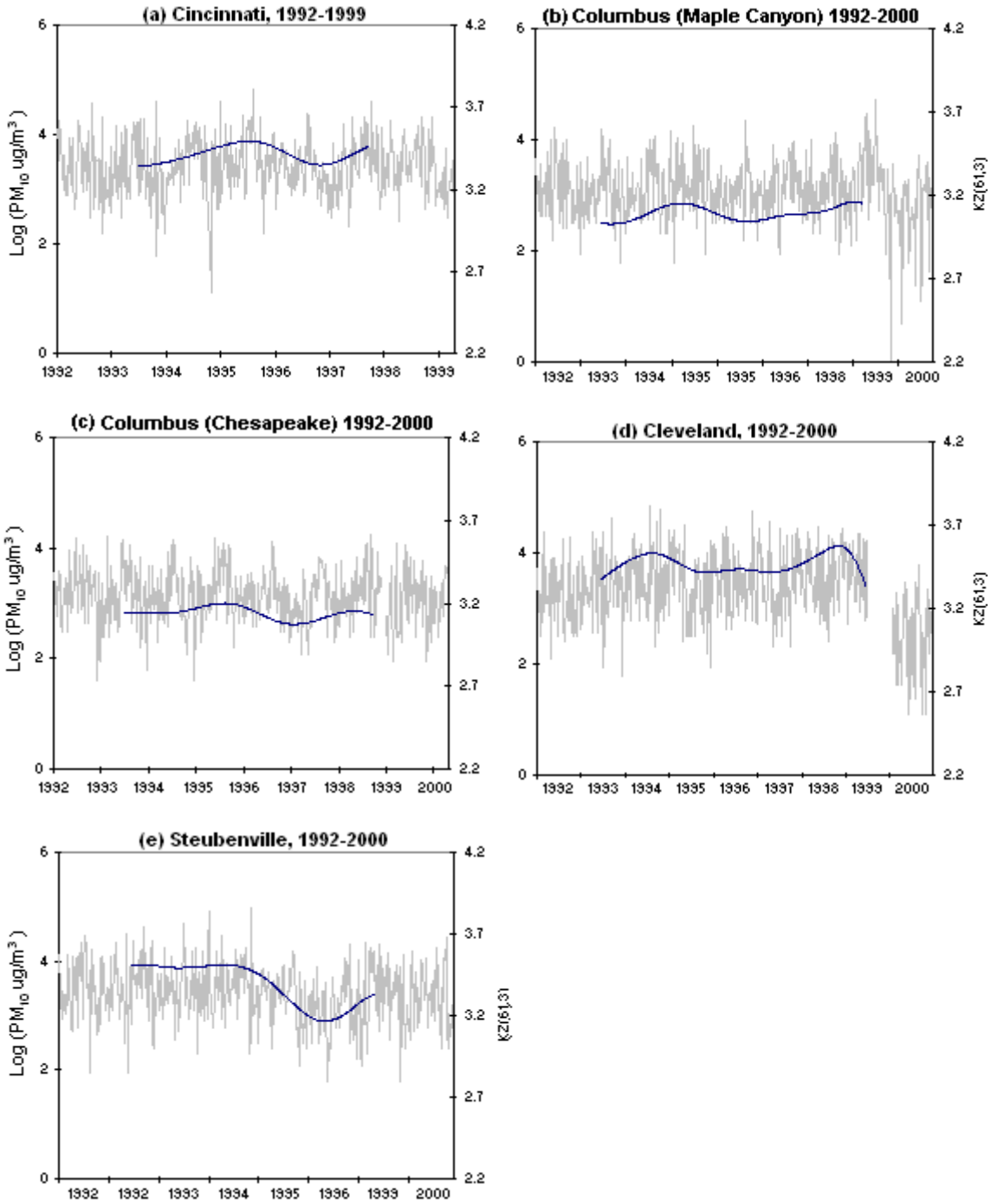


Figure III.1.34. KZ[365,3] of PM_{10} levels in Ohio: Gray line is raw data and blue line is KZ[365,3]

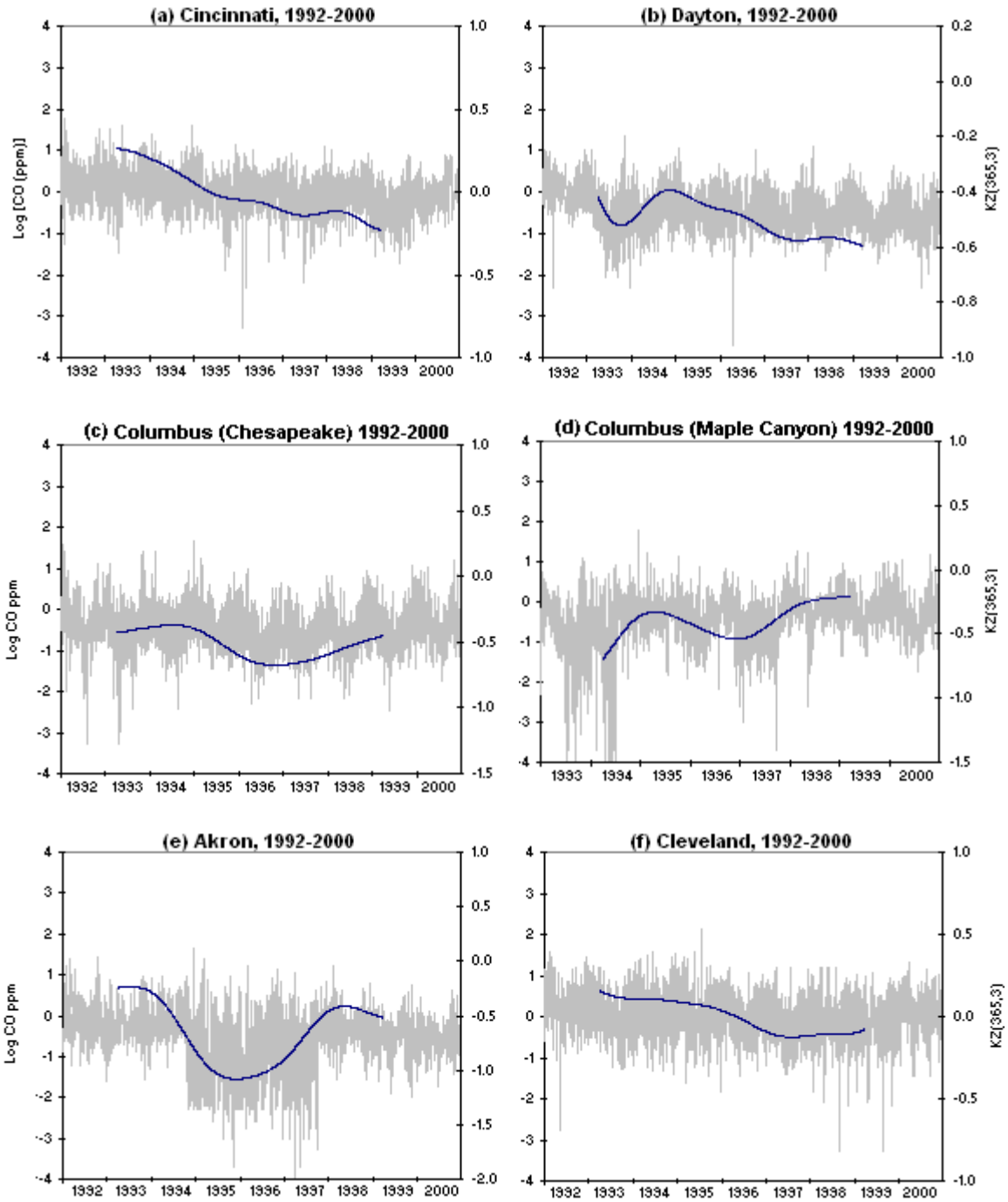


Figure III.1.35. KZ[365,3] of CO levels in Ohio: Gray line is raw data and blue line is KZ[365,3]

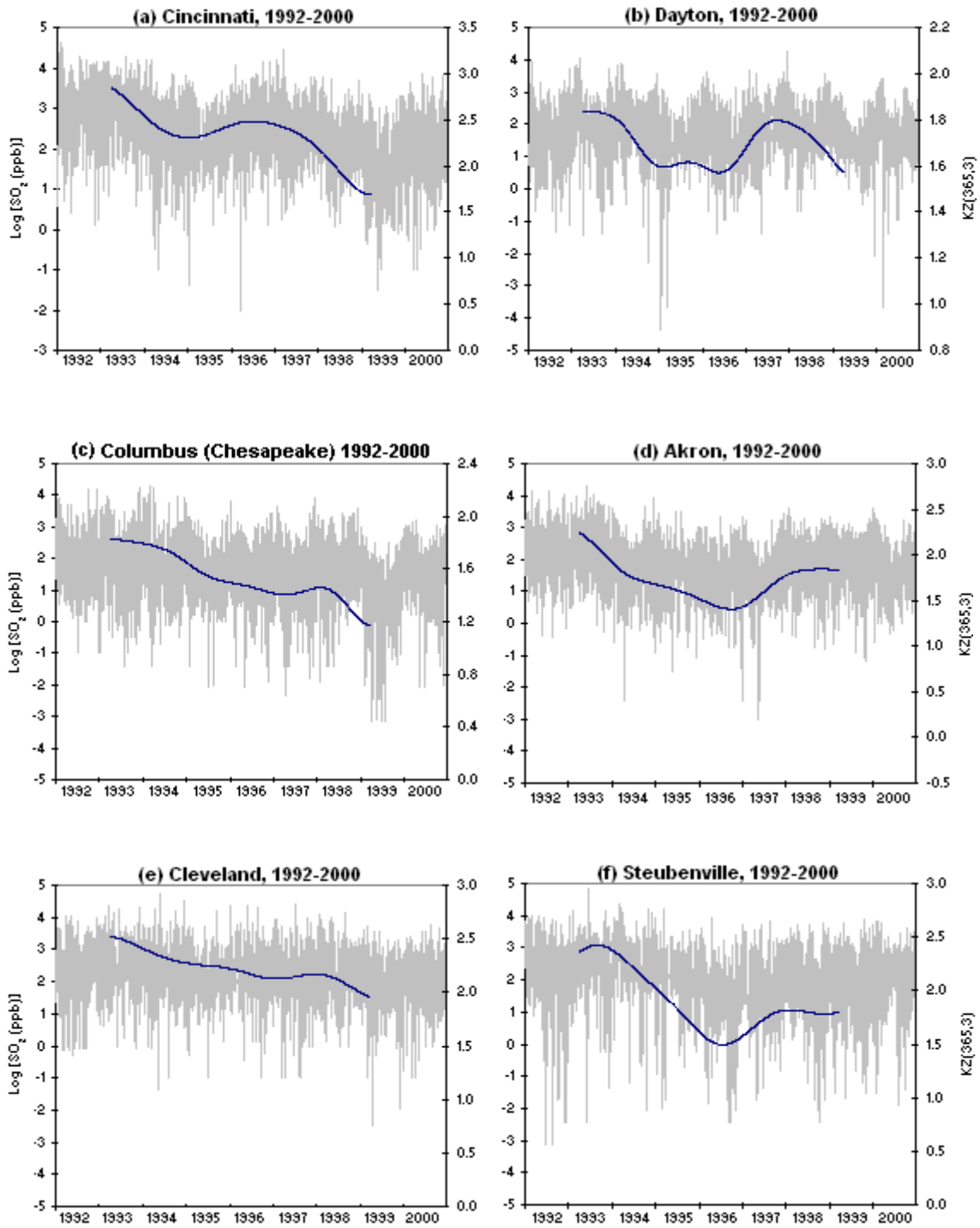


Figure III.136. KZ[365,3] of SO_2 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]

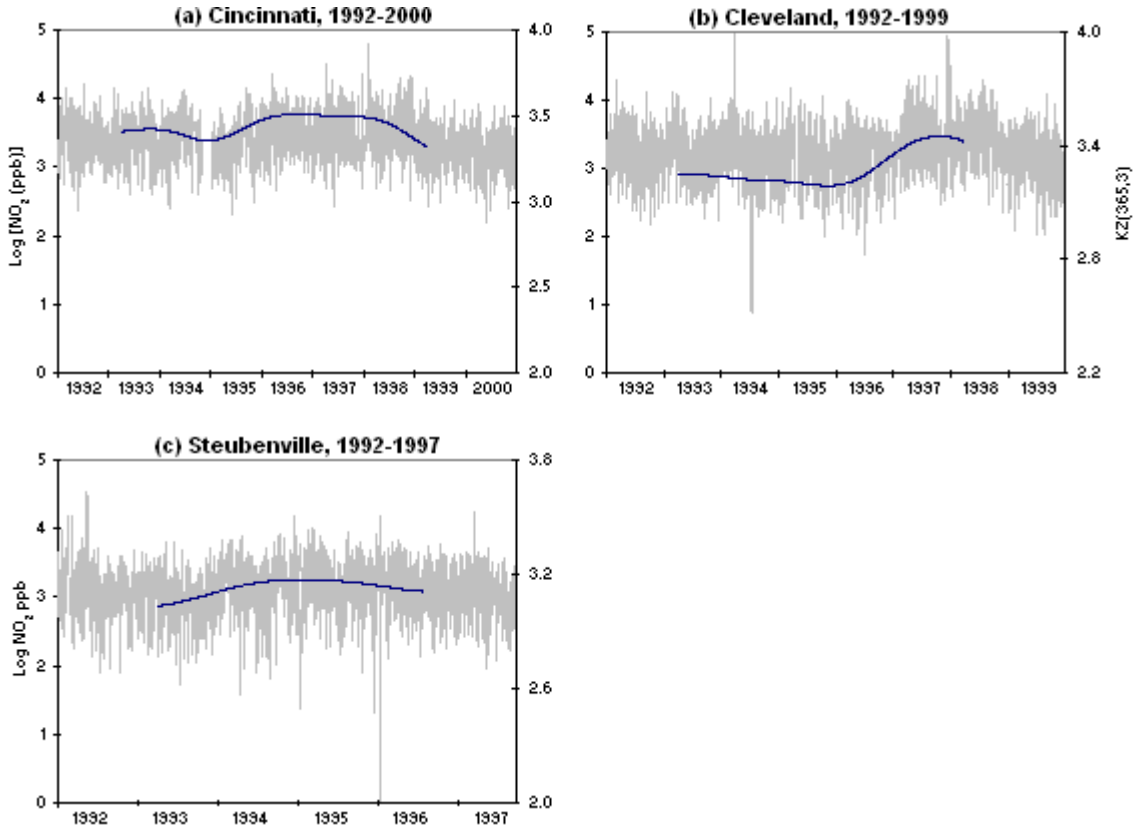


Figure III.1.37. KZ[365,3] of NO_2 levels in Ohio: Gray line is raw data and blue line is KZ[365,3]

Spatial Analysis

A spatial analysis was performed to evaluate the primary relationships in O_3, PM_{10}, CO, SO_2, and NO_2 concentrations between the sites. The results are presented in Tables III.1.6 through III.1.10. The shaded values in the tables represent distances between the sites and the unshaded table cells are the R^2 values. The spatial correlations for ozone are shown in Table III.1.6. The correlations for O_3 are relatively stronger than other pollutants, Tables III.1.7 through III.1.10. As expected the correlations increased as the distance between the sites decreased. For O_3, these strong correlations indicate a common regional influence on the sites such as meteorology or transport of ozone and its precursors. Graphs for these spatial correlations are shown in Appendix D.

Table III.1.6. R^2 Values of Ozone Spatial Correlation between cities in Ohio.

Monitoring Site*	CIN	DAY	MAP	CHE	CLE	TOL	AKR	MAR	STE
CIN	1	48	92	90	220	180	200	160	250
DAY	0.6239	1	71	68	175	140	170	150	193
MAP	0.5018	0.6011	1	4	125	122	110	88	130
CHE	0.668	0.7397	0.6941	1	126	121	111	92	128
CLE	0.3322	0.4514	0.5996	0.5146	1	100	25	145	90
TOL	0.5104	0.5476	0.3994	0.5051	0.3011	1	115	190	178
AKR	0.4942	0.5923	0.7461	0.7119	0.6501	0.3932	1	115	70
MAR	0.4193	0.4676	0.5016	0.5376	0.3488	0.3028	0.479	1	80
STE	0.1715	0.1565	0.1784	0.1726	0.1656	0.1564	0.195	0.1249	1

☐ : R^2 Values ■ : Distance Between Cities (miles)

*CIN: Cincinnati; DAY: Dayton; MAP: Columbus (Maple Canyon); CHE: Columbus (Chesapeake); CLE: Cleveland; TOL: Toledo; AKR: Akron; MAR: Marietta; and STE: Steubenville

Table III.1.7. R^2 Values of PM_{10} Spatial Correlation between cities in Ohio.

Monitoring Site	CIN	MAP	CHE	CLE	STE
CIN	1	92	90	220	250
MAP	0.0227	1	4	125	130
CHE	0.0425	0.3157	1	126	128
CLE	0.0384	0.0579	0.071	1	90
STE	0.0135	0.0164	0.0152	0.0875	1

Table III.1.8. R^2 Values of CO Spatial Correlation between cities in Ohio.

Monitoring Site	CIN	DAY	CHE	MAP	AKR	CLE
CIN	1	48	90	92	200	220
DAY	0.3091	1	68	71	170	175
CHE	0.3612	0.3874	1	4	111	126
MAP	0.3428	0.3326	0.3465	1	110	125
AKR	0.2133	0.2532	0.2344	0.2753	1	25
CLE	0.220	0.1928	0.2641	0.2512	0.2497	1

Table III.1.9. R^2 Values of SO_2 Spatial Correlation between cities in Ohio.

Monitoring Site	CIN	DAY	CHE	AKR	CLE	STE
CIN	1	48	90	200	220	250
DAY	0.221	1	68	170	175	193
CHE	0.1694	0.3066	1	111	126	128
AKR	0.1123	0.2831	0.2714	1	25	70
CLE	0.091	0.2514	0.1999	0.1253	1	90
STE	0.0634	0.134	0.0946	0.0526	0.0743	1

Table III.1.10. R^2 Values of NO_2 Spatial Correlation between cities in Ohio.

Monitoring Site	CIN	CLE	STE
CIN	1	220	250
CLE	0.0706	1	90
STE	0.0048	0.0001	1

Regional Episode Analysis

Regional ozone levels were studied from the historical dataset to evaluate high ozone episodes at the monitoring sites. Regional episodes based on the days when the 1-hour ozone values exceeds 100 ppb or the 8-hour ozone values exceeds 75 ppb were examined for the period of 1992-2000 and are listed in tables in Appendix D.

The regional analysis reveals that most high ozone episodes are typically observed for several consecutive days and can last up to seven days. High ozone values are typically measured on the same day for most of the sites, a tendency that is more prominent in 8-hour ozone readings rather than 1-hour ozone readings. There were some missing data sets from the Dayton site for the 8/3/96-8/8/96 episode, at the Toledo site for the 8/13/93-8/20/93, 8/2/98-8/9/98, and 7/13/99-7/17/99 episodes, at the Marietta site for the 7/17/93-7/26/93 and 7/11/95-7/15/95, at the Chesapeake for 7/11/94-7/15/94 and at the Steubenville for 5/13/98-5/27/98.

There were more exceedances of the 8-hour averaged NAAQS ozone standard than 1-hour averaged NAAQS ozone standard. For any given high ozone episode day, the number of sites violating the 8-hour ozone standard was larger than the number of sites violating the 1-hour standard. This suggests that the new 8-hour NAAQS ozone standard would result in spatial expansion of the ozone problem and many areas will be transformed into non-attainment areas from ozone attainment areas.

METEOROLOGICAL ANALYSIS OF AIR POLLUTANTS IN OHIO

Meteorological analysis can be performed using local surface wind and computed back trajectories for each area. The local surface wind analysis highlights the short-range meteorological patterns, while a comprehensive back trajectory analysis captures the long-range transport characteristics.

Back trajectories can evaluate the impact of upstream emissions and integrate information on winds in the upstream layer over time, distances, and source locations. Cluster analysis is an advanced method of back trajectory analysis that segregates and merges each trajectory by their direction or similarity. Cluster analysis as used in the air pollution research field is a multivariate statistical approach. The clusters contain a number of groups split from a data set by their distinct difference from the other variables in the data set. Recent studies have used cluster analysis for various purposes. Dorling et al. applied cluster analysis of trajectories to identify the relationship between large-scale surface pressure patterns and the pollution climatology of a site.[9] Also, they used cluster analysis as a tool for examining the influence of synoptic weather patterns on air and precipitation chemistry. Brankov et al. examined the relationship between synoptic-scale atmospheric transport patterns and concentration levels of several toxic trace elements with cluster analysis.[10] Another study by Rao et al. addressed the influence of a finite number of synoptic patterns associated with pollutant transport from a different source region. [11]

In this study, the following approach was used to examine the effect of meteorological conditions on ambient pollutant concentrations:

- Statistical analysis identifies significant correlations between the air pollutants and meteorological parameters, such as, temperature, wind direction, wind speed, relative humidity, etc.
- Trajectory analysis evaluates transport of air mass to and from the measurement sites and to characterize source-receptor relationships. Composite trajectories were developed and analyzed for high concentration days.
- Cluster analysis identifies the directional distribution of back-trajectories and apportions emission sources by region.

Method of Analysis

Meteorological Correlation Analysis

For evaluating strategies to control air pollutants concentrations, it is important to determine the meteorological factors that influence air pollutant levels. Correlations between air pollutant and weather components, such as

temperature, wind speed, wind direction, and relative humidity were performed at the selected sites.

Back Trajectory Analysis

The meteorological dynamics that causes air to rise or fall, and determines its path can affect air quality by carrying air pollutants many miles from their sources.[12] A trajectory is the time integration of the position of a parcel of air as it is transported by the wind. The parcel's passive transport by the wind is computed from the average of the three-dimensional velocity vectors at the particle's initial-position P(t) and its first-guess position P'(t+dt). The velocity vectors are interpolated in both space and time. The first guess position is described as follows,

$$P'(t+dt) = P(t) + V(P,t)\, dt \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

with the final position as

$$P(t+dt) = P(t) + 0.5\, [\, V(P,t) + V(P',t+dt)\,]\, dt \qquad \ldots\ldots\ldots\ldots \quad (5)$$

Trajectories may be integrated both forward and backward in time. A measure of the integration error may be obtained by computing a backward trajectory from the end-point-position of its forward counterpart.[13] The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model was developed over the last fifteen years and is widely used for trajectory analysis. The HYSPLIT model is a complete system for computing simple air trajectories to complex dispersion simulations.

Back trajectories efficiently show the relationships between an air parcel in the transport layer, distance, and regions encompassing a source and a receptor. Individual trajectories, however, do not infer a direct connection between a source and a receptor because trajectories have limitations on interpreting the transportation of a specific air parcel. Rather, trajectories convey an estimate of the mean movement of a dispersing air parcel.

This study applied the HYSPLIT4 model to estimate backward trajectories of air parcels influencing several regions in Ohio. The HYSPLIT4 was adopted to develop 24-hour back trajectories using wind field data from the Eta Data Assimilation System (EDAS) dataset for 1998-2000 and the Nested Grid Model (NGM) dataset for 1992-1997. The starting height of this model was adjusted at 500m, which is generally in the middle of the mixed layer. This study adapted a start time, 16 UTC, same as noon in local time, which usually exhibits the highest ozone values each day. These back trajectories were drawn for the selected high concentration days whose air pollutants values exceed 85 ppb in eight-hour ozone; 65 $\mu g/m^3$ or 50 $\mu g/m^3$ in 24 hour PM_{10}; 3 or 2.5 ppm in eight-hour CO; 50 or 53 ppb in eight-hour SO_2 and 50 or 45 ppb in eight-

hour NO_2 from 1992 to 2000. These back trajectories were then analyzed for further evaluation of transport patterns of air pollutants. It should be noted that the accuracy of upper air data acquired from the HYSPLIT4 model is not optimal in Ohio because of the lack of extensive upper air monitoring sites. However, since a large amount of trajectories were used to obtain an average trajectory, the errors are decreased.[14]

Cluster Analysis

Cluster analysis to identify pollutant sources in a region is frequently applied in air pollution research. This analysis consists of splitting a data set into several dominant groups that are homogeneous but as different from each other as possible. In this study, the clustering approach proposed by Dorling et al.[15] was chosen and modified. For each one-day (24-hour) back trajectory, 6 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 and assigned each of the 3-day real trajectories to the seed that is closest in terms of the distance between their corresponding 6-hourly coordinates. Then the seed or average trajectory of each cluster is recalculated with each real trajectory and the number of clusters is reduced by the same process that merges the two clusters whose average trajectories are closest.[16] This algorithm, however, was modified in this study. Each trajectory was assigned to several clusters in terms of directions of original source regions that are x-y coordinates of starting points 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. In addition, a cluster category called "Close" was 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 treated a small region and this projection was more convenient to plot clusters than polar stereographic projection.

Meteorological Correlation Analysis

Figures III.1.38 through III.1.41 show the correlations for O_3 and PM_{10} with respect to the meteorological parameters. The analysis for the other pollutants and sites are presented in Appendix D. The correlation plot between ozone and PM_{10} and wind speed shows that air pollutant concentrations are generally low when the wind speed was high and high when wind speeds were low. This

would indicate that the wind speed has a significant influence on ozone and PM_{10}. A similar pattern is shown for CO, SO_2 and NO_2 in Appendix D. High air pollutant concentration levels were generally observed when the wind speed was lower than 8 mph.

It was also revealed that ozone levels were high when winds were from the south and southwest and that PM_{10} concentrations are high when the winds are from the east and south. In terms of point source and pollutant transport evaluation, this comparison is limited. Back trajectory and cluster analysis, as described earlier, can provide a more detailed evaluation of where the pollutants and their precursors affecting a site may have originated.

Temperature significantly affects high O_3 and PM concentrations (see Figures III.1.39(c) and III.1.41(c)). O_3 and PM_{10} levels are high when the temperature exceeds 70 or 80 °F. There was no significant correlation between the concentration of CO, SO_2 and NO_2 and temperature.

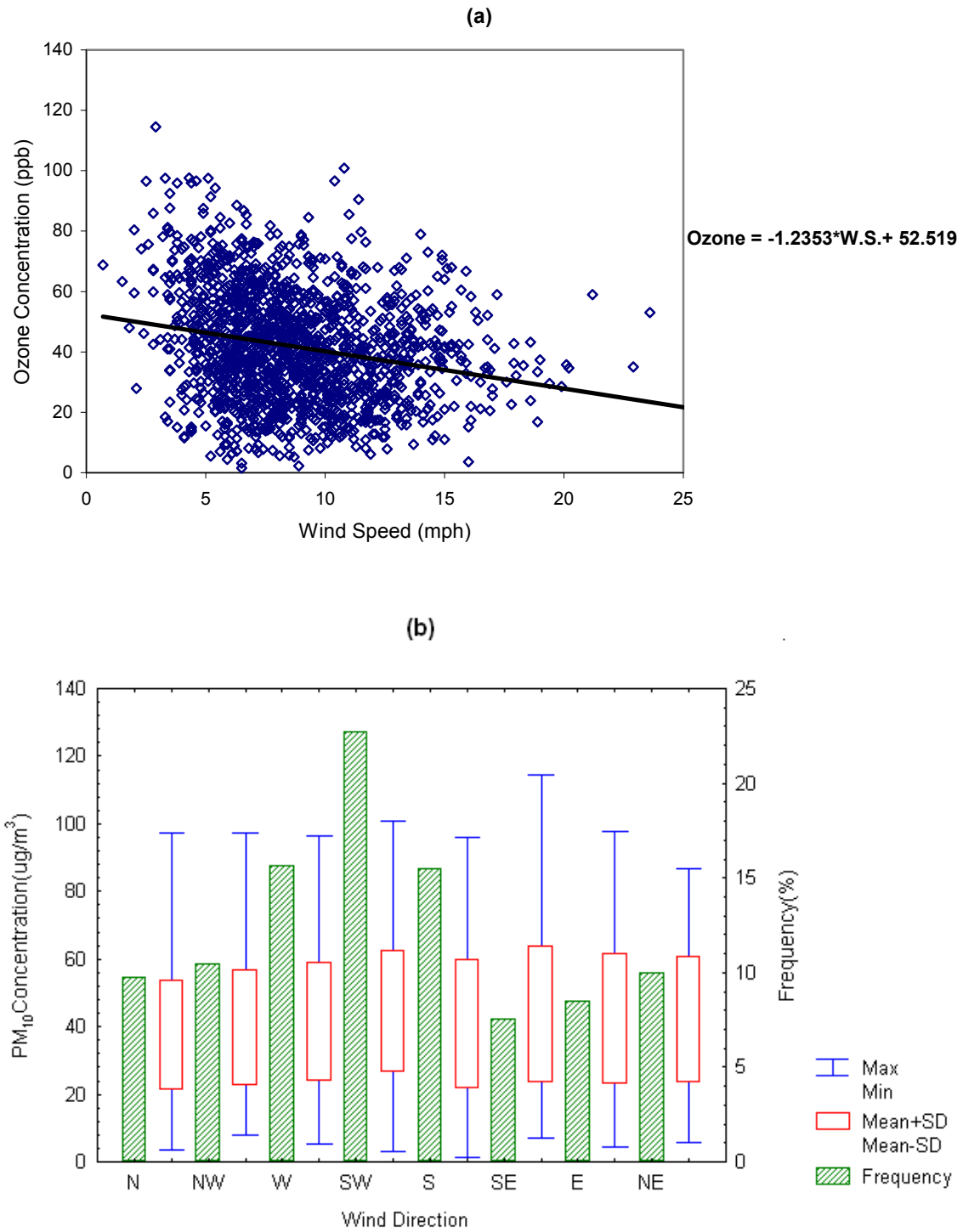


Figure III.1.38. Correlations between ozone and weather components at Cincinnati, Ohio in 1992-2000: (a) ozone vs. wind speed and (b) ozone vs. wind direction

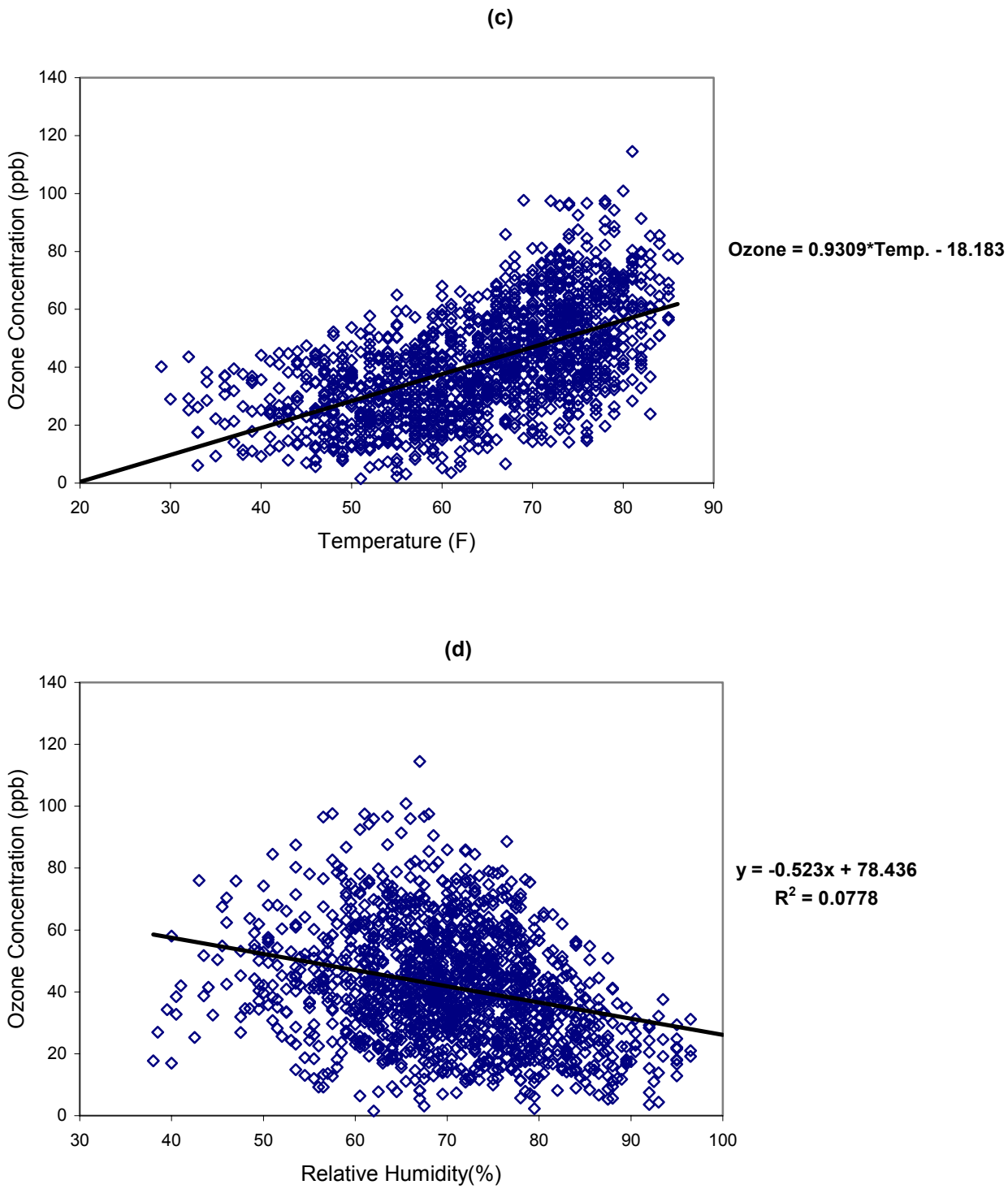


Figure III.1.39. Correlations between ozone and weather components at Cincinnati Ohio in 1992-2000: (c) ozone vs. temperature and (d) ozone vs. relative humidity

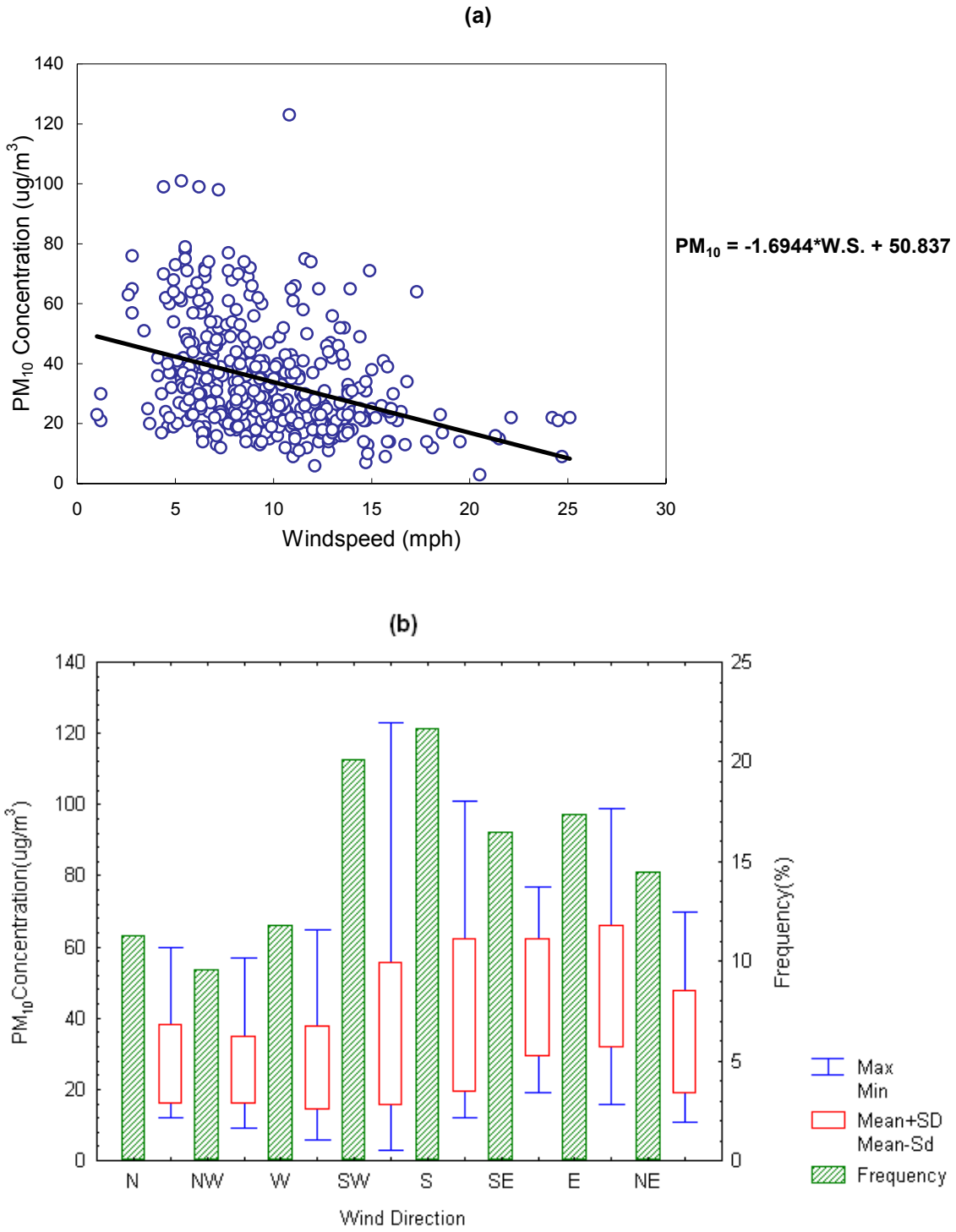


Figure III.1.40. Correlations between PM_{10} and weather components at Cincinnati, Ohio in 1992-1999: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction

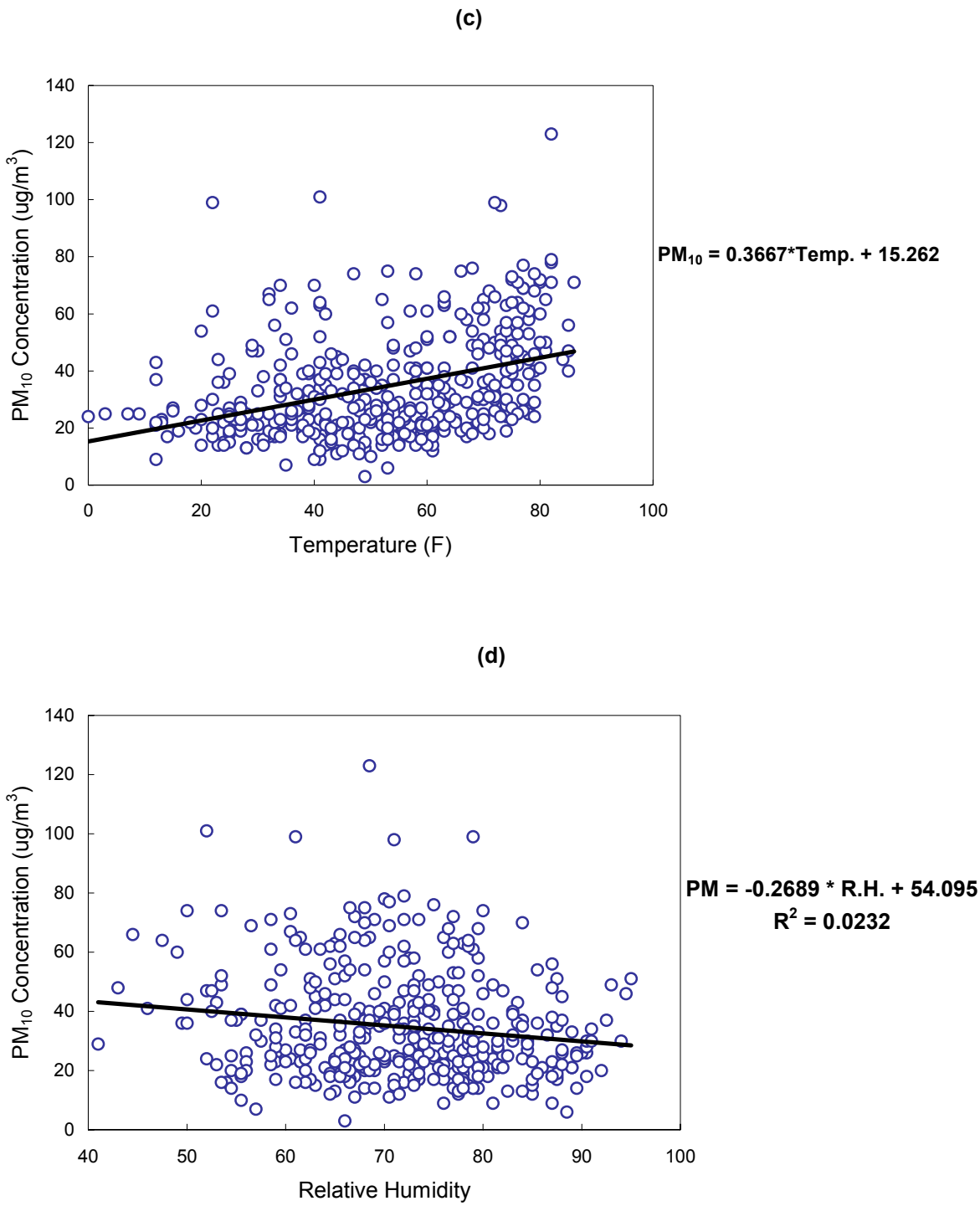


Figure III.1.41. Correlations between PM_{10} and weather components at Cincinnati Ohio in 1992-1999: (c) PM_{10} vs. temperature and (d) PM_{10} vs. relative humidity

No significant relationship was found between air pollutant concentrations and relative humidity. Correlation charts between the air pollutants and humidity were not presented in Appendix D because very similar results to those presented above were experienced.

Back Trajectory Analysis

Figures III.1.42. through III.1.49.depict the back trajectories for O_3 and PM_{10} on high concentration days. Trajectories from every quadrant were identified during high concentration days. However, trajectories from the north and the east were rare. These back trajectories calculated for the high concentration days reveal that major air parcels originate from the west to the south quadrant during the study period in Ohio.

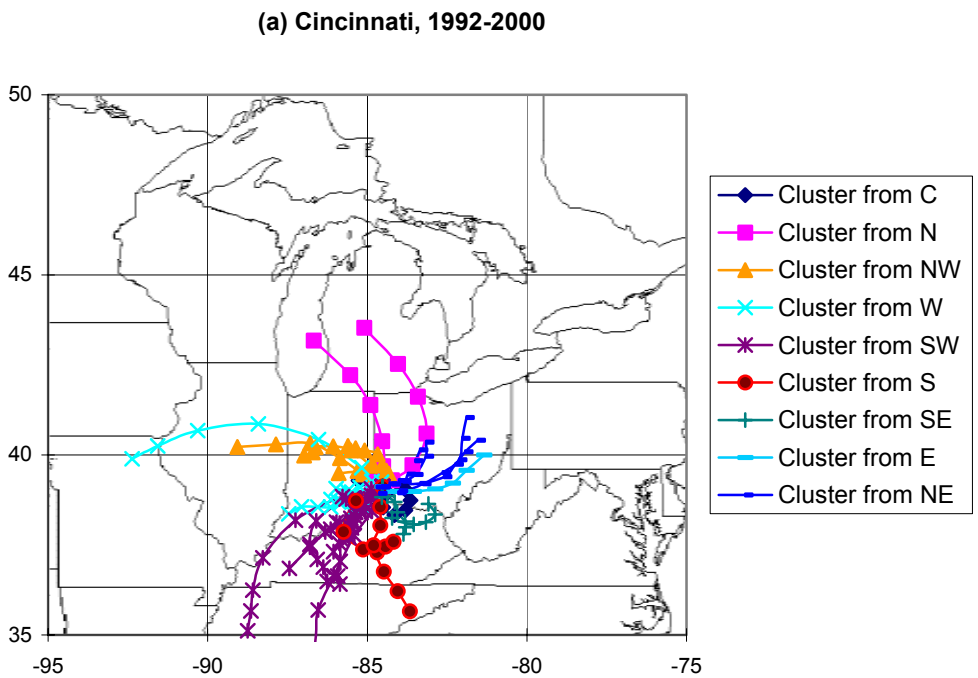
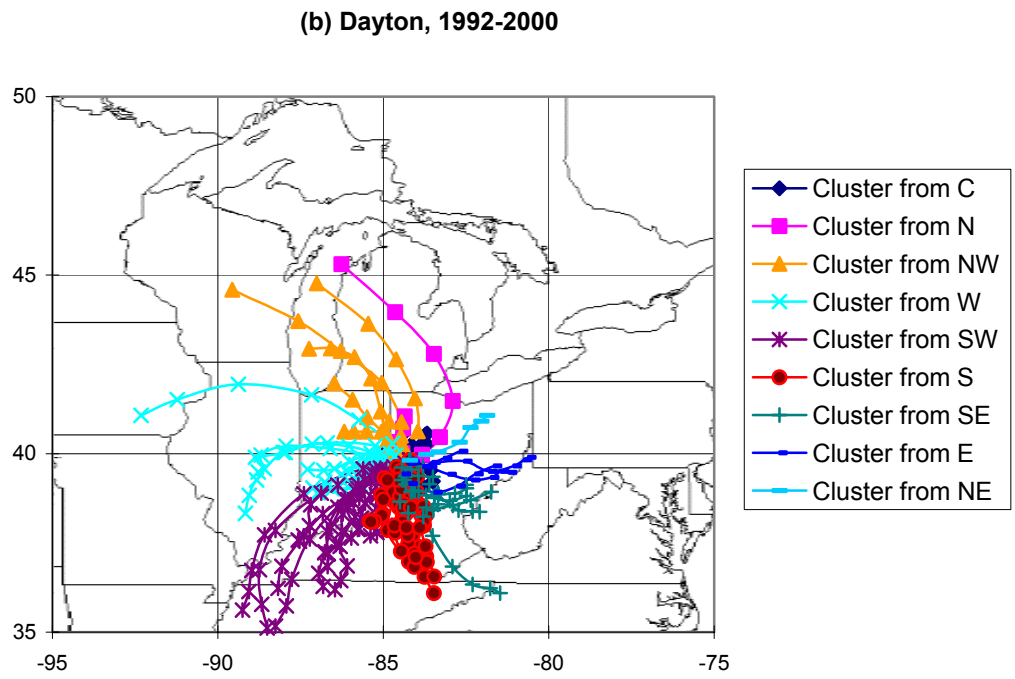


Figure III.1.42. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati



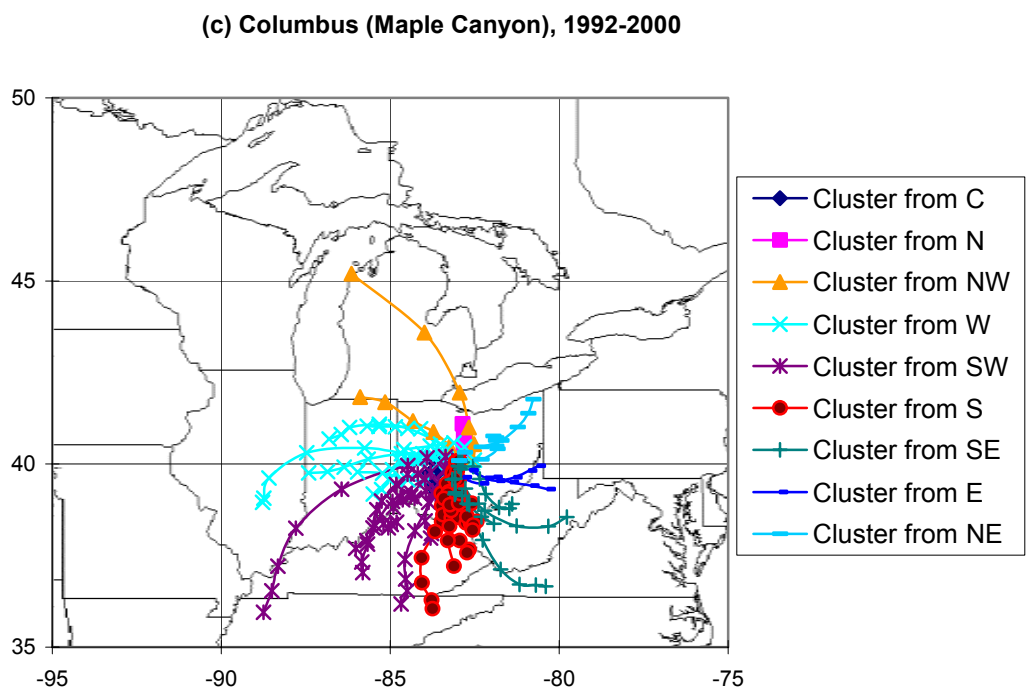
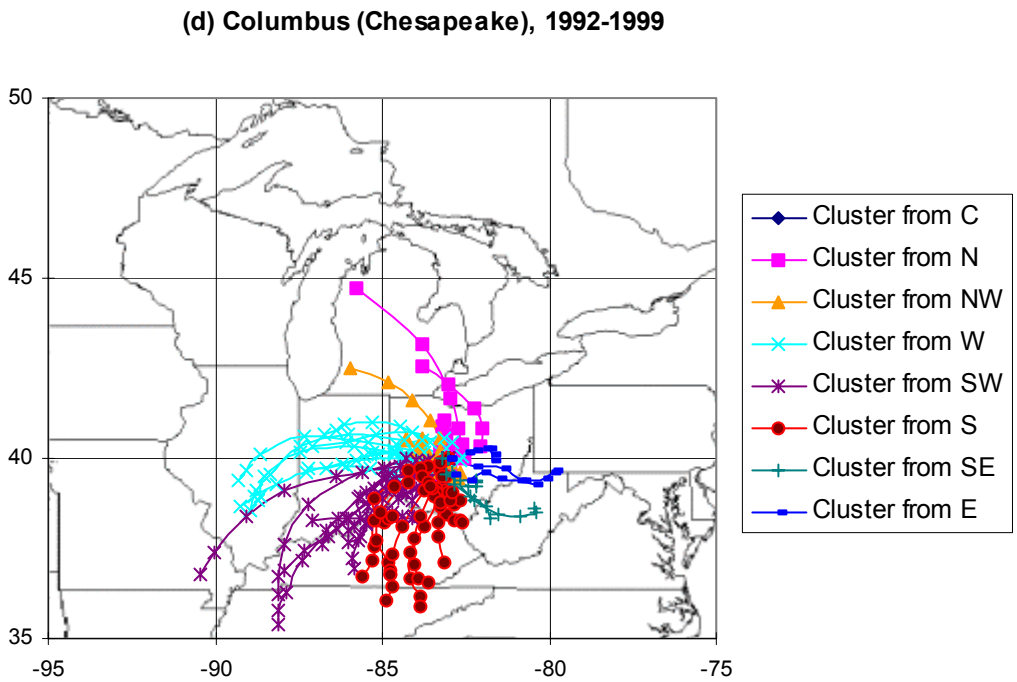


Figure III.1.43. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (b) Dayton and (c) Columbus (Maple Canyon)



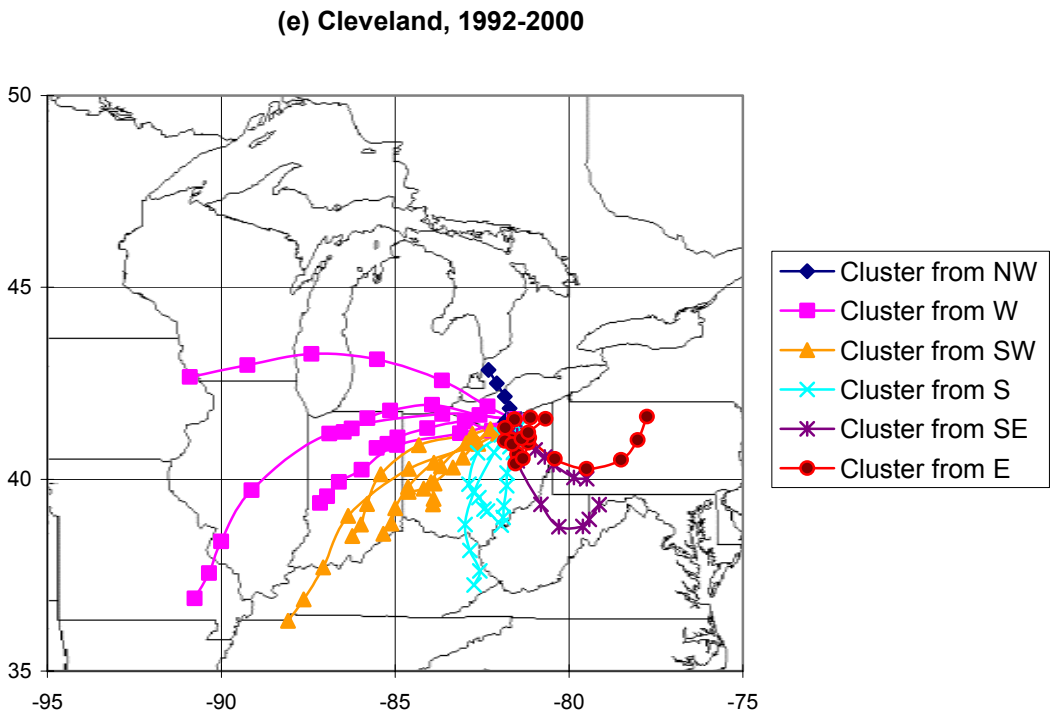
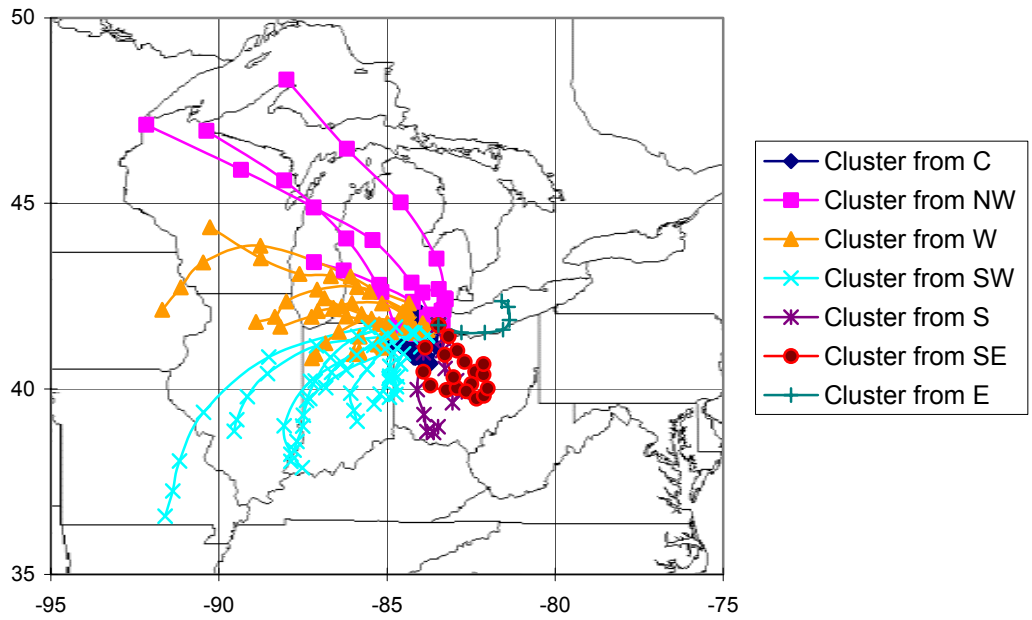


Figure III.1.44. Back trajectories for high ozone days at the monitoring sites sllected in Ohio, 1992-2000: (d) Columbus (Chesapeake) and (e) Cleveland

(f) Toledo, 1992-2000



(g) Akron, 1992-2000

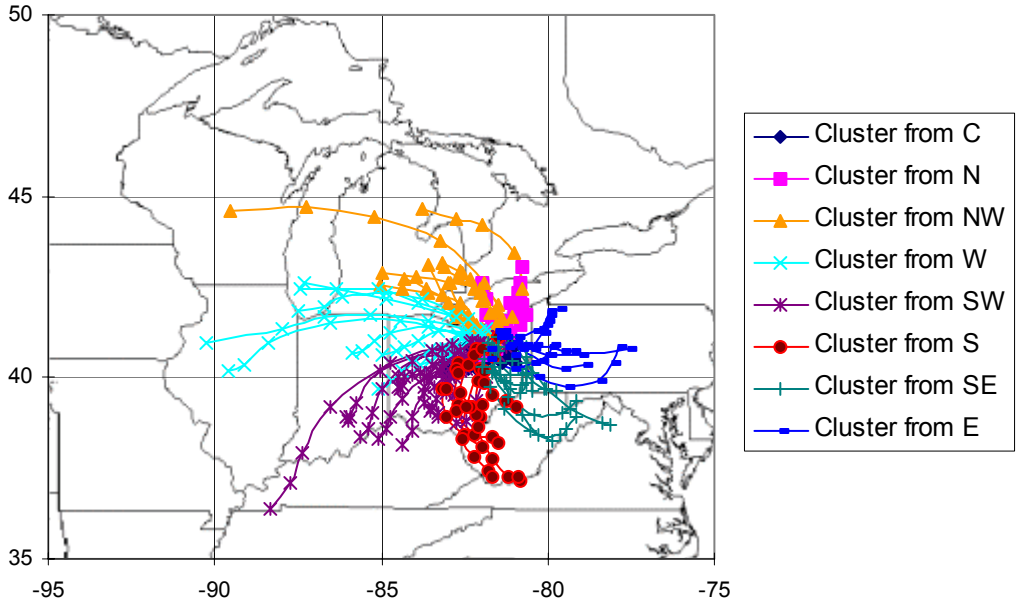
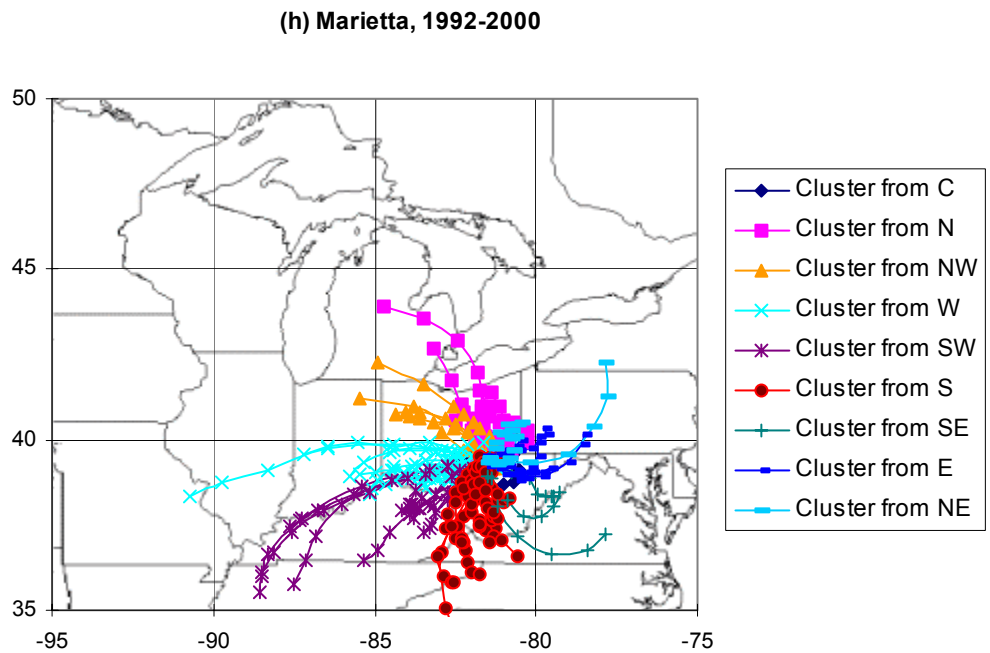


Figure III.1.45. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (f) Toledo and (g) Akron



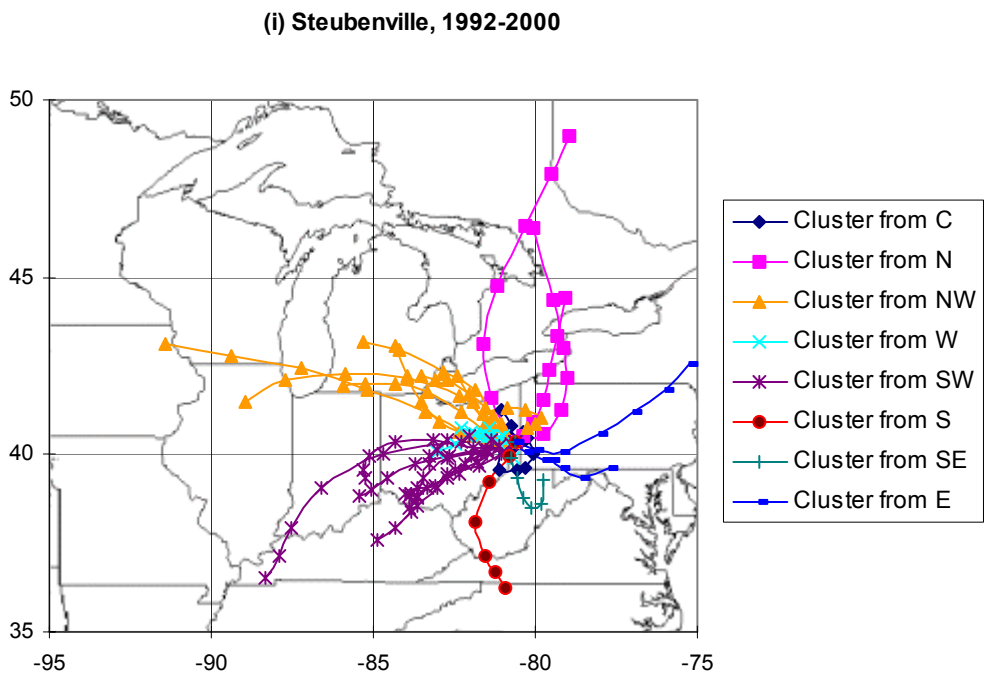


Figure III.1.46. Back trajectories for high ozone days at the monitoring sites selected in Ohio, 1992-2000: (h) Marietta and (i) Steubenville

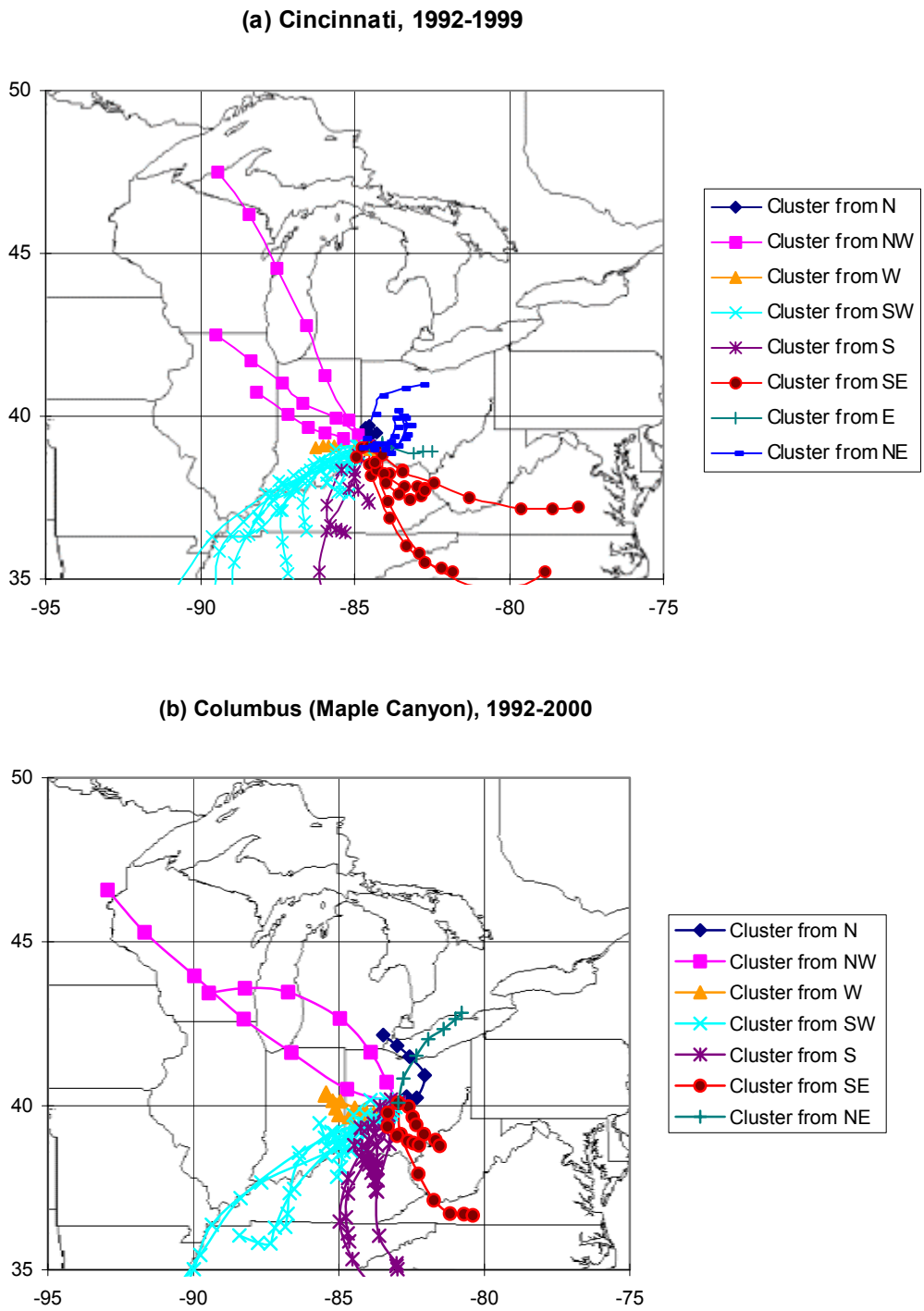
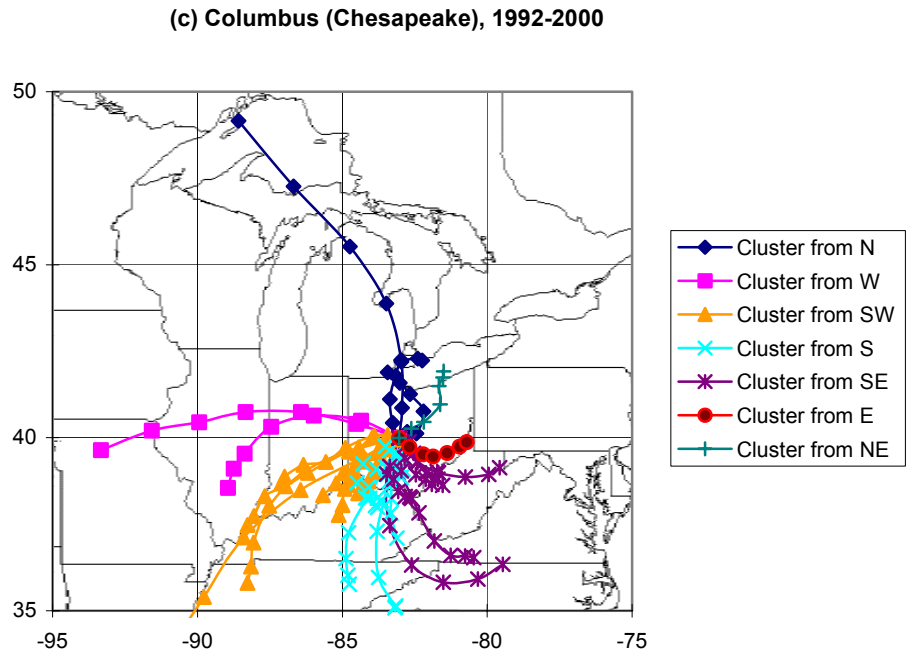


Figure III.1.47. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati and (b) Columbus (Maple Canyon)



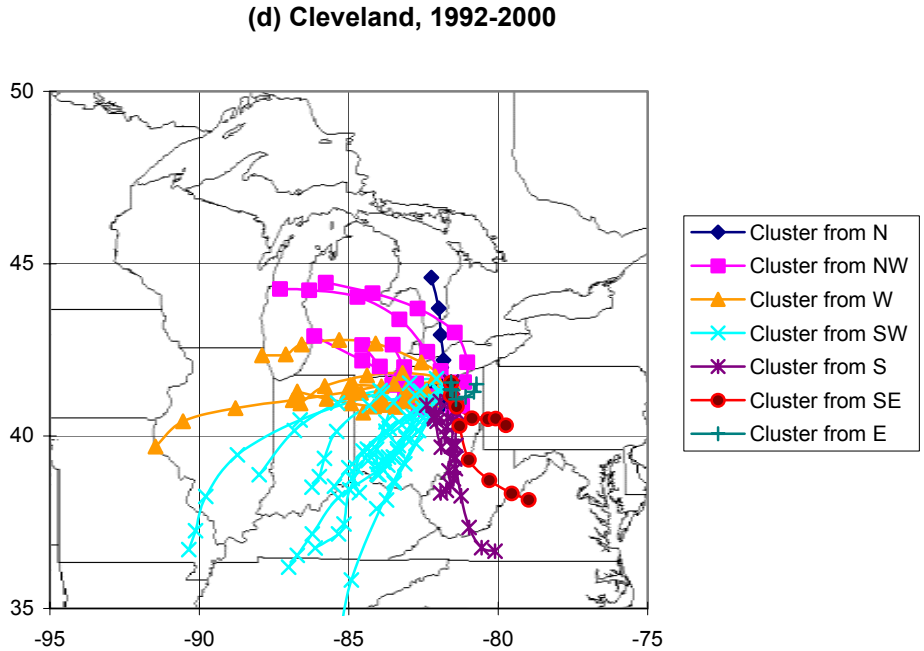


Figure III.1.48. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1992-2000: (c) Columbus (Chesapeake) and (d) Cleveland

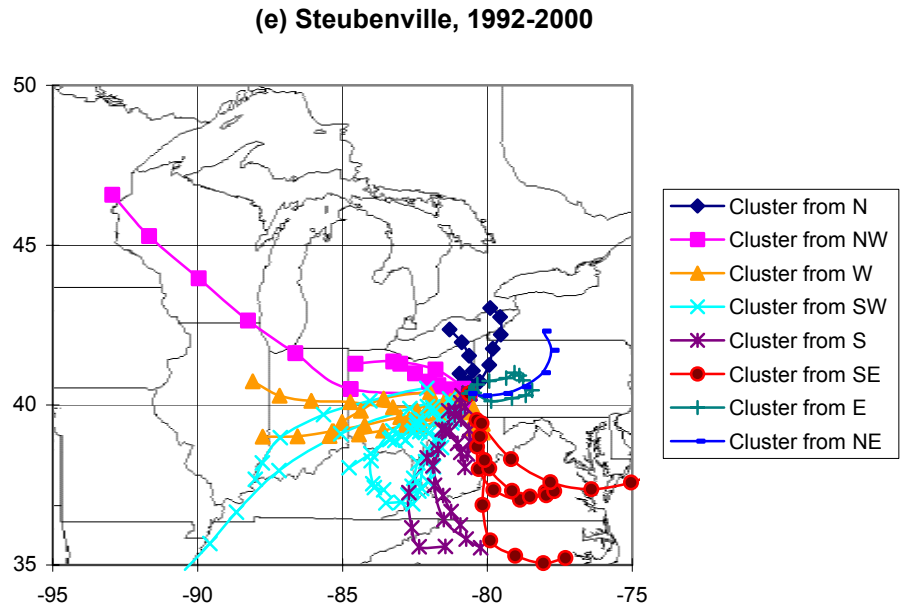


Figure III.1.49. Back trajectories for high PM days at the monitoring sites selected in Ohio, 1992-2000: (e) Steubenville

Cluster Analysis

Ozone

The cluster analysis was conducted for high ozone days. These clusters, their percentiles, frequencies and average concentrations for each of the clusters are presented for the nine monitoring sites for the period of 1992 to 2000, in Figures III.1.50 to III.1.58.

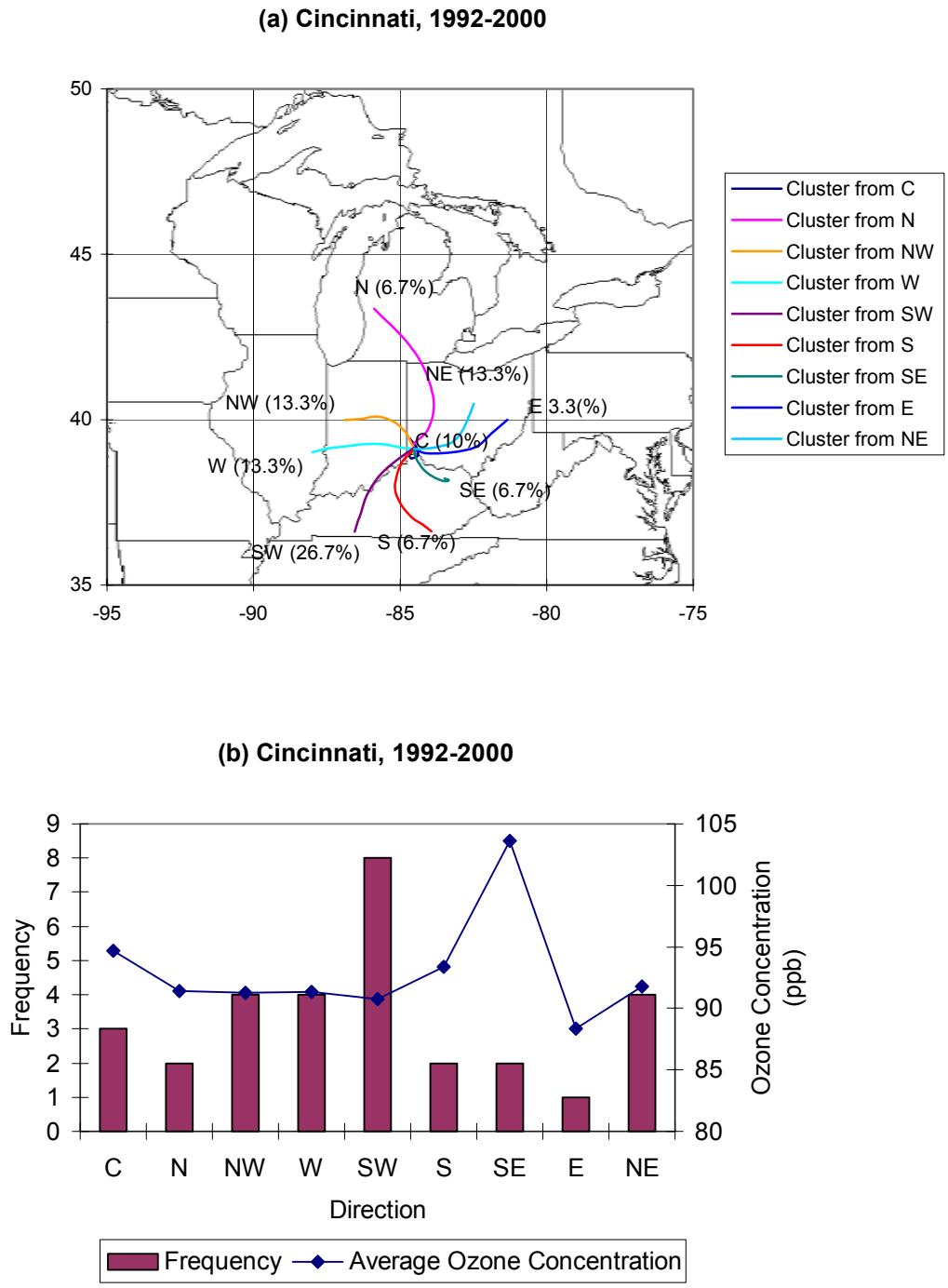
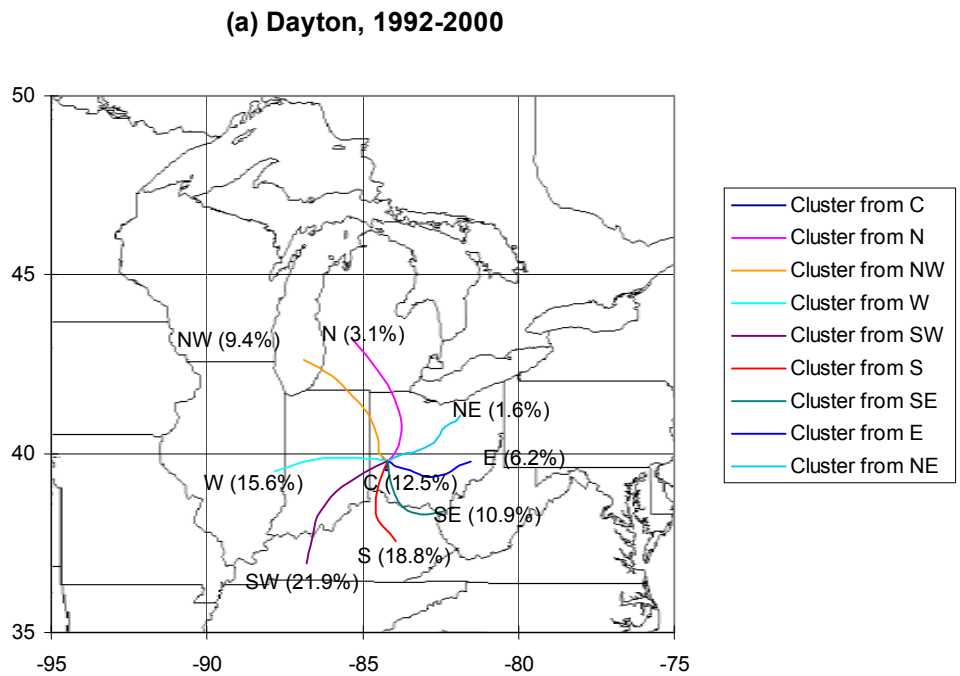


Figure III.1.50. (a) Cluster plot for Cincinnati, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Cincinnati, 1992 -2000



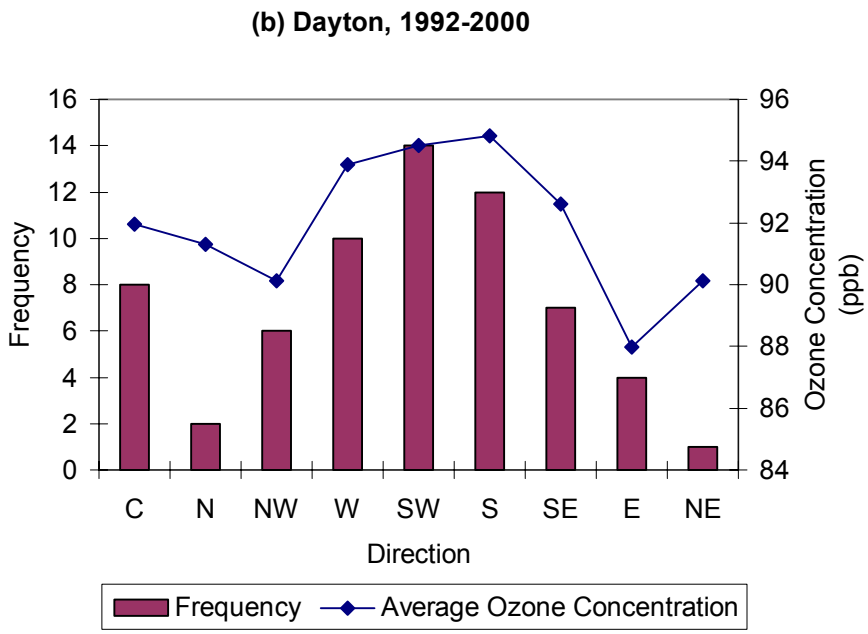


Figure III.1.51. (a) Cluster plot for Dayton, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Dayton, 1992- 2000

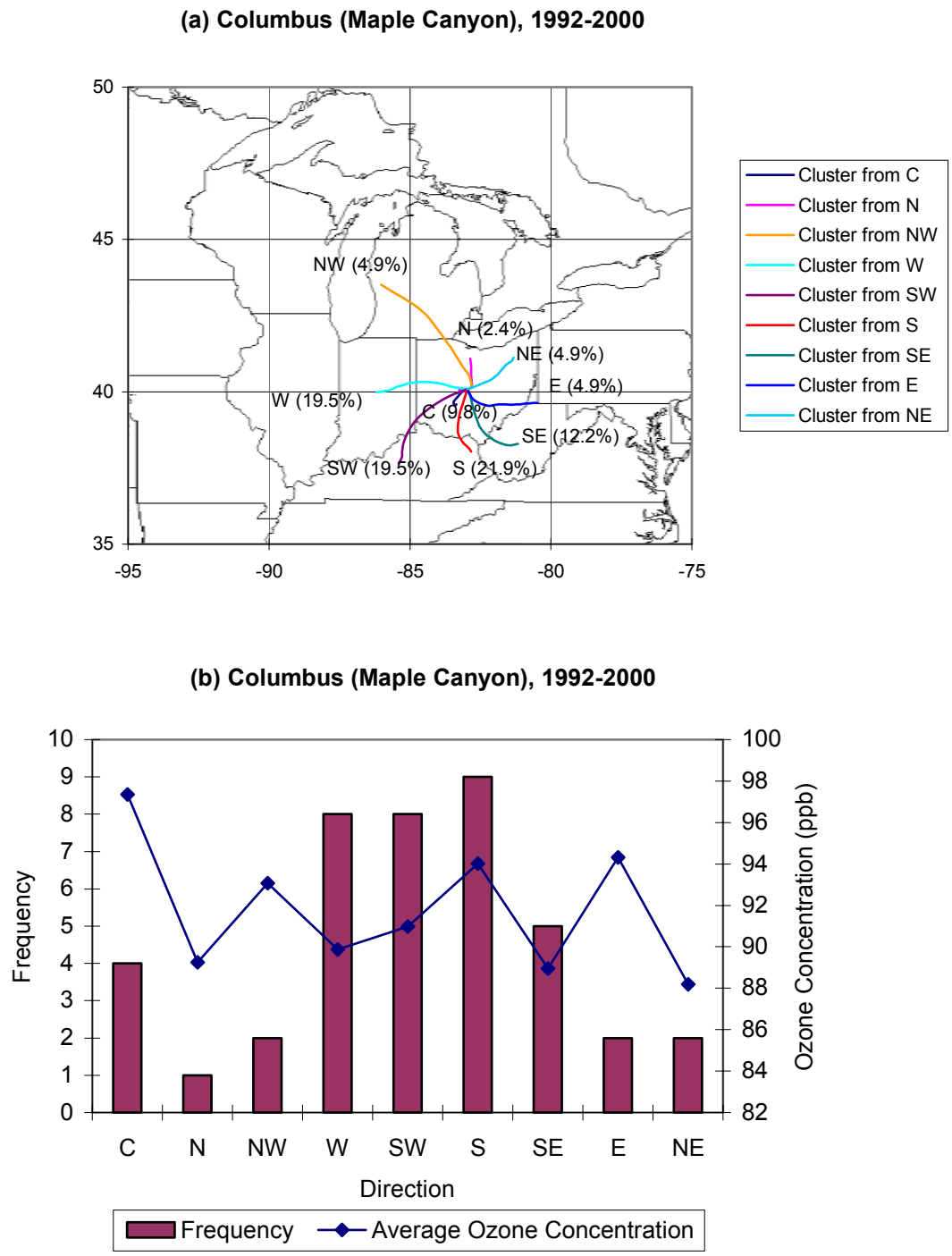


Figure III.1.52. (a) Cluster plot for Columbus (Maple Canyon), 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Columbus (Maple Canyon), 1992-2000

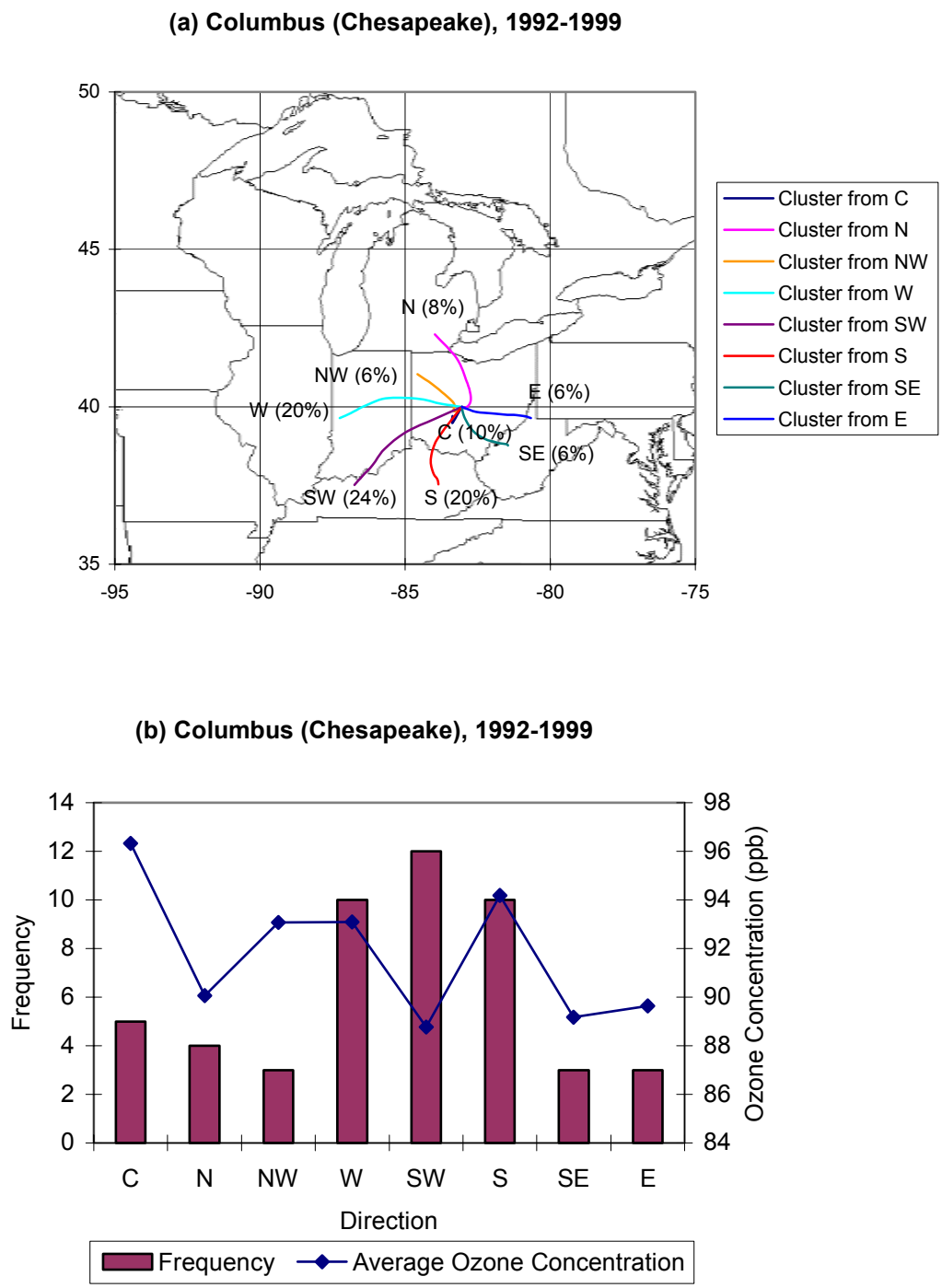


Figure III.1.53. (a) Cluster plot for Columbus (Chesapeake), 1992-1999 (b) Frequencies and average ozone concentrations by cluster for Columbus (Chesapeake), 1992-1999

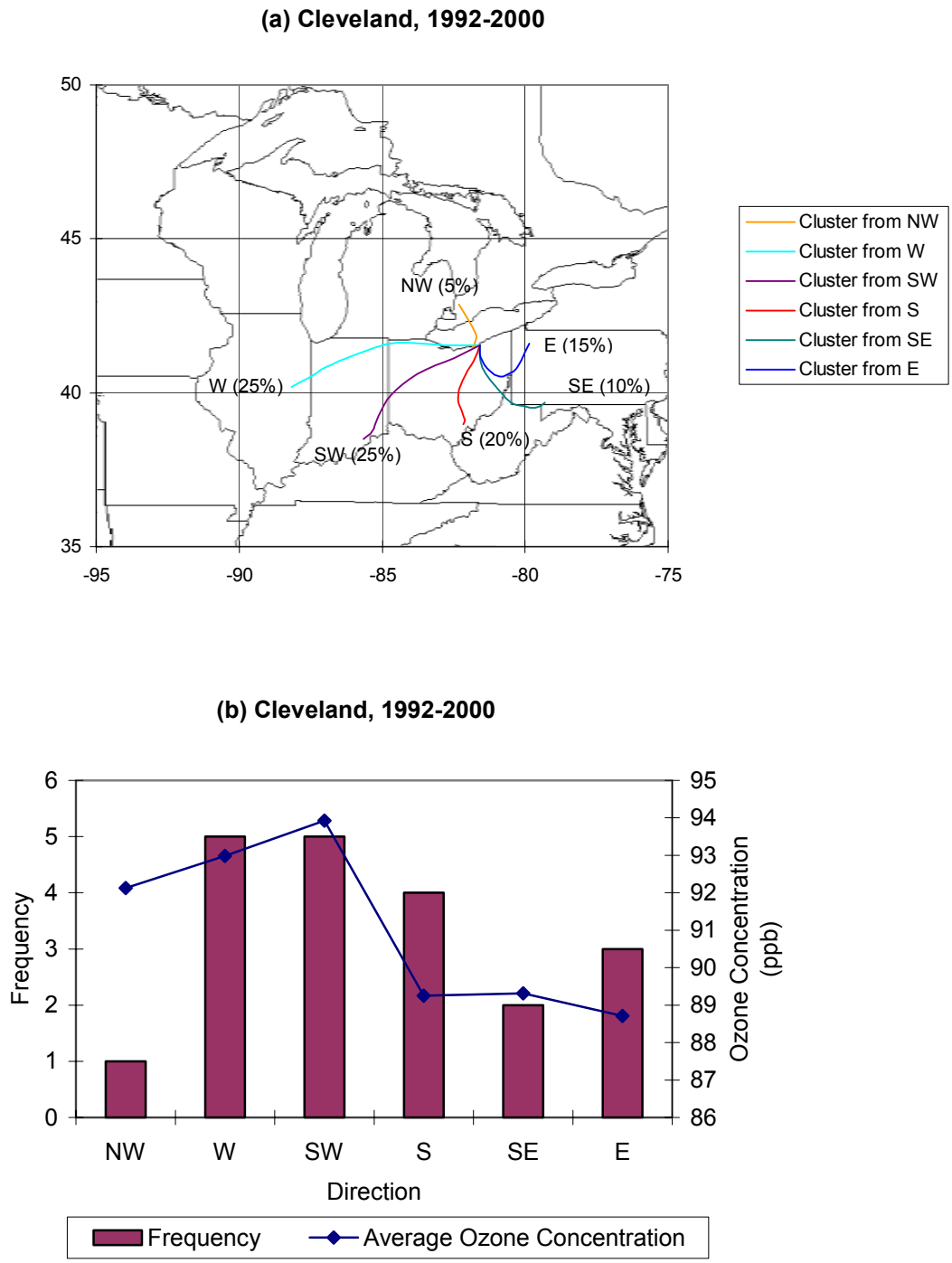
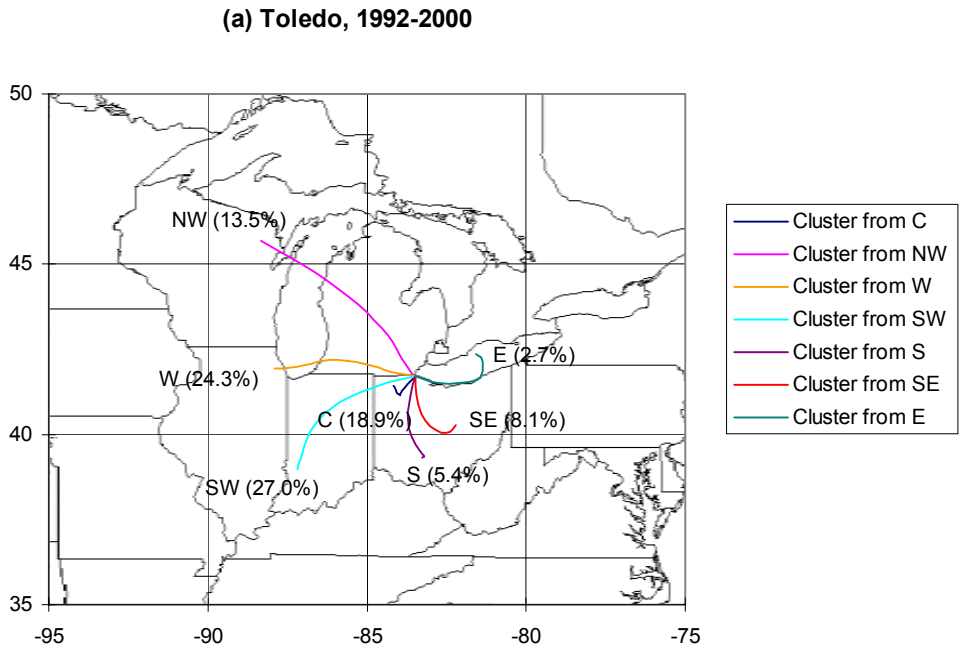


Figure III.1.54. (a) Cluster plot for Cleveland, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Cleveland, 1992-2000



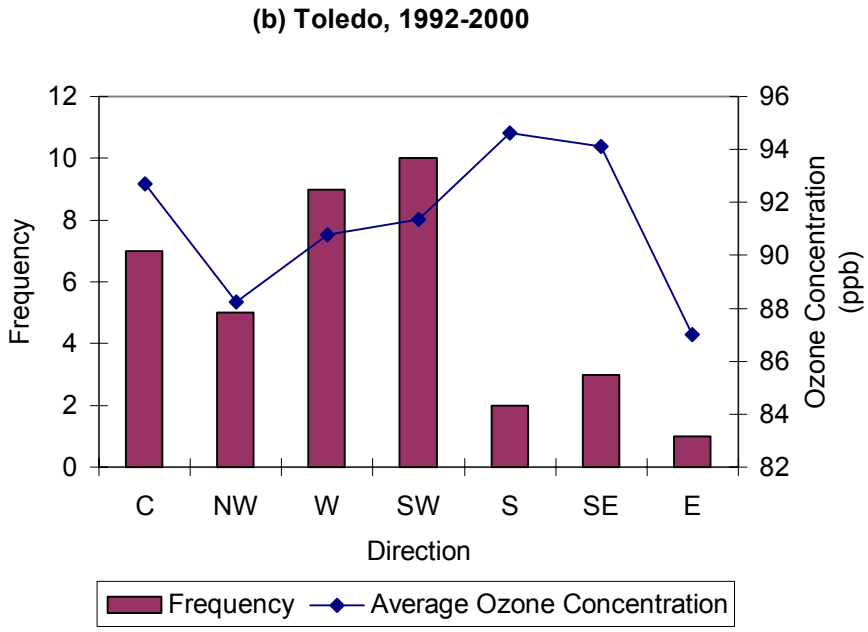


Figure III.1.55. (a) Cluster plot for Toledo, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Toledo, 1992-2000

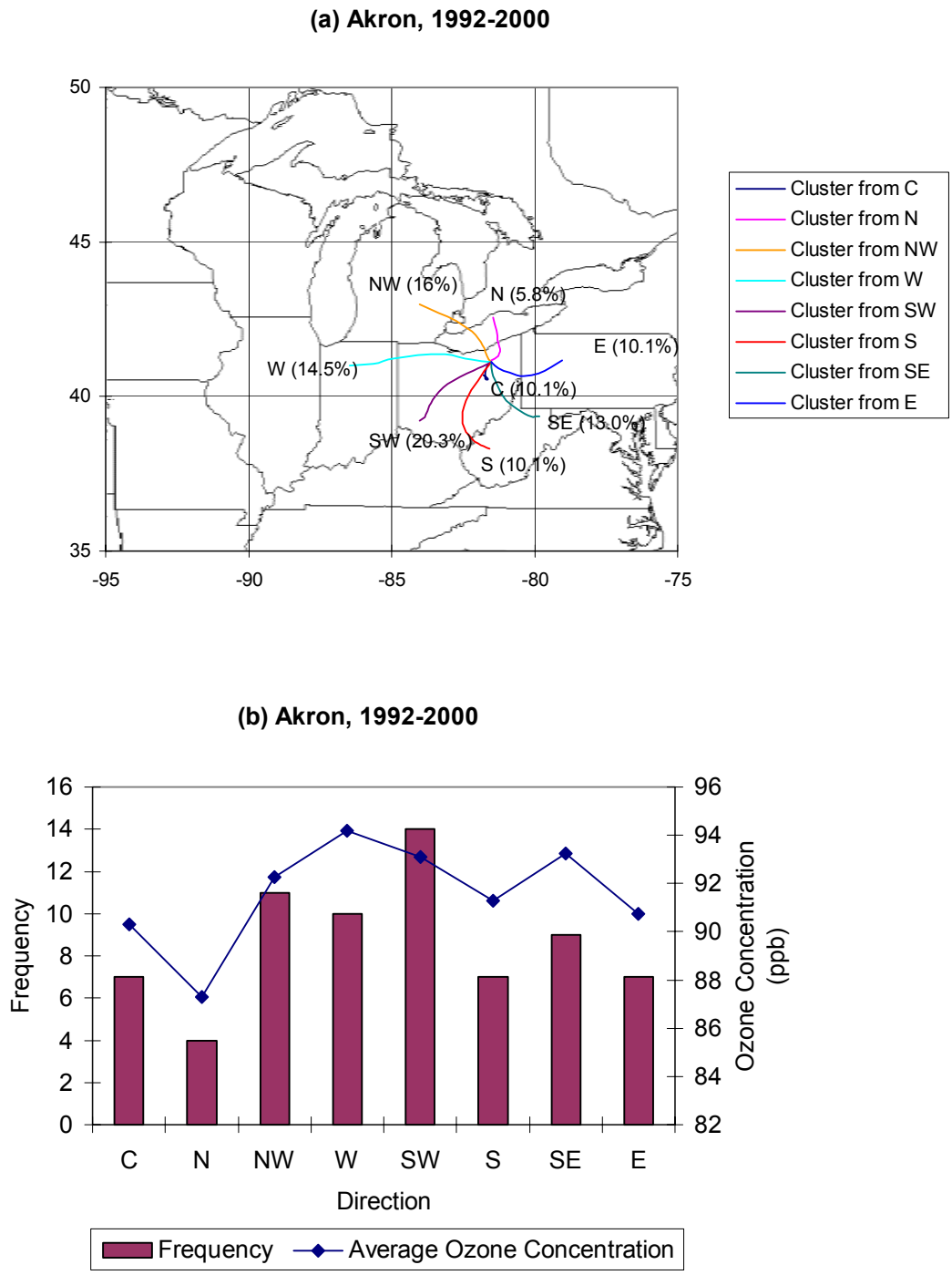


Figure III.1.56. (a) Cluster plot for Akron, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Akron, 1992-2000

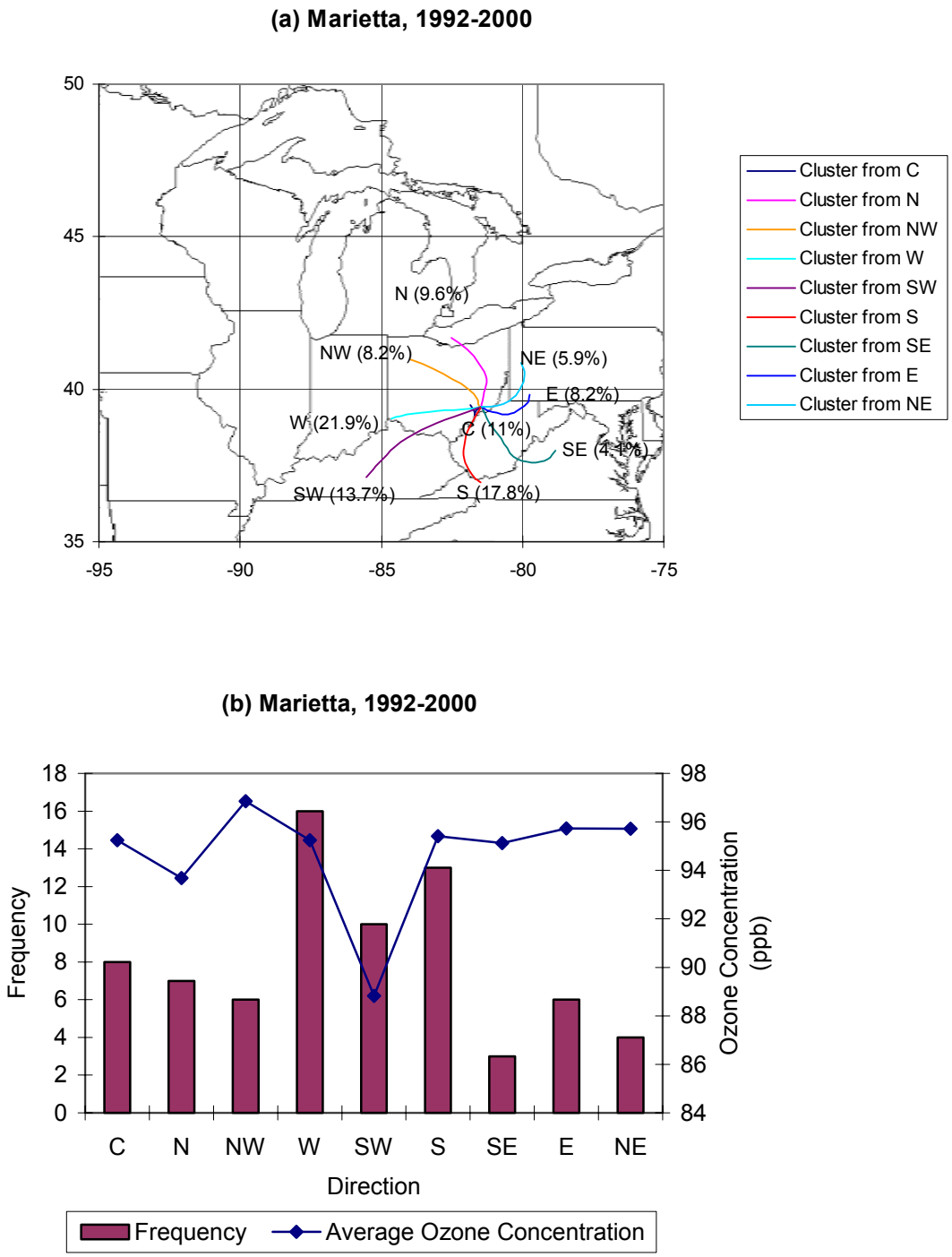


Figure III.1.57. (a) Cluster plot for Marietta, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Marietta, 1992-2000

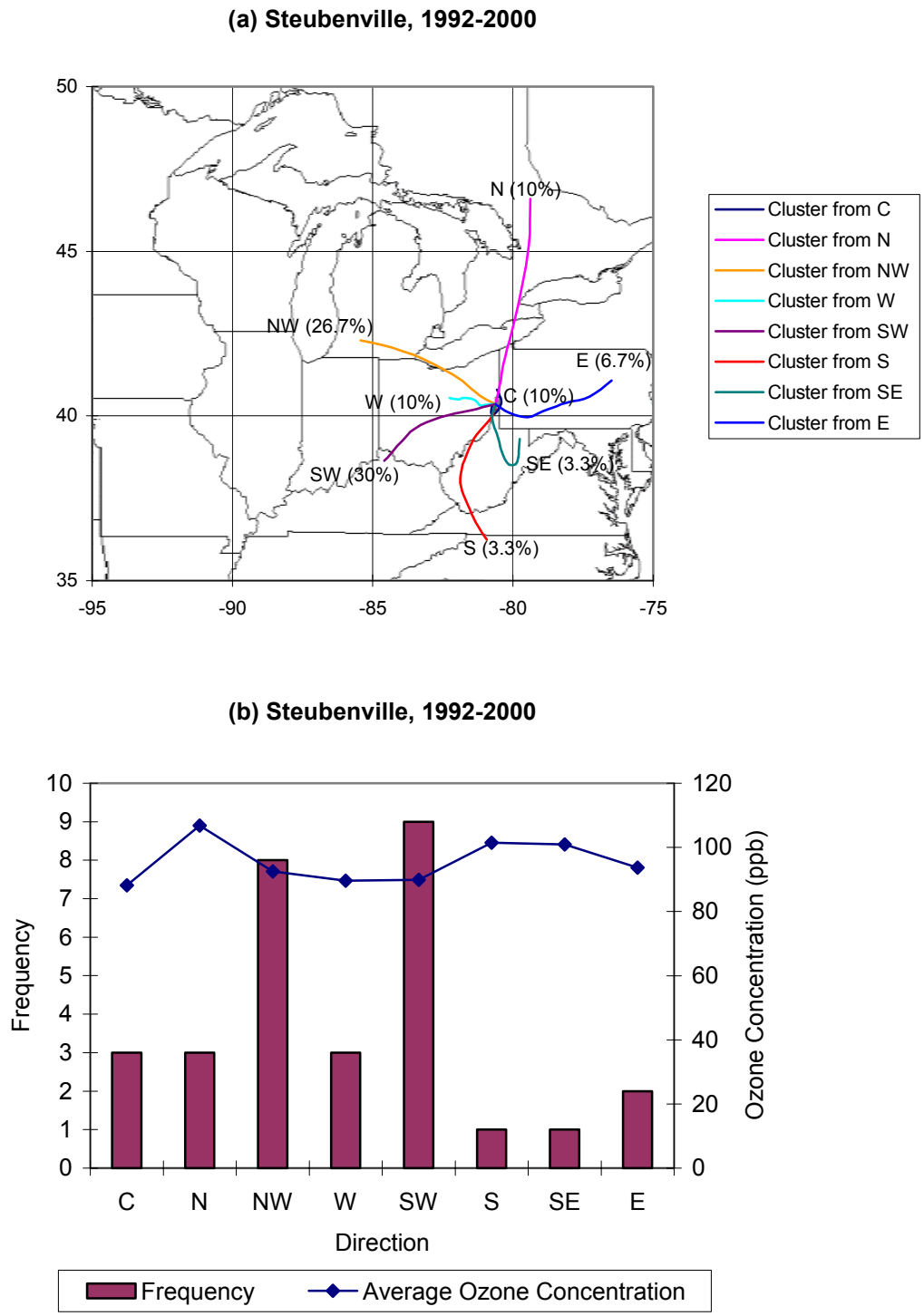


Figure III.1.58. (a) Cluster plot for Steubenville, 1992-2000 (b) Frequencies and average ozone concentrations by cluster for Steubenville, 1992-2000

These results reveal that high ozone days occur more often on days with trajectories associated with the southwest cluster and that the highest ozone concentrations are generally associated with the south or southeast clusters. Most clusters' source regions correspond with major cities in neighboring states, which includes Detroit Michigan, Chicago Illinois, Indianapolis and Fort Wayne Indiana, Louisville and Lexington Kentucky, Charleston West Virginia, Pittsburgh Pennsylvania, Buffalo, New York and major cities in Ohio including Columbus, Cleveland, Cincinnati, Dayton, and Toledo. This suggests that neighboring urban centers affect the ozone levels. Also, since a large amount of clusters pass over the Ohio River valley, the analysis indicates that the Ohio River valley acts as one of the main source regions of ozone precursors for the major cities in Ohio.

Particulate Matter (PM_{10})

Figures III.1.59. through III.1.64. depict the cluster analysis for high PM_{10} days. These clusters, their percentiles, frequencies, and average concentrations for each cluster for the five monitoring sites during 1999-2000 are presented. For all the sites the most frequent trajectory on high PM days was associated with the southwest cluster.

Similar to ozone, the most frequent trajectories for high PM_{10} days correspond with major cities in neighboring states. Also a high frequency of trajectories passing over the Ohio River valley, were experienced.

Back trajectory and cluster plots for CO, SO_2 and NO_2 are shown in Appendix F.

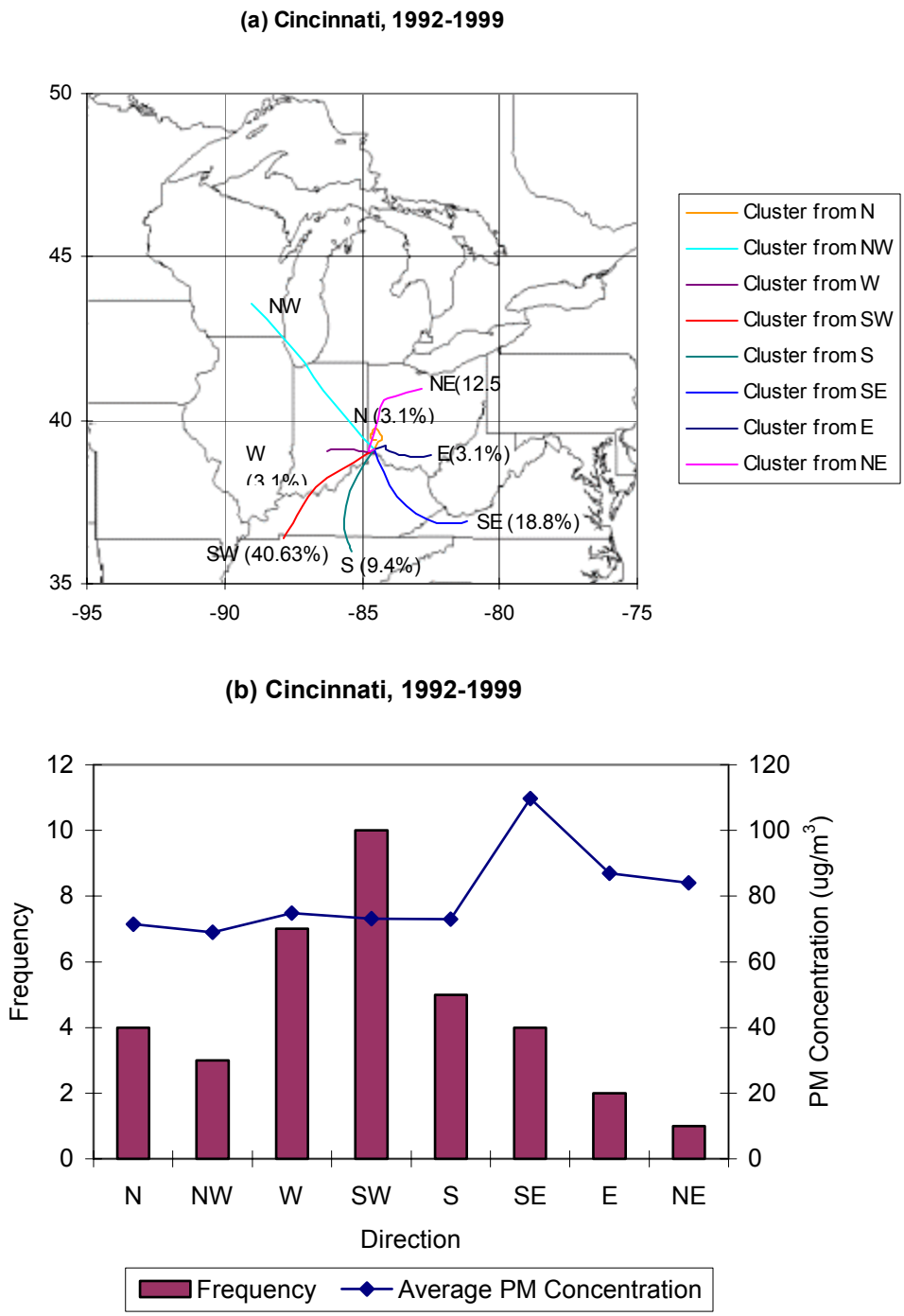


Figure III.1.59. (a) Cluster plot at Cincinnati, 1992-1999 (b) Frequencies and average PM_{10} concentrations by cluster at Cincinnati, 1992-1999

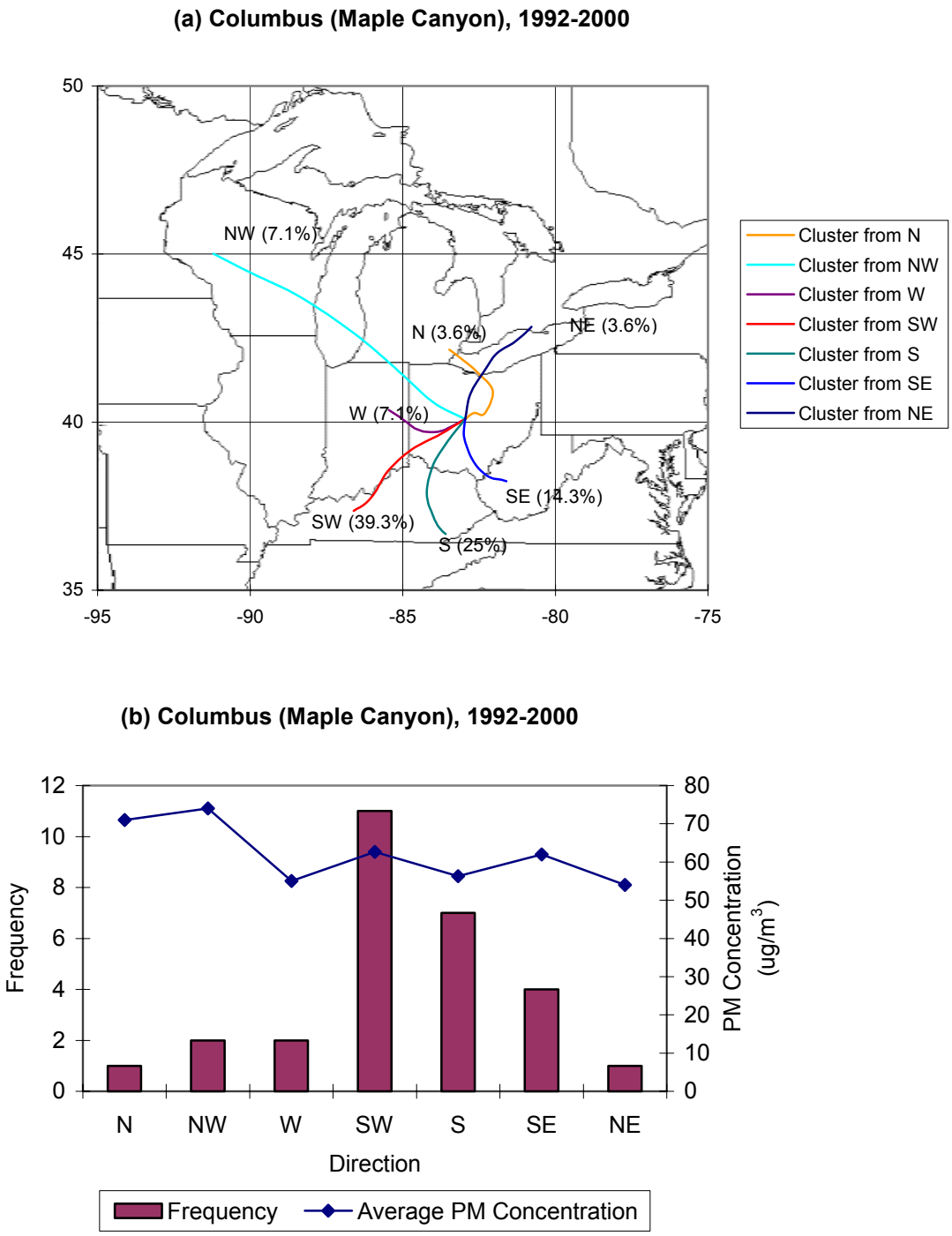


Figure III.1.60. (a) Cluster plot at Columbus (Maple Canyon), 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Columbus (Maple Canyon), 1992-2000

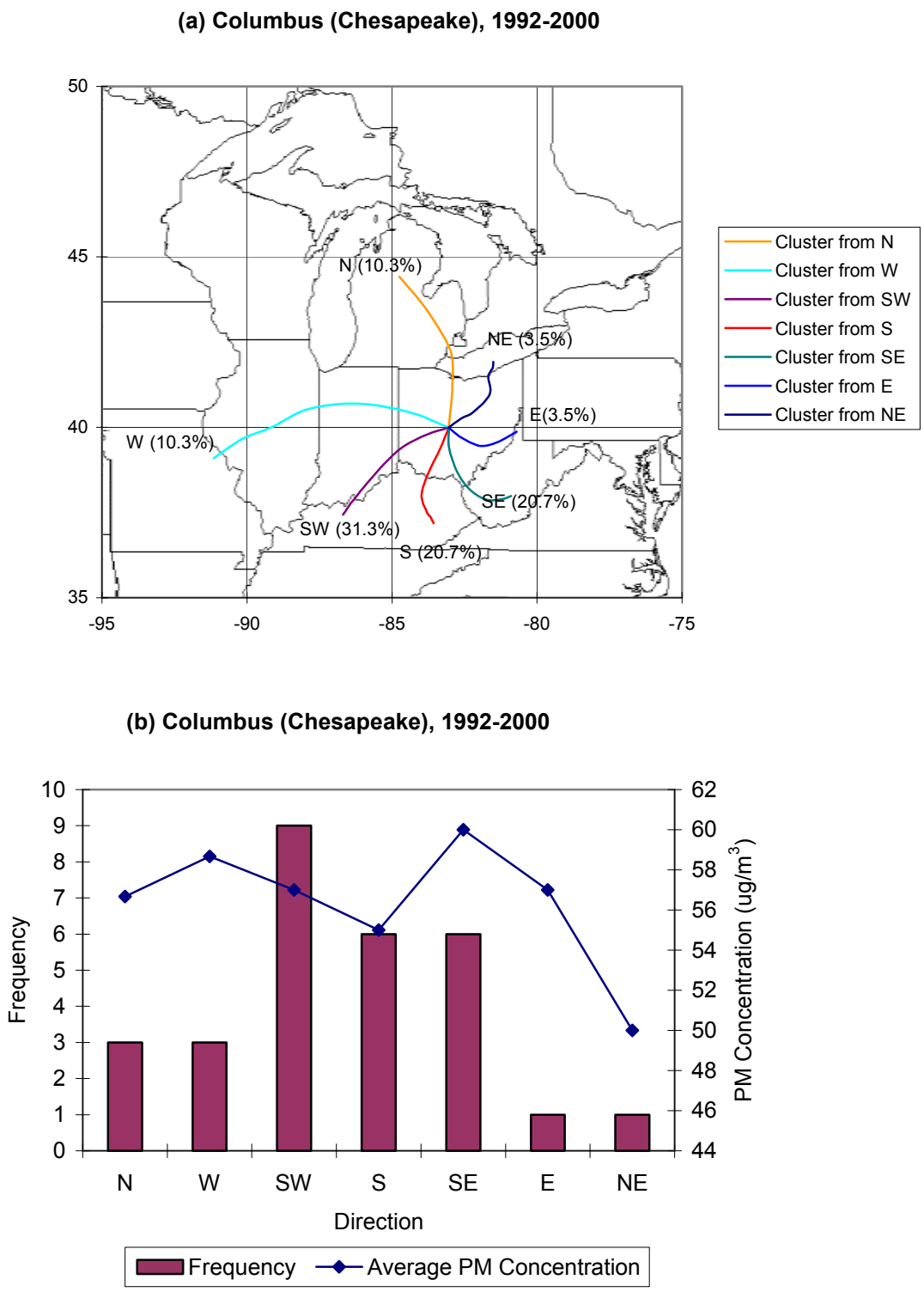


Figure III.1.61. (a) Cluster plot at Columbus (Chesapeake), 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Columbus (Chesapeake), 1992-2000

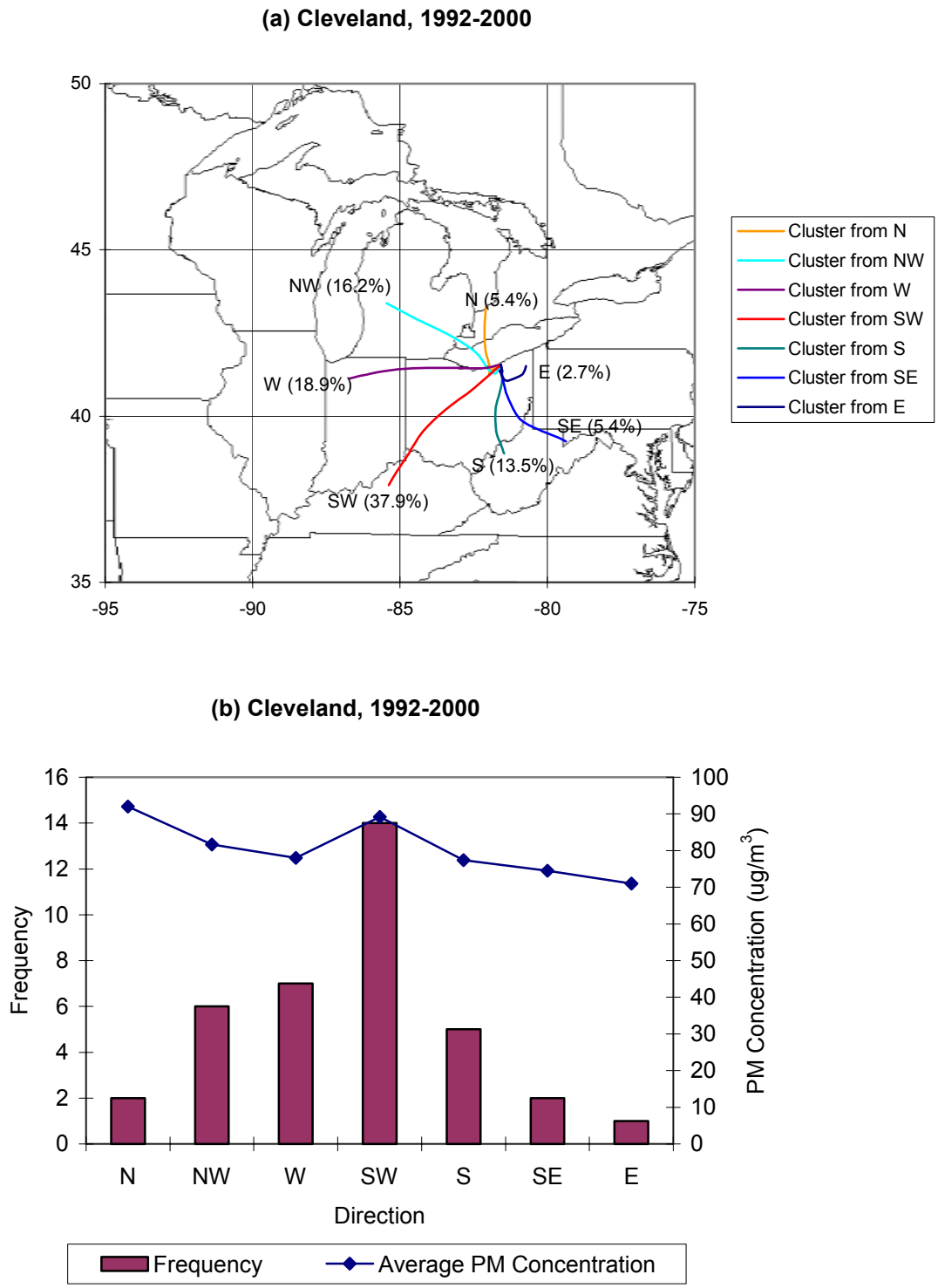


Figure III.1.62. (a) Cluster plot at Cleveland, 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Cleveland, 1992-2000

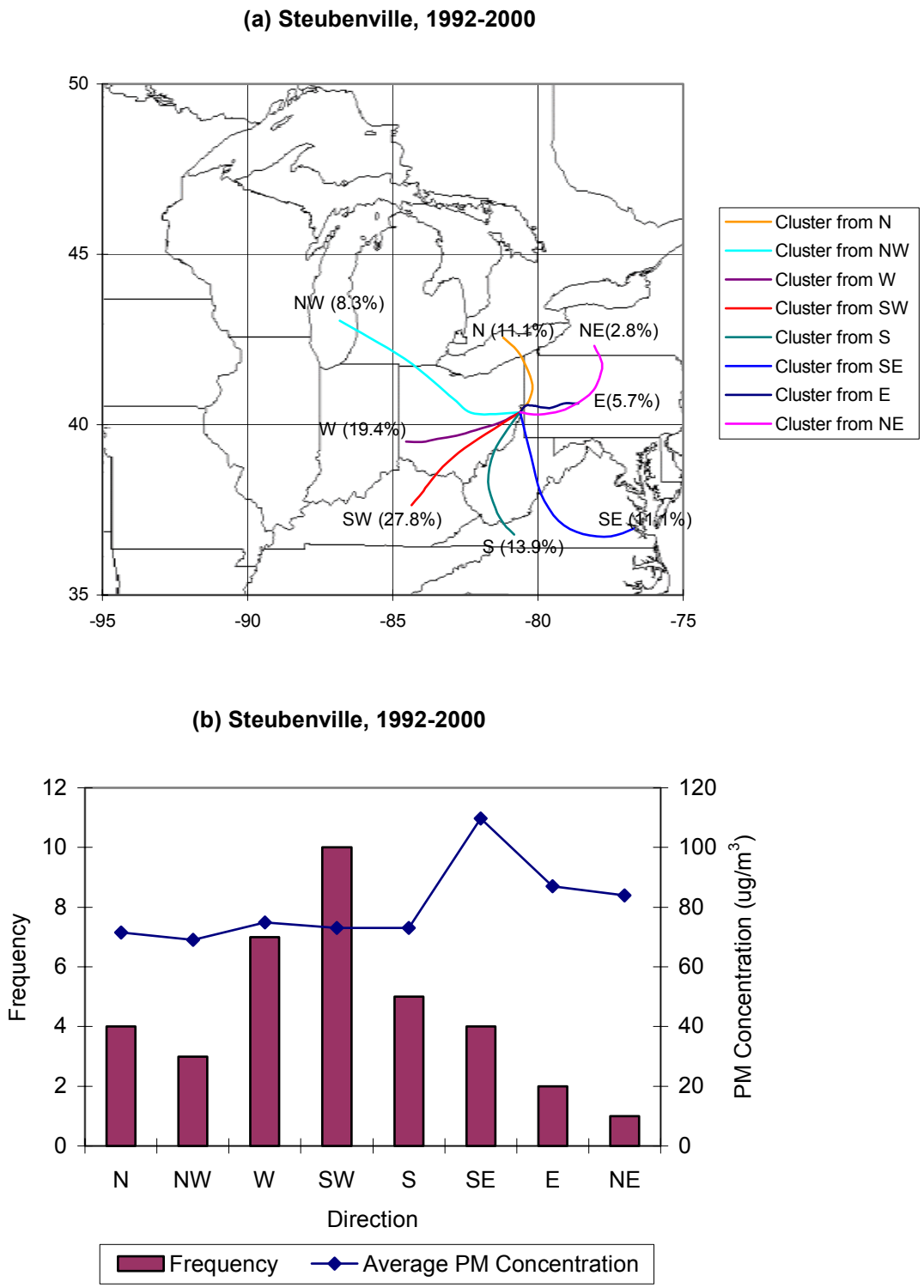


Figure III.1.63. (a) Cluster plot at Steubenville 1992-2000 (b) Frequencies and average PM_{10} concentrations by cluster at Steubenville, 1992-2000

CONCLUSIONS

This study provides a detailed analysis of the air quality issues affecting the major metropolitan areas in Ohio and evaluates the atmospheric transport patterns associated with ozone, particulate matter, carbon monoxide, sulfur dioxide and nitrogen dioxide and potential source regions affecting the air pollutants levels in Ohio. Statistical and meteorological analysis was performed to evaluate the influence of specific meteorological parameters on the air pollutants concentrations. Some key conclusions are enumerated in the following sections for O_3, PM, CO, SO_2 and NO_2.

Ozone

The design value, the three-year average of the fourth highest 8-hour ozone value was used to evaluate ozone trends in Ohio. The 8-hour average concentrations increased during the study period for most of the sites. Exceedances of the 8-hour NAAQS for ozone occurred continuously during the study period.

Most of the 8-hour ozone exceedances occurred in June through August. A greater frequency of high ozone days occurred during the weekend days at a majority of the sites. A strong correlation between the 1-hour and 8-hour ozone values was identified. It was also noted that 8-hour exceedances can occur in the absence of 1-hour ozone exceedances and that 1-hour ozone exceedances usually results in 8-hour ozone exceedances.

Spatial analysis was performed to evaluate the relationships in ozone concentrations between the sites evaluated in this study. A relatively strong correlation between sites was identified. These correlations between the sites highlight the regional nature of ozone and its precursors in Ohio.

Evaluation of the ozone episodes shows that most episodes last for several consecutive days. Maximum ozone values during these episodes occur on the same day for most of the sites and this tendency is more prominent in the 8-hour ozone distribution rather than the 1-hour ozone distribution. This reveals that the new 8-hour NAAQS for ozone could result in the spatial expansion of the ozone problem in Ohio.

Trajectory analysis employed to evaluate meteorological conditions identified long-range trajectories from the north, west, and south directions. These trajectories were then applied to a cluster analysis that segregates and merges each trajectory by their direction so that original pollutant source regions could be traced. High ozone days predominated along the southwest cluster but the highest average ozone concentrations appeared along the south and the southeast clusters.

Most source regions of clusters correspond with major cities in neighboring states, including Detroit, Chicago, Indianapolis, Louisville, Lexington, Charleston, and Pittsburgh. Ozone levels at most of the sites were affected by neighboring urban areas. In addition many of the clusters passed over the Ohio River Valley and were associated with higher average ozone concentrations indicating that the Ohio River Valley is one of the main source regions for ozone.

Particulate Matter

Twenty four-hour averaged PM_{10} concentrations were analyzed from 1999-2000. The time series analysis showed no exceedances at the monitoring locations used in this study during 1999-2000. Long-term trends analysis of PM_{10} identified relatively constant PM_{10} concentrations during the study period. The exception was Steubenville, which experienced a slight decrease in PM_{10} concentrations.

Monthly PM_{10} distributions indicate that the mean PM_{10} concentrations are high during the summer months, especially in June and July, and low during the winter months, implying that temperature has a significant influence on the PM concentration.

Correlation analysis determined the significant relationships between PM_{10} and meteorological components, temperature, wind speed, wind direction, and relative humidity. Temperature, wind speed, and wind direction were highly correlated with PM_{10} concentrations. High PM_{10} concentration levels were generally observed when wind speed was lower than 8 mph and temperature was higher than 70 °F or 80 °F and the PM_{10} concentrations were higher when the winds were blowing from the south and east direction.

Cluster analysis traced PM_{10} source regions and showed that most high PM_{10} days occurred along the southwest cluster, but the highest average PM_{10} concentrations appeared along the southeast or north clusters. Main source regions correspond with major cities in neighboring states, which include Detroit, Chicago, Indianapolis, Louisville, and Pittsburgh. Many of the clusters also passed over the Ohio River valley during high PM days indicating that the Ohio River Valley is a major regional of PM_{10} in Ohio.

CO, SO_2 and NO_2

Second highest 8-hour averaged CO concentrations, annual averaged SO_2 concentrations, and annual average NO_2 concentrations were analyzed to evaluate the trends for these pollutants from 1992-2000. CO and SO_2 levels in Ohio have significantly decreased across the entire state. While NO_2 concentrations have shown a slight increase in the long-term trends.

The monthly distribution indicates that the mean CO and SO_2 concentrations are high during the winter months and low during the summer months. Weekday concentrations are relatively higher than weekend concentrations for CO, SO_2 and NO_2.

Correlation analysis determined the significant relationship between CO, SO_2 and NO_2 and weather components. Wind speed was inversely correlated with CO, SO_2 and NO_2 concentrations. A predominate wind direction was not identified with high concentrations of CO, SO_2 and NO_2. There was no significant correlation between the pollutant concentrations with temperature and relative humidity.

Spatial analysis was performed to evaluate the relationships in CO, SO_2 and NO_2 concentrations between locations. No significant correlations were identified.

NOTES

1.EPA. 1997 *Revised Ozone Standard-fact sheet*. Office of Air Quality Planning and Standards [online] [cited 11 November 2002] (www.epa.gov/ttncaaa1/t1/fact_sheets/ o3fact.pdf)

2. EPA. 1998. EPA's Air Quality Maps and Monitoring Data-Region 5, Areas Violating the 8-Hour Ozone Standard, September 1998. [online] [cited 11 November 2002] (www.epa.gov/ARD-R5/naaqs/8o3_nmap.htm)

3. *Ohio EPA Air Quality Data Analysis*[online] [cited 11 November 2002] (www.epa.state.oh.us/dapc/ams/data.html).

4. *EPA Region 5 Agenda for Action, Goal 1: Clean Air*, (December 1998). [online] [cited 11 November 2002] (http://www.epa.gov/reg5oopa/agenda99/goal_1.htm)

5. *EPA's Revised Particulate Matter Standard-fact sheet*. (Office of Air Quality Planning and Standards, July 1997). [online] [cited 11 November 2002] (www.epa.gov/ttncaaa1/ t1/fact_sheets/pmfact.pdf)

6. J. B. Flaum & S.T. Rao, Moderating influence of meteorological conditions on ozone. *Journal of AWMA* 46 (1996): 35.

7. D. Chan, S.T. Rao, I.G. Zurbenko , & P.S. Porter, Linking changes in ozone to change in emissions and meteorology, *Air Pollution VII* (United Kingdom: WIT Press, 1999).

8. S.R. Dorling. T.D. Davies, & C.E. Pierce, Cluster analysis: a technique for estimating the synoptic meteorological controls on air and precipitation chemistry-method and applications, *Atmospheric Environment* 26A(1992): 2575-2581.

9. S.R. Dorling, T.D. Davies & C.E. Pierce, Cluster analysis: a technique for estimating the synoptic meteorological controls on air and precipitation chemistry-results from Eskdalemuir, South Scotland, *Atmospheric Environment,* 26A(1992); 2583-2602.

10. E. Brankov, S.T. Rao, & P.S. Porter, Identifying pollution source regions using multiply-censored data, *Environmental Science and Technology*: 33(1999): 2273-2277.

11. S.T. Rao et al., A trajectory-clustering-correlation methodology.

12. TNRCC Web Page. [cited 5 November 2002]. Available from World Wide Web: www.tnrcc.state.tx.us/updated/air/monops/data/trajectories/maintraj.html /maintraj.html

13. *Air Resources Laboratory. HYSPLIT4* (Hybrid Single-Particle Lagrangian Integrated Trajectory) *Model,* (National Oceanic and Atmospheric Administration, 1997). (http://www.arl.noaa.gov/ready/hysplit4.html)

14. S.T Rao., E.B. Brankov, & P.S. Porter, A trajectory-clustering-correlation methodology for examining the long-range transport of air pollutants, *Atmospheric Environment* 32(1998): 1525-1534.

15. Dorling et al., 1992, Cluster analysis (see note 9).

16. Ibid.; Rao et al., A trajectory-clustering-correlation methodology (see note 12).

Section 3, Chapter 2
RESPIRATORY ILLNESS AND AIR QUALITY

The monitoring data in this report was gathered to assess levels of air pollutants in the ambient environment. When examining health effects associated with environmental contaminants, it is common for researchers to argue that the presence of a pollutant is indicative of adverse health effects. In other words, if contaminants are present, then health effects are inferred. However, a more rational approach to linking environmental contaminants with adverse health effects is to look for signs of illness that can be statistically associated with levels of pollution. This chapter summarizes the statistical relationship between levels of air pollution and respiratory illness.

OUTCOME MEASURES

Hospital admissions data were purchased from the Ohio Hospital Association (OHA). OHA represents 170 hospitals throughout the state and maintains one of the most comprehensive hospital admission data sets available. Admissions data were obtained for the years 1992 through 1998. As Table III.2.1.shows, five outcome measures were computed using the International Classification of Disease (ICD-9) diagnoses provided in the database:

1) Daily counts of total respiratory illness (ICD-9 462, 463, 487, 464, 465, 466, 490, 480, 481, 482, 483, 484, 485, 486, 493, but not 493.2 and 493.21, 490, 491, 492, 494, and 496);
2) Daily counts of asthma in children aged 14 and younger (ICD-9 493, but not 493.2 and 493.21);
3) Daily counts of coronary obstructive pulmonary disease (COPD) in adults aged 65 and older (ICD-9 490, 491, 492, 494, and 496);
4) Daily counts of deaths attributable to respiratory illness; and

5) Daily counts of non-respiratory illnesses (ICD-9 365, 540, 590, 531, and 532), served as a control for the other measures.

Table III.2.1. Principal Diagnosis codes (ICD-9) Used in this Study

Illness category	ICD-9 Code
Respiratory	
Upper respiratory	462, 463, 487
Acute infections	464-466
Pneumonias	480-486
COPD	490-492, 496
Asthma	493
Non- respiratory:	
Glaucoma	365
Acute Apendicitis	540
Renal Infections	590
Stomach and Duodenum	531, 532

Eight cities were the focus of this study: Cincinnati, Columbus, Dayton, Toledo, Cleveland, Steubenville, Youngstown and Akron. For each city, daily hospital admissions for each of the outcome measures were tallied for all patients who lived within 20 miles of a central ozone monitor within the city. The distance a patient lived from the ozone monitoring site was determined by the zip code of the patient's home address.

Hospital admissions data in the state of Ohio may include as many as nine different diagnoses. Counts of deaths attributable to respiratory illness included all patients who had received a diagnosis of respiratory illness upon admission to the hospital, whether or not respiratory illness was the primary diagnosis. For the other outcome measures, counts included only those patients whose *primary* diagnosis upon admission to the hospital was the appropriate one.

Smoothed time series plots of total respiratory admissions, including asthma, are shown in Figures III.2.1, II.2.2, and II.2.3 for Cleveland, Columbus and Cincinnati. These plots show the seasonal pattern and the similarity in this pattern between cities. The smoothed time series plots were obtained using a

three pass 31-day moving average. As the Figures depict, higher rates of total respiratory admissions were noted during the winter months which is most likely the result of increased incidents of respiratory infections associated with colder weather patterns.

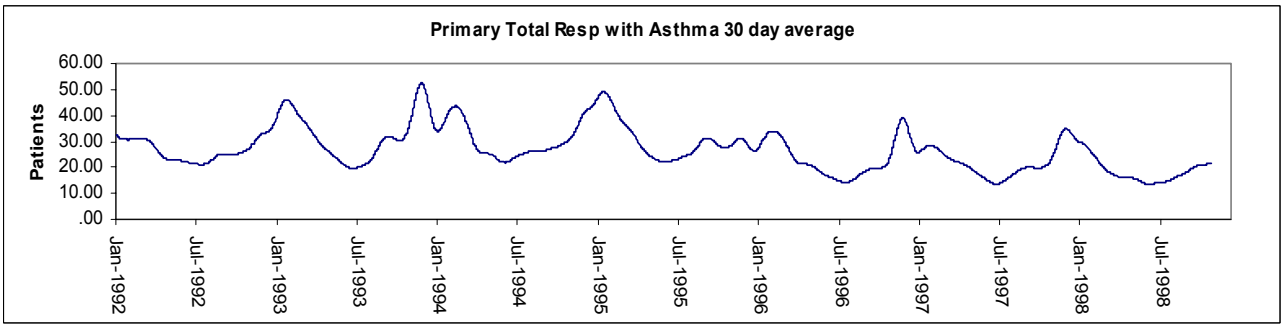


Figure III.2.1. Smoothed Time Series of Cleveland Respiratory Admissions

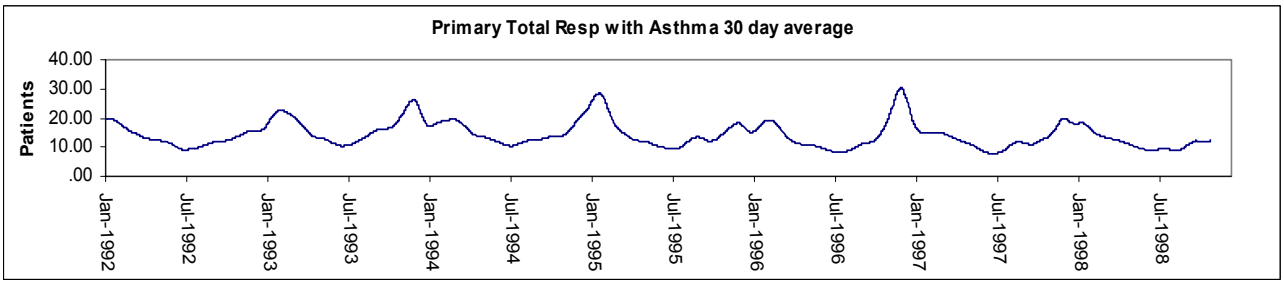


Figure III.2.2. Smoothed Time Series of Columbus Respiratory Admissions

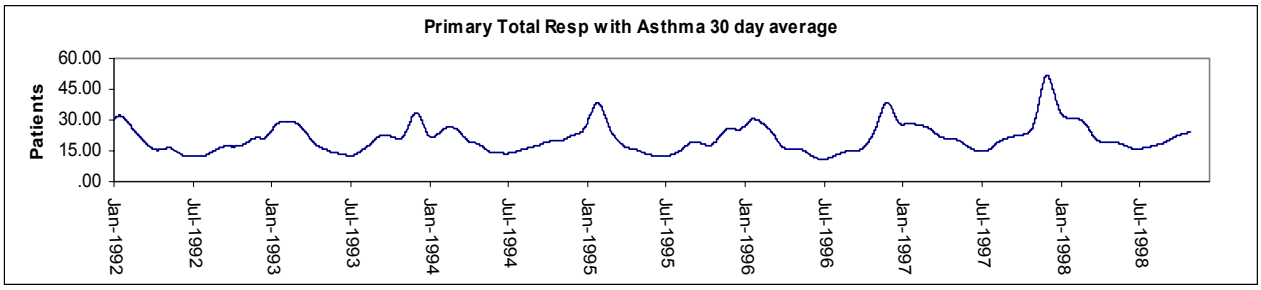


Figure III.2.3. Smoothed Time Series of Cincinnati Respiratory Admissions

The increased incidents of respiratory admission during the cold months are inversely related to the season patterns of PM_{10} and ozone identified in Chapter 1 of this section. Monitoring data indicates that ambient levels of both PM_{10} and ozone are higher during the summer months than the winter months. These differences in seasonal patterns highlight the importance of accounting

for the confounding effects of seasonality when statistically evaluating the relationships between air quality and respiratory illness.

AIR QUALITY AND METEOROLOGICAL DATA

Air quality data were obtained from EPA's Aerometric Informational Retrieval System (AIRS) through Ohio EPA. The air pollution measurements used in this study were PM_{10}, SO_2, NO_2, O_3, and CO. A central ozone monitor in each city was chosen as the anchor location. From this site a 20-mile radius was established to screen the hospital admission data. Additional pollutant monitoring data, if available, were obtained at the O_3 monitoring site or at the nearest location within the city. We computed two metrics for an exposure assessment at each site for O_3, CO, and NO_2: the maximum daily 1-hour and 8-hour average. For PM_{10} a 24-hour average was utilized.

Meteorological data was obtained from the National Climatic Data Center (NCDC). Daily values for average and maximum temperature, average relative humidity, total precipitation, average barometric pressure and average wind speed were retrieved from the NCDC data sets for each city represented in this study.

STATISTICAL ANALYSES

The relationship between respiratory health and air quality may be confounded by other variables, such as meteorological variables, that are related to both. In the analysis that follows, long-term trends were controlled by including a linear effect of time. We controlled for seasonal variation in respiratory health by including a dummy variable for each month of the study; that is, one dummy variable represented January of 1999, and so on. Dummy variables are commonly used in statistics to represent subgroups in a sample. There were two exceptions to the use of a monthly dummy variable. First, at many of the sites (Cincinnati, Columbus, Toledo, and Youngstown), PM_{10} data were collected approximately every six days. For these analyses, dummy variables for year (1992 and so on) and month (January and so on) were included in the analyses to control for yearly and monthly effects.

Second, at some of the sites (Akron and Dayton), very few cases of asthma among children were reported. To fit the data, it was necessary to use dummy variables for year and month, as was the case with the PM_{10} data. In all analyses, we included a dummy variable for each day of the week. We also included a dummy variable representing all major holidays (New Year's Day, Memorial Day, Fourth of July, Labor Day, Thanksgiving, and Christmas).

In the statistical analysis, meteorological variables were also controlled. Because many researchers have argued that the relationship between temperature and respiratory health is a complex one, we chose to model it

using linear, quadratic, and cubic effects. Because ozone is only collected during warm months, for analyses involving ozone, we included only a linear effect for temperature. In all analyses, we also included linear effects for average wind speed, average relative humidity, average barometric pressure, and the occurrence of precipitation.

In any analysis of time series data, the possibility that the residuals exhibit autocorrelation must be considered. Preliminary analyses were conducted with only the seasonal and weather variables in the models. Analyses of the residuals indicated the presence of autocorrelation. A first-order autocorrelation structure was as effective as any of the more complex structures examined for modeling the autocorrelation present in the data.

Separate analyses were conducted for each pollutant. Analyses were also conducted for each pollutant lagged one, two, and three days. Because ozone is essentially nonexistent during the winter—indeed, it is usually only collected during warm months—we only used data collected for May, June, July, August, and September in analyses involving ozone.

We used Poisson regression models based on the generalized estimating equations approach developed by Liang and Zeger[1,2] with a first-order autoregressive structure. For analyses of the PM_{10} data collected at the Cincinnati, Columbus, Toledo, and Youngstown sites, an independent error term was assumed.

RESULTS

Due to the amount of data generated in this component of the research, appendices are used to display the data. Descriptive statistics for the meteorological, air pollution, and respiratory measures, respectively, at the study sites can be found in Appendix E. Correlation matrices for the three sets of variables are also found in Appendix E.

Akron

Table III.2.1. summarizes significant correlations between air pollutants and health effects in Akron. A significant positive zero-order correlation was obtained between daily counts of hospital admissions for respiratory illness and PM_{10}, while significant negative zero-order correlations were obtained between daily counts of hospital admissions for respiratory illness and O_3 and PM_{10}. After controlling for seasonality and weather conditions, none of the air pollutants was positively related to daily counts of hospital admissions for respiratory illness.

Table III.2.1. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Akron (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}	+	-	+	-
O_3	-	-		-
CO			+	
SO_2		+		-

Daily hospital admissions for childhood asthma were significantly negatively related to O_3 and PM_{10} and significantly positively related to SO_2. After controlling for seasonality and weather conditions, there remained a positive relationship between SO_2 (1 Hr) and childhood asthma (RR = 1.002) and between O_3 following a 2-day lag and childhood asthma (RR = 1.009).

Carbon monoxide (8-Hr) and PM_{10} were significantly positively correlated with daily hospital admissions for COPD among the elderly. After controlling for seasonality and weather, no air pollutants remained significantly related to COPD.

Deaths attributable to respiratory illness were negatively related to O_3, and positively related to SO_2 (8 Hr) and PM_{10}. There was no clear evidence of any relationship between deaths that were at least partially attributable to respiratory illness and any of the air pollutants after controlling for seasonality and weather.

Cincinnati

Significant correlations between air pollution and health effects are summarized in Table III.2.2. Significant zero-order correlations were obtained between daily counts of hospital admissions for respiratory illness and NO_2 (1 Hr), CO, O_3, and PM_{10}. After controlling for seasonality and weather conditions, only CO remained significantly related to daily counts of hospital admissions for respiratory illness (RR = 1.03 for 8-Hr CO).

Daily hospital admissions for childhood asthma were significantly negatively related to NO_2 (1 Hr), CO (8 Hr), and O_3. The negative relationship between asthma and air pollution, particularly ozone, is one that is commonly observed and apparently occurs because many respiratory illnesses peak during the winter months when ozone is virtually nonexistent. Indeed, ozone is only recorded from April through October in Cincinnati. After controlling for

Table III.2.2. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Cincinnati (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}	+			
O_3		-	+	-
CO	+	-	+	+
SO_2	+			+
NO_2	+	-		-

seasonality and weather, we detected a positive relationship between O_3 and admissions of children to hospitals for asthma (RR = 1.01 for both 1-Hr and 8-Hr O_3).

Significant negative relationships were observed between O_3 and childhood asthma at lags of 1 and 2 days. Negative relationships were also observed between childhood asthma and NO_2 (1-Hr) at 0 and 1-day lags and between childhood asthma and CO at 1-day lags. It is difficult to know what to make of these relationships. Perhaps the negative relationships are an artifact of the extremely small number of hospital admissions for childhood asthma, particularly during the summer months. For example, in 1996, the number of children admitted to the hospital for asthma ranged from a low of 2 in July to a high of 15 in November. During the seven years covered by this study, there were never more than seven children in the Cincinnati area admitted to hospitals for asthma during the month of July. More generally, there were no children admitted to hospitals in Cincinnati for asthma on 70 percent of the days covered by this study.

CO and O_3 were significantly positively correlated with daily hospital admissions for COPD among the elderly. After controlling for seasonality and weather, only CO (8-Hr) remained significantly related to COPD (RR = 1.07).

Deaths attributable to respiratory illness were negatively related to NO_2 (1-Hr) and O_3, and positively related to CO and SO_2. There was no clear evidence of any relationship between deaths that were at least partially attributable to respiratory illness and any of the air pollutants after controlling for seasonality and weather.

Cleveland

As summarized in Table III.2.3, there were significant negative correlations between daily hospital admissions for respiratory illness in Cleveland and NO_2 (1 Hr), O_3, and PM_{10}, while there were significant positive correlations between daily hospital admissions for respiratory illness in Cleveland and CO and SO_2. After controlling for seasonality and weather conditions, daily counts of hospital admissions for respiratory illness were positively related to NO_2 with a 1-day lag (RR = 1.001 for 1 Hr NO_2; RR = 1.002 for 8 Hr NO_2) and to PM_{10} with a 1-day lag (RR = 1.001).

Table III.2.3. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Cleveland (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}	-	-	-	
O_3	-	-		-
CO	+	+	+	+
SO_2	+	+	+	+
NO_2	-	-	-	-

Daily hospital admissions for childhood asthma were significantly positively correlated with CO and SO_2 (8 Hr), but negatively correlated with NO_2 (1-Hr), O_3, and PM_{10}. There appeared to be a positive relationship between childhood asthma and O_3 with a 1-day lag (RR = 1.001 for both 1-Hr and 8-Hr O_3), even after controlling for seasonality and weather.

CO and SO_2 were significantly positively correlated and NO_2 and PM10 were negatively correlated with daily hospital admissions for COPD among the elderly. After controlling for seasonality and weather, none of the air pollutants were positively related to this measure of respiratory health.

Deaths attributable to respiratory illness were positively related to CO and SO_2 and negatively related to NO_2 (1-Hr) and O_3 (8-Hr). After controlling for seasonality and weather, only CO with a 3-day lag had even a marginal positive relationship with deaths that were at least partially attributable to respiratory illness (RR = 1.02).

Columbus

Table III.2.4. summarizes the significant correlations between health effects and air pollution in Columbus. CO and SO_2 had significant positive zero-order correlations with daily counts of hospital admissions for respiratory illness, while O_3 and PM10 had significant negative zero-order correlations with daily counts of hospital admissions for respiratory illness. After controlling for seasonality and weather conditions, there was no evidence of a positive relationship between daily counts of hospital admissions for respiratory illness and any of the pollutants.

Table III.2.4. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Columbus (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}	-			-
O_3	-	-		
CO	+	+	+	+
SO_2	+		+	+
NO_2				

Daily hospital admissions for childhood asthma were significantly positively correlated with CO, but negatively correlated with O_3. The negative relationship between asthma and air pollution, particularly ozone, is one that is commonly observed and apparently occurs because many respiratory illnesses peak during the winter months when ozone is virtually nonexistent. Indeed, ozone is only recorded from April through October in Columbus.

After controlling for seasonality and weather, we detected significant negative relationships childhood asthma and both O_3 and SO_2. A negative relationship was also observed between childhood asthma and PM_{10} at 1- and 2-day lags. It is difficult to know what to make of these relationships. Perhaps the negative relationships are due to the extremely small number of hospital admissions for childhood asthma, particularly during the summer months. For example, in 1996, the number of children admitted to the hospital for asthma ranged from a low of 2 in August to a high of 13 in November. More generally, there were no children admitted to hospitals in Columbus for asthma on 78% of the days covered by this study.

CO and SO_2 were significantly positively correlated with daily hospital admissions for COPD among the elderly. After controlling for seasonality and weather, CO (8 Hr) with a lag of 3 days (RR = 1.10) and SO_2 with a lag of 3 days (RR = 1.002 for 1 Hr SO_2; RR = 1.005 for 8 Hr SO_2) remained significantly positively related to COPD.

Deaths attributable to respiratory illness were positively related to CO and SO_2 and negatively related to PM_{10}. After controlling for seasonality and weather, SO_2 with a 1-day lag was positively related to deaths that were at least partly attributable to respiratory illness (RR = 1.003).

Dayton

A summary of significant correlations between health effects and air pollution in Dayton is found in Table III.2.5. CO and SO_2 had significant positive zero-order correlations with daily counts of hospital admissions for respiratory illness, while O_3 had significant negative zero-order correlations with daily counts of hospital admissions for respiratory illness. After controlling for seasonality and weather conditions, there was no evidence of a positive relationship between daily counts of hospital admissions for respiratory illness and any of the air pollutants.

Table III.2.5. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Dayton (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}				
O_3	-	-	-	-
CO	+		+	-
SO_2	+		+	+
NO_2				

Daily hospital admissions for childhood asthma were significantly negatively correlated with O_3. After controlling for seasonality and weather, there did not appear to be a positive relationship between childhood asthma and any of the air pollutants.

CO and SO_2 were significantly positively correlated and O_3 was significantly negatively correlated with daily hospital admissions for COPD

among the elderly. After controlling for seasonality and weather, O_3 (8 Hr) with a 1-day lag (RR = 1.10) had a significant positive relationship with COPD (RR = 1.005 for both 1-Hr and 8-Hr O_3).

Deaths attributable to respiratory illness were positively related to SO_2 and negatively related to CO and O_3. After controlling for seasonality and weather, there did not appear to be a positive relationship between deaths due to respiratory illness and any of the air pollutants.

Steubenville

Table III.2.6. is a summary of significant correlations between health effects and air pollution in Steubenville. NO_2, CO, and SO_2 (8-Hr) had significant positive zero-order correlations with daily counts of hospital admissions for respiratory illness, while O_3 had significant negative zero-order correlations with daily counts of hospital admissions for respiratory illness. After controlling for seasonality and weather conditions, there were positive relationships between hospital admissions for respiratory illness and NO_2 (RR = 1.004 for 1-Hr NO_2; RR = 1.005 for 8-Hr NO_2), CO (8 Hr) (RR = 1.027), and O_3 with a 1-day lag (RR = 1.003 for both 1-Hr and 8-Hr O_3).

Table III.2.6. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Steubenville (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}				
O_3	-	-		-
CO	+			
SO_2	+			
NO_2	+			

Daily hospital admissions for childhood asthma were significantly negatively correlated with O_3. After controlling for seasonality and weather, there appeared to be a positive relationship between daily hospital admissions for childhood asthma and NO_2 with a 2-day lag (RR = 1.02 for both 1-Hr and 8-Hr NO_2), CO with a 2-day lag (RR = 1.07 for 1-Hr CO; RR = 1.14 for 8-Hr CO) and a 3-day lag (RR = 1.06 for 1-Hr CO; RR = 1.14 for 8-Hr CO), SO_2 with a 2-day lag (RR = 1.004 for 1-Hr SO_2; RR = 1.006 for 8-Hr SO_2), and PM10 with a 2-day lag (RR = 1.006).

None of the air pollutants was correlated with daily hospital admissions for COPD among the elderly. After controlling for seasonality and weather, there did not appear to be a positive relationship between daily hospital admissions for COPD among the elderly and any of the air pollutants.

Deaths attributable to respiratory illness were negatively related to O_3. There was weak evidence of a positive relationship between deaths and CO with a 3-day lag (RR = 1.030 for 1-Hr CO; RR = 1.067 for 8-Hr CO), after controlling for seasonality and weather.

Toledo

A summary of significant correlation between health effects and air pollution in Toledo can be found in Table III.2.7. CO and SO_2 had significant positive zero-order correlations with daily counts of hospital admissions for respiratory illness, while O_3 had significant negative zero-order correlations with daily counts of hospital admissions for respiratory illness. After controlling for seasonality and weather conditions, there was only weak evidence of a positive relationship between daily counts of hospital admissions for respiratory illness and CO (1-Hr) (RR = 1.002) and O_3 (RR = 1.002).

Table III.2.7. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Toledo (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}				+
O_3	-	-		-
CO	+		+	+
SO_2	+		+	
NO_2				

Daily hospital admissions for childhood asthma were significantly negatively correlated with O_3. After controlling for seasonality and weather, there did not appear to be a positive relationship between childhood asthma and any of the air pollutants.

CO and SO_2 were significantly positively correlated with daily hospital admissions for COPD among the elderly. After controlling for seasonality and weather, there did appeared to be a positive relationship between COPD

among the elderly and SO_2 with a 3-day lag (RR = 1.003 for 1-Hr SO_2; RR = 1.005 for 8-Hr SO_2).

Deaths attributable to respiratory illness were positively related to CO and PM_{10} and negatively related to O_3. After controlling for seasonality and weather, there did not appear to be a positive relationship between deaths due to respiratory illness and any of the air pollutants.

Youngstown

Table III.2.8 is a summary of significant correlations between health effects and air pollution in Youngstown. SO_2 had significant positive zero-order correlations with daily counts of hospital admissions for respiratory illness, while O_3 had significant negative zero-order correlations with daily counts of hospital admissions for respiratory illness. After controlling for seasonality and weather conditions, there was evidence of a positive relationship between daily counts of hospital admissions for respiratory illness and SO_2 (8-Hr) at no lag (RR = 1.002), SO_2 (1 Hr) at a 1-day lag (RR = 1.001), and PM10 at no lag (RR = 1.003).

Table III.2.8. Summary of Significant Correlations Between Observed Health Effects and Measured Air Pollutants in Youngstown (Prior to Controlling for Meteorological Effects)

Pollutant	Respiratory illness admissions	Childhood asthma	COPD in the elderly	Respiratory deaths
PM_{10}				
O_3	-	-		
CO				
SO_2	+	+		
NO_2				

Daily hospital admissions for childhood asthma were significantly positively correlated with SO_2 (8 Hr), but negatively correlated with O_3. As was the case with the other sites, there were relatively few hospital admissions of children for asthma. More specifically, no children were admitted to hospitals with asthma as the primary diagnosis on 90% of the days covered in this study. As discussed later, this may help to explain why no relationship was detected between childhood asthma and air pollution, after controlling for seasonality and weather.

None of the air pollutants were significantly with daily hospital admissions for COPD among the elderly or with deaths attributable to respiratory illness. Not surprisingly, we found no evidence of any relationship between the air pollutants and either of these respiratory health measures, after controlling for seasonality and weather.

DISCUSSION

An examination of the zero-order correlations between respiratory health and air pollution reveals a significant amount of consistency across the eight sites included in this study. At every site, O_3 is significantly negatively correlated with hospital admissions for all respiratory illnesses and for asthma in children at every one of the eight sites. O_3 is also significantly negatively correlated with hospital admissions for COPD in the elderly at two sites and with total respiratory deaths at five sites. As explained previously, the reason for the negative correlations is that respiratory illness peaks during the winter months when ozone is virtually nonexistent. Indeed, ozone is only recorded from April through October in most sites in Ohio.

The other pollutants that were also negatively correlated with respiratory health were NO_2 and PM_{10}. Surprisingly, the correlation between respiratory health and PM_{10} varied substantially from one site to another. For example, the correlation between total respiratory illness and PM_{10} was positive at Akron, negative at Cincinnati, Cleveland, and Columbus, and non-significant at Steubenville and Youngstown.

Not unexpectedly, CO and SO_2 were generally positively correlated with respiratory health. The results from the eight sites were far from unanimous, however, as many of the correlations failed to attain the traditional significance, suggesting that CO and SO_2 were either uncorrelated or weakly correlated with respiratory health at many of the sites.

After partitioning out the effects of seasonality and weather, there was little evidence of a consistent relationship between any of the air pollutants and any of the measures of respiratory health across the eight sites. Figures III.2.4 and III.2.5 show the relative risk for total respiratory illness, and children's asthma for the 8 cities for lags 0 through 3 days. These figures highlight that no consistent positive relative risk for an individual pollutant was experienced between the cities. The cities in the Northeast (Figure III.2.4.a) did experience a slightly higher incidence of relative risks greater than 1 for total respiratory illness than the cities in central and eastern Ohio (Figure III.2.4.b). However, no general pattern for a given pollutant across the state was identified.

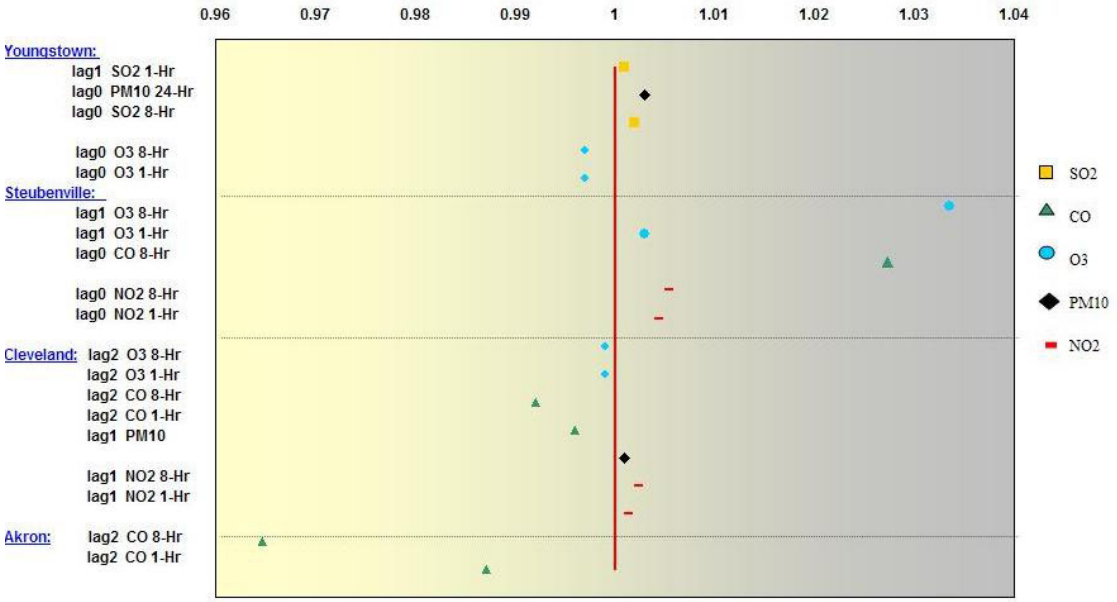


Figure III.2.4.a. Relative Risk of Respiratory Illness (Northeast Ohio Cities)

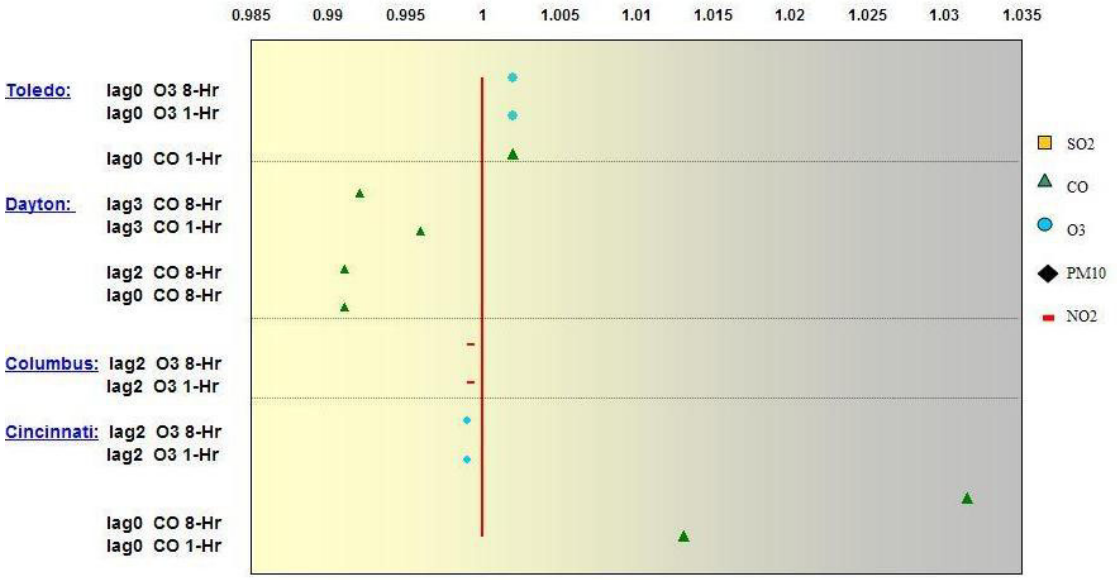


Figure III.2.4.b. Relative Risk of Respiratory Illness (Central/Western Cities)

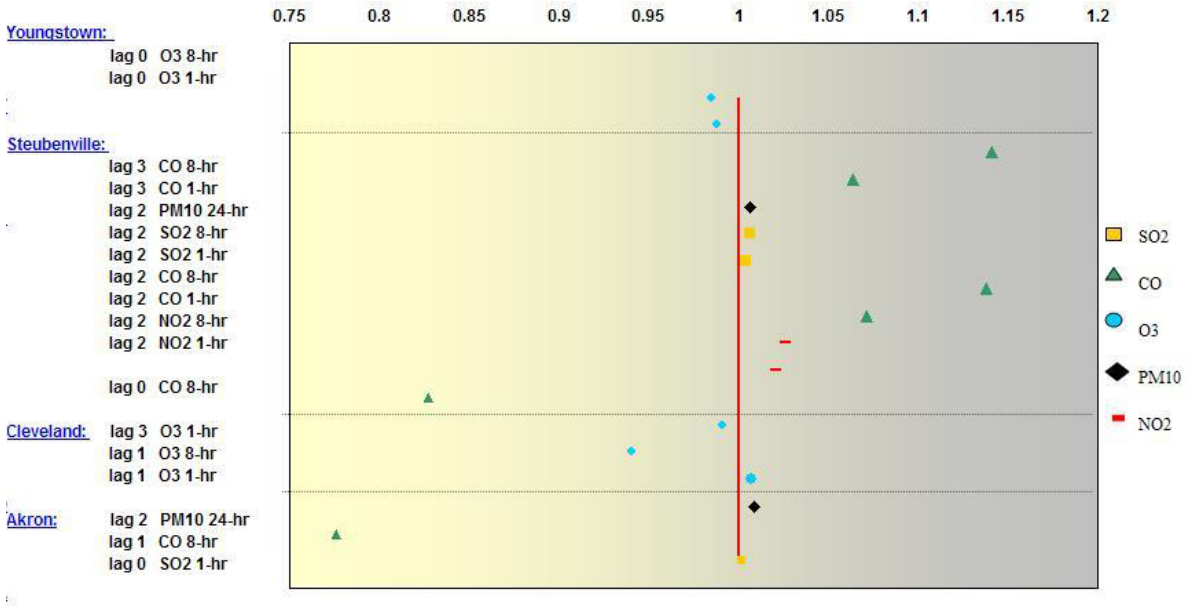


Figure III.2.5.a. Relative Risk for Children's Asthma (Northeast Ohio Cities)

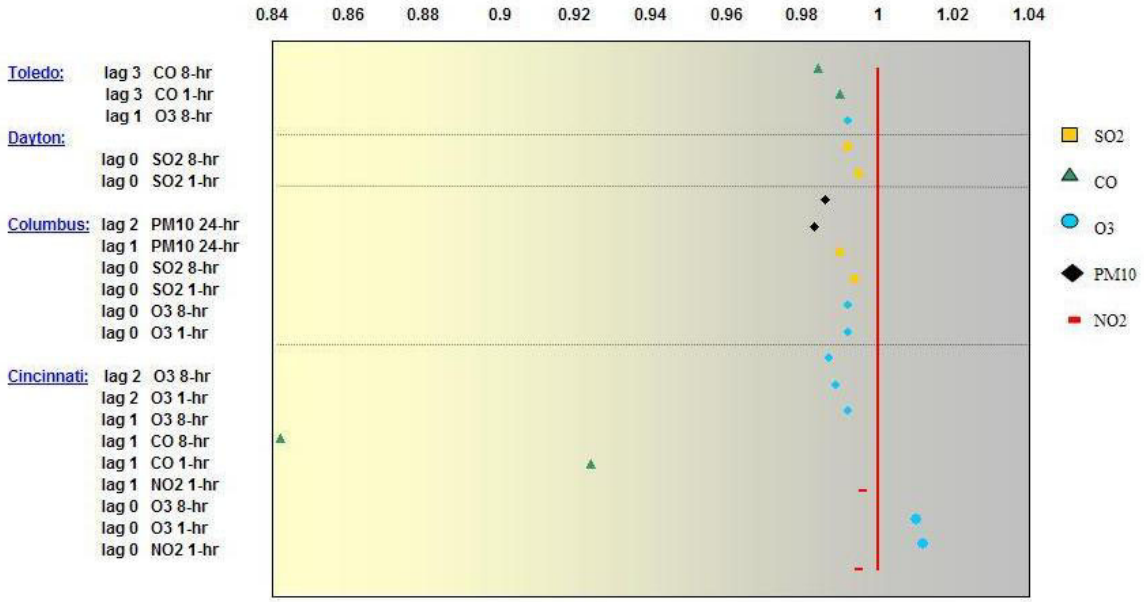


Figure III.2.5.b. Relative Risk for Children's Asthma (Central/Western Ohio Cities)

For children's asthma again no consistent pattern was seen from city to city. Steubenville showed the greatest prevalence of positive correlations, with positive correlations for all the pollutants except ozone. Slight positive correlations with ozone and children's asthma were experienced in Cincinnati, and Cleveland.

Given the abundance of evidence suggesting that the two sets of variables ought to be related, it is important to consider why they were not in this study. A number of explanations seem possible. First, a given air pollutant may pose a problem in some locales, but not in others. It may be unreasonable to expect consistency across the different sites.

Second, because of decreases in the levels of many air pollutants over the last decade, it has become difficult to detect the presence of a relationship between air pollution and respiratory health. Most of the evidence for a strong link between air pollution and respiratory health comes from studies that used data that were collected at least 10 years ago, when levels of air pollution were generally higher, and selected sites, e.g., London, Mexico City, and so on, with relatively high concentrations of air pollution. In contrast, our aim was to survey sites throughout the state of Ohio, without considering the a priori levels of air pollution in the various sites that we selected.

A third explanation is a possible lack of statistical power, especially in choosing measures of respiratory health that showed relatively little daily variability. Although care is always warranted in considering the results from any study, it is particularly important to be cautious in using the results of this study to draw conclusions about hospital admissions of children for asthma. We were surprised by the extremely small number of such cases reported by hospitals during the years covered by this study. The lack of daily variation in asthma cases complicated the statistical analyses that were conducted, as was discussed earlier. One of the consequences of this lack of variability may have been a lack of power for detecting relationships between air pollution and asthma at the different sites.

The fourth explanation is the appropriateness of the respiratory health indices. As we pointed out, there were relatively few hospital admissions for asthma among children. The number of respiratory deaths was also relatively small compared to the number reported in other studies. It is difficult to know the reason for this. Two possibilities are that urban areas in Ohio are less heavily polluted than other urban areas that are frequently studied and that we used data from the Ohio Hospital Association, rather than from the federal death registry. It is also conceivable that our decision to use a twenty-mile radius for deciding whether or not cases were to be included in counts for a site affected our results.

The fifth and final explanation is the conservativeness of the statistical analyses. An examination of the zero-order correlations between the air pollutants and the respiratory health measures depicts that air pollution is related to respiratory health. However, the results of this research do not allow the conclusion that air pollution causes adverse health effects. The difficulty in drawing a conclusion about causality is that both health and air pollution exhibit seasonal trends and both are related to a wide variety of meteorological variables, as was evident in this research.

Our goal in attempting to answer the question about the causal relationship between air pollution and respiratory health was to eliminate seasonality and weather as explanations for the observed relationships between air pollution and respiratory health. Even after controlling for seasonality and weather, respiratory health and air pollution remained correlated with one another, although to a far lesser extent than what would have been expected after an examination of the bivariate correlations between the air pollutants and the respiratory health measures. This suggests that a sizeable amount of the relationship between air pollution and respiratory health can be attributed to other factors. In considering this possibility, it is worth considering whether it is indeed changes in these other variables that produce changes in respiratory health. In other words, to conclude that a sizeable amount of the relationship between air pollution and respiratory health can be attributed to other factors is not the same as concluding that a sizeable amount of the relationship between air pollution and respiratory health is actually due to other factors.

NOTES

1. K. Liang & S. Zeger, Longitudinal data analysis for discrete and continuous outcomes, *Biometrics* 73(1986): 13-22.

2. S. Zeger & K. Liang Longitudinal data analyisis for discrete and continuous outcomes, *Biometrics* 42(1986): 121-130.

Section 4, Chapter 1
AIR TOXICS MONITORING

INTRODUCTION

The Ohio Air Quality Development Authority funded the second phase of this project which involved the continuation of the monitoring program outlined in Section 2 Chapter 1 for the 1999 – 2000 school year. In addition to monitoring for $PM_{2.5}$ the second phase involved the evaluation of exposures to air toxics at the elementary schools participating in this study. These sites offered the opportunity to obtain a compressive time series of indoor, outdoor, and personal exposures to air toxics at three unique locations within central and southeast Ohio.

Past research using the Total Exposure Assessment Methodology (TEAM) approach has shown a significant difference between indoor and outdoor concentrations of volatile organic compounds (VOCs) when an indoor contaminant source is present.[1] The TEAM approach was first used in the 1980s to determine individual indoor, outdoor, and personal VOC exposures. The most often cited finding of TEAM is that a person can spend more than 80 percent of his or her day indoors. This finding is significant when combined with two other key conclusions: (1) relatively high outdoor VOCs can make substantial contributions to indoor levels, and (2) in homes where there are no indoor sources of individual compounds, the indoor concentration can be driven by outdoor VOC levels.

Evidence from Pellizari suggests that stagnant and non-stagnant air plays different but major roles in how outdoor air affects indoor air quality.[2] On stagnant days, the concentrations of pollutants indoor and outdoor both increased, showing a correlation between outdoor and indoor air concentrations of VOCs. On non-stagnant days, the ratio of indoor to outdoor contaminant concentrations was lower. This was thought to be due to a combination of factors, including the presence of major indoor sources (e.g., a smoker at one of the test sites), and a lack of significant outdoor sources in the study area. Personal sampling was accompanied by a diary of daily events,

through which it was found that VOC levels were dependent not only on where a person spent most of the day, but also on the activities in which he or she engaged. A person's exposure to benzene, for instance, was far greater when the person had visited a gas station that day than on days the person had not done so. These findings have been confirmed by recent studies completed in at least three countries and seven U.S. states.[3]

In the late 1980s another significant project explored sources and factors affecting indoor and outdoor air quality. Cohen et al. studied the Kanawha Valley region of West Virginia to determine the impact of the sizeable regional chemical industry on human exposure to VOCs.[4] Extrapolation from high VOC dose data suggests the possibility of asthma and cancer attributable to low-level, chronic VOC exposures. The Kanawha study was geographically situated so that higher than normal levels of air toxins could be detected. The close proximity of residential areas to pollutant sources resulted in the possibility of elevated VOC exposures to the nearly 250,000 residents who lived in the valley.

The Kanawha Valley study is also important with respect to the current research because it utilized passive occupational monitors to obtain air samples; however, the Kanawha Valley dosimeters were used only for ambient sampling. Indoor and outdoor ambient samples alone do not accurately represent the total exposure that a person receives from a full day of activities. Personal monitoring, wherein a sampling device is located within a one foot radius of the nose and mouth, is needed to assess the exposure a person receives from his or her normal routines. The Kanawha monitor was functionally identical to the dosimeter employed in this study—the 3M 3500 series organic vapor monitor, or OVM. This device samples VOCs at empirically determined rates through a membrane face, where they are subsequently deposited onto a thin activated charcoal pad. This technique is still in wide use and has been relied upon most recently in the Finish EXPOLIS-Helsinki work, where Tenax TA was used with active sampling to assess personal exposures.[5] Since the Kanawha Valley work, several additional studies have been completed utilizing an OVM. The USEPA Region V NHEXAS, Germany's GerES II, and the Arizona NHEXAS project all employed the 3M 3500 OVM to collect VOC data that met predetermined limits of quality assurance and quality control.[6]

It should be noted that earlier TEAM studies and Pellizzari's study both employed active sampling, using Tenax GC for air contaminant trapping.

Despite their methodological differences, the Kanawha Valley work, Pellizzari's 5 states study, and the TEAM studies reached essentially the same conclusions. Factors like airtight building construction, extensive time spent inside, and outdoor ambient pollutant levels, make indoor VOC sources important to determining total personal VOC exposures.

There are currently 188 hazardous air pollutants (HAPs) regulated as such by the U.S. Environmental Protective Agency. These compounds have been associated with a wide variety of adverse health effects, including neurological, reproductive, cancer, and developmental problems. In addition, many of these chemical compounds pose environmental problems. In the spring of 1999, the USEPA released an air toxics concept paper that outlined protocols being developed for monitoring air toxics.[7] Currently, the USEPA has identified the following fifteen VOCs as problematic air pollutants in urban settings (Table IV.1.1), and more are likely to be added.

Table IV.1.1. USEPA Draft List of 15 VOCs of Concern in Urban Settings

acrylonitrile
benzene
1,3-butadiene
chloroform
1,2-dibromoethane
hexachlorobenzene
1,3-dichloropropene
1,2-dichloropropane
1,2-dichloroethane
ethylene oxide
methylene chloride
1,1,2,2-tetrachloroethane
tetrachloroethylene
trichloroethylene
vinyl chloride

The stated goal of the USEPA project is to reduce air toxics to 25 percent of 1993 levels.[8] As techniques for easy and accurate air quality tests improve, testing in nonindustrial environments has increased. In an effort to monitor these chemicals, the USEPA's program proposed to set up a national system to assess air quality so that the air quality in the United States could be quantified. Clearly, any technological advances that allow for more extensive monitoring at lower unit cost should be of interest to the USEPA. For this reason, the use of OVMs may prove important in helping the USEPA monitor pollutant levels at a multitude of locations, thereby advancing data procurement that may eventually be used for source reduction purposes.

The health significance of exposures to indoor and ambient pollution is far from clear. Direct exposure data is logistically, and therefore economically, difficult to obtain. Therefore regulators use epidemiological methods to study at-risk populations, such as school age children. Children are more susceptible to air pollution, due to the ratio between their size and contaminants and their stage of development (i.e. high growth rate and lower body mass to pollutant ratio).[9] Children maybe more susceptible than adults to suffering adverse effects from VOCs due to intensive growth and organ system development, and different metabolic responses to these chemicals. Despite such facts, there has been little research on the risks posed specifically to children by most chemicals. The majority of exposure research has focused on adult occupational exposures to industrially important organic compounds. Some common illnesses suspected to be linked to VOC (and particulate) pollutants include asthma, cancer, learning disorders, and pulmonary disorders.[10] These studies have shown that the most significant negative effects from low-level VOC exposures is irritation and discomfort.[11] Exposure to ambient levels of some pollutants has been shown to have detrimental health effects on children.[12]

The goal of this project was to determine VOC levels in elementary schools in various settings and to explain how personal, indoor, and outdoor ambient samples relate to variables such as season, population density, and geographic region. The implications of the study results are multidimensional. First, the study provides a picture of the state of air quality in schools. Second, the study information can be used by regulating entities to determine whether current levels of VOCs are of potential concern. Third, the data collected can be used to determine the difference among VOC concentrations in inner-city, suburban, and rural areas in Ohio, as well as the differences between outdoor and indoor concentration of the target compounds at each school. Results of this study can be used as the basis for further examination of the utility and feasibility of passive dosimeter technology for ambient air pollution assessments. Work to date has shown good agreement between active and passive sampling devices[13], and because of positive outcomes from rigorous testing the 3M OVM is emerging as the long term passive sampler of choice in U.S.[14]

OBJECTIVES

This work was conducted as part of a comprehensive project examining multiple parameters of air pollution in Ohio. The objectives were:

- To focus on the potential and actual health risk(s) associated with air pollution in Ohio;
- To investigate the health effects of the proposed National Ambient Air Quality Standards for ozone and fine particulate matter ($PM_{2.5}$);

- To collect information and data that measures the correlation between potential air pollution exposures and health;
- To evaluate current or real-time collection of health data, especially for sensitive sub-populations;
- To compare populations, in different geographic areas; and
- To conduct monitoring for a set of VOCs as identified by the USEPA in the *Urban Air Toxics Strategy* to have the greatest potential effect on the public and the environment in urban areas.

To achieve project compliance with the last objective, the following actions were taken with respect to air toxics monitoring:

- Environmental measurements of VOC levels were made during the school year (September 1999 to May 28, 2000). Weekly VOC measurements (indoor, outdoor, and personal) were conducted at each site, beginning in November 1999, and ending with the close of the school year (May, 2000); and
- VOC measurements included benzene, 1-3-butadiene, carbon tetrachloride, chloroform, methylene chloride, 1,1,2,2-tetrachloroethane, and trichloroethylene.

Health status of the affected population was examined as part of the larger study, But those findings are not considered with this section of the report. Actions taken during the sampling period toward the above mentioned objectives, and their results, form the basis for this section of the report.

SAMPLING AND ANALYTICAL PROCEDURES

Passive Dosimeters

Using ambient indoor or outdoor data alone to extrapolate personal exposure to VOCs has distinct limitations. One's exposure will be determined by his or her daily routine and VOCs associated with those activities. The overall daily exposure is highly influence by microenvironments. Consequently personal monitoring is the preferred method for determining potential exposures.

Due to technological limitations personal monitoring has historically been difficult, often limited by cost. In addition, because of their size, personal samplers interfere with the subject's daily routine.[15] Before the advent of the passive sampler, personal sampling units consisted of an air pump hooked to a sampling filter that removed VOCs from the air. These air sampling units were relatively noisy, large, and hindered day-to-day activities.[16] With the refinement of passive dosimeters however, many of these issues have become

less important. Modern passive monitoring devices have no moving parts, are lightweight, and small enough to offer minimal interference.

A passive dosimeter is defined by Montalvo as "an air sampler requiring no pumps, handling of chemicals, or wearing of cumbersome apparatus such as impingers."[17] A passive dosimeter collects the species of interest via natural diffusion, and then traps them within the sampler by a sink (sampling media). In contrast, an active sampler brings the species of interest into contact with the sampling media by force using convection or pumping.[18] The theoretical design of a passive dosimeter is simple. The dosimeter consists of a draft shield (also know as a windscreen), a static diffusion layer, and a primary sink. Sometimes a secondary sink, or backup, is used when there are sampling atmospheres that could contain a high enough concentration of the species to cause breakthrough.[19] The basic design of the 3M passive dosimeter utilized in this study is shown in Figure IV.1.1.

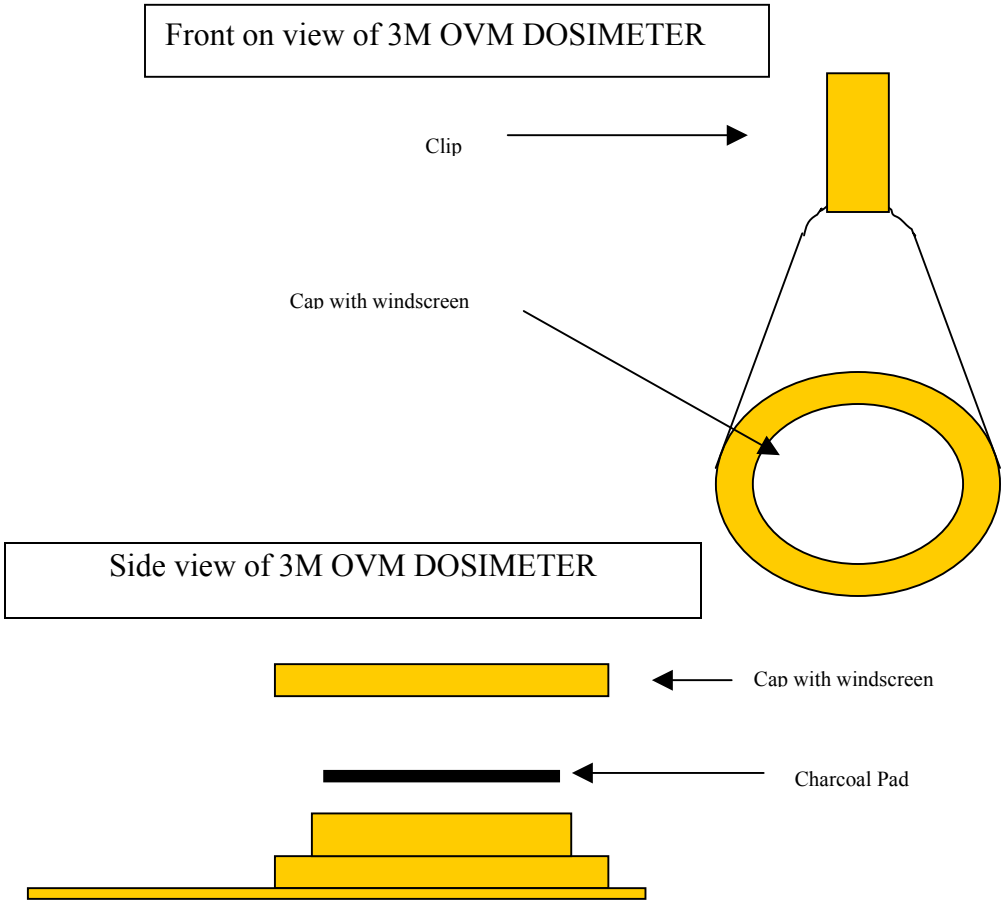


Figure IV.1.1. Diagram of a 3M Passive Organic Vapor Monitor

Drawbacks to dosimeters are that they require longer sampling times because the dosimeter's sampling rate is a function of diffusion. Therefore, for the low parts-per-billion concentrations measured in most nonindustrial indoor air work, dosimeters require a longer placement time to acquire an adequate sample to be analyzed.[20] Despite the drawbacks of personal passive dosimeters, they deliver consistent results and are viewed as dependable devices and were actively used in this project.

Each VOC will demonstrate a different rate of diffusion into a passive dosimeter, and that rate is directly affected by atmospheric conditions.[21] The three most important atmospheric conditions are temperature, humidity, and pressure. These can change the diffusion rates of the compound and cause problems with the ability of the sink to collect and hold the species being sought.[22] Another issue of concern is the effect of face velocity on the passive dosimeter. Extremely stagnant air conditions can lead to a depletion of the species of interest in the air directly outside of the sampler inlet. The result is erroneously low results, a situation that can be avoided by selecting a location with adequate airflow. Stagnant air is seldom an issue when performing personal sampling, but stagnation can still be problematic if the subject is immobile for long periods of time (e.g. sitting at a desk).[23]

In contrast to the dosimeter, the USEPA has developed and used its own methodology for collecting ambient air samples. This method employs a SUMMA™ canister device to collect an air sample. These devices are rugged and can be reused, but there are some aspects that limit their use in research. The primary disadvantages are the issues of artifacts, sample size, and sampling time. Some chemicals are more difficult to remove from the canister than others, and some chemicals actually bond to the inside of the canister, requiring physical means (such as scrubbing) to remove the material from the sides. Currently, canisters are cleaned using negative pressure and steam heating. Another limitation is that canisters are too large to collect personal exposure data and, like pump operated active samplers, will interfere with personal monitoring. The primary advantage of a canister is the precision in which it captures a known volume of air enabling the extraction and analysis of multiple samples.

A study by Daughtrey et al.[24] compares canister and sorbent sampling media samplers. The study used USEPA method TO-14, which is specific to the use of canisters for air sampling in order to analyze their samples. Using a duplicate analysis from the same canister, the results show that the difference between the two methods was insignificant. Canister cleanliness limits the detection limit of such devices below the TO-14 acceptance standard of 2.0 ppb per unit volume (0.2-2 ppb by concentration for target analytes). Thus, the lower limit of detection for canisters is higher than that of sorbent samplers.

The GC/FID method is used primarily when analyzing canister samples, and the GC/MS method is used primarily with sorbent material samples. The relative accuracy between the GC/FID and GC/MS method is excellent. Although very popular in industrial applications, sorbent sampling media has distinct disadvantages for ambient work, such as artifact issues in the presence of ozone and/or high humidity, and logistical problems related to all active sample collection.

In summary, there are several factors that need to be considered when attempting to utilize a passive dosimeter for an ambient or personal air sampling project. For this research, a passive dosimeter containing a charcoal pad is appropriate because charcoal is adequate for collecting volatile organics. Other considerations are the conditions at the sampling location and magnitude of airflow at the site. In all cases of sampling in this study, these factors were judged to be of minor concern and passive dosimeters were considered suitable for use in the study. A commercially available passive dosimeter (3M 3500 Organic Vapor Monitor, St. Paul, Minnesota) was utilized to perform indoor and outdoor ambient sampling as well as personal sampling. This dosimeter was extensively and rigorously evaluated by,Morandi et al. [25] Stock et al.[26] and Cohen et al.[27] and found suitable for use as an ambient sampler.

Sampling Protocol

Sampling was carried out for an eight-month period, beginning in January 2000 and continuing through August 2000. Although initial study objectives called for sampling to be conducted throughout the entire nine-month school term, start-up difficulties associated with procuring, installing, and operating the analytical instrument prevented acceptable data acquisition before January 2000.

To analyze the regional differences in concentration of chemical compounds in various residential settings, the study was conducted at three sites representing an urban, suburban and rural location. Koebel Elementary School, located in Columbus, Ohio, was selected to represent an urban location. The suburban site was represented by New Albany Elementary School, located northeast of Columbus, Ohio. Athens Elementary School, located in Athens, Ohio, was included to represent a rural site. A detailed description of the sampling locations is presented in Section 1 Chapter 2 (Research Methods). From all three schools a total of 183 indoor, 230 outdoor, and 180 weekly personal samples were collected during the sampling period (n=593).

For ambient samples, one dosimeter was placed inside the classroom and a second was located outside the school building at each site. Both of these samples were placed four to five feet about the floor/ground within the

breathing zone height of most of the children. The indoor sample was placed near the $PM_{2.5}$ ambient monitor (refer to Section 2 Chapter 1). The outdoor monitor was placed near a major entrance to the school under the roof line to protect it from the rain or snow. The indoor and outdoor samples were collected continuously from Monday morning through Friday afternoon ("weekly" samples), with weekend samples being collected from Friday afternoon until Monday morning respectively ("weekend" samples). Therefore, the approximate sampling period for the ambient samplers was 103 hours for weekly samples and 65 hours for weekend samples. In addition, two samplers were located immediately adjacent to each other ("co-located") at outdoor locations to determine variability in sample collection. Post-exposure, indoor, and outdoor samplers were closed and refrigerated at less than 10° C.

Personal samplers were attached to students selected at random each weekday between 7:30 and 8:00 am and worn until approximately 3:30 to 4:00 pm. The same sampler was utilized for five consecutive days for a total run time between 37.5 and 40 hours per week. At the end of each sampling day, personal OVMs were capped and refrigerated at less than 10° C for use the following day.

Every week at each site, one or two field blanks were also generated. Ambient blanks were created by opening a tube each Monday morning and immediately recapping the tube and refrigerating for transport on Friday. The weekly personal blanks were opened each morning and immediately recapped, then refrigerated. At the end of each sampling week, all samplers were transported in a cooler to a laboratory for analysis.

Analysis

Dosimeter Sample Extraction Procedures

All samples were kept refrigerated at less than 10° C and processed within two weeks of their arrival to the laboratory. OVMs were desorbed by removing the charcoal filters using PTFE coated tweezers and placing them into a 2.0 ml amber crimp vial (HP part #5181-3376). A gastight 1.0 ml syringe (Hamilton Co., #1001) was used to aspirate 1.0 ml of 99.9 + pure carbon disulfide (Aldrich Chemical, #42,464-1, Lot #LU 06855LU) into the vial. The vial was then capped using a crimping tool (HP part #9301-0720) and crimp caps (HP part #5181-1211) physically verifying cap tightness to ensure an adequate seal. The vial was then placed in an ice water bath and sonicated for forty minutes. Dosimeter extraction was based on a procedure described by Stock et al.[28], except that sample vials were sonicated instead of shaken on a rotary plate shaker. After desorbtion, 200 µl of sample was removed from the vial using a 250-µl syringe (Microliter, #725) with a set-stop

and placed in a second amber 2 ml vial containing a vial insert (HP part #631-9330). Using a 25-µl syringe (Microliter, #702), 10µl of a 100µg/µl internal standard mix (Bestek Corp., #30074; see below) was added to the vial. The vial was then crimp-capped and immediately placed into an HP 6890 series auto sampler (HP part #G2613A and G2614A) for analysis.

GC/MS Configuration

Samples were qualitatively and quantitatively analyzed using a Hewlett-Packard 6890 gas chromatograph coupled to a Hewlett-Packard 5973 mass spectrometer. Analytes were separated with a 90 m x .32 mm i.d. HP-VOC special performance capillary column coated to a 1.8 µm liquid film thickness (HP, #19091R-319). Run parameters are shown in Table IV.1.2 and were similar to those utilized by Stock et al.[29] for analysis of 3M dosimeters employed as ambient samplers.

Briefly, an injector port temperature of 180 °C was used with an initial oven temperature of 35 °C and an eight minute hold, followed by a ramp rate of 8 °C/min to 180 °C, and then 20 °C/min to a final temperature of 270 °C with a seven minute hold. The unit was run splitless for the first two minutes to load the sample, then run split 40:1. An initial inlet pressure of 3.0 psi was utilized for two minutes, and was increased at 10 psi/min to a final pressure of 25 psi. The mass spectrometer was programmed "off" for the first five minutes and again from 11.7-12.7 minutes into each run, to allow for carrier solvent passage. Total run time for each analysis cycle was 37.6 minutes.

Table IV.1.2. Gas Chromatography/Mass Spectrometer Settings

GC/MS Parameter	Parameter Setting
Mode	
-Port temperature	180°C
-volume	1 ml
-split	splitless first 2.0 min split 40 to 1 after 2.0 min
Inlet Pressure	
-initial	3.0 p.s.i. with 2 min hold
-ramp rate	10 p.s.i./min
Oven Temperature	
-Initial	35°C with 8 min hold
-ramp rate	8°C/min to 180°C, then 20°C/min
-final	270°C with 7 min hold
-Detector Off	0-5.0 min, 11.68-12.74 min
-Total Run Time:	37.6 min

Quality Control

Sample Chain of Custody, Holding, and Processing

Samples were kept in refrigerators at the sampling sites, then transported by project employees via private car to the analysis laboratory. All samples were kept refrigerated at less than 10° C at the laboratory and processed within two weeks of their arrival. Field sampling sheets were used to determine hours and minutes of actual exposure for each OVM based on recorded times. Completed sample transfer sheets are available for inspection in room E318 A, Grover Center, Ohio University, Athens, Ohio.

Standards and Quantitation

A VOC standards mix (Ultra Scientific, #DWM-588) was used for VOC quantification through the creation of standard 5 point minimum curves. The

mix is marketed for USEPA Method 8260B. That method is primarily used in air and water sampling to determine VOCs from a variety of solid matrices, including halogenated and non-halogenated organics. For that reason the VOCs employed in that method were deemed appropriate for use in this study. All of the compounds in the mix could not be discriminated by the column, desorption solvent, and run parameters used in this study. Table IV.1.3 lists the 60 compounds included in the standards mix and the 45 chemicals this method was able to resolve.

Table IV.1.3. VOCs Available to USEPA Method 8260 B in Standard Mix, Quantified, and Semi-Quantified

Compound Name	**Standard Mix n=60**	**Quantified n=20***	**Semi-Quantified** n=25**
Benzene	X	X	
Bromobenzene	X		X
Bromochloromethane	X	X	
Bromodichloromethane	X		X
Bromoform	X		X
Bromomethane	X		
n-Butylbenzene	X		
Carbon tetrachloride	X	X	
Chlorobenzene	X	X	
Chlorodibromomethane	X		X
Chloroethane	X		
Chloroform	X	X	
Chloromethane	X		
2-Chlorotoluene	X		
4-Chlorotoluene	X		
1,2-Dibromo-3-chloropropane	X		X
1,2-Dibromoethane	X		X
Dibromomethane	X		X
1,2-Dichlorobenzene	X	X	
1,3-Dichlorobenzene	X	X	
1,4-Dichlorobenzene	X		
Dichlorodifluoromethane	X		
1,1-Dichloroethane	X	X	
1,2-Dichloroethane	X		X
1,1-Dichloroethene	X	X	
trans-1,2-Dichloroethene	X		X
cis-1,2-Dichloroethene	X		X

Compound Name	Standard Mix n=60	Quantified n=20*	Semi-Quantified** n=25
1,2-Dichloropropane	X		X
1,3-Dichloropropane	X		X
2,2-Dichloropropane	X		X
cis-1,3-Dichloropropene	X		X
trans-1,3-Dichloropropene	X		X
1,1-Dichloropropene	X		X
Ethylbenzene	X	X	
Hexachlorobutadiene	X		X
Isopropylbenzene	X		
4-Isopropyltoluene	X		
Methylene chloride	X	X	
Naphthalene	X	X	
n-Propylbenzene	X		X
sec-Butylbenzyne	X		
Styrene	X	X	
1,2,3 tert-Butylbenzyne	X		X
1,1,1,2-Tetrachloroethane	X		X
1,1,2,2-Tetrachloroethane	X	X	
Tetrachloroethylene	X		X
Toluene	X	X	
1,2,3-Trichlorobenzene	X		X
1,2,4-Trichlorobenzene	X		X
1,1,1-Trichloroethane	X	X	
1,1,2-Trichloroethane	X	X	
Trichloroethylene	X	X	
Trichloromonofluoromethane	X		X
1,2,3-Trichloropropane	X		
1,2,4-Trimethylbenzene	X		
1,3,5-Trimethylbenzene	X		X
Vinyl chloride	X		
o-Xylene	X	X	
m-Xylene	X	X	
p-Xylene	X	X	

* m- and p-Xylene co-elute and so are considered as a single compound for the purposes of categorization.

** See text for criteria of “Semi-quantified” compounds

Approximately monthly, standard curves were generated using the 60 compound standard mix. The mix is received at a concentration of 2,000µg/ml. Ten points were used to generate a calibration curve, with concentrations of 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, and 0.005 µg/ml being prepared. First, the 2,000µg/µl VOC mix was diluted to 20µg/µl by taking 10µl of the VOC mixture and adding it to 990µl of 99.9 + pure carbon disulfide, for a total volume of 1,000µl. Using this 20µg/µl VOC mix solution, the other dilutions were made per Table IV.1.4.

Table IV.1.4. Dilutions for Standard Curve Generation

Curve concentrations in µg/µl	Dilution ratio from starting solution	Starting solution concentration in µg/ml	Volume made in µl	Dilution ratio from stock solution
20	1/100	2000	1000	1/100
10	1/2	20	1000	1/200
5	1/4	20	1000	1/400
2	1/10	20	1000	1/1000
1	1/20	20	1000	1/2000
0.5	1/2	1	1000	1/4000
0.2	1/5	1	1000	1/10000
0.1	1/10	1	1000	1/20000
0.05	1/20	1	1000	1/40000
0.005	1/200	1	1000	1/400000

All dilutions were made to a final volume of 1,000 µl. Vials containing the standard mix were then run through the GC/MS using the method described earlier. After the initial analysis was completed, HP ChemStation software was utilized to analyze the curve data and assign a concentration.

To best assess mass spectrometer response, four compounds were utilized in each processed sample as internal standards. These compounds, pentafluoro-benzene, 1,4-diflouro-benzene, chlorobenzene d5, and 1,4-dichlorobenzene d4, are available as a mixture (Bestek Corp., # 30074). The internal standard mix was purchased at 2,500µg/µl, and was diluted to the concentration desired for spiking the vials before sampling using 99.9 + pure carbon disulfide (Aldrich Chemical, # 42,464-1, Lot # LU 06855LU). One milliliter of internal standard mix is made at 100µg/µl by taking 40µl of 2,500µg/ml internal standard and diluting it with 960µl of CS_2.

Both calibration and environmentally collected sample results were reviewed for probability of match in a set of steps recommended by Hewlett-Packard[30] in a procedure termed "Qediting". Qedited results were then entered into a spreadsheet to calculate the amount of a VOC in the air in $\mu g/m^3$ and parts per billion (ppb), employing exposure time and 3M supplied sampler desorption coefficient and sampling rate for a given chemical.[31] Of the 45 standard components detectable in this study, there were 20 for which 3M OVM desorption coefficients and sampling rate data were available. Where 3M data was available concerning sampler desorption coefficient and sampling rate for a given chemical, those values were employed in the calculation. These are indicated as "Quantified" in Table IV.1.3. An additional 25 chemicals in the standard mix were identified and semi-quantitatively reported using the average desorption coefficient (0.915) and average sampling rate (30.9 ml/min) calculated for all chemicals for which 3M reported such parameters (n = 127). These are indicated as "Semi-quantified" in Table IV.1.3. Thus, of the 60 compounds in the standard mix, 45 can be resolved by the GC/MS method used, 20 can be positively quantified, and 25 can be semi-quantified.

As noted earlier, sampling sheets submitted with each passive dosimeter and Qedited analytical results were entered into a spreadsheet to calculate the amount of a VOC in $\mu g/m^3$ and ppb. To do so, Qedited data from the GC/MS was converted from µg/ml total volume to $\mu g/m^3$ concentration in the air per Equation IV.1.1.

Equation IV.1.1. Calculation of Dosimeter Concentration in $\mu g/m^3$

$$(X_1 - X_0)/(T*De*Ra*1e\text{-}6) = C$$

Where:
X_1 = the sample reading from the GC/MS (µg/ml)
X_0 = the sample reading from the blank (µg/ml)
T = sampling time (minutes)
De = desorption coefficient for the compound
Ra = sampling rate (ml/min)
C = concentration of VOC in air in $\mu g/m^3$
MW = molecular weight of compound
ppb = amount present in ppb

Conversion from $\mu g/m^3$ to ppb was accomplished using Equation IV.1.2.

Equation IV.1.2. Conversion to ppb

$$(C\ 1e\text{-}6*\ 0.02445)/(MW*1e9) = ppb$$

Limit of Detection

The limit of detection (LOD) is the lowest standard concentration reproducibly generating a signal above the background noise of the GC/MS (after removing laboratory blank values). The standard deviation, mean, max, median, and correlation coefficient were calculated for standard curve data using Microsoft Excel 2000. Table IV.1.5 lists the compounds used in this study (OH) compared to the Kanawha Valley (KV) and Total Exposure Assessment Methodology (TEAM) studies, and compares the LODs by chemical for the thirteen compounds shared by the three studies.

Table IV.I.5. Limits of Detection (LOD) in Ohio 3 School Study as Compared to KV and TEAM Studies

Limits of Detection			
Compound	**µg /m^3 LOD OH[a]**	**µg /m^3 LOD KV[b]**	**ug/m^3 LOD TEAM[c]**
o-xylene	0.18	1.8	0.13
m & p-xylene	0.7	1.8	0.13
1,3-dichloro-benzene	0.18	1.9	0.17
trimethyl benzene	0.18	2	0.00
tetrachloroethylene	0.16	1.8	0.29
benzene	0.01	7.1	0.12
ethylbenzene	0.18	1.8	0.13
carbon tetrachloride	0.17	8.3	0.37
trichloroethylene	0.18	4.1	0.37
styrene	0.16	1.9	0.12
chlorobenzene	0.02	4.3	0.21
1,2-dibromoethane	0.18	8.5	0.00
trichlorobenzene	0.35	11.1	0.00

[a] Limit of detection for this study based on GC/MS analysis of passive OVMs in µg/m^3
[b] Limit of detection for the Kanawha Valley study in µg/m^3
[c] Limit of detection for the TEAM study in µg/m^3

The KV study defined their LOD as "the lowest concentration standard for which a signal was obtained, correcting for desorption efficiency and volume."[32] For this study the LOD was taken as the lowest standard concentration for which a signal that did not fall below background noise of the instrument. Thus, the definitions of LOD between KV and this project are similar. The TEAM study calculated its limit of detection based on the volume of sample collected and the instrumental LOD.[33] By using the TEAM study

sampling time (12 hours), sampling rate (30 ml/min), and instrumental LOD reported for each compound (originally reported in ng/canister), an LOD in $\mu g/m^3$ was calculated to generate the LODs reported in Table IV.1.5. Results are within expected ranges and thus the comparisons of Table IV.1.5 are appropriate.

Quality control and data integrity are important in any study purporting to represent a populations' exposure to a given contaminant. In their 2001 assessment of data quality in the NHEXAS (Region V) study, Pellizzari et al.[34] reported median detection limits of 7 of the 13 compounds in Table IV.1.5. that were considerably higher than this study, the TEAM project, or even their earlier work. For example, benzene reportedly had a lower quantification limit of 740 ug/m^3 in air. The authors noted two significant factors in this regard: 1) two identical GC/MS systems employed for VOC analysis generated remarkably different relative standard deviations (for example , 34% versus 6.8% for benzene), and 2) the precision and analysis of benzene, specifically, did not meet the NHEXAS data quality goals. These findings are important in light of some of the difficulties seen in work utilizing charcoal pads in passive dosimeters for benzene collection. It should also be noted that the less precise GC/MS system was employed for the majority (>75%) of the NHEXAS (Region V) VOC samples.

RESULTS AND DISCUSSION

Results have been tabulated and tested for significance in Table IV.1.6. The significance of these values is best appreciated relative to other studies of a similar nature. For this reason, the results will be discussed and compared to the findings of the New Jersey TEAM report[35], Pellazari's 5 states study[36], and the Kanawha Valley report.[37] These studies reported considerably fewer compounds than this report, so the majority of the discussion in the following sections will be limited to the thirteen compounds shared by these projects. In addition, results from several more recent studies will also be used to benchmark values obtained in this study. These recent studies include; the National Human Exposure Assessment Survey (NHEXAS) conducted in Arizona[38] and in USEPA Region V[39] from 1995-1997, the German environmental survey (GerES II)[40] conducted from 1990-1992, and EXPOLIS-Helsinki, Finland[41] study conducted from 1995-1997.

Table IV.I.6. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for the Entire Study Period

Compound	Average personal exposure µg /m^3 (n=180) [b]	Standard Deviation (n=180) [b]	Indoor average ambient concentration µg /m^3 (n=549) [c]	Standard Deviation (n=549) [c]	Outdoor average ambient concentration µg /m^3 (n=693) [d]	Standard Deviation (n=693) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	3.62	11.44	1.99	2.13	1.00	1.11	< 0.001	< 0.001	< 0.001
m & p-xylene	5.93	18.79	3.5	4.17	1.69	2.08	< 0.001	< 0.001	< 0.001
1,3-dichloro-benzene	36.11	103.98	42.67	122	1.22	3.41	< 0.001	< 0.001	< 0.001
trimethyl benzene	0.5	0.73	0.36	0.31	0.19	0.19	< 0.001	< 0.001	< 0.001
tetrachloroethylene	1.05	1.63	1.16	3.21	0.47	0.46	< 0.001	< 0.001	< 0.001
benzene	3.88	8.76	2.59	2.92	2.50	2.73	0.01	0.01	< 0.001
ethylbenzene	3.17	8.02	2.09	2.52	0.93	1.22	< 0.001	< 0.001	< 0.001
carbon tetrachloride	1.24	1.69	1.04	0.84	1.17	0.9	0.11	0.76	0.08
trichloroethylene	0.72	1.89	1.79	13.54	0.56	4.5	0.1	0.01	< 0.001
styrene	0.97	2.38	0.17	0.75	0.05	0.3	< 0.001	< 0.001	< 0.001
chlorobenzene	0.15	0.26	0.09	0.39	0.15	0.85	0.27	0.83	0.23
1,2-dibromoethane	0.03	0.21	0.01	0.02		0.03	0.04	0.12	< 0.001
trichlorobenzene	0.03	0.08	0.01	0.04	0.03	0.05	0.01	0.97	0.01
TVOC[e]	57.39		57.45		9.96				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected during this study at all three schools combined
[c] The total number of indoor ambient samples collected during this study at all three schools combined
[d] The total number of outdoor ambient samples collected during this study at all three schools combined
[e] The total volatile organic compound amount for the entire study for the selected compounds

One approach to examining VOC data is through the sum of VOC species present. Molhave et al. define Total Volatile Organic Compounds as "…the total mass of measured VOCs per unit volume of air, exclusive of very volatile (e.g., formaldehyde) organic compounds."[42] TVOCs are therefore a simple, integrated measure of VOCs irrespective of the individual toxicity of any particular species within the whole. As an indicator of health effects, a TVOC concentration is inherently flawed because the potency of individual VOCs to elicit irritating symptoms varies by orders of magnitude.[43] Nevertheless, the TVOC measure is frequently used as a risk index for health and comfort, particularly in indoor air quality remediation cases.[44]

In general, very low TVOCs were found in this study. Like several other studies examining background, or baseline, concentrations of VOCs in nonproblematic settings, levels found in this study were in the low ug/m^3 range. For example, the USEPA's ongoing Building Assessment and Survey Evaluation (BASE) of 100 nonproblematic U.S. office buildings reported toluene, 1,1,1-trichloroethane, benzene, and xylenes among the most frequently measured VOCs in studied locations.[45] These Ohio findings echo such results, frequently finding these species at levels on par with the BASE data (i.e., at concentrations < 100 ug/m^3, usually much lower).

The significance of exposures to VOC mixtures at low levels is unclear. As mentioned, the BASE study concentrations have been collected from office buildings devoid of any indoor air quality (IAQ) issues. In his study of 50 'normal' Finnish homes, Kostiainen routinely found speciated VOC concentrations at less than 5 ug/m^3.[46] Of the 48 compounds he quantified, the TVOC average for the healthy homes was 123 ug/m^3 (121 ug/m^3, median), as compared with the TVOC average for the 45 compounds quantified and semi-quantified in this study of 57 ug/m^3 (see Table IV.1.6). Kostiainen reported that in 38 'sick' homes included in his study, specific VOC species were two to three higher than 'normal' homes. In contrast to that study, Weschler et al.[47] determined more than forty individual VOCs which combined to generate TVOCs in excess of 3,000 ug/m^3 in facilities exhibiting "sick building syndrome" (SBS). It is noteworthy that in both studies, speciated concentrations were 10,000-100,000 times lower than current OSHA Permissible Exposure Limits[48] or American Council of Governmental Industrial Hygienists Threshold Limit Values[49] established for workplace exposures to these chemicals.

Since the application of occupational limits to the concentrations detected in this study is inappropriate, and in lieu of other binding standards pertaining to low level VOCs in indoor air, interpretation of the findings of this study must be guarded. Hodgson et al.[50] reported that European nations were moving toward IAQ guidelines analogous to radiological health concept of "as low as reasonably achievable" (ALARA). They also summarized a recommendation by Seifert of 250 ug/m^3 as an "acceptable level" of VOCs in

indoor air, and another suggestion by Molhave of a maximal TVOC limit of 300 ug/m^3, with no one species exceeding 20 percent of the total. If such limits were presently in place, none of the three schools studied in this project would be considered to have IAQ issues.

Data in the following sections should be considered as representing VOC levels at the high end of ambient concentrations. OVM charcoal absorbent pads were typically found to contain trace levels of benzene. For example the 32 blank OVMs processed for Athens had an average benzene level of 0.38 ppm with a standard deviation of 0.48 ppm. Similar difficulties were reported by Stock et al. in their initial evaluation of the 3M OVM.[51] Benzene was also a quantification problem in the NHEXAS, Region 5 study[52] which used 3M OVMs.

Although reported the values reported in the following tables were corrected with respect to the values obtained on the field blanks the inherent variability in the contaminant levels on the charcoal pads could result in artificially elevated reported levels of benzene. Caution in the interpretation of concentration maxima in particular is therefore warranted. Work is presently underway exploring the use of tube axial and radially diffusive samplers with much reduced levels of benzene or its artifacts. Using thermal desorption, these samplers have the added advantage of not requiring the use of carbon disulfide possibly containing further sources of benzene contamination.

Co-located Field Sampler Comparisons

Outdoor duplicate samples were run January through March at all study locations, and the relative standard deviation were calculated for co-located samplers. The relative standard deviation of a co-located measurement is an assessment of the uncertainty in a single measurement. Table IV.I.7 shows the results of correlations of study of badges over the entire sampling period, by date and school. The average relative standard deviation at each school is approximately 0.31, and is acceptably low in all cases. These results, examined in light of the limits of detection data, can be interpreted as demonstrating an adequate level of precision for the OVMs as ambient samplers.

Table IV.1.7. Results for Co-located OVM Badges
Relative Standard Deviation (RSD) for Co-located Badges at Schools
January 3rd to April 3rd, 2000

Date	Athens[a] RSD	Koebel[b] RSD	New Albany[c] RSD
January 3rd-7th	0.20	0.38	
January 7th-10th	0.06		
January 10th-14th	0.22	0.06	0.10
January 14th-17th			0.06
January 17th-21st			0.02
January 21st-24th			0.15
January 24th-28th			0.19
January 28th-31st			0.25
Jan. 31st-Feb. 4th	0.20	0.76	0.40
February 4th-7th	0.35		0.37
February 7th-11th	0.24	0.35	
February 11th-14th	0.47		0.44
February 14th-18th	0.23	0.49	0.40
February 18th-21st	0.22	0.14	0.61
February 21st-25th	0.15	0.28	0.32
February 25th-28th			0.44
Feb. 28th-March 3rd		0.25	0.25
March 3rd-6th	0.26	0.03	0.19
March 6th-10th		0.33	0.23
March 10th-13th	0.62	0.01	0.37
March 13th-17th	0.65	0.49	0.53
March 17th-20th	0.65		0.38
March 20th-24th	0.06		
March 24th-27th	0.41		
March 27th-31st	0.37		
March 31st-April 3rd	0.40		
Average	0.32	0.30	0.30

[a] Sample set for Athens where n = 18 sample pairs
[b] Sample set for Koebel where n = 12 sample pairs
[c] Sample set for New Albany where n = 19 sample pairs

Graphical depiction of co-located results are presented in Figures IV.1.2-A, -B, and -C for four of the fifteen compounds that the USEPA has indicated are of potential long-term interest.[53] Results are shown for the three sampling locations of this study, along with best line of fit regressions for the data for each chemical.

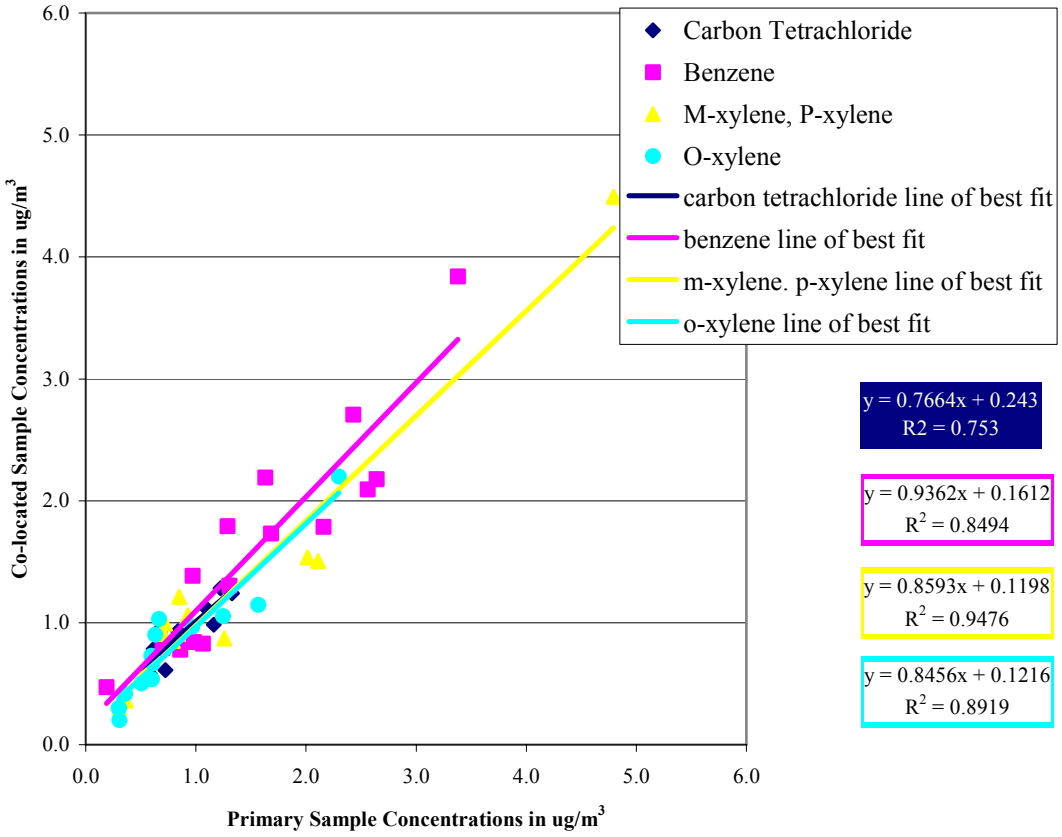


Figure IV.1.2A
Co-locate Data for Four Compounds at Athens

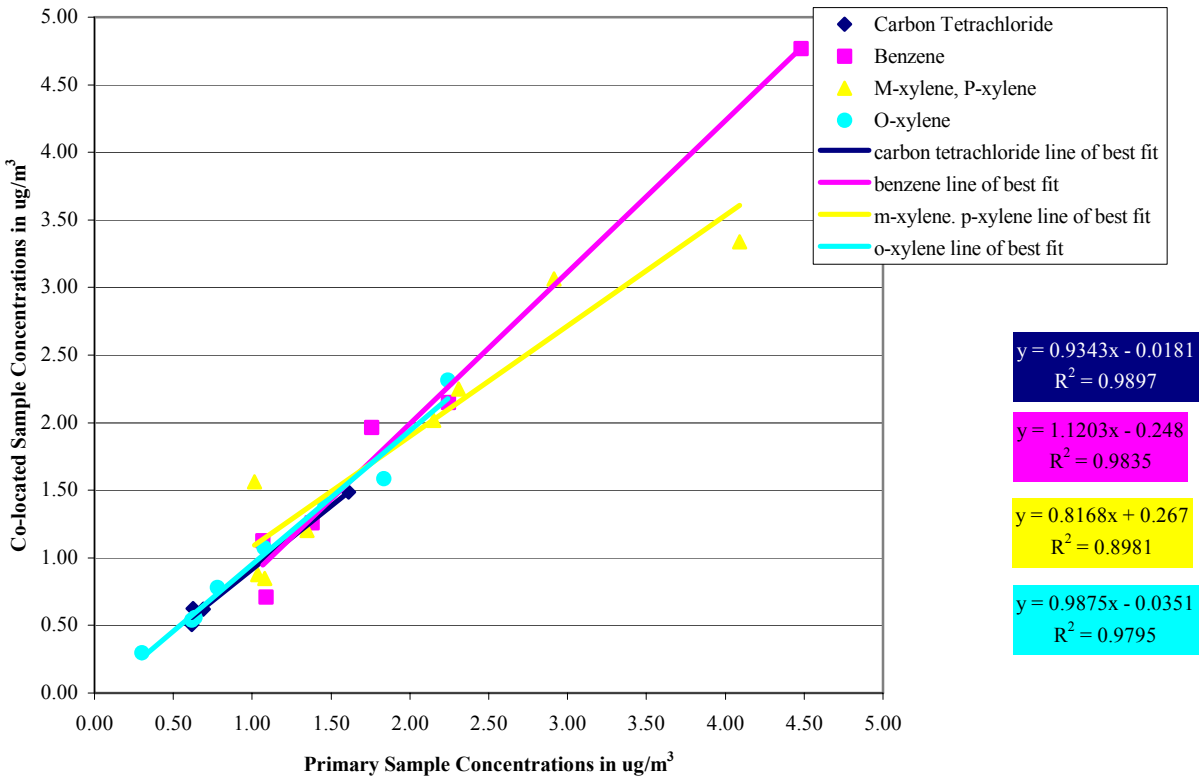


Figure IV.1.2B
Co-locate Data for Four Compounds at Koebel

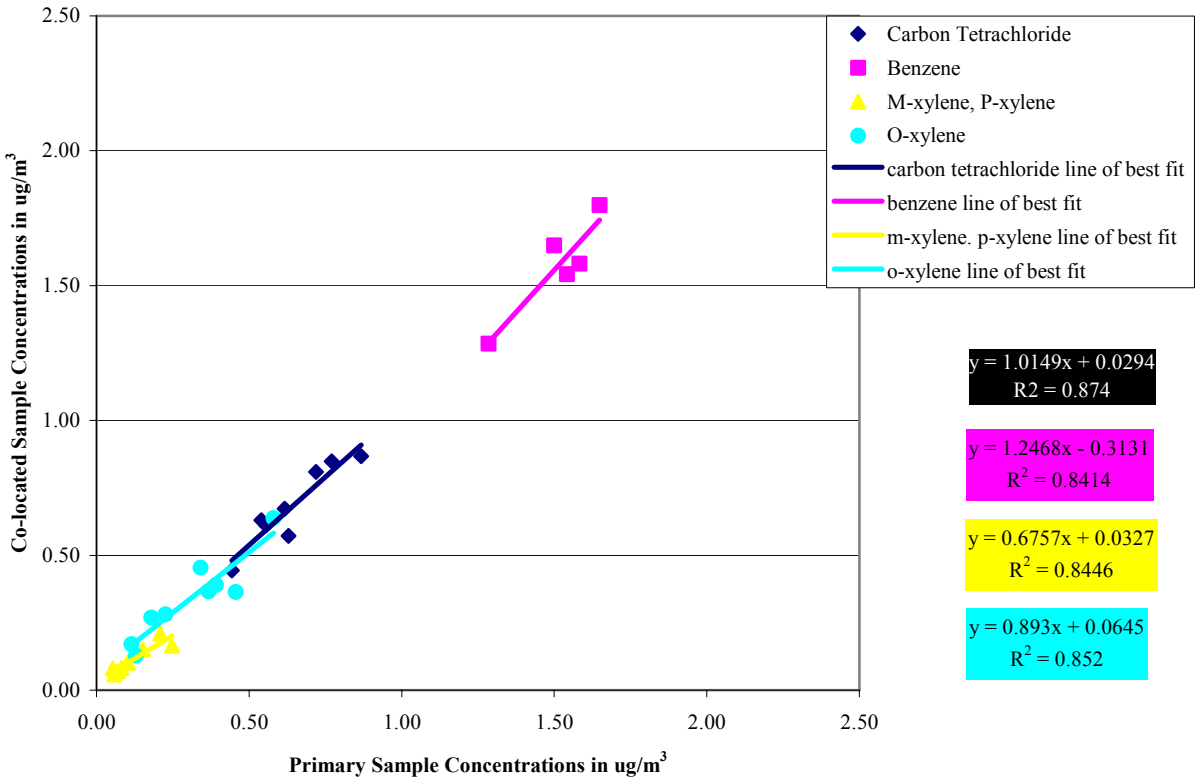


Figure IV.1.2C
Co-locate Data for Four Compounds at New Albany

Indoor to Outdoor Comparisons

Table IV.1.8 compares the percentage of samples above the LOD for this study against several similar studies conducted in the US and Findland. For comparison purposes, the table reports only those compounds measured in all the studies. This study found a greater percentage of detectable compounds than than all the other studies referenced in Table IV.1.8.

Table IV.1.8. Percent of Measurements with Concentrations Greater Than LOD : Comparison with other studies

	Indoor (%)						Outdoor (%)					
Compound	OH[a]	AZ[b]	KV[c]	Reg V[d]	TEAM[e]	EX[f]	OH	AZ	KV	Reg V	TEAM[g]	EX
o-xylene	99		60		85	93	95		0		65	68
m & p-xylene	98		100		>90	99	94		71		>90	87
1,3-dichloro-benzene	96		49		60		70		0		18	
trimethyl benzene	95		80		ND[h]	7	78		9		ND	64
tetrachloroethylene	95		17	57	90		93		0	50	60	
benzene	95	49	26	99	75	71	91	34	0	100	48	85
ethylbenzene	93		66		90	94	84		3		30	63
carbon tetrachloride	93		26		10		92		0		<1	
trichloroethylene	88		34	36	30		66		0	26	18	
styrene	61		11		45	50	19		0		8	7
chlorobenzene	56		63		ND		43		0		ND	
1,2-dibromoethane	8		29		ND		4		0		ND	
trichlorobenzene	4		23		ND		6		0		ND	

[a] OH -results from this study
[b] AZ – results from the NHEXAS Arizona study
[c] KV -results from the Kanawha Valley study
[d] Reg V- results from the NHEXAS Region V. study
[e] Indoor Values taken from "night personal air" samples from TEAM study in Elizabeth-Bayonne, NJ
[f] EX- results from the EXPOLIS Helsinki study
[g] Outdoor Values taken from "night outdoor air" samples from TEAM Study in Elizabeth-Bayonne, NJ
[h] ND = not determined

The results depicted in Table IV.1.8 are most likely explained by differences in analytical methods among the studies. For example the KV study utilized 3M 3500 series charcoal pad dosimeters analyzed by GC/FID while the TEAM study utilized Tenax-GC tubes analyzed by GC/MS. This project utilized 3M 3500 series charcoal pad dosimeters analyzed by GC/MS. As shown previously in Table 5, LODs for this project are comparable to

TEAM study LODs, and significantly lower than the KV study LODs. In addition this study used a long sample duration, up to four days, which decrease the LODs.

Tables IV.I.9A, -B, and -C, display indoor VOC concentrations for the thirteen shared compounds for Athens, Koebel, and New Albany, respectively. These tables can be compared to outdoor levels (Tables IV.1.10-A, -B, and -C) and to personal values (Tables IV.1.11-A, -B, and -C) for the same sites. For most of the compounds, the arithmetic average concentrations are greater than median values, indicating skewed concentration distributions. This is typical for distributions of indoor air pollutants and air pollutants in general.[54] Casual comparison of the three data table series indicates that personal exposures are generally in excess of indoor values, which are, in turn, higher than outdoor values.

Elevated levels of 1,3-dichlorobenzene reflected in Table IV.1.9A merit some discussion, as no conclusive explanation adequately addresses their existence. Possible causes of these values were explored with school personnel at Athens, 1,3-dichlorobenzene is an active ingredient in insecticides (MW=147, BP=174 degrees C). No conformation was obtained of insecticide spraying during the spring of 2000 at Athens. Consequently the elevated levels of this chemical in indoor samples from Athens can neither be wholly explained nor dismissed.

Table IV.1.9A. Summary Statistics for Indoor VOC Samples (ug/m^3) for Athens

Compound	Mean	Std. Dev.	Max	Median
o-xylene	2.65	2.76	13.67	1.47
m & p-xylene	4.96	5.68	28.66	2.67
1,3-dichloro-benzene	117.80	191.53	697.65	4.43
trimethyl benzene	0.35	0.29	1.45	0.28
tetrachloroethylene	0.68	0.85	5.09	0.36
benzene	3.94	4.09	22.62	2.56
ethylbenzene	3.11	3.40	17.15	1.80
carbon tetrachloride	0.98	0.87	3.42	0.77
trichloroethylene	0.24	0.35	1.71	0.10
styrene	0.13	0.15	0.81	0.10
chlorobenzene	0.19	0.67	5.16	0.06
1,2-dibromoethane	0.01[a]	0.02	0.09	0.00[a]
trichlorobenzene	0.02[a]	0.05	0.34	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.9B. Summary Statistics for Indoor VOC samples (ug/m^3) for Koebel

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.51	1.11	5.92	1.23
m & p-xylene	2.41	1.87	10.11	1.91
1,3-dichloro-benzene	1.24	0.64	3.41	1.25
trimethyl benzene	0.50	0.37	2.42	0.42
tetrachloroethylene	2.50	5.54	28.72	0.75
benzene	2.57	2.19	9.48	1.82
ethylbenzene	1.30	1.24	6.35	1.06
carbon tetrachloride	1.04	0.80	4.21	0.73
trichloroethylene	3.63	24.63	182.95	0.21
styrene	0.10	0.15	0.76	0.06
chlorobenzene	0.04[a]	0.06	0.23	0.00[a]
1,2-dibromoethane	0.00[a]	0.03	0.18	0.00[a]
trichlorobenzene	0.01[a]	0.03	0.09	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1. 9C. Summary Statistics for Indoor VOC samples (ug/m^3) for New Albany

Compound	Mean	Std. Dev.	Max	Median
O-xylene	1.78	1.98	12.52	1.18
M & P-xylene	3.08	3.55	22.45	2.06
1,3-dichloro-benzene	8.78	9.28	54.05	5.61
Trimethyl benzene	0.25	0.22	1.08	0.18
tetrachloroethylene	0.49	0.74	4.62	0.27
benzene	1.39	1.19	5.48	1.20
Ethylbenzene	1.82	2.05	12.65	1.18
carbon tetrachloride	1.09	0.84	3.70	0.78
trichloroethylene	1.69	2.54	14.28	0.66
styrene	0.25	1.21	10.03	0.07
chlorobenzene	0.04[a]	0.05	0.18	0.00[a]
1,2-dibromoethane	0.01[a]	0.03	0.18	0.00[a]
trichlorobenzene	0.01[a]	0.02	0.11	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.10A. Summary Statistics for Outdoor VOC Samples (ug/m^3) for Athens

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.38	1.72	7.26	0.62
m & p-xylene	2.36	3.38	14.52	0.85
1,3-dichloro-benzene	3.10	6.41	26.26	0.08
trimethyl benzene	0.20	0.20	0.82	0.14
tetrachloroethylene	0.48	0.55	2.94	0.34
benzene	3.55	4.16	18.05	1.73
ethylbenzene	1.38	1.90	8.29	0.49
carbon tetrachloride	1.14	1.00	3.74	0.81
trichloroethylene	0.15	0.21	0.79	0.06
styrene	0.11	0.61	4.57	0.00[a]
chlorobenzene	0.10	0.16	0.89	0.00[a]
1,2-dibromoethane	0.00[a]	0.01	0.06	0.00[a]
trichlorobenzene	0.03	0.05	0.23	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.10B. Summary Statistics for Outdoor VOC Samples (ug/m^3) for Koebel

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.26	0.98	4.74	1.07
m & p-xylene	2.15	1.72	8.62	1.77
1,3-dichloro-benzene	0.31	0.35	1.61	0.21
trimethyl benzene	0.30	0.23	1.27	0.24
tetrachloroethylene	0.53	0.43	1.96	0.42
benzene	2.90	2.78	15.04	1.97
ethylbenzene	1.04	1.19	5.54	0.86
carbon tetrachloride	1.16	0.98	5.57	0.81
trichloroethylene	1.45	9.21	68.46	0.13
styrene	0.03	0.07	0.40	0.00[a]
chlorobenzene	0.15	0.77	5.72	0.00[a]
1,2-dibromoethane	0.00[a]	0.02	0.11	0.00[a]
trichlorobenzene	0.01[a]	0.02	0.09	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.10C. Summary Statistics for Outdoor VOC Samples (ug/m^3) for New Albany

Compound	Mean	Std. Dev.	Max	Median
o-xylene	0.37	0.26	1.33	0.31
m & p-xylene	0.55	0.45	2.13	0.39
1,3-dichloro-benzene	0.24	0.40	2.93	0.16
trimethyl benzene	0.07	0.07	0.27	0.06
tetrachloroethylene	0.41	0.53	2.89	0.27
benzene	1.06	0.82	4.12	0.97
ethylbenzene	0.38	0.31	1.37	0.30
carbon tetrachloride	1.20	0.96	4.34	0.80
trichloroethylene	0.09	0.12	0.50	0.07
styrene	0.01	0.04	0.25	0.00[a]
chlorobenzene	0.20	1.41	11.60	0.00[a]
1,2-dibromoethane	0.01[a]	0.04	0.33	0.00[a]
trichlorobenzene	0.02	0.07	0.50	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.11A. Summary Statistics for Personal VOC Samples (ug/m^3) for Athens

Compound	Mean	Std. Dev.	Max	Median
o-xylene	7.39	19.31	83.27	1.66
m & p-xylene	12.40	31.73	132.07	2.51
1,3-dichloro-benzene	102.50	163.11	606.25	1.66
trimethyl benzene	0.53	0.90	3.68	0.28
tetrachloroethylene	0.89	1.33	6.00	0.58
benzene	7.38	14.02	60.00	1.94
ethylbenzene	6.07	13.13	47.72	1.92
carbon tetrachloride	1.18	1.33	5.92	0.85
trichloroethylene	0.49	0.73	3.30	0.40
styrene	1.07	1.51	4.86	0.31
chlorobenzene	0.26	0.38	1.68	0.15
1,2-dibromoethane	0.02[a]	0.07	0.30	0.00[a]
trichlorobenzene	0.03[a]	0.09	0.36	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.11B. Summary Statistics for Personal VOC Samples (ug/m^3) for Koebel

Compound	Mean	Std. Dev.	Max	Median
o-xylene	2.57	3.23	12.88	1.92
m & p-xylene	3.83	4.67	19.03	2.88
1,3-dichloro-benzene	1.90	1.69	6.03	2.09
trimethyl benzene	0.81	0.83	2.74	0.70
tetrachloroethylene	1.61	2.13	8.14	1.13
benzene	3.59	4.46	14.86	2.37
ethylbenzene	2.76	3.60	14.49	1.90
carbon tetrachloride	1.82	2.55	11.08	1.53
trichloroethylene	0.34	0.37	1.23	0.28
styrene	1.93	3.88	16.46	0.76
chlorobenzene	0.11	0.17	0.51	0.00[a]
1,2-dibromoethane	0.09	0.37	1.58	0.00[a]
trichlorobenzene	0.02[a]	0.06	0.21	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.11C. Summary Statistics for Personal VOC samples (ug/m^3) for New Albany

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.05	0.77	2.71	1.07
m & p-xylene	1.77	1.41	5.57	1.48
1,3-dichloro-benzene	3.73	2.44	9.68	3.77
trimethyl benzene	0.21	0.18	0.56	0.16
tetrachloroethylene	0.77	1.33	6.55	0.49
benzene	0.94	0.69	2.82	0.85
ethylbenzene	0.87	0.76	2.89	0.73
carbon tetrachloride	0.81	0.80	2.95	0.56
trichloroethylene	1.26	2.99	14.05	0.29
styrene	0.09	0.12	0.38	0.00[a]
chlorobenzene	0.08	0.15	0.60	0.00[a]
1,2-dibromoethane	0.01[a]	0.04	0.17	0.00[a]
trichlorobenzene	0.04[a]	0.09	0.31	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Statistical comparison of the means of the three data types (personal, indoor and outdoor) for the three schools is summarized in Tables IV.1.12A, -B, and -C. These comparisons also support the observation of personal exposures greater than indoor concentrations, and indoor values exceeding outdoor values. For both Athens (Table IV.1.12A) and New Albany (Table IV.1.12C), indoor ambient levels were statistically greater than outdoor

concentrations ($p < 0.001$). Koebel indoor levels also tended to be higher than outdoor levels ($p < 0.10$). When sampling results from the schools were pooled by sample category (Table IV.1.6), all but four of the thirteen compounds (carbon tetrachloride, chlorobenzene, 1,2-dibromoethane, and trichlorobenzene) demonstrated this relationship ($p<0.10$ - 0.001). Both 1,2-dibromomethane and trichlorobenzene concentrations were typically below the LOD of the method (Table IV.1.5) but are included in Table IV.1.6 for consistency.

Table IV.1.12A. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for Athens

Compound	Average personal exposure µg /m³ (n=60) [b]	Standard Deviation (n=60) [b]	Indoor average ambient concentration µg /m³ (n=183) [c]	Standard Deviation (n=183) [c]	Outdoor average ambient concentration µg /m³ (n=231) [d]	Standard Deviation (n=231) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	7.39	19.31	2.65	2.76	1.38	1.56	0.007	< 0. 001	0.007
m & p-xylene	12.4	31.73	4.96	5.68	2.36	3.04	0.006	< 0. 001	0.006
1,3-dichloro-benzene	102.5	163.11	117.8	191.53	3.1	5.73	< 0. 001	< 0. 001	<. 001
trimethyl benzene	0.53	0.9	0.35	0.29	0.2	0.19	0.001	< 0. 001	0.001
tetrachloroethylene	0.89	1.33	0.68	0.85	0.48	0.5	0.004	< 0. 001	0.004
benzene	7.38	14.02	3.94	4.09	3.55	3.73	0.009	0.015	0.024
ethylbenzene	6.07	13.13	3.11	3.4	1.38	1.73	0.002	< 0. 001	0.002
carbon tetrachloride	1.18	1.33	0.98	0.87	1.14	0.91	0.249	0.81	0.858
trichloroethylene	0.49	0.73	0.24	0.35	0.15	0.2	< 0. 001	< 0. 001	< 0. 001
styrene	1.07	1.51	0.13	0.15	0.11	0.53	< 0. 001	0.156	0.156
chlorobenzene	0.26	0.38	0.19	0.67	0.1	0.14	< 0. 001	0.015	0.015
1,2-dibromoethane	0.02[a]	0.07	0.01[a]	0.02	0.00[a]	0.01	0.011	< 0. 001	0.011
trichlorobenzene	0.03[a]	0.09	0.02[a]	0.05	0.03	0.05	0.179	0.844	0.872
TVOC[e]	140.21		135.04		13.98				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected per school during this study
[c] The total number of indoor ambient samples collected per school during this study
[d] The total number of outdoor ambient samples collected per school during this study
[e] The total volatile organic compound amount for the entire study for the selected compounds

Table IV.1.12B. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for Koebel

Compound	Average personal exposure µg /m^3 (n=60) [b]	Standard Deviation (n=60) [b]	Indoor average ambient concentration µg /m^3 (n=183) [c]	Standard Deviation (n=183) [c]	Outdoor average ambient concentration µg /m^3 (n=231) [d]	Standard Deviation (n=231) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	2.57	3.23	1.51	1.11	1.26	0.91	0.001	0.001	< 0.001
m & p-xylene	3.83	4.67	2.41	1.87	2.15	1.61	0.002	0.014	< 0.001
1,3-dichloro-benzene	1.9	1.69	1.24	0.64	0.31	0.35	< 0.001	< 0.001	< 0.001
trimethyl benzene	0.81	0.83	0.5	0.37	0.3	0.23	< 0.001	< 0.001	< 0.001
tetrachloroethylene	1.61	2.13	2.5	5.54	0.53	0.4	0	< 0.001	< 0.001
benzene	3.59	4.46	2.57	2.19	2.9	2.6	0.064	0.668	0.043
ethylbenzene	2.76	3.6	1.3	1.24	1.04	1.14	0	0.001	< 0.001
carbon tetrachloride	1.82	2.55	1.04	0.8	1.16	0.94	0.011	0.605	0.007
trichloroethylene	0.34	0.37	3.63	24.63	1.45	8.28	0.943	0.1	0.094
styrene	1.93	3.88	0.1	0.15	0.03	0.06	< 0.001	< 0.001	< 0.001
chlorobenzene	0.11	0.17	0.04	0.06	0.15	0.69	0.597	0.967	0.577
1,2-dibromoethane	0.09	0.37	0[e]	0.03[a]	0.00[a]	0.02[a]	0.038	0.194	0.007
trichlorobenzene	0.02[a]	0.06	0.01	0.03[a]	0.01[a]	0.02[a]	0.055	0.085	0.005
TVOC[e]	21.39		16.88		11.28				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected per school during this study
[c] The total number of indoor ambient samples collected per school during this study
[d] The total number of outdoor ambient samples collected per school during this study
[e] The total volatile organic compound amount for the entire study for the selected compounds

Table IV.1.12C. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for New Albany

Compound	Average personal exposure µg /m³ (n=60) [b]	Standard Deviation (n=60) [b]	Indoor average ambient concentration µg /m³ (n=183) [c]	Standard Deviation (n=183) [c]	Outdoor average ambient concentration µg /m³ (n=231) [d]	Standard Deviation (n=231) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	1.05	0.77	1.78	1.98	0.37	0.25	< 0.001	< 0.001	< 0.001
m & P-xylene	1.77	1.41	3.08	3.55	0.55	0.44	< 0.001	< 0.001	< 0.001
1,3-dichloro-benzene	3.73	2.44	8.78	9.28	0.24	0.35	< 0.001	< 0.001	< 0.001
trimethyl benzene	0.21	0.18	0.25	0.22	0.07	0.06	< 0.001	< 0.001	< 0.001
tetrachloroethylene	0.77	1.33	0.49	0.74	0.41	0.47	0.015	0.057	0.001
benzene	0.94	0.85	1.39	1.19	1.06	0.8	0.917	0.003	0.003
ethylbenzene	0.87	0.76	1.82	2.05	0.38	0.29	< 0.001	< 0.001	< 0.001
carbon tetrachloride	0.81	0.8	1.09	0.84	1.2	0.86	0.994	0.593	0.59
trichloroethylene	1.26	2.99	1.69	2.54	0.09	0.1	0.001	0	< 0.001
styrene	0.09	0.12	0.25	1.21	0.01	0.03	< 0.001	0.004	< 0.001
chlorobenzene	0.08	0.15	0.04	0.05	0.2	1.24	0.82	0.933	0.765
1,2-dibromoethane	0.01[a]	0.04	0.01[a]	0.03	0.01[a]	0.04	0.578	0.793	0.459
trichlorobenzene	0.04[a]	0.09	0.01[a]	0.02	0.02	0.06	0.057	0.991	0.057
TVOC[e]	11.63		20.67		4.6				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected per school during this study
[c] The total number of indoor ambient samples collected per school during this study
[d] The total number of outdoor ambient samples collected per school during this study
[e] The total volatile organic compound amount for the entire study for the selected compounds

Both the TEAM and KV studies concluded that indoor levels were higher than outdoor levels, and so would contribute more significantly to personal exposure to VOCs than outdoor air. As observed in this study, personal exposures and indoor concentrations of VOCs were higher than outdoor concentrations throughout the entire study. This result supports earlier findings that indoor air quality has a greater impact on personal exposures to VOCs than outdoor air quality, and extends that conclusion to the elementary school setting.

Personal to Indoor Comparisons

Lioy et al.[55] found no correlation between personal and outdoor samples in their Elizabeth/Bayonne study, and the results or this study echo those findings. However, in their comparison of personal and indoor sampling data,

strong correlations were experienced. In this study the same relationships were also found. Figures IV.1.3A, -B, and –C show the relationship between personal and indoor concentrations for benzene. Fairly large correlation coefficients (R) were experienced at all three schools, ranging from 0.74 at Koebel down to 0.41 at New Albany.

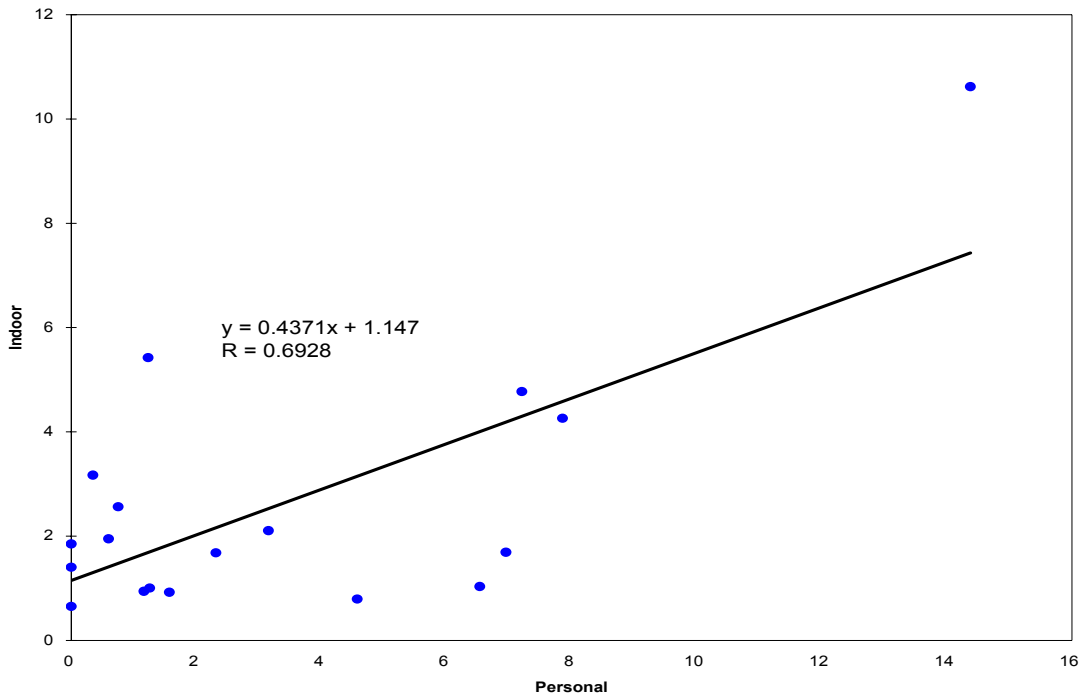


Figure IV.1.3A. Indoor Concentrations vs. Personal Exposures for Benzene at Athens ($\mu g/m^3$)

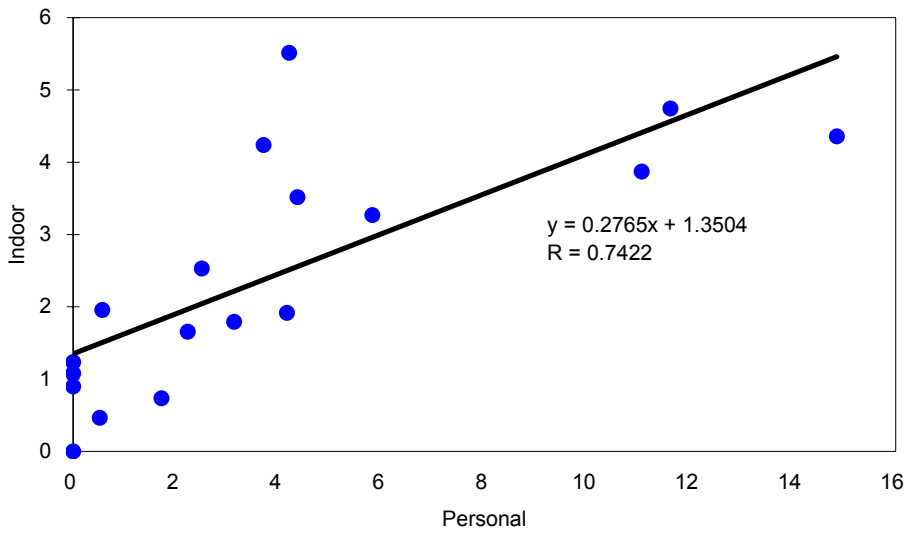


Figure IV.1.3B. Indoor Concentrations vs. Personal Exposures for Benzene at Koebel (µg/m^3)

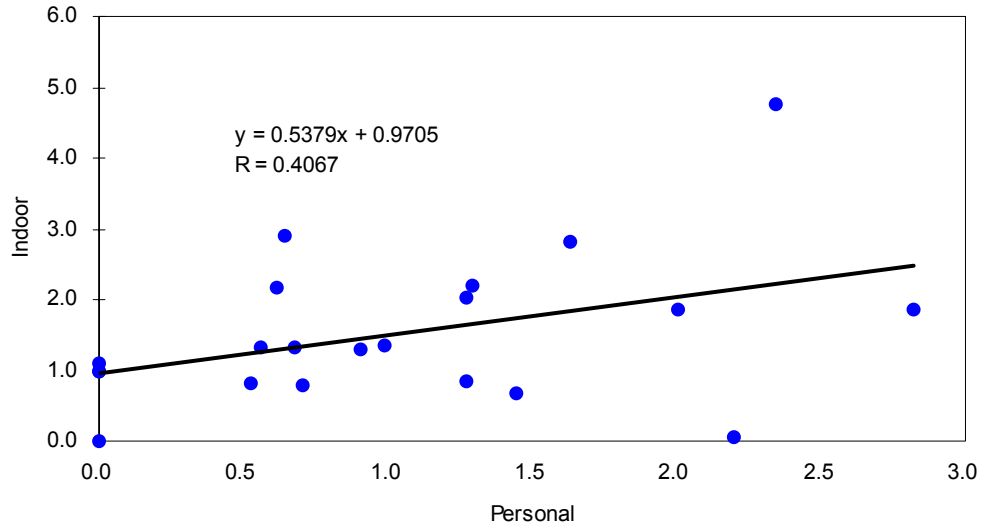


Figure IV.1.3C. Indoor Concentrations vs. Personal Exposures for Benzene at New Albany (µg/m^3)

Seasonal Comparisons

Sampling results for most species were not impacted by daily or weekly increases in temperature or relative humidity. Figures IV.1.4A, -B, and –C plot outdoor temperature and relative humidity averages against concentrations of o-xylene, and show no association between this chemical and either of the weather variables. Comparisons have been made for trichloroethylene and benzene with similar results. Because of their redundancy those graphs are not presented.

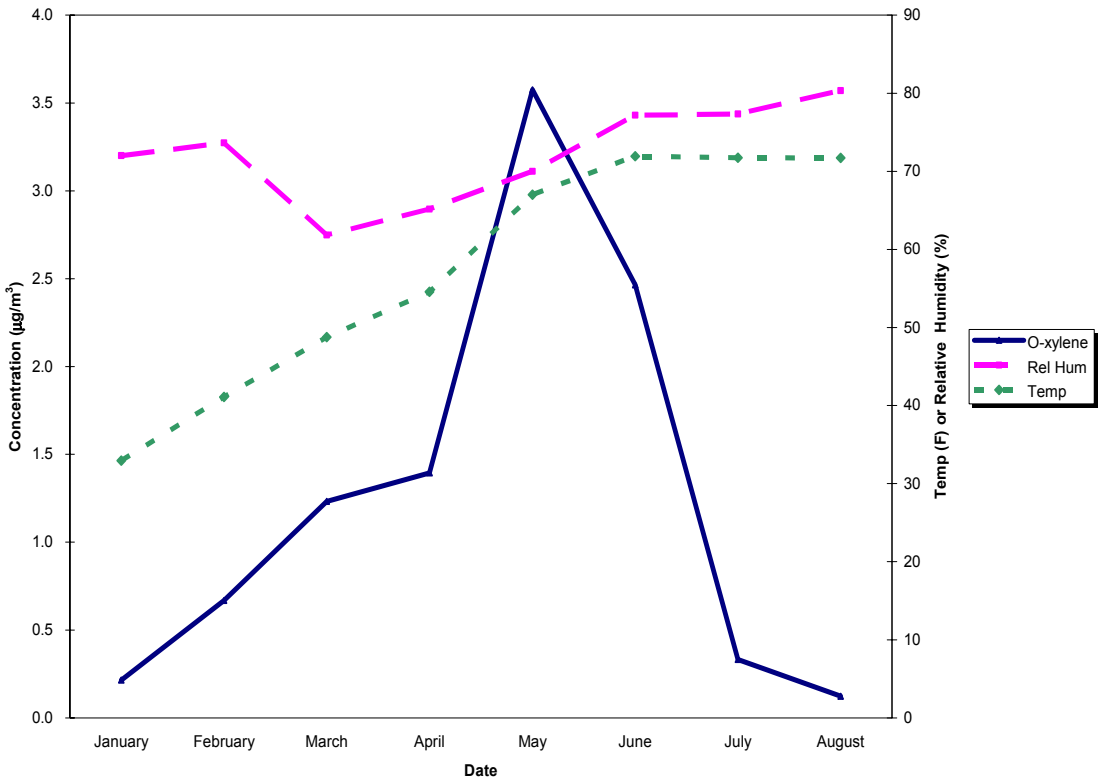


Figure IV.1.4A. Athens Monthly Averaged Outdoor O-Xylene Concentrations[a]

[a] Units are Fahrenheit, percent and ug/m^3 for temperature, relative humidity and concentration, respectively

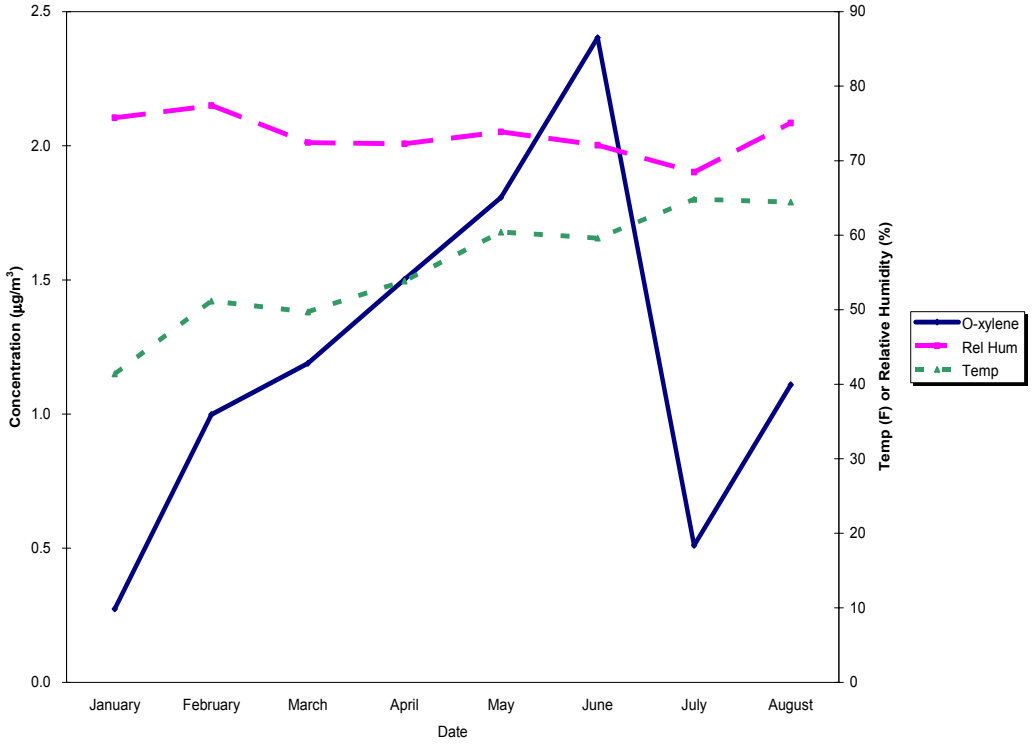


Figure IV.1.4B. Koebel Monthly Averaged Outdoor O-Xylene Concentrations[a]

[a] Units are Fahrenheit, percent and ug/m^3 for temperature, relative humidity and concentration, respectively

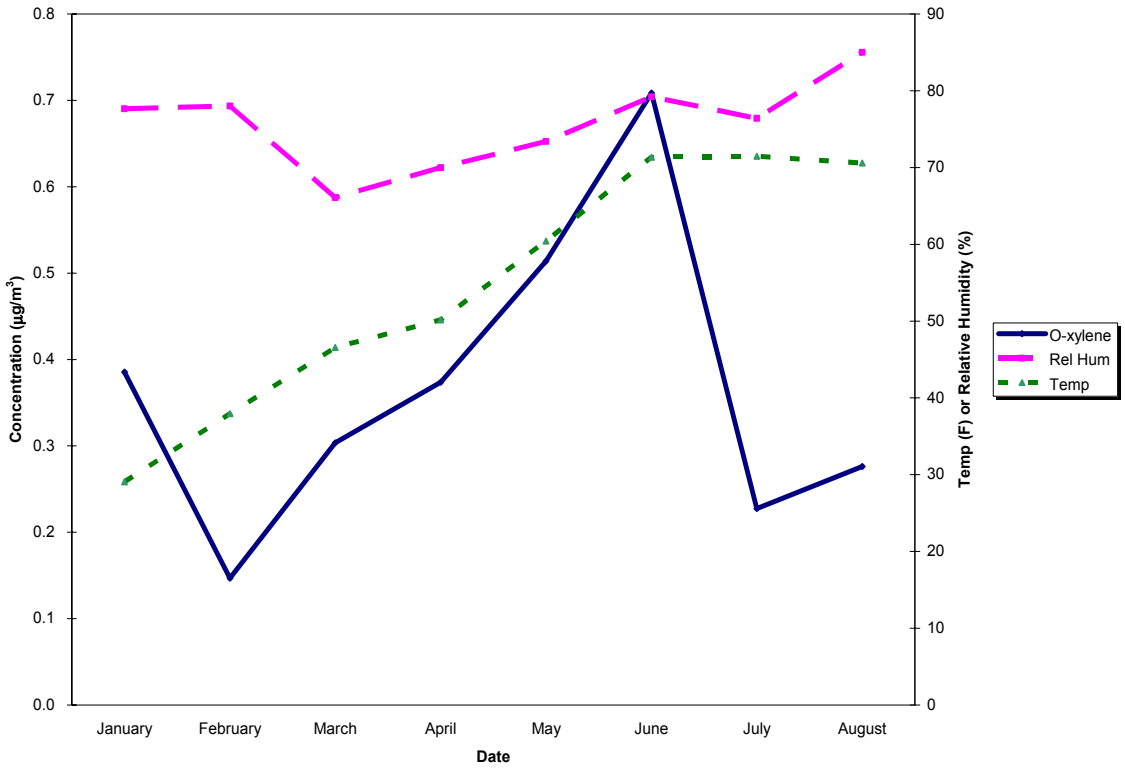


Figure IV.1.4C. New Albany Monthly Averaged Outdoor O-Xylene Concentrations[a]

[a] Units are Fahrenheit, percent and ug/m^3 for temperature, relative humidity and concentration, respectively

Although specific VOC concentrations were not distinctly affected by weekly temperature or airborne moisture, this study shows a significant seasonality to VOC prevalence. Higher levels of most chemical species occurred in spring months as compared to either winter or summer. Table IV.1.13 displays a summary of seasonal trends by sample type for each school. Owing to 1,3-dichlorobenzene concentrations, Athens had significantly higher overall levels of VOCs than either Koebel or New Albany. When 1,3-dichlorobenzene was removed from the dataset, Koebel showed the highest VOC levels but Athens VOC levels were still higher than New Albany.

Table IV.1.13. Seasonality Trends in TVOC for All Schools and All Sample Types ($\mu g/m^3$)

Athens		**Winter**	**Spring**	**Summer**
	Personal	7.53	272.88	N/A [a]
	Indoor	5.45	297.32	41.24
	Outdoor	5.21	23.25	3.93
Koebel				
	Personal	5.78	33.88	N/A
	Indoor	7.61	24.53	15.72
	Outdoor	6.19	16.99	8.56
New Albany				
	Personal	10.92	12.34	N/A
	Indoor	16.33	32.13	10.56
	Outdoor	3.73	6.45	3.29
Seasonal trend averaged for all three schools				
	Personal	8.08	106.37	N/A
	Indoor	9.80	117.99	22.51
	Outdoor	5.05	15.56	5.26
Overall Seasonal trend for all sample types				
	Average TVOC	7.64	79.97	13.88

[a] No personal data was collected during the summer since school was not in session at the elementary schools

As detailed earlier, inquiries were made of site personnel at Athens elementary but the source of 1,3-dichlorobenzene could not be determined. Its presence could be due to the use of insecticides in the school. 1,3-dichlorobenzene is an active ingredient in insecticides. To enable a more precise determination of abnormally high levels of a given compound, a contemporaneous diary of activities in the classroom, as well as a diary of the activities of the student wearing the personal sampler, could be kept. Such

diaries would create a precise data log to be associated with chemicals used in the classroom, thereby enhancing the ability to determine sources of VOC contaminants.

As foretold by the speciated data, TVOC levels were highest in the spring season at all three sites. This was unexpected since the winter months would typically have the least fresh air available indoors, resulting in higher indoor levels from anthropogenic sources. Higher personal exposures were likewise expected due to cold weather keeping the children indoors, and the likelihood that the schools were saving energy by limiting the supply of fresh outdoor air.

Seifert et al.[56] studied 12 Berlin households over the course of a 12 month period, employing passive dosimeters to collect bi-monthly samples (i.e., 26, two-week periods). In most of the residences, TVOCs in winter months exceeded summer values by a margin of 3:1. TVOCs were employed as a parameter measure to indicate general influence of seasonal conditions on all VOC concentrations. Although no average or median values were reported by season, the authors cite Krause et al.[57] who, in a study of sixty VOCs in some 500 German homes, reported a mean TVOC value of 400 ug/m^3 and a 50-percentile value of 330 ug/m^3. As compared with this study (Table 13), German 50-percentile residential values of TVOCs were approximately 40, 4, and 24 times greater than the Ohio winter, spring, and summer TVOC values, respectively. Seifert attributed the higher average TVOC concentrations in his study to specific activities taking place in the homes, such as renovation work, use of felt markers, cleaning agents, correction fluids, and adhesives. Lewis, in a study of ten homes in winter in Boise, Idaho, also found indoor contributions of various VOCs to be the significant cause for the higher VOC concentrations detected.[58]

Given the magnitude of the differences seen between Seifert's work and the current study, it is also possible that sampling differences were responsible for higher levels seen in Germany in winter months and in Ohio in late spring. For example, Chen et al.[59] studied the relationship of VOC vapor pressure to temperature at time of sampling, and found that elevated temperatures increased specific airborne concentrations significantly. Since no temperature data is available from Seifert et al. it can only be postulated that potentially higher indoor temperatures may have had some effect on sampling rates of the badges. In this study, it is possible that sampling rates in late spring were increased owing to elevated indoor temperatures during atypical hot days occurring prior to the use of building air conditioning.

Pellizzari's TEAM study produced a seasonality comparison between winter and summer seasons.[60] In that study, winter VOC levels for most target compounds were two to three times higher than summer levels. For both Elizabeth/Bayonne, NJ, as well as Los Angeles, the majority of chemicals common to both studies were more frequently measured in indoor settings

during winter months than in indoor locations during summer months. Over all geographical areas incorporated into that study, indoor to outdoor concentrations were statistically different (p = 0.05) in 58 of the 280 matched pairs examined. However, in some locations all studied chemicals during Fall months were higher indoors than outdoors (Elizabeth/Bayonne, NJ), or a large percentage (13/19 at Antioch/ W. Pittsburg, CA.) were greater indoors as compared to outdoors. Thus it seems that what few studies have been done comparing indoor to outdoor concentrations indicate indoor values are greater in colder months than warmer months. Clearly, Athens and Koebel data contradicts those findings whereas New Albany data affirms them.

Figures IV.1.5A, -B, and –C show the monthly averaged concentrations for selected VOCs at each school. These figures illustrate the rise in concentration, that was experienced for a majority of the VOCs measured, during the spring months. The concentrations also tended to drop during the summer months for both indoor and outdoor samples (personal samples were not taken during the summer months).

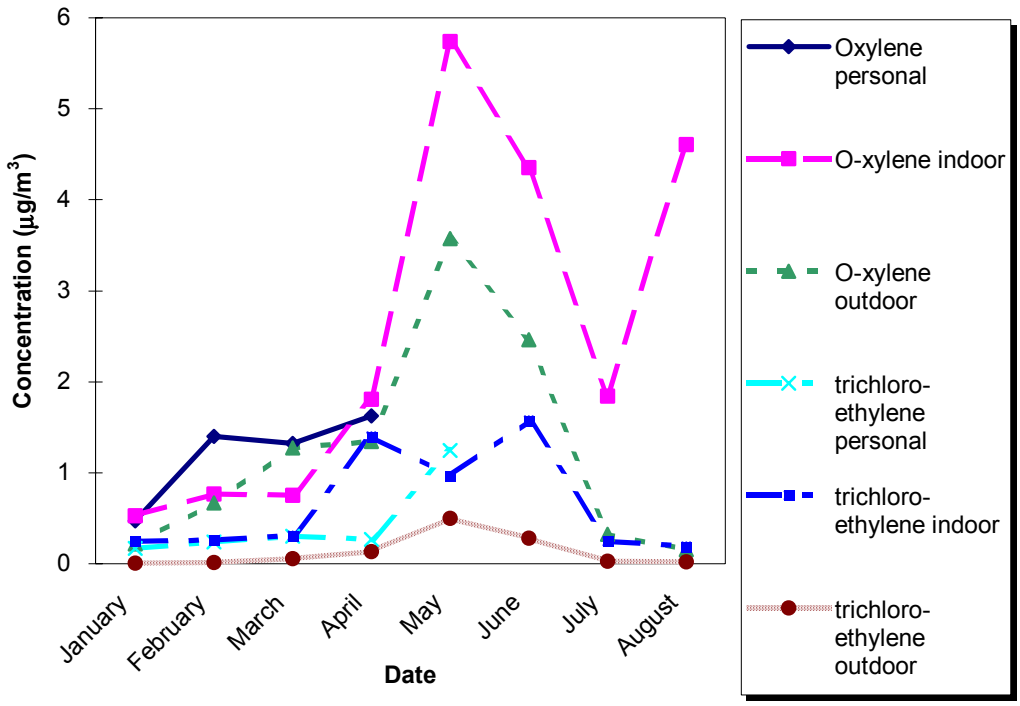


Figure IV.1.5A. Athens Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.

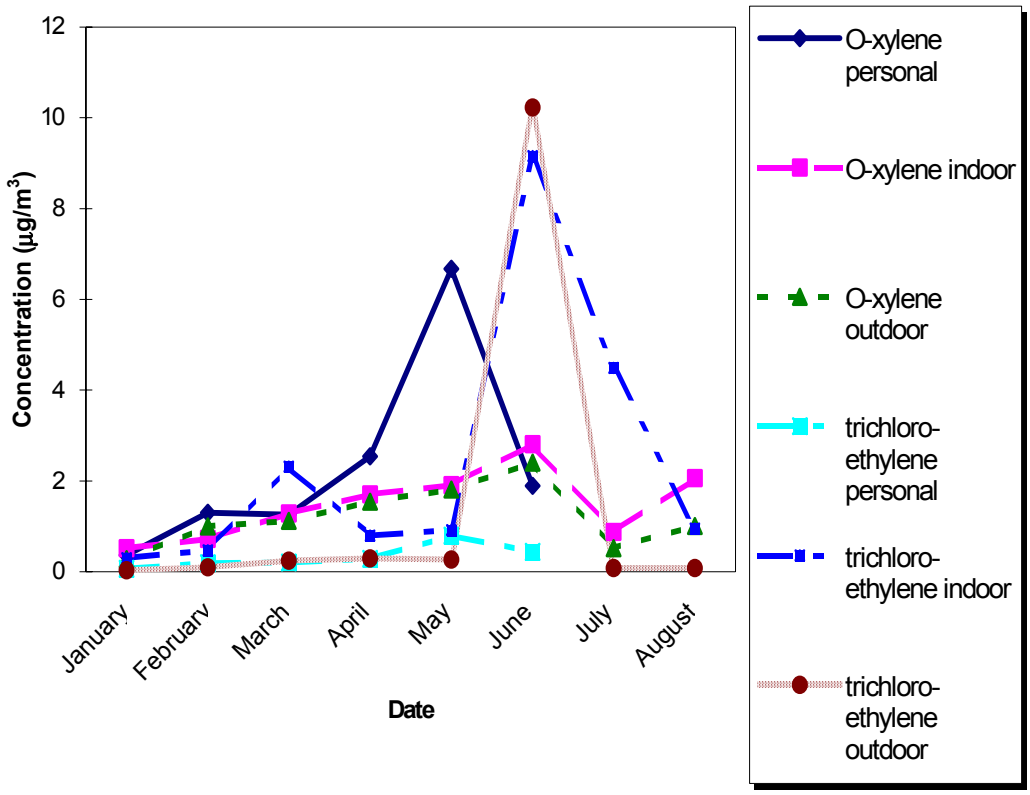


Figure IV.1.5B. Koebel School Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.

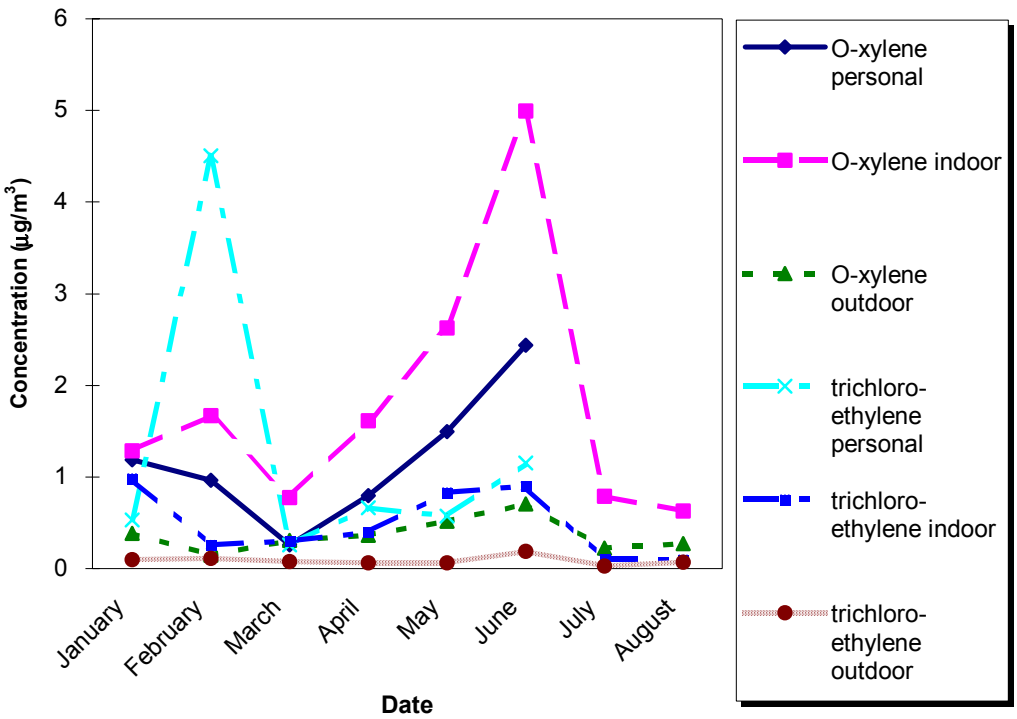


Figure IV.1.5C. New Albany Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.

Weekend

Figures IV.1.6A, -B, and -C show weekday and weekend concentrations at each site for a typical sample result, o-xylene. What seems notable is the similarity between the concentrations regardless of site. For this chemical and most others, the location variable (rural, suburban, and urban) had no major impact on VOC concentration. Weekend levels were not consistently higher or lower than weekday concentrations.

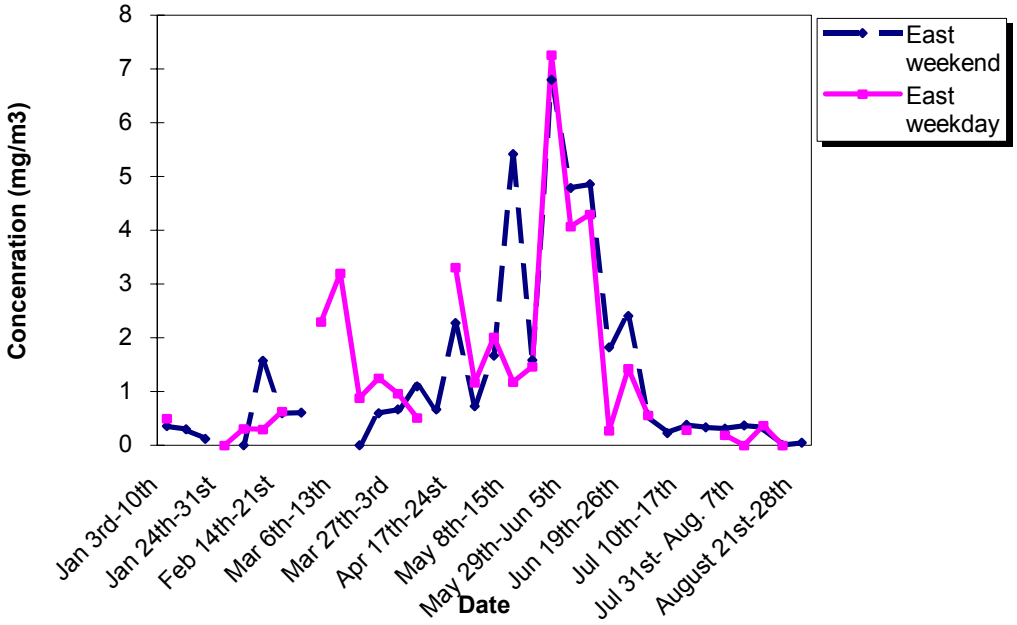


Figure IV.1.6A. Weekday and Weekend Comparison of O-xylene Concentrations at Athens

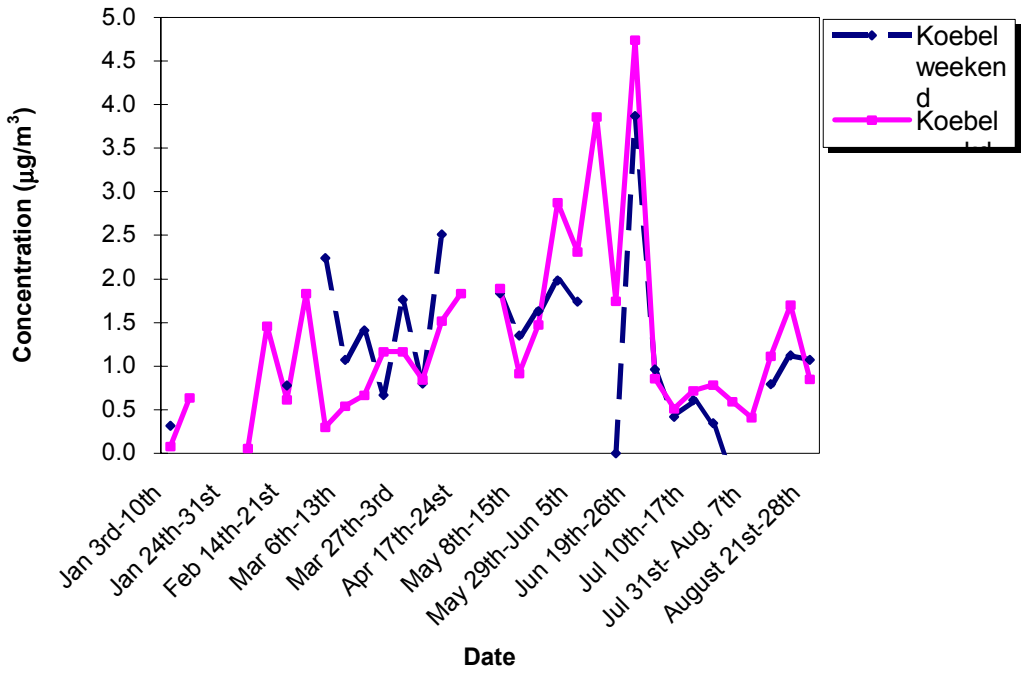


Figure IV.1.6B. Weekday and Weekend Comparison of O-xylene Concentrations at Koebel School

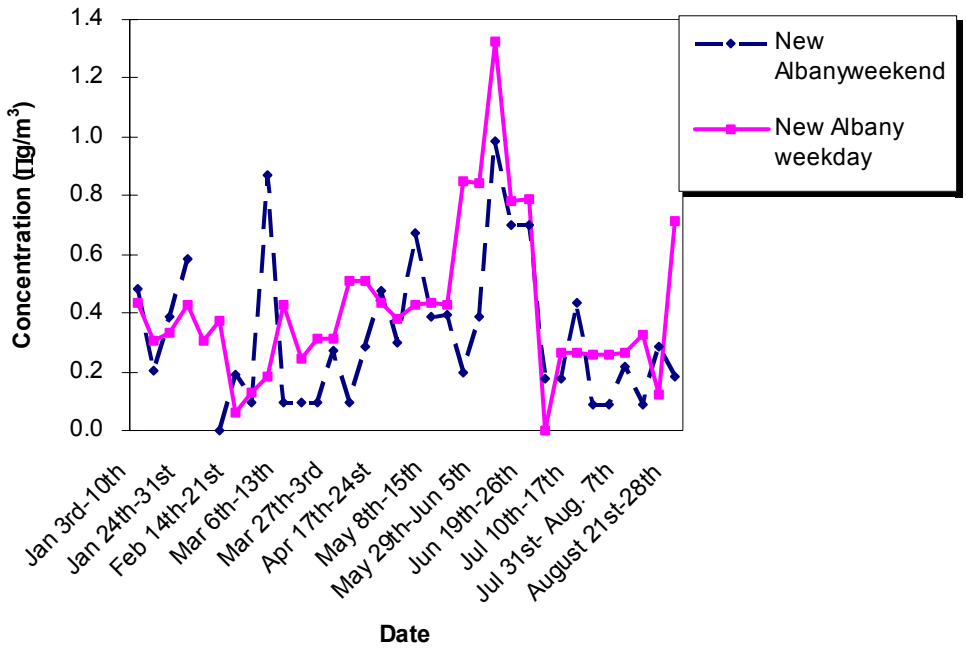


Figure IV.1.6C. Weekday and Weekend Comparison of O-xylene Concentrations at New Albany

Regional Geographical Variation

A higher percentage of samples with detectable VOC levels was found in Los Angeles than in Elizabeth/Bayonne, NJ.[61] For the eight compounds shared by this study and those two locations (o-xylene, m,p-xylenes, m,p-dichlorobenzenes, tetrachloroethylene, ethylbenzene, carbon tetrachloride, trichloroethylene, and styrene), the Ohio median data from New Albany show overall lower VOC measures as compared with Los Angeles summertime data (Tables IV.1.14A and -B). This same relationship held for median Ohio concentrations relative to the New Jersey summertime study sites. New Albany was chosen for comparison because its designation as a suburban site is most similar to the Los Angeles and New Jersey sites. Only two compounds from Region V data [62] are applicable to this geographic comparison (tetracholoroethylene and trichloroethylene). As can be seen from Tables IV.1.14A and –B, the Ohio values are very similar with the values reported for the USEPA Region V for trichloroethylene indoors and significantly lower for the other comparisons.

As demonstrated earlier in Table IV.1.8, in 9 of 13 chemical specific indoor comparisons, this study found higher percentages of detectable VOCs than did the Kanawha Valley study[63], and 13 of 13 such comparisons were greater than in the TEAM evaluations of Pellizzari.[64] This study found higher outdoor concentrations in all cases as compared to both the KV and Pellizzari work. Differences in methodology have already been noted between the three studies, as has the issue with elevated blanks for benzene. It is presumed that the analytical differences account for the observed higher levels of speciated VOCs in this study compared to the other two studies, and that the differences are not attributable to geographic differences. Indeed, since the center of the KV study was only 60-130 nautical miles from the Ohio study sites, large outdoor differences would not be expected. This is in accord with the conclusion of Pellizzari[65] that no statistically significant different concentrations were measured in their study of heavily industrialized and control locations.

Separate comparisons of our study results with other New Jersey data for geographic variation is not possible and does not appear necessary, as all study locations in that report were taken from just three homes in Elizabeth and Bayonne, NJ.[66] Furthermore, it appears that these same data may have been included in Pellizzari's report.

Table IV.1.14A. New Albany Concentrations[a] versus Los Angeles, New Jersey Summer and Region V. (Indoor)

Compound	LA Summer	NJ Summer	Region V	New Albany
O-xylene	2.6	5.9		1.18
m & p-xylene	8.2	14		2.06
1,3-dichloro-benzene	1.0	2.6		5.61
tetrachloroethylene	1.7	4.7	1.9	0.27
ethylbenzene	2.2	5.4		1.18
carbon tetrachloride	.71	1.4		0.78
trichloroethylene	.51	3.9	0.56	0.66
styrene	.60	1.8		0.07

[a] all values in ug/m^3

Table IV.1.14B. New Albany Concentrations[a] versus Los Angeles, New Jersey Summer and Region V. (Outdoor)

Compound	LA Summer	NJ Summer	Region V	New Albany
o-xylene	2.1	3.4		0.31
m & p-xylene	7.8	9.0		0.39
1,3-dichloro-benzene	.72	1.2		0.16
tetrachloroethylene	1.3	1.8	1.2	0.27
ethylbenzene	2.0	2.5		0.30
carbon tetrachloride	.63	.97		0.80
trichloroethylene	.11	1.4	0.32	0.07
styrene	.57	.44		0.00[b]

[a] all values in ug/m^3
[b] This value indicates a concentrations less than the limit of detection

VOC and PM 2.5 Correlations

For the majority of chemicals in this study, there is no, or only slight, correlation between their concentrations and $PM_{2.5}$. This finding is summarily illustrated in Figure IV.1.7, comparing $PM_{2.5}$ with all VOCs (TVOCs).

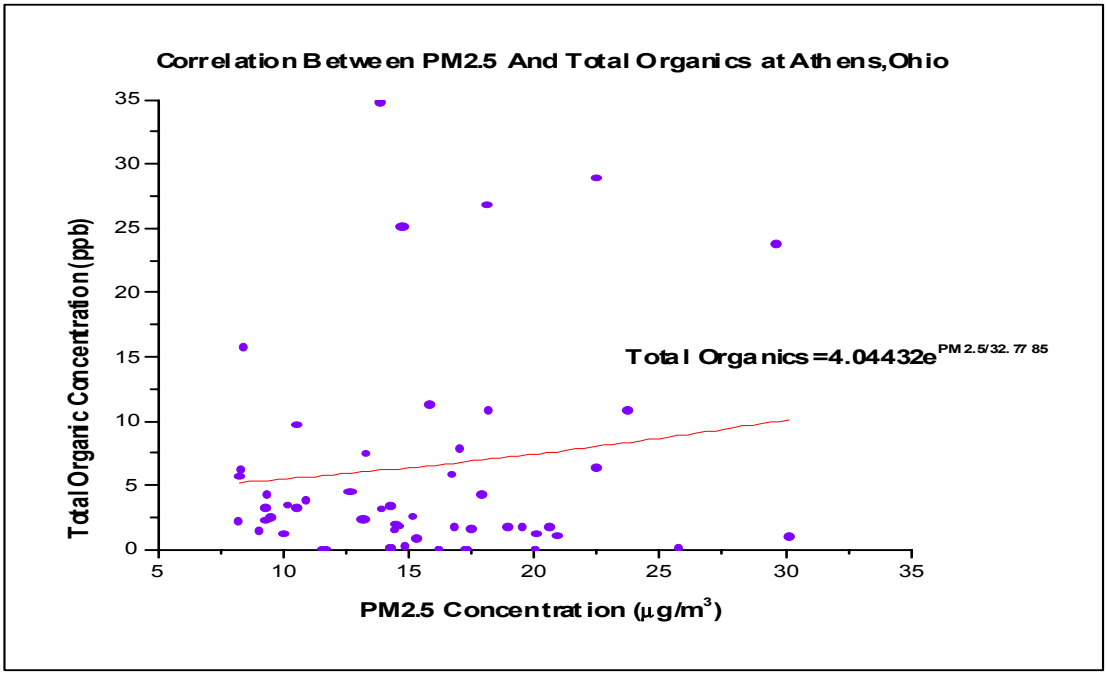


Figure IV.1.7. TVOC and $PM_{2.5}$ Relationship

One notable exception to the overall TVOC and speciated VOC trend is that of benzene and $PM_{2.5}$. As in Figure IV.1.8, there is an increase in this particular VOC with particulate concentration. It is tempting to attribute this association to fuels but no other such relationship was seen with other fuel constituents. Chemically related species with similar chemical properties include the xylenes, where no such trend was detected.

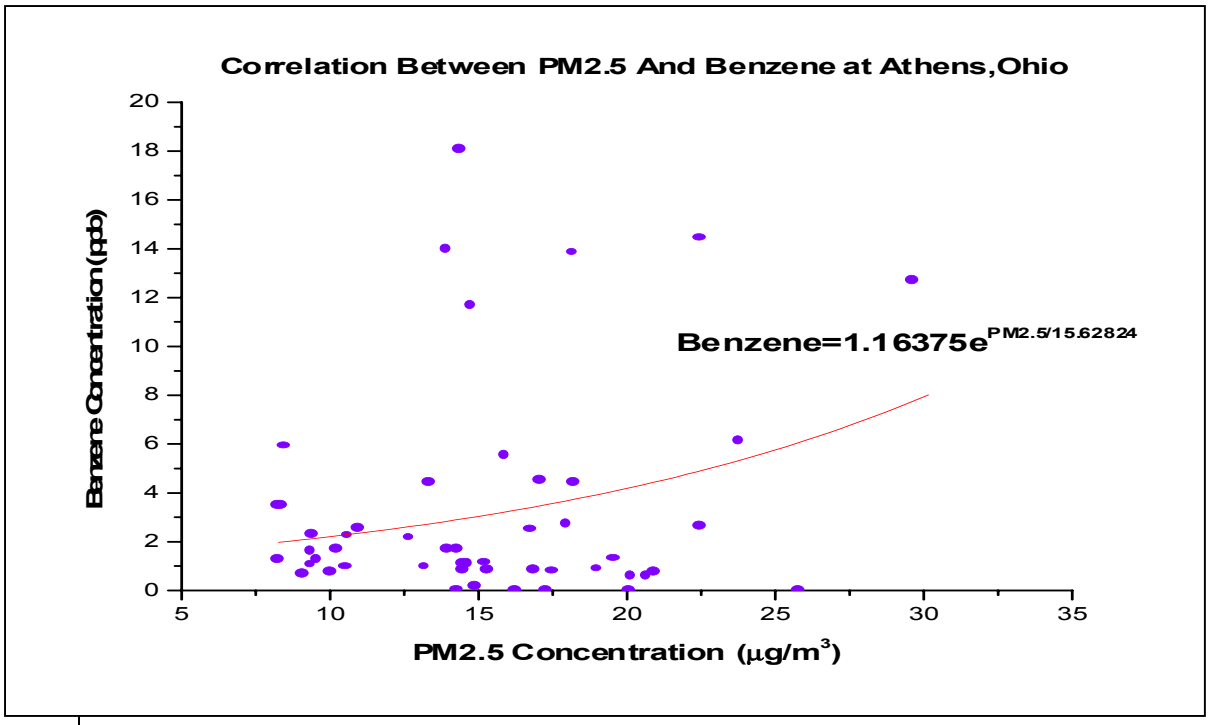


Figure IV.1.8. Benzene and $PM_{2.5}$ Relationship

SUMMARY

Indoor, outdoor, and personal concentrations of 45 volatile organic compounds were simultaneously assessed in separate semi-rural, suburban, and inner city schools in Ohio over an eight-month period. Samples were collected with passive dosimeters analyzed by gas chromatography and mass spectrometry.

Results showed overall levels of exposures in the parts per billion range with rare excursions approaching parts per million. Indoor concentrations typically exceeded outdoor levels, and personal exposures were generally the highest of the three levels analyzed. Of the three locations studied, it was found that the rural setting had the highest TVOC levels. This was unexpected and contradicts the intuitive expectation that the inner city site, with ostensibly greater local emissions, would contain the highest levels of TVOCs. This finding indicates that location may not always determine the concentration of VOCs present at a site, and that local variability may play a greater role in contaminant levels present. This study further confirms earlier work showing

that indoor and personal sample VOC concentrations are higher than outdoor concentrations.

Many studies have examined VOC concentrations, but this study is one of a very few to examine ambient and personal VOC concentrations in elementary schools. This work is also notable in that it employed a passive dosimeter for the assessment of these low-level organic contaminants. Despite difficulties with elevated background concentrations of benzene on some dosimeters, passive dosimeters show promise for ambient air monitoring.

Because of the success of this study in using passive dosimeters to assess indoor air quality, further work to explore the utility of this methodology should be considered. Compared with conventional methods, passive dosimeters are much easier to deploy and return from field sampling locations, have high accuracy and versatility, low unit cost, and no maintenance expenses. Passive dosimeter sampling can be initiated as quickly as dosimeters can be provided to the study site, and sampling can be carried out by laypersons with virtually no scientific training. For all these reasons, research aimed at establishing passive dosimeters as primary ambient air pollution monitors for VOCs should be considered.

NOTES

1. P. J. Lioy, L. Wallace & E. O. Pellizzari, Indoor/outdoor, and personal monitoring and breath analysis relationship for selected volatile organic compounds measured at three homes during New Jersey TEAM – 1987; *Journal of Exposure Analysis and Environmental Epidemiology* 1.1(1991):45-61.

2. E. D. Pellizzari, T. D. Hartwell, R. L. Perritt, C. M. Spaeacino, L. S. Sheldon, H. S. Zelon & R. W. Whitmore, Comparison of indoor and outdoor residential levels of volatile organic chemicals in five U.S. geographic areas; *Environment International* 12 (1986): 619-623; E. D. Pellizzari, K. Perritt, T. D. Hartwell, L. C. Micheal, C. M. Sparacino, L. S. Sheldon, R. Whitmore, C. Leninger, H. Zelon, W. Handy & D. Smith, *Total exposure assessment methodology (TEAM) study: Elizabeth and Bayonne, New Jersey, Devils Lake, North Dakota and Greensboro, North Carolina*. (Washington, DC: U.S. Environmental Protection Agency, 1987) A/600/6-87/002b.

3. E.D. Pellizzari, R.L. Perritt, & C.A. Clayton, National human exposure assessment survey (NHEXAS): exploratory survey of exposure among population subgroups in EPA Region V; *Journal of Exposure Analysis and Environmental Epidemiology* 9 (1999): 49-55; B. Seifert, K. Becker, K. Hoffmann, C. Krause & C. Schulz, The German environmental survey 1990/1992 (GerES II): a representative population study, *Journal of Exposure Analysis and Environmental Epidemiology* 10 (2000): 103-114; S.M. Gordon, P.J. Callahan, M.G. Nishioka, M.C. Brinkman, M.K. O'Rourke, M.D. Lebowitz, and D.J. Moschandreas, Residential environmental measurements in the National Human Exposure Assessment Survey (NHEXAS) pilot study in Arizona: preliminary results for pesticides and VOCs; *Journal of Exposure Analysis and Environmental Epidemiology* 9 (1999): 456-470; R.D. Edwards, J. Jurvelin, K. Koistenen, K. Saarela, & M. Jantunen, VOC source identification from personal and residential indoor, outdoor, and workplace microenvironment samples in EXPOLIS-Helsinki, Finland; *Atmospheric Environment* 35 (2001):4529-4841.

4. M. A. Cohen, P. B. Ryan, Y. Yanagisawa & J. D. Spengler, Indoor/outdoor measurements of volatile organic compounds in the Kanawha Valley of West Virginia, *Journal of the Air Pollution Control Association* 39 (1989): 1086-1093.

5. R.D. Edwards, J. Jurvelin, K. Saarela, & M. Jantunen, VOC concentrations measured in personal samples and residential indoor, outdoor, and workplace microenvironments in EXPOLIS-Helsinki, Finland; *Atmospheric Environment* 35 (2001):4531-4543.

6. E.D. Pellizzari, D.J. Smith, C.A. Clayton, L. Michael, & J.J. Quackenboss, An assessment of the data quality for NHEXAS-Part I: exposure to metals and volatile organic chemicals in Region 5; *Journal of Exposure Analysis and Environmental Epidemiology* 11 (2001): 140-154; Seifert et al., The German environmental survey; Gordon et al., Residential environmental measurements.

7. J. D. Mobley & S. Shaver, *Air Toxics Monitoring Concept Paper*. (Washingon, DC: Office of Air Quality Planning and Standards, USEPA, 1999).

8. I bid.

9. J. V. Bruckner & William B. Well, Biological factors which may influence an older child's or adolescent's response to toxic chemicals, *Regulatory Toxicology and Pharmacology*, 29 (1999): 158-164.

10. I bid.

11. L. Molhave, B. Bach & O. F. Pedersen, Human reaction to low concentrations of volatile organic compounds *Environmental International* 12 (1986): 167-175.

12. G. Hoek and B. Brunekreef, Effects of low-level winter air pollution concentrations on respiratory health of Dutch children, *Experimental Research* 64 (1994): 136-150.

13. B. Seifert, W. Mailahn, C. Schulz & D. Ullrich, Seasonal variation of concentrations of volatile organic compounds in selected German homes, *Environment International* 15 (1989): 397-408; R. Pristas. Benzene in air—organic vapor monitors versus charcoal tubes, *American Industrial Hygiene Association* 52. 7 (1991); 297-304.

14. M.T. Morandi, T.H. Stock, C.-W. Chung & M. Afshar, Personal exposures to toxic air pollutants; Contract Final Report, Mickey Leland National Urbran Air Toxics Research Center, Houston, TX. 1998.

15. C-W. Chung, M. T. Morandi, T. H. Stock & M. Afshar, Evaluation of a passive sampler for volatile organic compounds at ppb concentrations, varying temperatures, and humidities with24-h exposures. 1. description of exposure chamber system, *Environmental Science and Technology* 33 (1999); 3661-3665.

16. T. H. Stock, M. T. Morandi, C-W. Chung and M. Afshar, Feasibility study: laboratory evaluation and field method comparison. *NUATRC Study of Personal Exposure to Toxic Air Pollutants* (Jan. 19th, 1996) 1-54.

17. Joseph G. Montalvo Jr., Total elemental content of passive personal monitors, *American Industrial Hygiene Association Journal* 40 (1979): 1046-1054.

18. W. K. Fowler, Fundamentals of passive vapor sampling. *American Laboratory*, (December 1982): 80-87.

19. Montevalvo, Total element content.

20. C-W Chung, M. T. Morandi, T. H. Stock & M. Afshar, Evaluation of a passive sampler for volatile organic compounds at ppb concentrations, varying temperatures, and humidities with 24-h exposures. 2. sampler performance, *Environmental Science and Technology* 33 (1999): 3666-3671.

21. Montevalvo, Total element content.

22. I bid.

23. Fowler, Fundamentals of passive vapor sampling.

24. E. H. Daughtrey Jr., K. D. Oliver, J. R. Adams, W. A. Kronmiller and W. A. McClenny, A comparison of sampling and analysis methods for low-ppb levels of volatile organic compounds in ambient air, *Journal of Environmental Monitoring* 3 (2000): 166-174.

25. Morandi et al., Personal exposures.

26. Stock et al., Feasibility study.

27. Cohen et al., Indoor/outdoor measurements.

28. Stock et al., Feasibility study.

29. I bid.

30. *HP GC-MSD Chemstation and Instrument Operation Volume 2. Manual Part No. H4043-90000*. (Atlanta, GA: Hewlett-Packard Company, 1998) 91.

31. Minnesota Mining and Manufacturing, Inc. *3M Technical Data Bulletin # 1028, Organic vapor monitor sampling and analysis*. (1999).

32. Cohen et al., Indoor/outdoor measurements.

33. Pellizzari et al., Total exposure assessment methodology.

34 Pellizzari et al., An assessment of the data quality.

35. Lioy et al., Indoor/outdoor and personal monitoring.

36. Pellizzari et al., Total exposure assessment methodology.

37. Cohen et al., Indoor/outdoor measurements.

38. Gordan et al., Residential environmental measurements.

39. C.A. Clayton, E.D. Pellizzari, R.W. Whitmore, R.L. Perritt, & J.J. Quackenboss, National human exposure assessment survey (NHEXAS): distributions and associations of lead, arsenic and volatile organic compounds in EPA Region 5; *Journal of Exposure Analysis and Environmental Epidemiology* 9 (1999): 381-392.

40. Seifert et al., The German environmental survey.

41. Edwards et al., VOC concentrations measured.

42. L. Molhave, Z. Lui, A. H. Jorgensen, O. F. Pedersen, and S. K. Kjaergaard, Sensory and physiological effects on humans of combined exposures to air temperatures and volatile organic compounds, *Indoor Air* 3(1993): 155-169.

43. J. Ten Brinke, *Development of new VOC exposure metrics and their relationship to sick building syndrome symptoms* (Berkeley, CA: Lawrence Berkeley National Laboratory Report, LBL-37652: 1995).

44. Molhave et al., Sensory and physiological effects; K. Andersson, J. V. Bakke, O. Bjorseth, C. G. Bornehag, G. Clausen, J. K. Hongslo, M. Kjellman, S. Kjaergaard, F. Levy, L. Molhave, S. Skerfving & J. Sundell, J., TVOC and health in non-industrial indoor environments: report from a Nordic Scientific Consensus Meeting at Langholmen in Stockholm, *Indoor Air* 7(1997): 78-91.

45. G. W. Siple, EPA's focus on IAQ. *Environmental Protection* (December 1999): 28-31.

46. R. Kostiainen, Volatile organic compounds in the indoor air of normal and sick houses, *Atmospheric Environment* 29(1995): 693-702.

47. C. J. Weschler, H. C. Shields and D. Rainer, Concentrations of volatile organic compounds at a building with health and comfort complaints, *American Industrial Hygiene Association Journal* 51(1990): 261-268.

48. *29 Code of Federal Regulations. Subpart Z—Toxic and Hazardous Substances*. 1910.1000 Air Contaminants. Revised July, 2001.

49. American Conference of Governmental Industrial Hygienists. *2001 TLVs and BEIs. Threshold limit values for chemical substances and physical agents*. (Cincinnati, OH: ACGIH, 2001).

50. M. Hodgson, H. Levin & P. Wolkoff, Volatile organic compounds in indoor air, *Journal of Allergy and Clinical Immunology* 94 (1994): 296-303.

51 Stock et al., Feasibility study.

52. Claton et al., National human exposure assessment survey.

53. Mobley and Shaver, *Air Toxics Monitoring*.

54. P. A. Scheff, V. K. Paulius, S. W. Huang & L. M. Conroy, Indoor air quality in a middle school, part I: use of CO_2 as a tracer for effective ventilation, *Applied Occupational and Environmental Hygiene* 15(2000): 824-834.

55. Lioy et al., Indoor/outdoor and personal monitoring.

56. Seifert et al., Seasonal variation of concentrations.

57. C. Krause, W. Mailahn, R. Nagel, C. Schulz, B. Seifer & D. Ullrich, Occurrence of volatile organic compound in the air of 500 homes in the Federal Republic of Germany; In: Seifert, B. et al., eds., *Proceedings 4th International Conference on Indoor Air Quality and Climate (INDOOR AIR '87),* (West Berlin: August 17-21, 1987), Vol. 1, 102-106.

58. C. W. Lewis, Source of air pollutants indoors: VOC and fine particulate species, *Journal of Exposure Analysis and Environmental Epidemiology* 1(1991): 31-44.

59. M-L. Chen, M-S Uang and I-F Mao, Vaporizing characteristics of mixed solvents in indoor environment, *The Science of the Total Environment* 205 (1997): 129-135.

60. Pellizzari et al., Total exposure assessment methodology.
61. I bid.
62. Pellizzari et al. National human exposure assessment survey.
63. Cohen et al., Indoor/outdoor measurements.
64. Pellizarri et al., Total exposure assessment methodology.
65. I bid.
66. Lioy et al., Indoor/outdoor and personal monitoring.

Appendix A

Parent's and Child Health Questionnaire

Parent's Questionnaire
Air Pollution and Pediatric Health Impact Study

Kevin Crist, Ph.D.
Associate Professor, School of Health Sciences
Ohio University
Athens, Ohio

A Note from Dr. Crist

Thank you so much for helping us with this project. You are providing information that will help the Ohio Environmental Protection Agency and others make decisions about air pollution levels.

The answers that you provide in this questionnaire will not be connected to your child in any way. All information will be studied and reported as group information only, without identification. By completing this questionnaire, you are giving us permission to analyze your responses along with the responses of the parents of the other children at school.

Please answer every question carefully and accurately. If you have trouble answering any questions or need help completing the questionnaire, please contact the school principal, who will then contact me. I will arrange for one of my co-workers to get back to you to provide assistance.

Every child who turns in a completed questionnaire will receive a small gift as a sign of our appreciation.

47

PARENT'S QUESTIONNAIRE

INSTRUCTIONS:

1. This booklet asks about your child's health and well-being. Your individual answers will not be shared with anyone.

2. If choose not to participate it will not affect your child's grades.

3. Answer the questions by placing an X in the appropriate box or by filling in the appropriate blank.

4. Please answer each question. Certain questions may look alike but each one is different. Some questions ask about problems your child may not have. That's great, but it's important for us to know. Please answer each question.

5. There are no right or wrong answers. If you are unsure how to answer a question, please give the best answer you can and make a comment in the margin.

6. All comments will be read, so please feel free to make as many as you wish.

1. In general, would you say your child's health is:
Excellent Very good Good Fair Poor

2. Is your child:
Male -Female

3. What is your child's date of birth?

Month Day Year

The following questions pertain mainly to your child's chest. Please place a check next to *yes* or *no if* possible. *If* a question does not appear to be applicable to your child, check the *does not apply* box.

COUGH

4a. Does he/she usually have a cough with colds? Yes No Does not apply

4b. Does he/she usually have a cough apart from colds? Yes No Does not apply

If you answered YES to 4a or 4b, please answer questions 4c and 4d.

4c. For how many years has he/she had this cough?

Number of years

4d. Does he/she cough on most days (4 or more days per week) for as much as three months of the year?
Yes
No

WHEEZING

5a. Has your child ever had an attack of wheezing that has caused him/her to be short of breath? Yes No

If you answered YES to 5a, please answer questions 5b through 5e.

5b. Has he/she had 2 or more such episodes? Yes No

5c Has he/she ever required medicine or treatment for any of the episodes? Yes No

5d. How old was this child when he/she had his/her first such attack?

5e. Is or was his/her breathing completely normal between attacks? Yes No

6. Does your child ever get attacks of wheezing after he/she has been playing hard or exercising? Yes No

CHEST ILLNESSES

7a. During the past 3 years has this child had any chest illness that has kept him/her from usual activities for as much as 3 days?

Yes
No

If you *answered YES to 7a, please answer questions 7b, 7c, and 7d.*

7b. Did he/she bring up more phlegm or seem more congested than usual with any of these illnesses.? .

Yes
No

7c. How many illnesses like this has he/she had in the past 3 years?

Less than 1 illness per year
1 illness per year
2-5 illnesses per year
More than 5 illnesses per year

7d. How many of these illnesses have lasted for as long as 7 days?

8. Was he/she ever hospitalized for a severe chest illness or chest cold before the age of 2 years?

Yes, only once Yes, 2 times Yes, 3 or more times NO

9. Did your child have any other severe chest illness or chest cold before the age of 2 years?

Yes
No

OTHER ILLNESSES

10. Has your child had any of the following illnesses, and if yes, give the age at which it first occurred.

a. Measles (not German)	Yes	No	At age
b. Sinus trouble	Yes	No	At age
c. Bronchiolitis	Yes	No	At age
d. Bronchitis	Yes	No	At age
e. Asthmatic bronchitis	Yes	No	At age
f. Pneumonia	Y e s	N o	At age
g. Whooping cough	Yes	No	At age
h. Croup	Yes	No	At age
i. Cystic fibrosis	Yes	No	At age

11. Did the doctor ever say that your child had eczema before the age of 2 years? Yes NO

12. Does or did your child have external ear (ear canal) infections (swimmer's ear)? Yes No

ASTHMA

13a. Has a doctor ever said that your child had asthma? Yes No

If you answered YES to 13a, please answer questions 13b, 13c, and 13d.

13b. At what age did his/her asthma begin?

13c. Does he/she still have asthma?
Yes
No

13d. Does he/she currently take medicine or treatment for asthma? Yes No

If you answered NO to 13c, please answer question 13e.

l3e. At what age did his/her asthma stop?

ALLERGY

14. Has a doctor ever said that your child had an allergic reaction to pollen or dust? Yes No

OTHER

15a. Does anyone in the family staying in this house with you smoke cigarettes, cigars, or pipes?
Yes
No

15b. If yes, how many people smoke including parents?
1 2 3 4 5 and more

15c. If people in the house smoke cigarettes, how many cigarettes do they smoke each day?
Less then 10
10-20
20-40
More than 40

15d. If people in the house smoke cigars or pipes, how many cigars or pipes do they smoke each day?
1-2
2-3
4-5
More than 5

16. Is there an air-conditioner in your house? Yes No

17. Are there any pets in your house?
Yes No

COMMENTS: Is there anything else that you think is important for us to know about your child's health or other conditions to which your child is exposed?

Date _____

Thank you for completing the questionnaire.

Please fill out the card below with your child's name and the name of your child's teacher. At school, the card will be removed so that your child's name will not be on this form.

Your child should now return the entire questionnaire to his/her classroom teacher. -

Parents who do not return the questionnaire will be contacted at a later date.

Child Health Questionnaire - Parent Report
CHQ-PF28

I N S T R U C T I 0 N S -

1. This booklet asks about your child's health and well-being. Your Individual answers will not be shared with anyone.

2. If you choose not to participate It will not affect the care you receive.

3. Answer the questions by marking the appropriate box 12L

4. Certain questions may look alike but each one Is different Some questions ask about problems your child may not have. That's great, but it's Important for us to know. Please answer each question.

5. There are no right or wrong answers. If you are unsure how to answer a question, please give the best answer you can and make a comment In the margin.

6. All comments will be read, so please feel free to make as many as you wish.

1991, 1996 0 Landgraf and Ware AN rights reserved

SECTION 01: YOUR CHILD'S GLOBAL HEALTH

1.1. In general, would you say your child's health Is:

Excellent	Very good	Good	Fair	Poor

SECTION #2: YOUR CHILD'S PHYSICAL ACTIVITIES

The following questions ask about physical activities your child might do during a day

2.1. During the last 4 weeks, has your child been limited In any of the following activities due to health problems?

		Yes, limited a lot	Yes, limited some	Yes, limited a little	No, not limited
a.	Doing things that take a lot of energy, such as playing soccer or running?	0	0	0	0
b.	Doing things that take some energy such as riding a bike or skating?	0	0	0	0
C.	Bending, lifting, or stooping?	0	0	0	0

SECTION 03: YOUR CHILD'S EVERYDAY ACTIVITIES

3.1. During the past 4 weeks, has your child been limited in the AMOUNT of time he/she could spend on schoolwork or activities with friends due to EMOTIONAL difficulties or problems with his/her BEHAVIOR?

0	0	0	0
Yes, limited a lot	Yes, limited some	Yes, limited a little	No, not limited

3.2. During the past 4 weeks has your child been limited in the KIND of schoolwork or activities he/she could do with friends due to problems with his/her PHYSICAL health?

0	0	0	0
Yes, limited a lot	Yes, limited some	Yes, limited a little	No, not limited

All rights reserved

SECTION #4: PAIN

4.1. During the past 4 weeks, how often has your child had bodily pain or discomfort?

0	0	0	0	0	0
None of the time		Once or twice	A few times	Fairly often	Very oftenEvery/almost every day

SECTION #5: GETTING ALONG

Below is a list of items that describe children's behavior or problems they sometimes have.

5.1. How often during the past 4 weeks did each of the following statements describe your child?

	Very Often	Fairly Often	Sometimes	Almost Never	Never
a. argued a lot	0	0	0	0	0
b. had difficulty concentrating or paying attention	0	0	0	0	0
c. lied or cheated	0	0	0	0	0

5.2. Compared to other children your child's age, in general would you say -his/her behavior -is:

0	0	0	0	0
Excellent	Very good	Good	Fair	Poor

1991, 1996 0 Landgraf and Ware AJI rights reserved

SECTION #6: GENERAL VVELL-BEING

6.1. During the past 4 weeks, how much of the time do you think your child:

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a. felt lonely?	0	0	0		0
b. acted nervous?		0	0		0
c. acted bothered or upset?		0	0	811	0

SECTION X7: SELF-ESTEEM

The following ask about your child's satisfaction with self, school, and others. It may be helpful If you keep In mind how other children your child's age might feel about these areas.

7.1. During the past 4 weeks, how satisfied do you think your child has felt about:

	Very Satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Very dissatisfied
a. his/her school ability?					
b. his/her friendships?					
c. his/her life overall?					

SECTION #8: YOUR CHILD'S HEALTH

8.1. How true or false Is the statement for your child? **Options** (definitely true, mostly true, don't know, mostly false, definitely false)

a. My child seems to be less healthy than other children I know.
b. My child has never been seriously ill.
c. I worry about my child's health more than other people worry about their children's health.

8.2. Compared to one year ago, how would you rate your child's health now:

0	0	0	0	0
Much better now than 1 year ago	Somewhat better now than 1 year ago	About the same now as 1 year ago	Somewhat worse now than 1 year	Much worse now than I year ago

ago

All rights reserved

SECTION #9: YOU AND YOUR FAMILY

9.1. During the past 4 weeks, how MUCH emotional worry or concern did each of the following cause YOU?

	None at all	A little bit	Some	Quite a bit	A lot
a. Your child's physical health					
b. Your child's emotional well-being or behavior					

9.2. During the past 4 weeks, were you LIMITED In the amount of time YOU have for your own needs because of:

	Yes, limited a lot	**Yes, limited** some	**Yes,** limited a little	No, not limited
a. Your child's physical health?				
b. Your child's emotional well-being or behavior?				

9.3. During the past 4 weeks, how often has your child's health or behavior:

	Very often	Fairly often	Sometimes	Almost never	Never
a. limited the type of activities you could do as a family?	0	0	0	0	0
b. interrupted various everyday family activities (eating meals, watching tv)?	0	0	0	0	0

9.4. Sometimes families may have difficulty getting along with one another. They do not always agree and they may get angry. In general, how would you rate your family's ability to get along with one another?

0	0	0	0	0
Excellent	Very good	Good	Fair	Poor

All rights reserved

SECTION #10: FACTS ABOUT YOUR CHILD

10.1. Is your child: Male or Female

10.2. Was this your first child (natural,or adopted)?

Yes No

10.3. What Is your child's date of birth?

MONTH DAY YEAR

10.4. What is the highest grade of school your child has completed? (Circle one number only)

Preschool	6th grade
Kindergarten	7th grade
1 st grade	8th grade
2nd grade	9th grade
3rd grade	10th grade
4th grade A"	11 th grade
5th grade	12th grade
Ungraded	If ungraded, how many years attended?

All rights reserved

11.5 Have you ever been told by a teacher. school official. doctor, nurse or other health professional that your child has any of the following conditions?

	Yes	No
a. anxiety problems		
b. asthma		
c. attentional problems		
d. behavioral problems		
e. chronic allergies or sinus trouble		
f. chronic orthopedic, bone or joint problems		
g. chronic respiratory, lung or breathing trouble (NOT ASTHMA)		
h. chronic rheumatic disease		
i. depression		
j. developmental delay or mental retardation		
k. diabetes		
l. epilepsy (seizure disorder)		
m. hearing impairment or deafness		
n. learning problems		
o. sleep disturbance		
p. speech problems		
q. vision problems		
r. does your child have any other chronic medical condition that is affecting what they do or how they feel? (Please describe below)		

1991, 1996 0 Landgraf and Ware All rights reserved

SECTION #11: FACTS ABOUT YOU

11.1. Are you:

Male Female

11.2. What Is your date of birth?

MONTH DAY YEAR

11.3. Which of the following best describes your current work status? (Check all that apply)

0	0	0	0	
Not working due to my child's health	Not working for other" reasons	Looking for work outside the home	Working full or part time (either outside the home or at a home based business)	Full time homemaker

11.4. Which of the following best describes your relationship to your child?

0	0	0	0	0	0
Biological parent	Step parent	Foster parent	Adoptive parent	Guardian	Other (please explain on the line below)

11.5. What is the highest grade of school you have completed?

0	0	0	0	0
Some high school or less	High school diploma/GED	Vocational school or some college	College degree	Professional or graduate degree

1991, 1996 0 Landgraf and Ware All rights reserved

11.6. Which of the following best describes your current marital status?

Married Widowed Divorced Separated Remarried Never married

11.7. Which of the following best describes your racial background?

Caucasian Afro-American Hispanic Asian/Oriental or Pacific Islander Other (please explain on the line below)

11.8.What is today's date?

MONTH DAY YEAR

PLEASE CONTINUE TO THE NEXT PAGE

Child Health Questionnaire - Parent Form 28 (CHO-PF28)
1991, 1996 0 Landgraf and Ware

CHO Manual
All rights reserved

1. How many people share this child's bedroom?
   I person
   2 persons
   3 or more persons

2a. How many rooms (not counting bathrooms, closets, pantries) are there in your house/apartment?

2b. How many people five in your home?

3. How is your home heated? 0 Steam or hot water
   0 Warm air furnace
   0 Floor, wall, or pipeless furnace
   0 Other means - with flue
   0 Other means - without flue
   0 Not heated

4. What fuel is used most for cooking in your home? 0 Coal or coke
   0 Wood
   0 Utility gas
   0 Bottled, tank, or LP gas
   O/Electricity
   0 Fuel oil, kerosene
   0 Other(specify)

5. Do you have any air conditioner(s), humidifier(s), or air filter(s) in your home? (5)
   0 None
   0 Air conditioner(s)
   0 Humidifier(s)
   0 Air filter(s)
   0Air conditioner(s) and humidifier(s)
   0 Air conditioner(s) and air filter(s)
   0 Humidifier(s) and air filter(s)
   0 Air conditioner(s) and humidifier(s) and filter(s)

6. Do you have a cat, dog, or bird living in your home?
   No
   Cat
   Dog
   Bird

0 Cat and dog
0 Cat and bird
0 Dog and bird
0 Cat and dog and bird

The following questions pertain mainly to your child's chest. Please answer yes or *no if* possible. *If* a question does not appear to be applicable to your child, check the *does not* apply box.

COUGH

7a. Does he/she usually have a cough with colds? (7a)
Yes
No

7b. Does he/she usually have a cough apart from colds? (7b)
Yes
No

If you answered YES to 7a or 7b, please answer questions 7c and V

7c. For how many years has he/she had this cough? (7c)
Number of years Does not apply

7d. Does he/she cough on most days (4 or more days per week) for as much as 3 months of the year?
Yes no

WHEEZING

8a. Has this child ever had an attack of wheezing that has caused him/her to be short of breath? (8a)
0 Yes
0 NO

If you answered YES to 8a please answer questions 8b through 8e

8b. Has he/she had 2 or more such episodes? (8b)
Yes
No

8c Has he/she ever required medicine or treatment for any of the episodes? (8c)
Yes
No

8d. How old was this child when he/she had his/her first such attack? (8d)
8e. Is or was his/her breathing completely normal between attacks? (8e)
Yes
No

9. Does this child ever get attacks of wheezing after he/she has been playing hard or exercising? (9)

Yes
N0

CHEST ILLNESSES

10a. During the past 3 years has this child had any chest illness that has kept him/her from usual activities for as much as 3 days? (I Oa)

Yes
No

If you answered YES to 10a, please answer questions I0b, I0c, and I0d

10b. Did he/she bring up more phlegm or seem more congested than usual with any of these illnesses? (10b)

0 Yes
0 No
0 Does not apply

10c. How many illnesses like this has he/she had in the past 3 years? (10c)

0 Less than I illness per year
0 1 illness per year
0 2-5 illnesses per year
0 more than 5 illnesses per year
0 Does not apply

I0d. How many of these illnesses have lasted for as long as 7 days? (10d)

11. Was he/she ever hospitalized for a severe chest illness or chest cold before the age of 2 years?
Yes, only once Yes, 2 times Yes, 3 or more times NO

12. Did this child have any other severe chest illness or chest cold before the age of 2 years?

Yes
No

OTHER ILLNESSES

13. Has this child had any of the following illnesses, and if yes, give the age at which it first occurred.

a. Measles (not German)	Yes	No	At age	(13a)
b. Sinus trouble	Yes	No	At age	(13b)
c. Bronchiolitis	Yes	No	At age	(13c)
d. Bronchitis	Yes	No	At age	(13d)
e. Asthmatic bronchitis	Yes	No	At age	(13e)
f Pneumonia	Yes	No	At age	(13f)
g. Whooping cough	Yes	No	At age	(13g)
h. Croup	Yes	No	At age	(13h)
i. Cystic fibrosis	Yes	No	At age	(13i)

14. Did the doctor ever say that this child had eczema before the age of 2 years?
0 Yes 0 NO

15. Does or did this child have external ear (ear canal) infections (swimmer's ear)?
Yes NO

ASTHMA

16a. Has a doctor ever said that this child had asthma? (16a)
0 Yes
No

If you answered YES to 16a, please answer questions 16b, 16c, and l6d.

l6b. At what age did his/her asthma begin? (16b)
16c. Does he/she still have asthma? (16c)
0 Yes
0 No

l6d. Does he/she currently take medicine or treatment for asthma? (16d)
0 Yes
0 No

If you answered NO to 16c, please answer question 16e.

l6e. At what age did his/her asthma stop? (16e)

ALLERGY

17a. Has a doctor ever said that this child had an allergic reaction to food or medicine? (17a)
0 Yes, food only
0 -Yes, medicine only
0 Yes, both food and medicine
0 No

17b. Has a doctor ever said that this child had an allergic reaction to pollen or dust? (17b)
0 Yes
0 No

17c. Has a doctor ever said that this child had an allergic skin reaction to detergents or other chemicals? (Do not include poison oak or poison ivy.)
0 Yes 0 No

FAMILY HISTORY

We would like to obtain some information about the parent(s) or guardian(s) living with this child. (In single-parent family, complete only A or B as appropriate.) Section C should be completed by all families.

A. MALE PARENT OR GUARDIAN

18. **Please indicate whether the male adult is** **(18)**
    natural father
    Stepfather
    Other
19. **What is the highest grade of school he has completed?** r (19)

20. **Does he now smoke regularly (at least I cigarette per day or I oz. of tobacco per month)?**
    Yes NO

    If yes: **(20b)**

cigarettes	**cigarettes and pipe**
cigars	**cigars and cigarettes**
pipe	**pipe and cigars**
	cigarettes, pipe and cigars
	don't know

21. Has he ever smoked regularly (at least 20 packs of cigarettes or 12 oz. of tobacco in a lifetime) while living in the home with this child? **(21a)**

Yes No
if yes: **(21b)**

cigarettes	**cigarettes and pipe**
cigars	**cigars and cigarettes**
pipe	**pipe and cigars**
	cigarettes, pipe and cigars
	don't know

B. FEMALE PARENT OR GUARDIAN

22. **Please indicate whether the female adult is:** **(22)**
    natural mother
    Stepmother
    Other

23. **What is the highest grade of school she has completed?** (23)

FAMILY HISTORY CONTINUED

24. Does she now smoke regularly (at least 1 cigarette per day or 1 oz. of tobacco per month)?
Yes No

If yes: (24b)

cigarettes	cigarettes and pipe
cigars	cigars and cigarettes
pipe	pipe and cigars
	cigarettes, pipe and cigars
	don't know

25. Has she ever smoked regularly (at least 20 packs of cigarettes or 12 oz. of tobacco in a lifetime) while living in the home with this child?
Yes No

If yes: (25b)

cigarettes	cigarettes and pipe
cigars	cigars and cigarettes
pipe	pipe and cigars
	cigarettes, pipe and cigars
	don't know

C. OTHER HOUSEHOLD NEMBERS

26. Are there other members of the household who currently smoke regularly (not counting persons mentioned above)? (26)
0 Yes 0 NO

If yes, specify number of persons

Appendix B

Results of Child Health Questionnaire

List of Tables

B.1 . Gender and Age Distribution, 1998-99
B.2. General Children Health, 1998-99
B.3. Current Pulmonary Status, 1998-99
B.4. Respiratory Medical History, 1998-99
B.5. General Medical History, 1998-99
B.6. Racial Background, 1998-99
B.7. Parents Educational background, 1998-99
B.8. Living Environment, 1998-99
B.9. Expanded Survey Results, Total (Males & Females) Rural Site Sample
B.10. Expanded Survey Results, Boys Rural Site Sample
B.11. Expanded Survey Results, Girls Rural Site Sample
B.12. Expanded Survey Results, Total (Males & Females) Urban Site Sample
B.13. Expanded Survey Results, Boys Urban Site Sample
B.14. Expanded Survey Results, Girls Urban Site Sample
B.15. Expanded Survey Results, Children with Non-Caucasian (Afro-American, Hispanic, and Asian) Background Urban Site
B.16. Expanded Survey Results, Children with Caucasian Background Urban Site Sample
B.17. Expanded Survey Results, Total (Males &Females) Suburban Site Sample
B.18. Expanded Survey Results, Boys Suburban Site Sample
B.19. Expanded Survey Results, Girls Suburban Site Sample
B.20. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for the Ages 11-12, Population Sample of U.S. Children
B.21. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for the Boys, Population Sample of U.S. Children
B.22. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for the Girls, Population Sample of U.S. Children
B.23. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for Children by Parents Ethnicity (Non-Caucasian), Population Sample of U.S. Children
B.24. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for Children by Parents Ethnicity (Caucasian) Population Sample of U.S. Children
B.25. General Children Health, 1999-2000
B.26. Current Pulmonary Status, 1999-2000
B.27. Respiratory Medical History, 1999-2000
B.28. Living Environment, 1999-2000

Table B.1 . Gender and Age Distribution, 1998-99

Age & Gender	Rural Area				Urban Area				Suburban Area			
	Frequency			% from total*	Frequency			% from total*	Frequency			% from total*
Male	31			**42.5**	32			**43.2**	77			**49**
Female	42			**57.5**	42			**56.8**	80			**51**
	Male	**Female**	**Total**	**% from total**	**Male**	**Female**	**Total**	**% from total**	**Male**	**Female**	**Total**	**% from total**
9 years	0	2	2	**2.9**	0	0	0	**0**	1	0	1	**0.6**
10 years	16	17	33	**47.1**	6	21	27	**37.0**	28	37	65	**41.9**
11 years	12	20	32	**45.7**	16	20	36	**49.3**	43	37	50.0	**51.6**
12 years	3	0	3	**4.3**	7	0	7	**9.6**	4	9	9	**5.8**
13 years	0	0	0	**0**	2	1	3	**4.1**	0	0	0	**0**
Sub-Total	31	39	70	**100.0**	31	42	73	**100.0**	76	79	155	**100.0**
Missing		3	3	**(4.1)**			1	**(1.4)**			5	**(3.1)**
Total			**73**				**74**				**160**	

%* - Valid percent (adjusted for missing data)

Table B.2. General Children Health**,** 1998-99

Health Status	Rural Area				Urban Area				Suburban Area			
	Frequency			%	Frequency			%	Frequency			%
	Male	**Female**	**Total**	**from total***	**Male**	**Female**	**Total**	**from total***	**Male**	**Female**	**Total**	**from total***
Excellent	16	21	37	**50.7**	8	9	17	**23.0**	47	43	92	**57.9**
Very Good	11	14	25	**34.2**	11	20	31	**41.9**	25	29	55	**34.6**
Good	3	5	8	**11.0**	11	13	24	**32.4**	4	7	11	**6.9**
Fair	0	1	1	**1.4**	2	0	2	**2.7**	1	0	1	**.6**
Poor	0	1	1	**1.4**	0	0	0	**0**	0	0	0	**0**
Sub-total	30	42	72	**98.6**	32	42	74	**100.0**	76	79	159	**99.4**
Missing System			1	**1.4**			0	**0**			1	**0.6**
Total	73			**100.0**	74			**100.0**	160			**100.0**

%* - Valid percent (adjusted for missing data)

Table B.3. Current Pulmonary Status, 1998-99

Respiratory Conditions	**Rural Area**				**Urban Area**				**Suburban Area**			
	Frequency				**Frequency**				**Frequency**			
	Male	**Female**	**Total***	**%***	**Male**	**Female**	**Total**	**%***	**Male**	**Female**	**Total***	**%**
Chronic cough	1	2	3	**4.1**	4	4	8	**10.8**	2	6	8	**5.0**
Wheezing	3	4	7	**9.6**	7	6	13	**17.6**	8	2	10	**6.3**
Chest illnesses	6	8	14	**19.2**	3	4	7	**9.5**	12	10	23	**14.5**
Asthma	0	3	3	**4.2**	3	6	9	**12.2**	5	3	8	**5.0**
Allergy	4	6	10	**13.9**	3	6	9	**12.2**	18	15	33	**21.0**

T* - total number of children with specified symptom
%* - valid percent (adjusted to missing data)

Table B.4. "Respiratory Medical History, 1998-99

Respiratory Conditions	**Rural Area**				**Urban Area**				**Suburban Area**			
	Frequency				**Frequency**				**Frequency**			
	Male	**Female**	**Total**	**%***	**Male**	**Female**	Total	**%***	**Male**	**Female**	**Total**	**%***
Measles (not German)	3	7	10	**13.7**	3	4	7	**10**	4	3	7	**4.5**
Sinus Trouble	8	6	14	**19.2**	5	3	8	**11.8**	18	18	36	**22.6**
Bronchiolitis	1	0	1	**1.4**	0	1	1	**1.5**	5	2	9	**5.8**
Bronchitis	9	9	18	**24.7**	6	1	7	**10.1**	17	13	32	**20.4**
Asthmatic Bronchitis	2	2	4	**5.5**	3	4	7	**10.1**	4	3	7	**4.5**
Pneumonia	7	4	11	**15.7**	5	1	6	**8.7**	10	8	19	**12**
Whooping Cough	0	2	2	**2.7**	2	2	4	**5.7**	0	1	1	**0.6**
Croup	7	2	9	**12.3**	4	3	7	**10**	10	12	24	**15.1**
Cystic Fibrosis	0	0	0	**0**	0	0	0	**0**	0	1	1	**0.6**

%* - Valid percentage from total surveyed (adjusted for missing data)

Table B.5. General Medical History, 1998-99

Respiratory Conditions	**Rural Area**		**Urban Area**		**Suburban Area**		**Norms**
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**	**%**
Anxiety problems	4	**5.5**	3	**4.1**	9	**5.8**	**5.2**
Asthma	4	**5.5**	7	**9.5**	6	**3.8**	**11.9**
Attention problems	19	**26**	15	**20.3**	34	**21.8**	**19.4**
Behavioral problems	11	**15.1**	25	**33.8**	16	**10.3**	**15.2**
Chronic allergies or sinus problems	7	**9.6**	8	**10.8**	24	**15.8**	**17.6**
Chronic osteopathic, bone, or joint problems	1	**1.4**	2	**2.7**	1	**0.6**	**3.4**
Chronic respiratory, lung, or breathing trouble	2	**2.7**	3	**4.1**	1	**0.6**	**4.4**
Chronic rheumatic diseases	0	**0**	0	**0**	0	**0**	**.3**
Depression	3	**4.1**	4	**5.4**	8	**5.1**	**4.7**
Developmental delay or mental retardation	2	**2.7**	2	**2.7**	2	**1.3**	**2.8**
Diabetes	0	**0**	0	**0**	0	**0**	**0**
Epilepsy	0	**0**	1	**1.4**	1	**0.6**	**1.3**
Hearing impairment	1	**1.4**	1	**1.4**	4	**2.6**	**4.4**
Learning problems	5	**6.8**	13	**17.6**	17	**10.9**	**11.7**
Sleep disturbance	1	**1.4**	1	**1.4**	2	**1.3**	**2.3**
Speech problems	3	**4.1**	4	**5.4**	9	**5.8**	**12.2**
Vision problems	10	**13.7**	13	**17.6**	34	**21.9**	**19.5**
Any other physical condition that affects their well-being	2	**2.7**	2	**2.7**	8	**5.2**	**5.3**
Sub-total	72	**98.6**	73	**98.6**	154	**97.5**	**100.0**
Missing System	1	**1.4**	1	**1.4**	6	**2.5**	**0**
Total answered	73	**100%**	74	**100%**	160	**100%**	**389 or 100%**

Table B.6. Racial Background, 1998-99

Race	**Rural Area**		**Urban Area**		**Suburban Area**		**Norms**
	Frequencies	**%**	**Frequencies**	**%**	**Frequencies**	**%**	**%**
Caucasian	53	**72.6**	26	**35.1**	152	**95.0**	83.5
Afro-American	5	**6.8**	43	**58.1**	0	**0**	7.2
Hispanic	2	**2.7**	1	**1.4**	1	**.6**	6.9
Asian/Oriental	4	**5.5**	2	**2.7**	4	**2.5**	1.0
Other	9	**12.3**	1	**1.4**	2	**1.3**	1.8
Subtotal	**73**	**100%**	**73**	**98.6%**	**159**	**99.4**	**100.0**
Total	**73**	**100%**	**74**	**100%**	**160**	**100.0**	**100.0**

Table B.7. Parents Educational background, 1998-99

Education Level	**Rural Area**				**Urban Area**				**Suburban Area**			
	Male Parent		**Female parent**		**Male Parent**		**Female parent**		**Male Parent**		**Female parent**	
	Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
Some High School or Less	2	**2.7**	4	**5.6**	10	**20.8**	11	**16.9**	1	**.7**	0	**0**
High School Diploma or Some College	11	**15.1**	9	**12.3**	30	**62.5**	39	**60.0**	38	**27.1**	51	**33.3**
Trade or Vocational School	0	**0**	3	**4.2**	1	**2.1**	4	**6.2**	2	**1.4**	1	**.7**
Associate Degree	1	**1.4**	5	**6.8**	1	**2.1**	9	**13.8**	12	**8.6**	21	**13.8**
College Degree	18	**24.7**	22	**30.1**	6	**12.5**	2	**3.1**	56	**40**	61	**39.9**
Masters' Degree	6	**8.2**	12	**16.4**	0	**0**	0	**0**	13	**9.3**	5	**3.3**
Professional or Doctor's Degree	14	**19.2**	9	**12.7**	0	**0**	0	**0**	15	**10.7**	13	**8.5**

Table B.8. Living Environment, 1998-99

	Rural Area					**Urban Area**					**Suburban**				
Total surveyed	**73**					**74**					**160**				
Mean N of people in the home	**4.1**					**4.51**					**4.35** **6**				
Range of people in home	**6**					**7**									
Adults smoking regularly	**15.1%** male parent	**15.1%** female parent			**6.8%** other members	**34%** male parent	**33.3%** female parent			**21.7%** other members	**14.1%** male parent	**12.9%** female parent			**3.8%** other members
Share child's room with	**27.8%** 0 person	**62.5%** 1 person		**8.3%** 2 persons	**1.4%** 3 or more persons	**8.5%** 0 person	**66.2%** 1 person		**19.7%** 2 persons	**5.6 %** 3 or more persons	**17%** 0 person	**74.1%** 1 person		**8.2%** 2 persons	**0.7%** 3 or more persons
Fuel used for cooking	**0%** wood	**46.6 %** util. gas	**4.1%** tank gas	**49.3%** electricity	**0%** fuel oil, kerosene, & other	**0%** wood	**51.4%** util. gas	**1.4%** tank gas	**44.6%** electricity	**2.8%** fuel oil, kerosene, &other	**0.6%** wood	**28.9%** util. gas	**3.8%** tank gas	**65.4%** electricity	**1.2%** fuel oil, kerosene, & other
Air Conditioner, Humidifier, air filter	**20.8%** none	**38.9 %** air cond. or filter only	**9.7%** air cond., & humidifier	**11.1%** air cond. & filter	**19.4%** air cond, &humidifier, & filter	**15.1%** none	**52.1%** air cond. or filter only	**11%** air cond, &humidifier	**9.6%** air cond. & filter	**12.3%** air cond, &humidifier, & filter	**5.7 %** none	**24.7%** air cond. or humidifier only	**18.4%** air cond, &humidifier	**20.9%** air cond. & filter	**29.7%** air cond, &humidifier, & filter
Cat, dog, or bird	**37%** none`	**21.9 %** cat	**17.8%** dog	**1.4%** bird	**20.8%** cat & dog	**54.1%** none`	**6.8%** cat	**18.9%** dog	**1.4%** bird	**13.5%** cat & dog	**27.7%** none`	**18.2%** cat	**28.3%** dog	**2.5%** bird	**17.6%** cat&dog

Extended Questionnaire, 1998-1999 Sample Only

Participants in the 1998-1999 study completed an extensive survey that assessed emotional, physical and behavioral factors to more completely understand perception of health. The results to this extensive survey are found in Tables B.9 through B.24. The discussion below offers an explanation about the variables measured in this survey.

Role/social limitations due to emotional-behavioral problems (REB) variable exhibits the frequency of limitations in the amount of time a child could spend on schoolwork or activities with friends due to emotional or behavioral problems. The frequency range goes from "yes, limited a lot" to "no, not limited." Low score indicates that child is limited a lot in any kind of activities as a result of emotional problems. High score shows that child has no limitations to school or other activities as a result of emotional health.

Physical functioning (PF) variable presents a range of limitations in child's physical activities due to health. The range goes from "yes, limited a lot" to "no, not limited" and includes range of physical activities from those that require a lot of energy to the basic physical functions. Low score indicates that child considerably limited in performing all physical activities due to health problems. High score shows that child performs all types of physical activities, including the most dynamic, without limitations.

Role/social limitations due to physical health (RP) category gives the frequency of limitations in the kind of schoolwork or activities with friends due to problems with child's physical health. The frequency ranges goes from "yes, limited a lot" to "no, not limited." Low score indicates that child is limited a lot in any kind of activities as a result of physical health. High score shows that child has no limitations to school or other activities as a result of physical health.

Bodily pain and discomfort question (BP) is another indicator of physical health. This category provides information on frequency of bodily pain from "none of the time" to "every/almost every day". Low score indicates that child has extremely severe, frequent, and limiting bodily pain. High score shows that child has no pain at all.

Behavioral scale (BE) presents the picture of general behavior as the overt indicator of mental health. It gives frequency of such behavioral patterns as aggressiveness, impulsivity, and delinquency and ranges from "very often" to "never." In addition to the stated components, parents were asked to rank overall child's behavior against other children of the same age. Low score indicates that child often exhibits aggressive or impulsive behavior. High score shows that child never exhibits immature behavior.

Mental health (MH) measures frequency of negative state such as feeling lonely, acting nervously, and acting bothered/upset. The frequency goes from "all of the time" to "none of the time." Low score shows that child feels anxiety and depression most of the time. Contrary, high score means that child feels peaceful and calm all of the time.

Self-esteem (SE) gives the multi-dimensional picture of child self esteem concept that arises in adolescent age. This category captivates satisfaction with school and athletic ability, looks/apperiance, ability to go along with others and family, and life overall. The answers range from "very satisfied" to "very dissatisfied." Final low score for a sample assumes that

child is very dissatisfied with appearance, looks, relationships, and life overall. High score means that child is very satisfied with all mentioned categories.

General health perceptions (GH) category provides overall picture of children health. This category combines two questions. The first question is the parent's subjective assessment of child's overall health. Parents were also asked to respond on statements regarding their child's health and illness in the past, present, and future in continuum from "definitely true" to definitely false." Low score indicates parents' believes that their child's health is poor and likely to get worse. High score is excellent and will continue to be so.

Parental emotional impact (PE) captures the amount of emotional distress experienced by child's parent due to the following areas: child's physical health, emotional well-being, attention or learning abilities, his/her ability to go along with others, and general behavior. Low score indicates that parents experienced significant amount of stress due to the child's emotional or physical health.

Parental time impact (PT) shows the amount of limitations in personal time the parent experienced due to the following problems: child's physical health, emotional well-being, attention or learning abilities, his/her ability to go along with others, and general behavior. Degree of limitations has four point scale and goes from "yes, limited a lot" till "no, not limited."

Family limitations in activities (FA) question provides frequencies of disruption of regular family 's activities over last four weeks from "very often" to "never." Low score indicates that the child very often limits or interrupts family activities or even a cause of family conflict. High score shows that the child never limits family activities or causes family tension.

Family cohesion (FC) determines the family's ability to go along. Low score indicates that parent rates the family's capacity to get along as "poor." High score rates "go along" ability as "excellent."

National Population Sample of U.S. Children was represented by 398 children with the broad age range from 6 to 18 years old. The National Norms sample for 11-12 years old children was represented by only 83 children. Contrary, 73 children represented rural and urban sites and 160 children represented suburban sample for the given age group in this study. The National Norms for Population Sample of U.S. Children with Parents with Non-Caucasian Ethnicity were calculated based on the survey of 66 children. The sample in this study with the same characteristics was represented by 43 children. This statistics shows that the National Norms are based on lower numbers than some samples in this study and may be disputed.

Comparing boys and girls groups, the trend can be seen. The girls samples consistently had lower scores than boys in physical functioning (PF), role/social limitations due to physical health (RP), and bodily pain (BP) categories. Contrary, the boys were always rated lower in self esteem (SE), role/social limitations due to emotional or behavioral difficulties (REB), behavior scale (BE), and mental health (MH) categories.

In self esteem category (SE), the boys were continuously rated lower than the girls groups or the total, males and females, groups in all sites. The scores for this category were also below the National Norms for the U.S. Population, males and females group of 11-12 years old.

Emotional impact on parent (PE) was always below the score for the time impact on parent (PT) category. Despite the fact the emotional impact on parent (PE) was consistently underscored compared to the National Norms, the time impact in parent category (PT) was steadily above the score presented in the National Norms. The same relationships could be observed for the family activities (FA) and family cohesion (FC) categories.

Overall, parents tend to give higher score to the general health perception category, they also scored high the mental health category. At the same time, bodily discomfort (BP) in most cases, and behavior scale (BE) consistently were rated far below the National norms for different gender, age, and ethnicity.

Table B.9. Expanded Survey Results, Total (Males & Females) Rural Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	73	72	73	73	73	73	73	73	73	73	72	72
	Missing	0	1	0	0	0	0	0	0	0	0	1	1
Mean		90.41	88.19	90.41	81.64	73.33	79.79	82.65	81.75	79.97	92.01	85.07	77.71
Std. Deviation		20.40	22.99	20.40	16.25	17.44	14.89	18.67	17.51	18.72	13.35	18.00	18.95
Percentiles	25	100.00	88.89	100.00	80.00	65.00	66.67	75.00	68.13	62.50	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	77.50	83.33	91.67	87.50	87.50	100.00	87.50	85.00
	75	100.00	100.00	100.00	100.00	87.50	91.67	100.00	95.00	100.00	100.00	100.00	85.00

Table B.10. Expanded Survey Results, Boys Rural Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	31	31	31	31	31	31	31	31	31	31	31	31
	Missing	0	0	0	0	0	0	0	0	0	0	0	0
Mean		84.95	92.83	84.95	83.23	69.37	76.34	79.57	83.05	78.63	91.94	85.89	78.23
Std. Deviation		25.59	18.27	25.59	17.96	18.27	16.26	20.51	18.78	18.87	12.82	20.09	22.19
Percentiles	25	66.67	100.00	66.67	80.00	65.00	66.67	66.67	71.25	62.50	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	71.25	75.00	83.33	90.00	87.50	100.00	100.00	85.00
	75	100.00	100.00	100.00	100.00	83.75	91.67	100.00	100.00	87.50	100.00	100.00	85.00

Table B.11. Expanded Survey Results, Girls Rural Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	42	41	42	42	42	42	42	42	42	42	41	41
	Missing	0	1	0	0	0	0	0	0	0	0	1	1
Mean		94.44	84.69	94.44	80.48	76.25	82.34	84.92	80.79	80.95	92.06	84.45	77.32
Std. Deviation		14.57	25.66	14.57	14.97	16.41	13.42	17.09	16.67	18.77	13.89	16.48	16.36
Percentiles	25	100.00	77.78	100.00	80.00	63.44	75.00	75.00	65.00	62.50	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	81.25	83.33	91.67	85.63	87.50	100.00	87.50	85.00
	75	100.00	100.00	100.00	85.00	87.50	91.67	100.00	93.75	100.00	100.00	100.00	85.00

a male or female = female

Table B.12. Expanded Survey Results, Total (Males & Females) Urban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	74	74	74	74	74	72	73	73	73	73	73	73
	Missing	0	0	0	0	0	2	1	1	1	1	1	1
Mean		84.68	92.12	84.68	79.19	58.08	80.79	75.68	68.64	75.68	86.99	77.91	64.73
Std. Deviation		28.77	21.84	28.77	21.31	23.44	16.99	18.78	18.93	23.93	19.89	27.84	24.69
Range		100.00	100.00	100.00	100.00	92.50	58.33	75.00	73.75	100.00	100.00	100.00	100.00
Percentiles	25	66.67	100.00	66.67	60.00	45.00	66.67	58.33	52.50	62.50	83.33	62.50	60.00
	50	100.00	100.00	100.00	80.00	58.75	83.33	75.00	71.25	75.00	100.00	87.50	60.00
	75	100.00	100.00	100.00	100.00	77.50	100.00	91.67	85.62	100.00	100.00	100.00	85.00

Table B.13. Expanded Survey Results, Boys Urban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	32	32	32	32	32	30	31	31	31	31	31	31
	Missing	0	0	0	0	0	2	1	1	1	1	1	1
Mean		71.88	88.37	71.88	78.75	46.02	75.28	66.13	68.67	67.34	81.18	72.18	64.68
Std. Deviation		33.98	27.88	33.98	22.11	20.89	17.02	20.06	21.39	23.42	22.25	29.53	20.81
Range		100.00	100.00	100.00	80.00	70.00	58.33	75.00	73.75	75.00	100.00	100.00	70.00
Percentiles	25	41.67	100.00	41.67	60.00	33.13	64.58	50.00	56.25	50.00	66.67	50.00	60.00
	50	83.33	100.00	83.33	80.00	46.25	75.00	66.67	71.25	75.00	83.33	75.00	60.00
	75	100.00	100.00	100.00	100.00	63.44	91.67	75.00	90.00	87.50	100.00	100.00	85.00

Table B.14. Expanded Survey Results, Girls Urban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	**PF: Physical Functioning**	**RP: Role/social limitations due to physical health**	**BP: Bodily pain and discomfort**	**BE: Behavior Scale**	**MH: Mental Health**	**SE: Self-Esteem Scale**	**GH: General Health Perceptions**	**PE: Emotional Impact on Parent**	**PT: Time Impact on Parent**	**FA: Family Activities**	**FC: Family Cohesion**
N	Valid	42	42	42	42	42	42	42	42	42	42	42	42
	Missing	0	0	0	0	0	0	0	0	0	0	0	0
Mean		94.44	94.97	94.44	79.52	67.27	84.72	82.74	68.63	81.85	91.27	82.14	64.76
Std. Deviation		19.36	15.56	19.36	20.95	21.18	16.04	14.30	17.15	22.63	16.96	26.07	27.45
Range		100.00	77.78	100.00	100.00	92.50	58.33	50.00	66.25	100.00	66.67	100.00	100.00
Percentiles	25	100.00	100.00	100.00	60.00	52.50	75.00	75.00	52.50	75.00	83.33	71.88	30.00
	50	100.00	100.00	100.00	80.00	68.13	91.67	83.33	71.25	87.50	100.00	100.00	60.00
	75	100.00	100.00	100.00	100.00	83.75	100.00	91.67	81.88	100.00	100.00	100.00	85.00

Table B.15. Expanded Survey Results, Children with Non-Caucasian (Afro-American, Hispanic, and Asian) Background Urban Site

		REB: Role/social limitations due to emotional or behavioral difficulties	**PF: Physical Functioning**	**RP: Role/social limitations due to physical health**	**BP: Bodily pain and discomfort**	**BE: Behavior Scale**	**MH: Mental Health**	**SE: Self-Esteem Scale**	**GH: General Health Perceptions**	**PE: Emotional Impact on Parent**	**PT: Time Impact on Parent**	**FA: Family Activities**	**FC: Family Cohesion**
N	Valid	43	43	43	43	43	42	42	42	42	42	42	42
	Missing	0	0	0	0	0	1	1	1	1	1	1	1
Mean		80.62	94.19	80.62	81.40	58.14	81.55	78.37	67.17	77.08	84.13	75.60	65.00
Std. Deviation		31.90	19.81	31.90	19.71	26.47	19.00	19.74	17.84	22.92	23.27	29.98	25.16
Range		100.00	100.00	100.00	80.00	92.50	58.33	75.00	73.75	75.00	100.00	100.00	70.00
Percentiles	25	66.67	100.00	66.67	60.00	45.00	66.67	66.67	55.31	62.50	66.67	59.38	30.00
	50	100.00	100.00	100.00	80.00	65.00	83.33	83.33	65.00	81.25	100.00	87.50	60.00
	75	100.00	100.00	100.00	100.00	77.50	100.00	91.67	77.50	100.00	100.00	100.00	85.00

TableB.16. Expanded Survey Results, Children with Caucasian Background Urban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	26	26	26	26	26	25	26	26	26	26	26	26
	Missing	0	0	0	0	0	1	0	0	0	0	0	0
Mean		92.31	91.45	92.31	76.92	59.34	82.00	72.76	73.65	80.29	94.23	82.69	66.54
Std. Deviation		17.15	22.73	17.15	24.46	19.64	12.66	18.04	17.86	15.48	10.48	24.26	22.97
Range		66.67	100.00	66.67	100.00	92.50	41.67	58.33	60.00	62.50	33.33	100.00	70.00
Percentiles	25	100.00	100.00	100.00	60.00	52.50	70.83	58.33	57.19	75.00	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	58.54	83.33	75.00	73.13	81.25	100.00	93.75	60.00
	75	100.00	100.00	100.00	100.00	69.38	91.67	91.67	90.00	87.50	100.00	100.00	85.00

Table B.17. Expanded Survey Results, Total (Males &Females) Suburban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	158	158	158	158	159	158	159	160	159	160	160	160
	Missing	2	2	2	2	1	2	1	0	1	0	0	0
Mean		91.14	96.20	91.14	77.97	69.80	78.53	78.83	84.82	78.22	89.17	84.06	75.25
Std. Deviation		18.59	10.84	18.59	19.83	16.72	14.61	20.15	14.26	18.08	17.05	19.27	18.97
Range		100.00	66.67	100.00	100.00	80.00	75.00	100.00	86.25	75.00	66.67	75.00	100.00
Percentiles	25	100.00	100.00	100.00	80.00	58.75	66.67	66.67	75.00	62.50	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	71.25	83.33	83.33	87.08	75.00	100.00	87.50	85.00
	75	100.00	100.00	100.00	100.00	81.25	91.67	91.67	99.06	87.50	100.00	100.00	85.00

Table B.18. Expanded Survey Results, Boys Suburban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	76	76	76	77	77	75	76	77	76	77	77	77
	Missing	1	1	1	0	0	2	1	0	1	0	0	0
Mean		87.28	97.81	87.28	81.04	66.35	78.56	77.52	84.81	77.30	88.10	83.44	73.83
Std. Deviation		20.34	8.71	20.34	17.74	17.46	16.22	21.82	16.15	19.23	17.28	18.85	18.71
Range		66.67	55.56	66.67	80.00	68.75	75.00	100.00	86.25	75.00	66.67	62.50	70.00
Percentiles	25	66.67	100.00	66.67	80.00	52.50	66.67	66.67	77.50	62.50	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	65.00	83.33	83.33	87.50	75.00	100.00	87.50	85.00
	75	100.00	100.00	100.00	100.00	80.63	91.67	91.67	100.00	87.50	100.00	100.00	85.00

Table B.19. Expanded Survey Results, Girls Suburban Site Sample

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
N	Valid	82	82	82	81	82	83	83	83	83	83	83	83
	Missing	1	1	1	2	1	0	0	0	0	0	0	0
Mean		94.72	94.72	94.72	75.06	73.04	78.51	80.02	84.83	79.07	90.16	84.64	76.57
Std. Deviation		16.12	12.37	16.12	21.34	15.42	13.09	18.54	12.34	17.03	16.88	19.75	19.24
Range		100.00	66.67	100.00	100.00	80.00	50.00	83.33	47.50	75.00	66.67	75.00	100.00
Percentiles	25	100.00	100.00	100.00	70.00	65.00	75.00	75.00	75.00	75.00	83.33	75.00	60.00
	50	100.00	100.00	100.00	80.00	76.25	83.33	83.33	83.75	87.50	100.00	87.50	85.00
	75	100.00	100.00	100.00	80.00	83.75	83.33	91.67	96.25	87.50	100.00	100.00	85.00

Table B.20. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for the Ages 11-12, Population Sample of U.S. Children

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
Mean		91.40	94.40	92.80	84.10	69.30	78.50	79.50	73.60	83.70	90.20	91.40	67.20
Std. Deviation		17.10	15.90	19.50	17.00	18.70	15.30	19.90	18.60	14.40	18.00	18.10	21.10
Percentiles	25	83.30	100.00	100.00	80.00	58.80	66.70	75.00	58.80	75.00	83.30	87.50	50.00
	50	100.00	100.00	100.00	80.00	71.30	83.30	83.30	75.00	87.50	100.00	100.00	60.00
	75	100.00	100.00	100.00	100.00	83.40	91.70	91.70	93.80	93.80	100.00	100.00	85.00

N=83

Table B.21. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for the Boys, Population Sample of U.S. Children

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
Mean		90.70	93.50	92.50	82.30	68.90	81.330	78.50	72.00	80.40	86.50	90.00	73.40
Std. Deviation		22.00	10.50	22.60	19.90	18.40	15.60	19.70	20.80	19.20	22.30	21.00	21.20
Percentiles	25	100.00	100.00	100.00	60.00	58.80	75.00	75.00	58.80	87.50	83.30	87.50	60.00
	50	100.00	100.00	100.00	80.00	71.30	83.30	83.30	75.00	90.30	100.00	100.00	85.00
	75	100.00	100.00	100.00	100.00	81.30	91.70	91.70	87.50	93.80	100.00	100.00	85.00

N=212

Table B.22. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for the Girls, Population Sample of U.S. Children

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
Mean		94.60	97.10	95.30	80.10	73.20	77.60	81.70	76.50	82.40	91.20	92.80	71.00
Std. Deviation		14.60	9.70	15.40	19.60	19.00	15.20	18.20	18.20	17.40	17.70	15.50	22.20
Percentiles	25	100.00	100.00	100.00	60.00	65.00	66.70	75.00	62.50	75.00	83.30	87.50	60.00
	50	100.00	100.00	100.00	80.00	77.50	75.00	83.30	77.50	87.50	100.00	100.00	85.00
	75	100.00	100.00	100.00	100.00	87.50	91.70	100.00	93.80	100.00	100.00	100.00	85.00

N=177

Table B.23. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for Children by Parents Ethnicity (Non-Caucasian), Population Sample of U.S. Children

		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
Mean		85.60	91.10	88.90	80.00	69.10	78.40	80.20	67.30	80.00	80.60	84.10	71.10
Std. Deviation		26.50	23.50	26.40	23.00	19.50	17.50	20.00	22.20	22.30	29.00	27.60	21.80
Percentiles	25	83.30	100.00	100.00	60.00	57.50	66.70	75.00	52.50	73.40	66.70	75.00	60.00
	50	100.00	100.00	100.00	80.00	71.30	83.30	83.30	65.00	87.50	100.00	100.00	85.00
	75	100.00	100.00	100.00	100.00	83.80	91.70	97.90	83.80	100.00	100.00	100.00	85.00

N=66

Table B.24. Expanded Survey Results, Child Health Questionnaire-P28 National Norms for Children by Parents Ethnicity (Caucasian) Population Sample of U.S. Children

.		REB: Role/social limitations due to emotional or behavioral difficulties	PF: Physical Functioning	RP: Role/social limitations due to physical health	BP: Bodily pain and discomfort	BE: Behavior Scale	MH: Mental Health	SE: Self-Esteem Scale	GH: General Health Perceptions	PE: Emotional Impact on Parent	PT: Time Impact on Parent	FA: Family Activities	FC: Family Cohesion
Mean		93.80	95.80	94.70	81.60	71.10	79.90	80.10	75.40	81.60	90.00	92.60	72.60
Std. Deviation		16.90	14.20	17.90	19.00	18.60	15.10	19.00	19.00	17.50	18.50	16.30	21.60
Percentiles	25	100.00	100.00	100.00	80.00	58.80	75.00	75.00	65.00	75.00	83.30	87.50	60.00
	50	100.00	100.00	100.00	80.00	75.00	83.30	83.30	77.50	87.50	100.00	100.00	85.00
	75	100.00	100.00	100.00	100.00	83.80	91.70	91.70	90.00	100.00	100.00	100.00	85.00

N=324

Table B.25. General Children Health, 1999-2000

Gender and Health Status	Rural Area				Urban Area				Suburban Area			
	Frequency			% from total*	Frequency			% from total	Frequency			% from total
Male	7			**41.2**	9			**39.1**	22			**55.0**
Female	10			**58.8**	14			**60.9**	18			**45.0**
	Male	**Female**	**Total**	**% from total**	**Male**	**Female**	**Total**	**% from total**	**Male**	**Female**	**Total**	**% from total**
Excellent	4	6	9	**58.8**	0	4	4	**17.4**	11	8	19	**47.5**
Very good	3	3	6	**35.3**	5	6	11	**47.8**	8	8	16	**40.0**
Good	0	1	1	**5.9**	4	3	7	**30.4**	2	2	4	**10.0**
Fair	0	0	0	**0**	0	1	1	**4.3**	1	0	1	**2.5**
Sub-total	7	10	17	**100.0**	9	14	23	**100.0**	22	18	40	**97.6**
Missing System			0	**0**			0	**0**			1	**2.4**
Total	17			**100.0**	23			**100.0**	41			**100.0**

%* - Valid percent (adjusted for missing data)

Table B.26. Current Pulmonary Status, 1999-2000

Respiratory Conditions	Rural Area				Urban Area				Suburban Area			
	Frequency			%*	Frequency			%*	Frequency			%
	Male	**Female**	**Total***		**Male**	**Female**	**Total**		**Male**	**Female**	**Total***	
Chronic cough	0	0	0	**0**	3	3	6	**26.1**	1	2	3	**7.3**
Wheezing	0	0	1	**5.9**	4	5	9	**39.1**	4	7	11	**26.8**
Chest illnesses	0	1	1	**5.9**	1	3	4	**17.4**	2	3	5	**12.5**
Asthma	0	0	0	**0**	4	6	10	**43.5**	3	5	8	**20.0**
Allergy	1	1	2	**11.8**	4	5	9	**40.9**	7	3	10	**25.0**

T* - total number of children with specified symptom
%* - valid percent (adjusted to missing data)

Table B.27. Respiratory Medical History, 1999-2000

Respiratory Conditions	Rural Area				Urban Area				Suburban Area			
	Frequency			%*	Frequency			%*	Frequency			%*
	Male	Female	Total		Male	Female	Total		Male	Female	Total	
Measles (not German)	0	2	2	**11.8**	1	3	4	**17.4**	0	0	0	**0**
Sinus Trouble	0	3	3	**17.6**	1	2	3	**13**	4	6	10	**25.0**
Bronchiolitis	1	0	1	**5.9**	0	1	1	**4.3**	1	4	5	**12.5**
Bronchitis	3	2	5	**29.4**	2	2	4	**17.4**	4	3	7	**17.5**
Asthmatic Bronchitis	0	0	0	**0**	3	4	7	**30.4**	1	2	3	**7.5**
Pneumonia	2	0	2	**11.8**	0	1	1	**4.3**	5	4	9	**22.5**
Whooping Cough	0	1	1	**5.9**	0	0	0	**0**	0	0	0	**0**
Croup	1	0	1	**5.9**	1	0	1	**4.3**	4	4	8	**20.0**
Cystic Fibrosis	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**

Table B.28. Living Environment, 1999-2000

Living Conditions	Rural Area		Urban Area		Suburban Area	
	Frequency	%	Frequency	%	Frequency	%
Pets home	10	**58.8**	7	**30.4**	23	**57.5**
Home air conditioning	14	**82.4**	17	**73.9**	38	**90.5**
Home smoking environment	5	**29.4**	14	**60.9**	7	**17.5**

Appendix C
Correlation Tables
Prospective Analysis

Table C.1. Correlation Matrix (and Significance Levels) for the Meteorological Variables

	1	2	3	4	5
			Athens		
1. Average wind speed		-.034	.099	-.390	-.141
		(.406)	(.015)	(.000)	(.001)
2. Average relative humidity			.320	-.334	-.010
			(.000)	(.000)	(.807)
3. Precipitation				-.278	.056
				(.000)	(.171)
4. Barometric Pressure					-.222
					(.000)
5. Average Daily Temperature					
			Koebel		
1. Average wind speed		-.047	.073	-.626	-.208
		(.246)	(.074)	(.000)	(.000)
2. Average relative humidity			.396	-.023	-.199
			(.000)	(.569)	(.000)
3. Precipitation				-.076	.013
				(.063)	(.755)
4. Barometric Pressure					-.117
					(.004)
5. Average Daily Temperature					
			New Albany		
1. Average wind speed		-.008	.099	-.532	-.130
		(.840)	(.015)	(.000)	(.001)
2. Average relative humidity			.393	-.032	-.121
			(.000)	(.437)	(.003)
3. Precipitation				-.119	.006
				(.003)	(.885)
4. Barometric Pressure					-.314
					(.000)
5. Average Daily Temperature					

Table C.2. Correlation Matrix (and Significance Levels) for the Air Quality Variables

	1	2	3	4	5
		Athens			
1. $PM_{2.5}$ Personal		.682	-.069	.024	.123
		(.000)	(.424)	(.764)	(.141)
2. $PM_{2.5}$ Indoor			-.075	-.150	.126
			(.269)	(.030)	(.058)
3. SO_4 - Indoor				.614	.350
				(.000)	(.000)
4. SO_4 - Ambient					.203
					(.005)
5. $PM_{2.5}$ Ambient					
		Koebel			
1. $PM_{2.5}$ Personal		.556	.114	.118	.440
		(.000)	(.211)	(.225)	(.000)
2. $PM_{2.5}$ Indoor			-.098	.082	.289
			(.196)	(.314)	(.000)
3. SO_4 - Indoor				.247	.179
				(.005)	(.026)
4. SO_4 - Ambient					.340
					(.000)
5. $PM_{2.5}$ Ambient					
		New Albany			
1. $PM_{2.5}$ Personal		.303	.043	.107	.171
		(.000)	(.633)	(.239)	(.023)
2. $PM_{2.5}$ Indoor			.094	-.002	.217
			(.179)	(.981)	(.001)
3. SO_4 - Indoor				.304	.478
				(.000)	(.000)
4. SO_4 - Ambient					.492
					(.000)
5. $PM_{2.5}$ Ambient					

Table C.3. Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables

	Average Wind Speed	Average Relative Humidity	Precipitation	Barometric Pressure	Average Daily Temperature
			Athens		
$PM_{2.5}$ Personal	.156	-.200	.073	-.063	.313
	(.025)	(.004)	(.294)	(.368)	(.000)
$PM_{2.5}$ Indoor	.049	-.111	.108	-.109	.234
	(.397)	(.055)	(.062)	(.060)	(.000)
SO_4 –	-.130	.081	.046	-.088	.390
Indoor	(.056)	(.233)	(.500)	(.195)	(.000)
SO_4 –	-.016	-.030	-.002	-.066	.294
Ambient	(.802)	(.644)	(.980)	(.307)	(.000)
$PM_{2.5}$ Ambient	-.201	.086	-.015	.014	.504
	(.000)	(.073)	(.755)	(.767)	(.000)
			Koebel		
$PM_{2.5}$ Personal	-.076	-.126	-.024	.125	.304
	(.289)	(.081)	(.736)	(.083)	(.000)
$PM_{2.5}$ Indoor	-.213	-.159	.039	.247	.338
	(.001)	(.012)	(.537)	(.000)	(.000)
SO_4 –	-.130	-.092	.088	-.300	.228
Indoor	(.074)	(.206)	(.226)	(.000)	(.001)
SO_4 –	-.108	.025	-.013	-.028	.358
Ambient	(.130)	(.722)	(.859)	(.694)	(.000)
$PM_{2.5}$ Ambient	-.245	-.087	.028	-.039	.536
	(.000)	(.053)	(.542)	(.391)	(.000)
			New Albany		
$PM_{2.5}$ Personal	-.155	-.068	.071	.222	.262
	(.026)	(.335)	(.309)	(.001)	(.000)
$PM_{2.5}$ Indoor	.021	-.122	-.033	.120	.124
	(.731)	(.045)	(.594)	(.050)	(.042)
SO_4 –	.029	.047	-.029	-.252	.308
Indoor	(.682)	(.503)	(.682)	(.000)	(.000)
SO_4 –	-.123	.230	-.085	.065	.407
Ambient	(.068)	(.001)	(.205)	(.334)	(.000)
$PM_{2.5}$ Ambient	-.174	-.027	-.010	-.112	.528
	(.000)	(.525)	(.811)	(.009)	(.000)

Table C.4.a Correlation Matrix (and Significance Levels) for Daily Respiratory Measures at Athens

	1	2	3	4	5	6	7	8
1. Mean Peak Flow – 1999		.656 (.000)	-.027 (.803)			-.251 (.019)	-.054 (.621)	-.084 (.440)
2. Mean Peak Flow – 1999 (Ill)			.018 (.872)			.049 (.662)	-.041 (.713)	-.030 (.787)
3. Number Attending – 1999 (Ill)						.019 (.861)	.090 (.407)	-.118 (.275)
4. Mean Peak Flow – 2000					.047 (.608)	.046 (.613)	-.081 (.376)	.031 (.736)
5. Proportion Absent – 2000						-.070 (.368)	-.140 (.072	.093 (.231)
6. Total - Respiratory Illness							.368 (.000)	.189 (.000)
7. Children – Asthma								.002 (.966)
8. Elderly – COPD								

Table C.4.b. Correlation Matrix (and Significance Levels) for Daily Respiratory Measures at Koebel

	1	2	3	4	5	6	7	8
1. Mean Peak Flow – 1999						-.336 (.001)	-.154 (.147)	.060 (.577)
2. Mean Peak Flow – 2000			.759 (.000)	-.223 (.007)	-.199 (.032)	-.155 (.062)	-.157 (.059)	-.003 (.967)
3. Mean Peak Flow – 2000 (I11)				-.149 (.075)	-.201 (.031)	-.192 (.021)	-.049 (.558)	-.187 (.024)
4. Number Attending – 2000 (I11)					-.347 (.000)	.223 (.006)	.089 (.282)	-.059 (.474)
5. Proportion Absent – 2000						.113 (.188)	-.152 (.075)	.154 (.072)
6. Total - Respiratory Illness							.238 (.000)	.284 (.000)
7. Children – Asthma								-.087 (.042)
8. Elderly – COPD								

Table C.4.c. Correlation Matrix (and Significance Levels) for Daily Respiratory Measures at New Albany

	1	2	3	4	5	6	7	8	9	10
1. Mean Peak Flow – 1999		.231 (.025)	.145 (.162)					-.143 (.166)	.110 (.287)	-.001 (.992)
2. Mean Peak Flow – 1999(Ill)			-.235 (.022)					.273 (.007)	.102 (.327)	.042 (.688)
3. Number Attending - 1999(Ill)								-.218 (.034)	-.170 (.100)	.031 (.768)
4. Mean Peak Flow – 2000					.597 (.000)	.250 (.001)	.062 (.425)	-.017 (.831)	.006 (.935)	.132 (.088)
5. Mean Peak Flow – 2000 (Ill)						.038 (.622)	-.061 (.436)	-.100 (.197)	.078 (.315)	-.008 (.920)
6. Number Attending – 2000(Ill)							.150 (.052)	.116 (.136)	-.065 (.404)	.146 (.059)
7. Proportion Absent – 2000								.347 (.000)	-.066 (.384)	.175 (.021)

Table C.5.a. Regression Coefficients (and Significance Levels) for the Relationships between Daily Respiratory Measures with the Air Quality Variables after Adjusting for Seasonality and Meteorological Variables at Athens

	$PM_{2.5}$ Personal	$PM_{2.5}$ Indoor	SO_4 – Indoor	SO_4 – Ambient	$PM_{2.5}$ Ambient
Mean Peak Flow – 1999					Lag 1 .001 (.086)
Mean Peak Flow – 1999 (Ill)			Lag 0 .005 (.029)	Lag 0 .004 (.094)	
Number Attending – 1999 (Ill)					
Mean Peak Flow – 2000					
Proportion Absent – 2000					
Total - Respiratory Illness				Lag 0 .108 (.017)	
Children – Asthma					Lag 1 .050 (.005)
Elderly – COPD					Lag 1 -.046 (.020)

Table C.5.b. Regression Coefficients (and Significance Levels) for the Relationships between Daily Respiratory Measures with the Air Quality Variables after Adjusting for Seasonality and Meteorological Variables at Koebel

	$PM_{2.5}$ Personal	$PM_{2.5}$ Indoor	SO_4 – Indoor	SO_4 – Ambient	$PM_{2.5}$ Ambient
Mean Peak Flow – 1999					
Mean Peak Flow – 2000					
Mean Peak Flow – 2000 (Ill)					Lag 0 -.001 (.062)
Number Attending – 2000 (Ill)		Lag 1 -.056 (.030)			
Proportion Absent – 2000					
Total - Respiratory Illness					
Children – Asthma					Lag 0 -.018 (.021)
Elderly – COPD					

Table C.5.c. Regression Coefficients (and Significance Levels) for the Relationships between Daily Respiratory Measures with the Air Quality Variables after Adjusting for Seasonality and Meteorological Variables at New Albany

	$PM_{2.5}$ Personal	$PM_{2.5}$ Indoor	SO_4 – Indoor	SO_4 – Ambient	$PM_{2.5}$ Ambient
Mean Peak Flow – 1999					Lag 0 -.001 (.059)
Mean Peak Flow – 1999 (Ill)					Lag 0 -.002 (.057)
Number Attending – 1999 (Ill)		Lag 1 -.026 (.006)	Lag 0 -.140 (.009) Lag 1 -.108 (.080)		Lag 0 -.047 (.017)
Mean Peak Flow – 2000					
Mean Peak Flow – 2000 (Ill)				Lag 0 -.004 (.062)	
Number Attending – 2000 (Ill)					
Proportion Absent – 2000	Lag 0 -.000 (.070)				
Total - Respiratory Illness					
Children – Asthma					
Elderly – COPD					

Appendix D
Retrospective Data

TABLES

D.1. Annual maximum one-hour average ozone, 1992-2000
D.2. Annual maximum eight-hour average ozone, 1992-2000
D.3. Number of annual exceedance days for one-hour ozone, 1992-2000
D.4. Number of annual exceedance days for eight-hour ozone, 1992–2000
D5. Regression equations for correlation analysis of one-hour vs. eight-hour
D6. Climatological equivalency (S: Standard, E: Equivalency calculated with standard)
D7. Regression Equation for Correlation Analysis between 1hr CO and 8hr CO
D8. Climatological equivalency (S: Standard, E: Equivalency calculated with standard)
D9. Regional analysis of ozone exceeding days for Cincinnati, Dayton, Toledo, Columbus (Maple Canyon), Cleveland, Akron, Marietta and Columbus (Chesapeake): 1992-2000 in ppb
D10. High Concentration and High Frequency in Correlation With Wind Direction.

FIGURES

D1. High ozone days exceeding 1-hour threshold level, 1992-2000
D2 (a&b). 24-hour averaged PM_{10} levels: (a) Cincinnati urban site, 1992-1999 (b) Maple Canyon suburban site
D2 (c&d). 24-hour averaged PM_{10} levels 1992-2000: (c) Columbus (Chesapeake) suburban site, (d) Cleveland suburban
D2 (e). 24-hour averaged PM_{10} levels in 1992-2000: (e) Steubenville urban Site
D3. 2nd Highest 1hr Averaged CO in 1992-20
D4-1 (a & b). Hourly CO distribution: (a) Cincinnati and (b) Dayton
D4-1 (c & d). Hourly CO distribution: (c) Columbus (Chesapeake) and (d) Columbus (Maple Canyon)
D4-1 (e & F). Hourly CO distribution: (e) Akron and (f) Cleveland
D4-2 (a & b). Hourly SO_2 distribution: (a) Cincinnati and (b) Dayton
D4-2 (c & d). Hourly SO_2 distribution in: (c) Chesapeake and (d) Cleveland
D4-2 (e & f). Hourly SO_2 distribution: (e) Akron and (f) Steubenville
D4-3 (a & b). Hourly NO_2 distribution: (a) Cincinnati and (b) Cleveland
D4-3 (c). Hourly NO_2 distribution: (c) Steubenville
D5-1 (a&b). Correlation between CO and Ozone Concentration in 1992-2000: (a) Cincinnati and (b) Dayton
D5-1 (c&d). Correlation between CO and Ozone Concentration: (c) Columbus (Chesapeake), 1992-2000 and (d) Columbus (Maple Canyon), 1993-2000
D5-2 (a&b). Correlation between SO_2 and Ozone Concentration in 1992-2000: (a) Cincinnati and (b) Dayton
D6-1. Spatial Coordination plots of PM_{10}, 1992-2000

D6-2. Spatial Coordination plots of CO, 1992-2000
D6-3. . Spatial Coordination plots of SO_2 , 1992-2000
D6-3. Spatial Coordination plots of SO_2, 1992-2000
D6-4. Spatial Coordination plots of NO_2, 1992-2000
D7 (a & b). KZ Filter of ozone levels in (a) Cincinnati and (b) Dayton, 1992-2000
D7 (c & d). KZ Filter of ozone levels in (c) Columbus (Maple Canyon) and (d) Columbus (Chesapeake), 1992-2000
D7 (e & f). KZ Filter of ozone levels in (e) Akron and (f) Cleveland, 1992-2000
D7 (g & h). KZ Filter of ozone levels in (g) Marietta and (h) Toledo, 1992-2000
D7 (i). KZ Filter of ozone levels in (i) Steubenville, 1992-2000
D8 (a & b). KZ Filter of PM_{10} levels in (a) Cincinnati, 1992-1999 and (b) Maple Canyon, 1992-2000
D8 (c & d). KZ Filter of PM_{10} levels in (c) Columbus (Chesapeake) and (d) Cleveland, 1992-2000
D8 (e). KZ Filter of PM_{10} levels in (e) Steubenville, 1992-2000
D9 (a & b). KZ Filter of CO levels in (a) Cincinnati and (b) Dayton, 1992-2000
D9 (c & d). KZ Filter of CO levels in (c) Columbus (Chesapeake) and (d) Columbus (Maple Canyon), 1993-2000
D9 (e & f). KZ Filter of CO levels in (e) Akron and (f) Cleveland, 1992-2000
D10 (a & b). KZ Filter of SO_2 levels in (a) Cincinnati and (b) Dayton, 1992-2000
D10 (c & d) KZ Filter of SO_2 levels in (c) Columbus (Chesapeake) and (d) Cleveland, 1992-2000
D10 (e & f) KZ Filter of SO_2 levels in (e) Akron and (f) Steubenville, 1992-2000
D11 (a & b) KZ Filter of NO_2 levels in (a) Cincinnati, 1992-2000 and (b) Cleveland, 1992-1999
D11 (c) KZ Filter of NO_2 at (c) Steubenville, 1992-1997
D12. Co-relational plots of maximum eight-hour vs. one-hour ozone concentrations at the six monitoring site, 1992-2000
D13. Co-relational plots of maximum eight-hour vs. one-hour ozone concentrations at the six monitoring site, 1992-2000
D14. Correlation between 1 Hour and 8 Hour CO1992-2000: (a) Cincinnati, (b) Dayton, (c) Columbus (Chesapeake), (d) Columbus (Maple Canyon), (e) Akron and (f) Cleveland
D15 (a & b). Correlations between PM_{10} and weather components at Columbus (Maple Canyon), Ohio in 1992-2000: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction
D15 (c). Correlations between PM_{10} and weather components at Columbus (Maple Canyon), Ohio in 1992-1999: (c) PM_{10} vs. temperature
D16 (a & b). Correlations between PM_{10} and weather components at Columbus (Chesapeake), Ohio in 1992-1999: (a) PM_{10} vs. wind speed and : (b) PM_{10} and wind direction.
D16 (c). Correlations between PM_{10} and weather components at Columbus (Chesapeake), Ohio in 1992-2000 and (c) PM_{10} vs. temperature
D17 (a & b). Correlations between PM_{10} and weather components at Cleveland, Ohio in 1992-2000: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction
D17 (c). Correlations between PM_{10} and weather components at Cleveland, Ohio in 1992-2000: (c) PM_{10} vs. temperature.

D18 (a & b). Correlations between PM_{10} and weather components at Steubenville, Ohio in 1992-2000: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction

D18 (c). Correlations between PM_{10} and weather components at Steubenville, Ohio in 1992-2000: and (c) PM_{10} vs temperature.

D19. Correlations between CO and weather components at Cincinnati, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

D20. Correlations between CO and weather components at Dayton, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

D21. Correlations between CO and weather components at Columbus (Chesapeake), Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

D22. Correlations between CO and weather components at Columbus (Maple Canyon), Ohio in 1993-2000 (a) CO vs. wind speed and (b) CO vs. wind direction

D23. Correlations between CO and weather components at Akron, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

D24. Correlations between CO and weather components at Cleveland, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

D25. Correlations between SO_2 and weather components at Cincinnati, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

D26. Correlations between SO_2 and weather components at Dayton, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

D27. Correlations between SO_2 and weather components at Columbus (Chesapeake), Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

D28. Correlations between SO_2 and weather components at Cleveland, Ohio in 1992-2000 (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

D29. Correlations between SO_2 and weather components at Akron, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

D30. Correlations between SO_2 and weather components at Steubenville, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

D31. orrelations between NO_2 and weather components at Cincinnati, Ohio in 1995-2000: (a) NO_2 vs. wind speed and (b) NO_2 vs. wind direction

D32. orrelations between NO_2 and weather components at Dayton, Ohio in 1992-1999: (a) NO_2 vs. wind speed and (b) NO_2 vs. wind direction

D33. orrelations between NO_2 and weather components at Steubenville, Ohio in 1992-1997: (a) NO_2 vs. wind speed and (b) NO_2 vs. wind direction

D34 (a & b). Back trajectories for high CO days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati and (b) Dayton

D34 (c & d). Back trajectories for high CO days at the monitoring sites selected in Ohio: (c) Columbus (Chesapeake), 1992-2000 and (d) Columbus (Maple Canyon), 1993-2000

D34 (e & f). Back trajectories for high CO days at the monitoring sites selected in Ohio, 1992-2000: (e) Akron and (f) Cleveland

D35. (a) Cluster plot at Cincinnati, 1992-2000 (b) Frequencies and average CO concentrations by cluster at Cincinnati, 1992-2000

D36. (a) Cluster plot at Dayton, 1992-2000 (b) Frequencies and average CO concentrations by cluster at Dayton, 1992-2000

D37. (a) Cluster plot at Columbus (Chesapeake), 1992-2000 (b) Frequencies and average CO concentrations by cluster at Columbus (Chesapeake), 1992-2000

D38. (a) Cluster plot at Columbus (Maple Canyon), 1993-2000 (b) Frequencies and average CO concentrations by cluster at Columbus (Maple Canyon), 1993-2000

D39. (a) Cluster plot at Akron 1992-2000 (b) Frequencies and average CO concentrations by cluster at Akron, 1992-2000

D40. (a) Cluster plot at Cleveland, 1992-2000 (b) Frequencies and average CO concentrations by cluster at Cleveland, 1992-2000

D41 (a & b). Back trajectories for high SO_2 days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati and (b) Dayton

D41 (c & d). Back trajectories for high SO_2 days at the monitoring sites selected in Ohio, 1992-2000: (c) Columbus (Chesapeake) and (d) Cleveland.

D41 (e & f). Back trajectories for high SO_2 days at the monitoring sites selected in Ohio, 1992-2000: (e) Akron and (f) Steubenville

D42. (a) Cluster plot at Cincinnati, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Cincinnati, 1992-2000

D43. (a) Cluster plot at Dayton, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Dayton, 1992-2000

D44. (a) Cluster plot at Columbus (Chesapeake), 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Columbus (Chesapeake), 1992-2000

D45. (a) Cluster plot at Cleveland, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Cleveland, 1992-2000

D46. (a) Cluster plot at Akron 1992-2000 (b) Frequencies and average SO2 concentrations by cluster at Akron, 1992-2000

D47. (a) Cluster plot at Steubenville, 1992-2000 (b) Frequencies and average SO2 concentrations by cluster at Steubenville, 1992-2000

D48. Back trajectories for high NO_2 days at the monitoring sites selected in Ohio: Cleveland, 1992-1999

D49. Back trajectories for high NO_2 days at the monitoring sites selected in Ohio: Steubenville, 1992-1997

D50. (a) Cluster plot at Cincinnati, 1995-2000 (b) Frequencies and average NO_2 concentrations by cluster at Cincinnati, 1995-2000

D51. a) Cluster plot at Cleveland, 1995-2000 (b) Frequencies and average NO_2 concentrations by cluster at Cleveland, 1995-2000

D52. (a) Cluster plot at Steubenville, 1992-1997 (b) Frequencies and average NO_2 concentrations by cluster at Steubenville, 1992-1997

Table D.1. Annual maximum one-hour average ozone, 1992-2000

	Cincinnati	Dayton	Columbus (Maple Canyon)	Columbus (Chesapeake	Akron	Cleveland	Marietta	Toledo	Steubenville
1992	87	99	89	**130**	117	109	105	96	113
1993	110	**125**	108	109	110	**126**	**137**	**131**	110
1994	109	118	98	106	110	**127**	**126**	113	**153**
1995	**128**	115	104	**130**	124	113	112	**130**	118
1996	115	117	98	118	113	110	113	108	100
1997	117	**130**	98	101	112	97	110	118	106
1998	115	116	122	113	**128**	112	**125**	116	93
1999	104	**128**	118	123	115	99	**125**	122	113
2000	109	112	111	-	110	94	113	97	103

Table D.2. Annual maximum eight-hour average ozone, 1992-2000

	Cincinnati	Dayton	Columbus (Maple Canyon)	Columbus (Chesapeake)	Akron	Cleveland	Marietta	Toledo	Steubenville
1992	78	83	79	**114**	**99**	87	**116**	**88**	**87**
1993	**88**	**99**	**94**	**95**	**100**	**103**	**108**	**101**	**101**
1994	**87**	**106**	**88**	**94**	**88**	**104**	**106**	**93**	**136**
1995	**115**	**104**	**96**	**108**	**99**	**91**	**99**	**115**	**102**
1996	**101**	**113**	**91**	**114**	**99**	**103**	**100**	**97**	**92**
1997	**98**	**106**	**90**	**97**	**99**	81	**97**	**95**	**94**
1998	**97**	**97**	**112**	**104**	**114**	**100**	**106**	**101**	83
1999	**95**	**113**	**107**	**110**	**95**	**92**	**118**	**101**	**102**
2000	**98**	**102**	**97**		**100**	**89**	**98**	**88**	**96**

Table D.3. Number of annual exceedance days for one-hour ozone, 1992-2000

	Cincinnati	Dayton	Columbus (Maple Canyon)	Columbus (Chesapeake)	Akron	Cleveland	Marietta	Toledo	Steubenville
1992	0	0	0	0	0	0	2	0	0
1993	0	1	0	0	0	1	1	1	0
1994	0	0	0	0	0	2	1	0	1
1995	1	0	0	1	0	0	0	1	0
1996	0	0	0	0	0	0	0	0	0
1997	0	1	0	0	0	0	0	0	0
1998	0	0	0	0	1	0	1	0	0
1999	0	2	0	0	0	0	1	0	0
2000	0	0	0		0	0	0	0	0

Table D.4. Number of annual exceedance days for eight-hour ozone, 1992–2000

	Cincinnati	Dayton	Columbus (Maple Canyon)	Columbus (Chesapeake)	Akron	Cleveland	Marietta	Toledo	Steubenville
1992	0	0	0	0	5	1	4	1	1
1993	2	**10**	6	5	**10**	7	**18**	3	1
1994	1	9	1	6	5	2	**13**	5	3
1995	4	7	7	5	**10**	3	9	7	**11**
1996	5	**14**	4	**10**	9	4	4	8	2
1997	4	4	3	4	5	0	3	5	1
1998	6	8	**12**	**14**	**14**	1	**12**	6	0
1999	7	**11**	11	**13**	**12**	1	**12**	3	6
2000	4	3	1		3	1	3	1	3

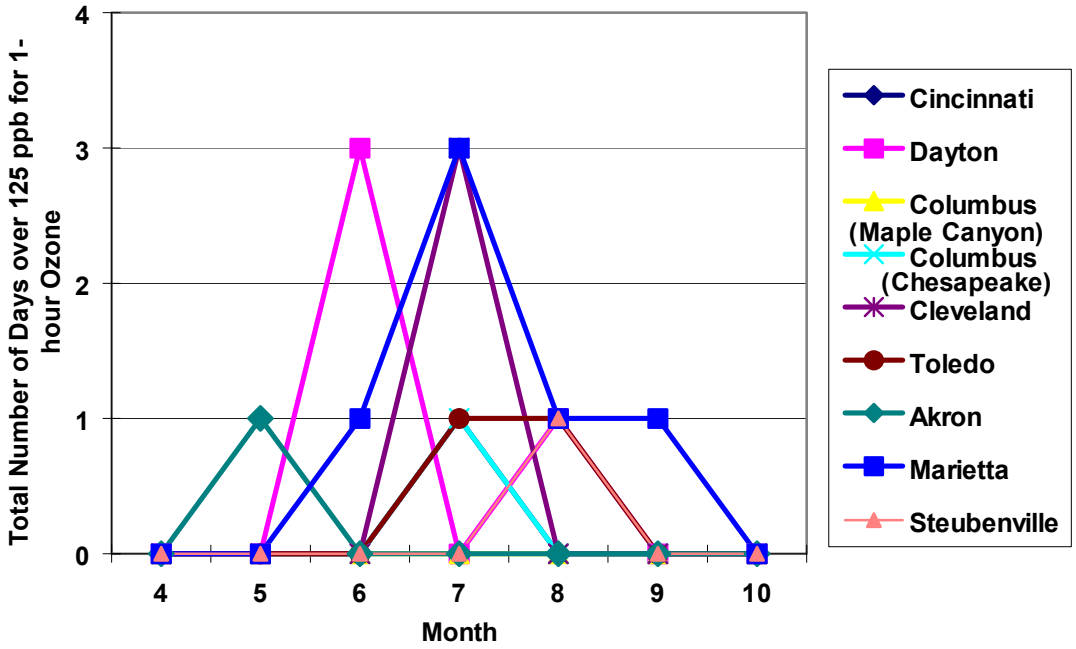


Figure D.1. High ozone days exceeding 1-hour threshold level, 1992-2000

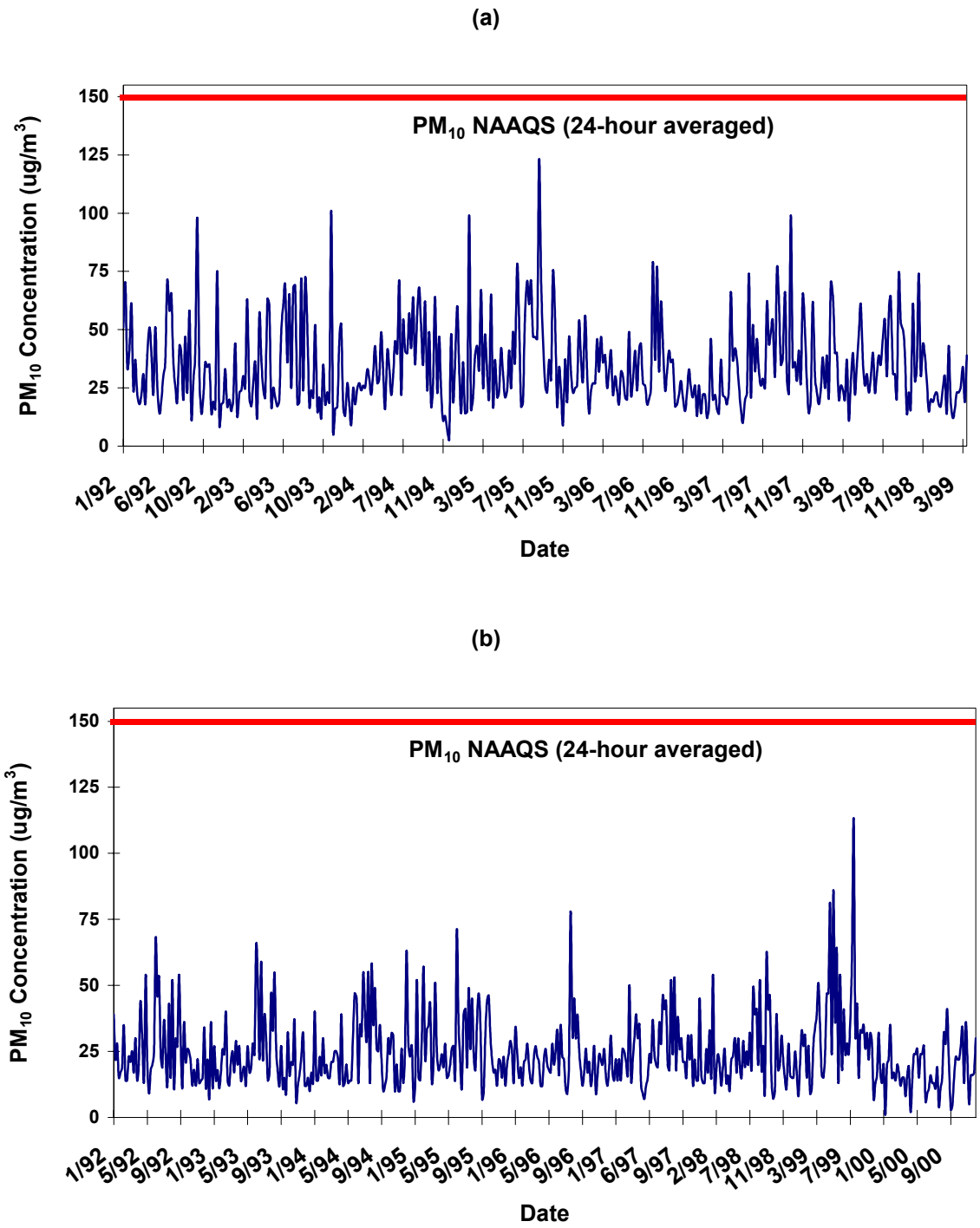
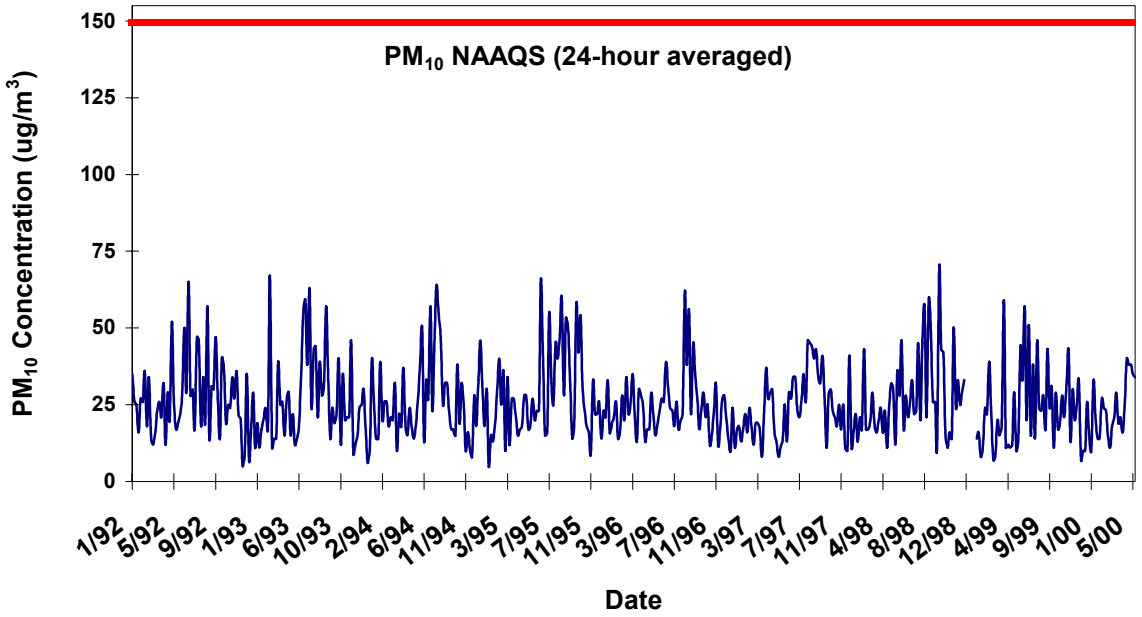


Figure D.2. 24-hour averaged PM_{10} levels: (a) Cincinnati urban site, 1992-1999 (b) Columbus (Maple Canyon) suburban site.

(c)



(d)

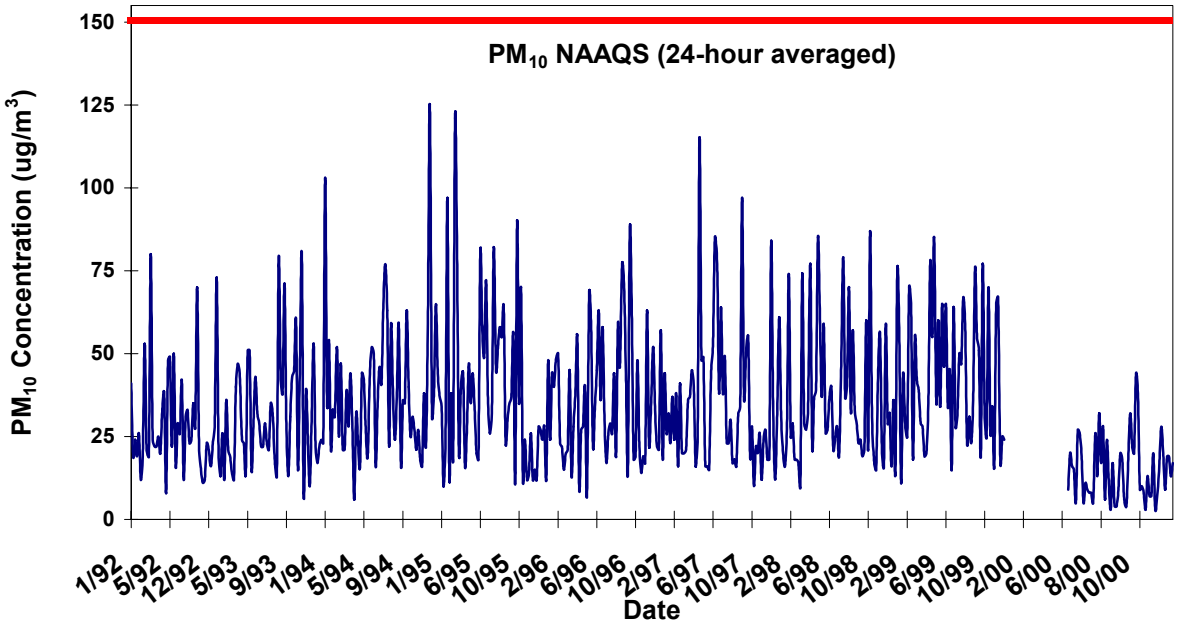


Figure D.2. 24-hour averaged PM_{10} levels 1992-2000: (c) Columbus (Chesapeake) suburban site, (d) Cleveland suburban

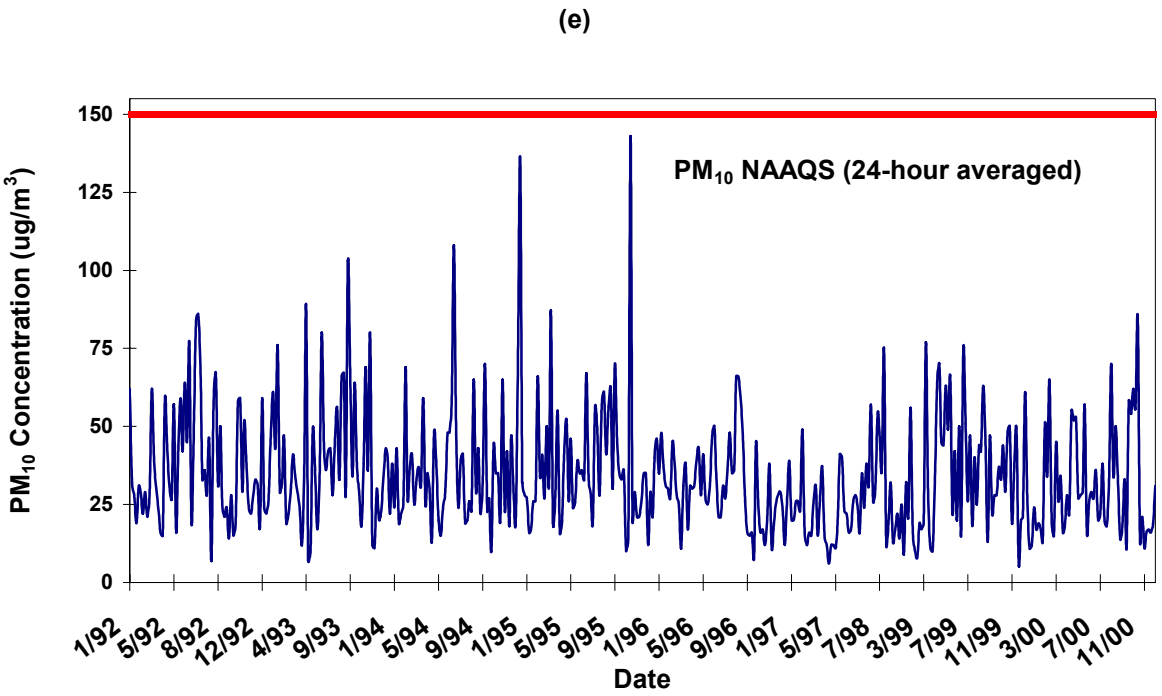


Figure D.2. 24-hour averaged PM_{10} levels in 1992-2000: (e) Steubenville urban Site

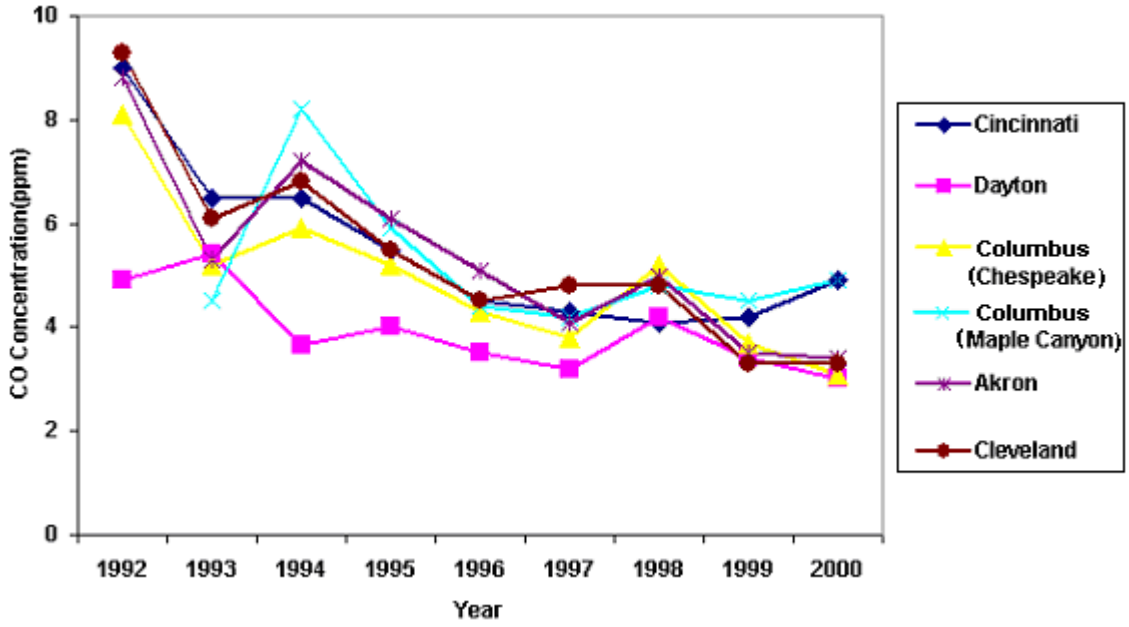


Figure D.3. 2nd Highest 1hr Averaged CO in 1992-2000

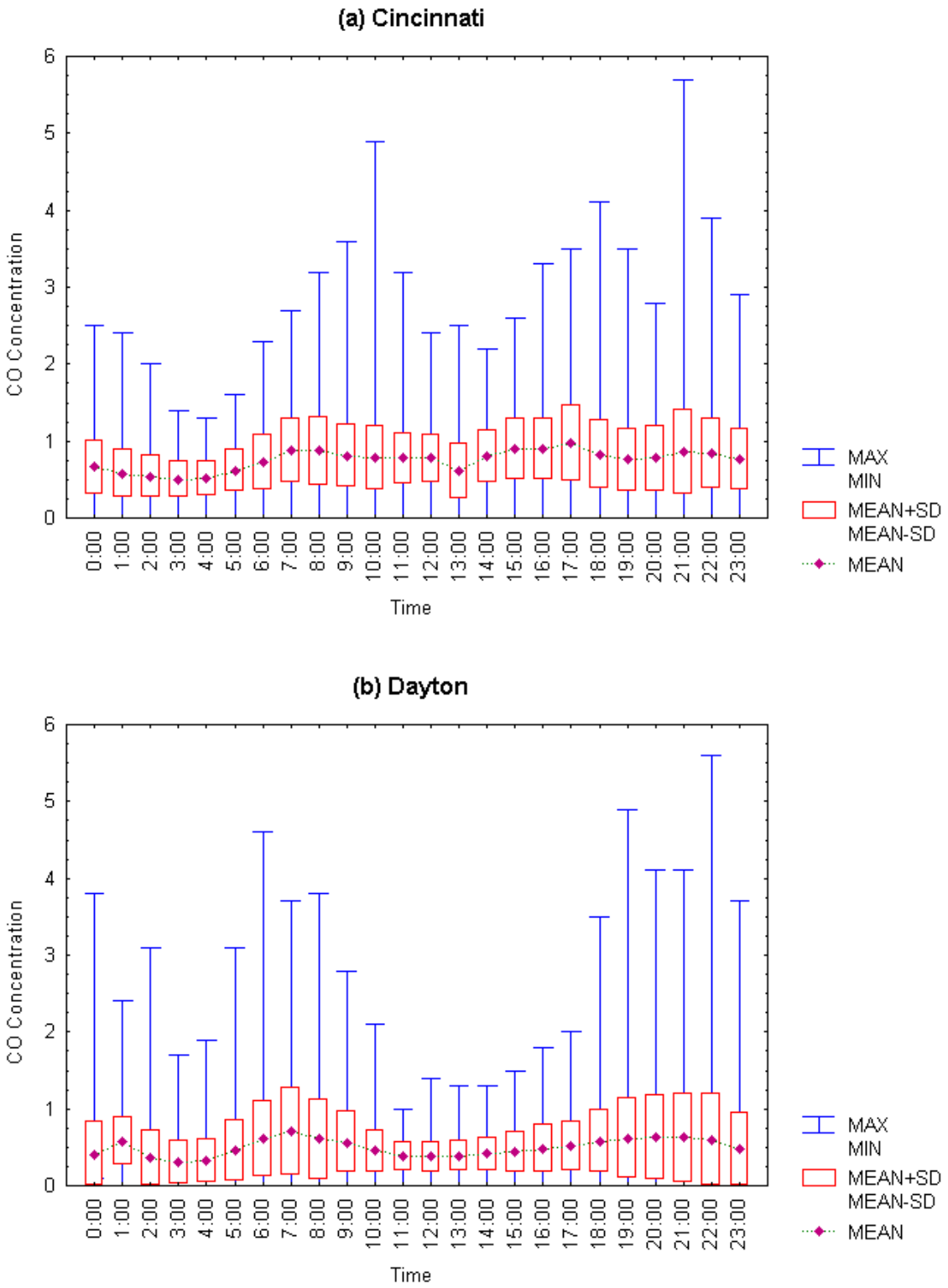


Figure D4-1. Hourly CO distribution: (a) Cincinnati and (b) Dayton

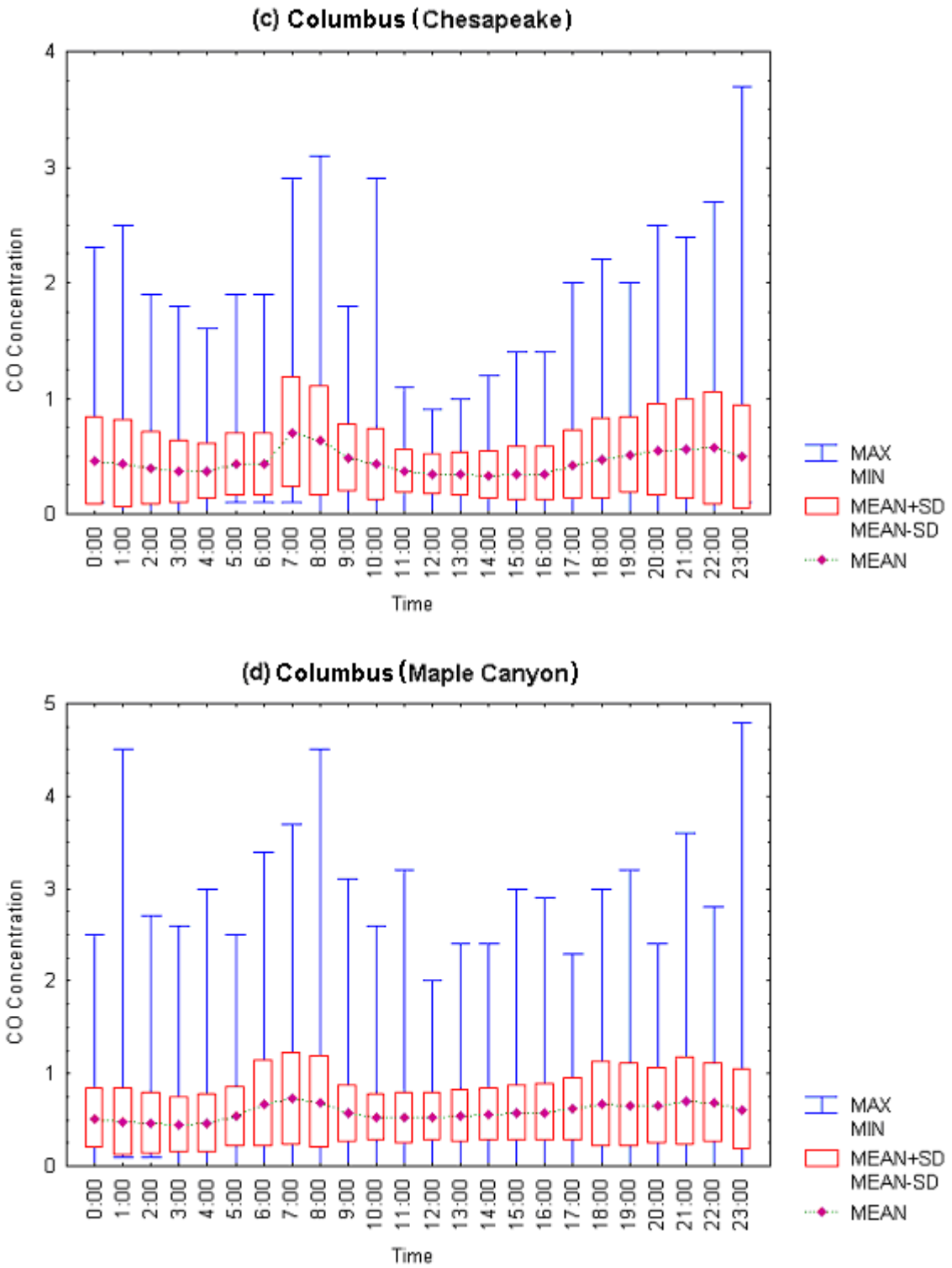
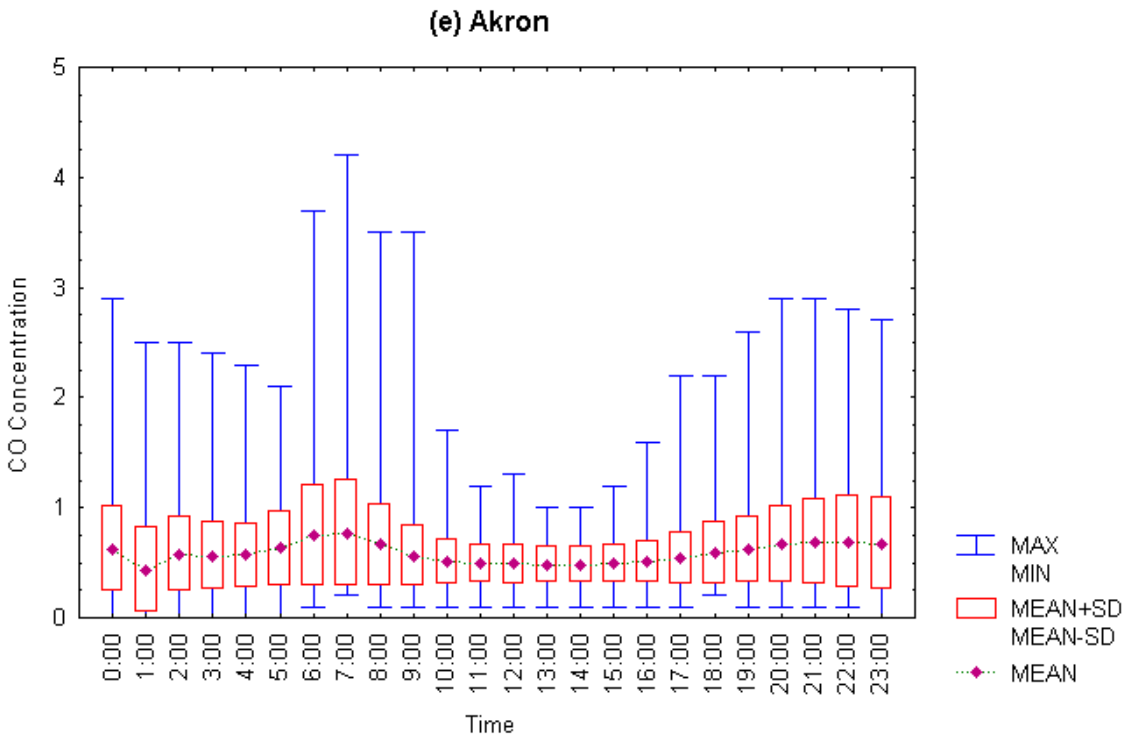


Figure D4-1. Hourly CO distribution: (c) Columbus (Chesapeake) and (d) Columbus (Maple Canyon)



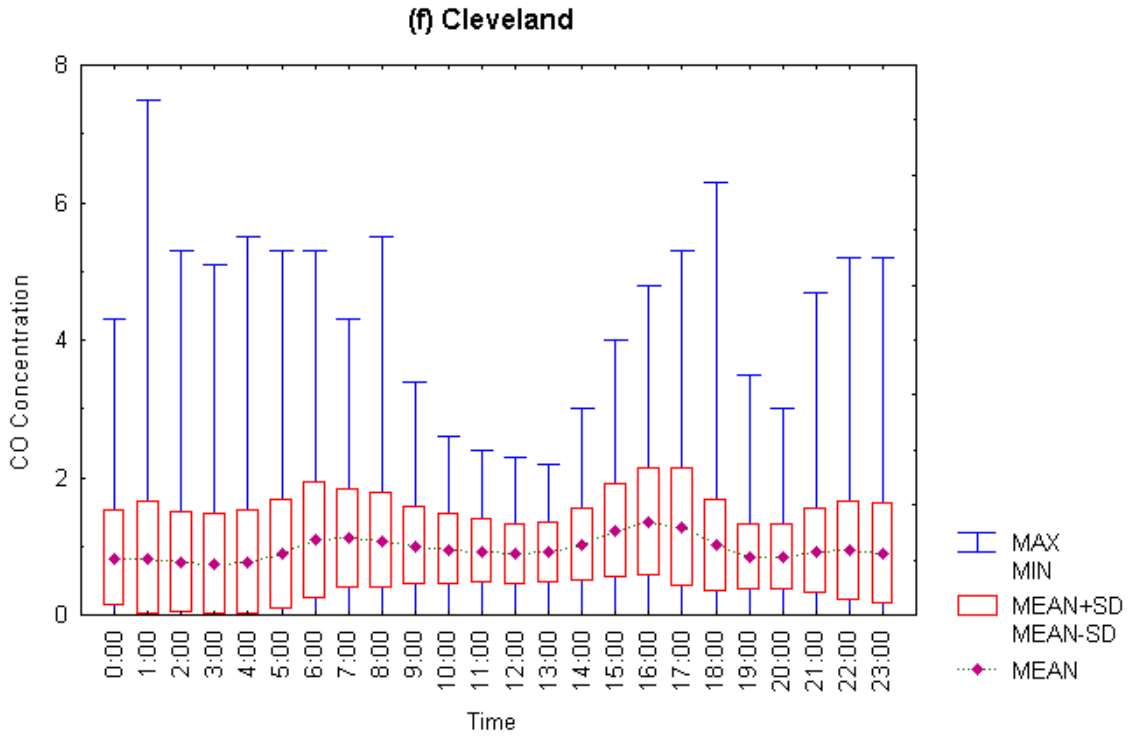


Figure D4-1. Hourly CO distribution: (e) Akron and (f) Cleveland

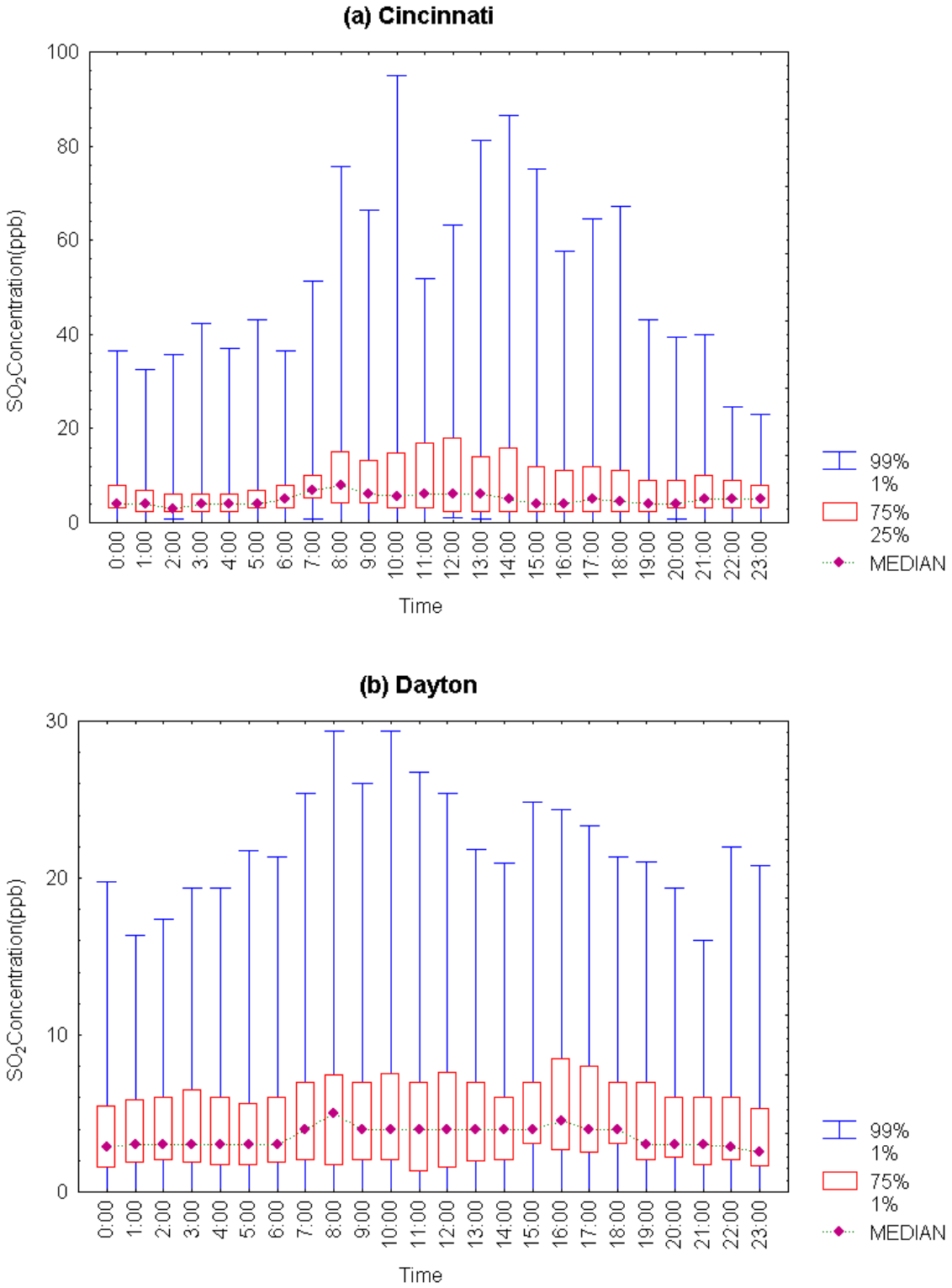
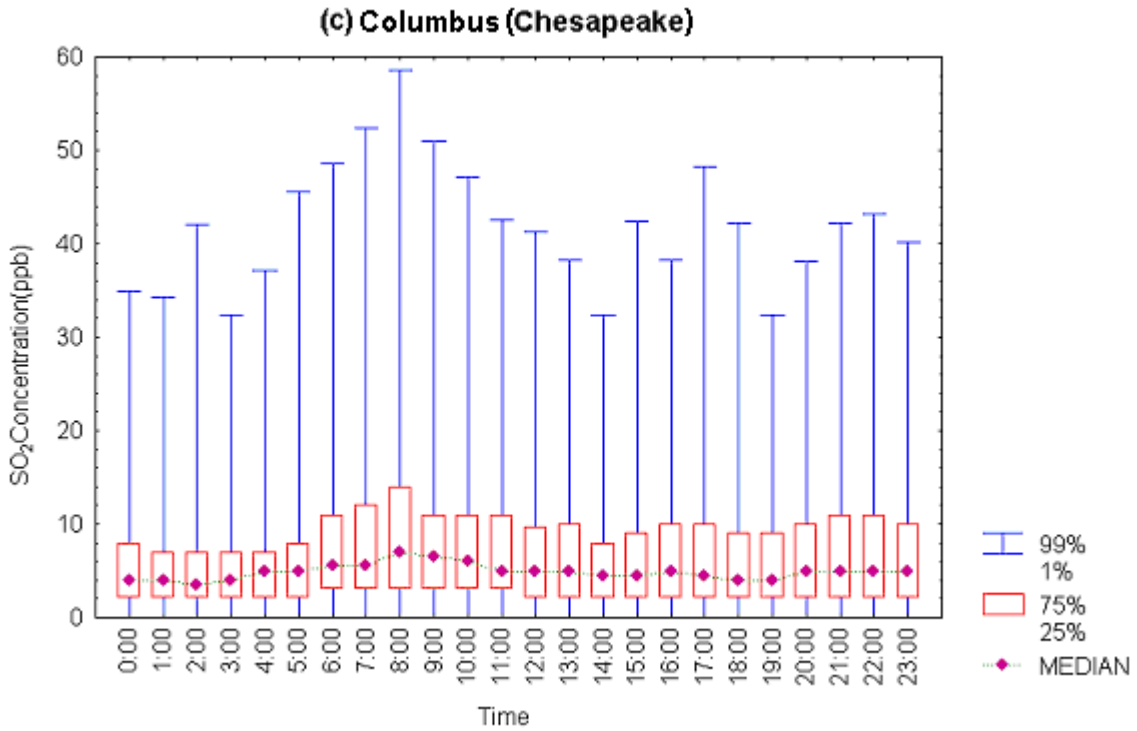


Figure D4-2. Hourly SO_2 distribution: (a) Cincinnati and (b) Dayton



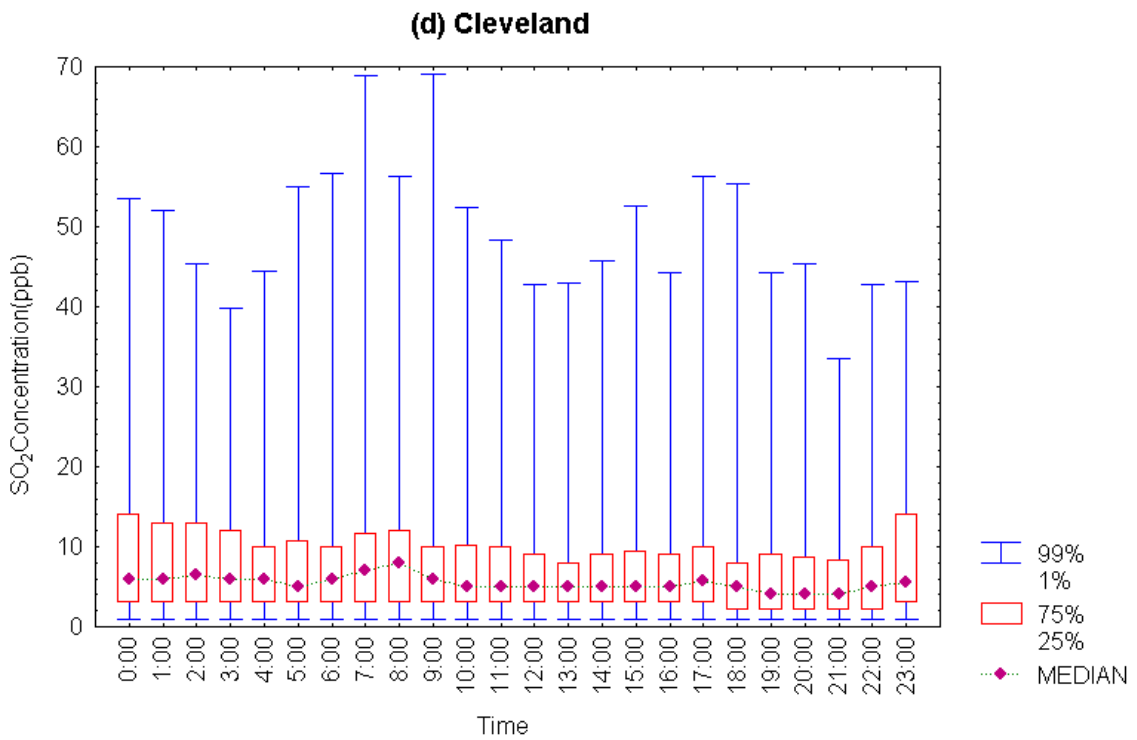


Figure D4-2. Hourly SO_2 distribution in: (c) Columbus (Chesapeake) and (d) Cleveland

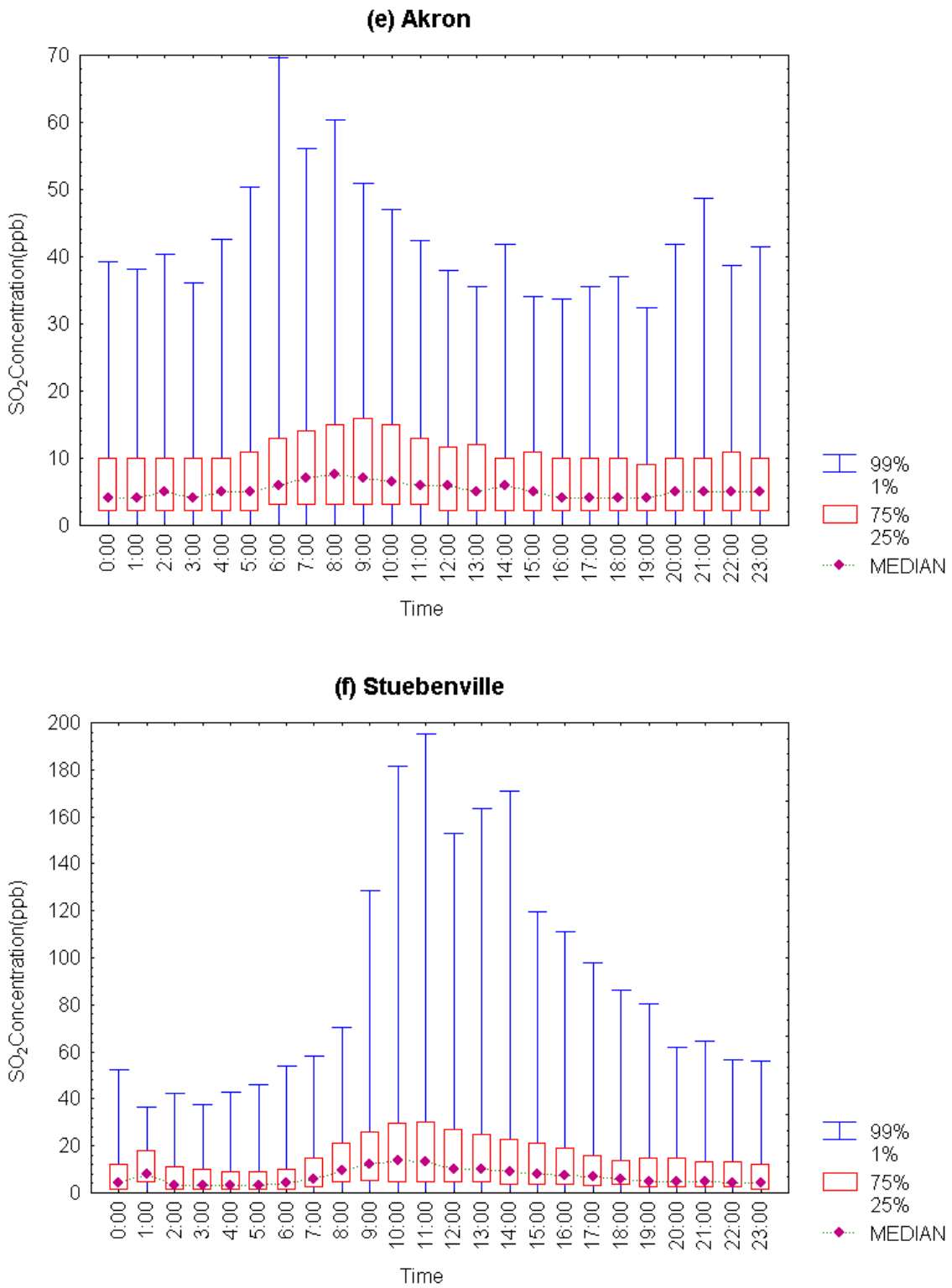


Figure D4-2. Hourly SO_2 distribution: (e) Akron and (f) Steubenville

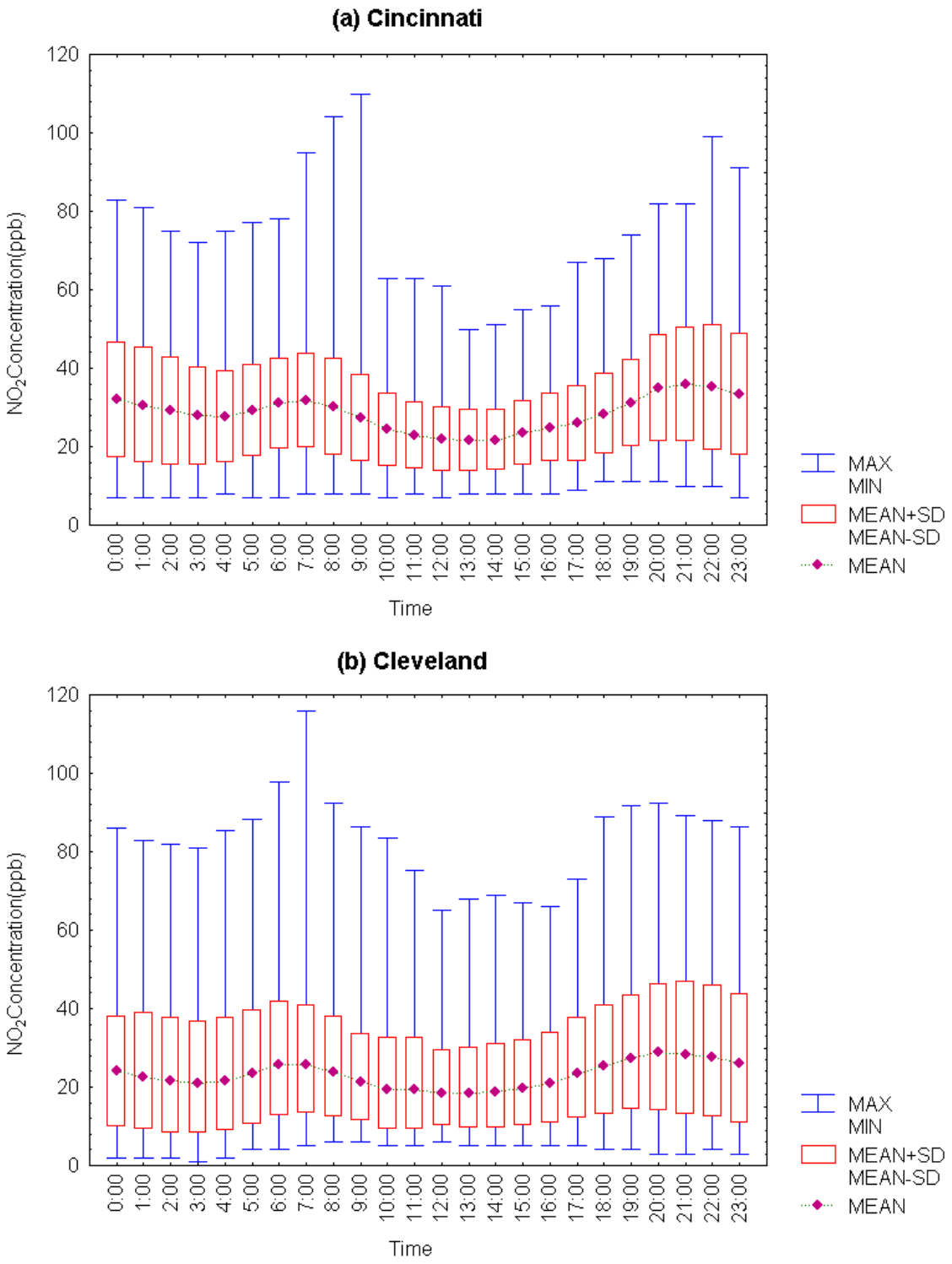


Figure D4-3. Hourly NO_2 distribution: (a) Cincinnati and (b) Cleveland

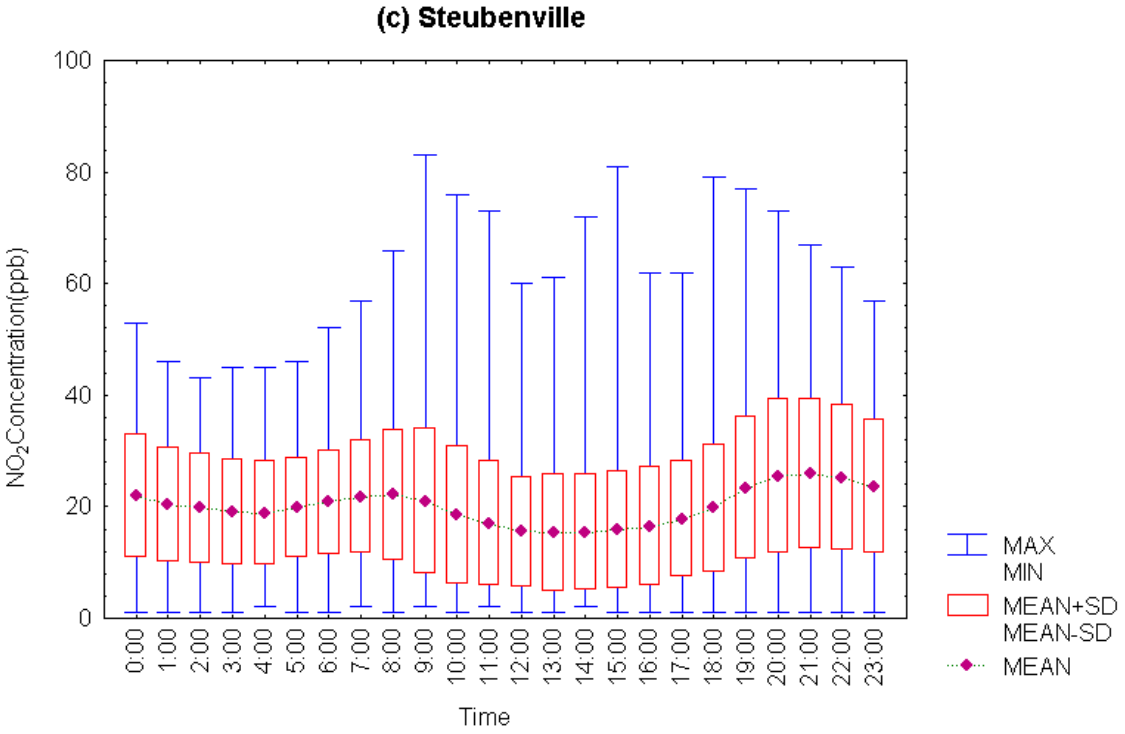
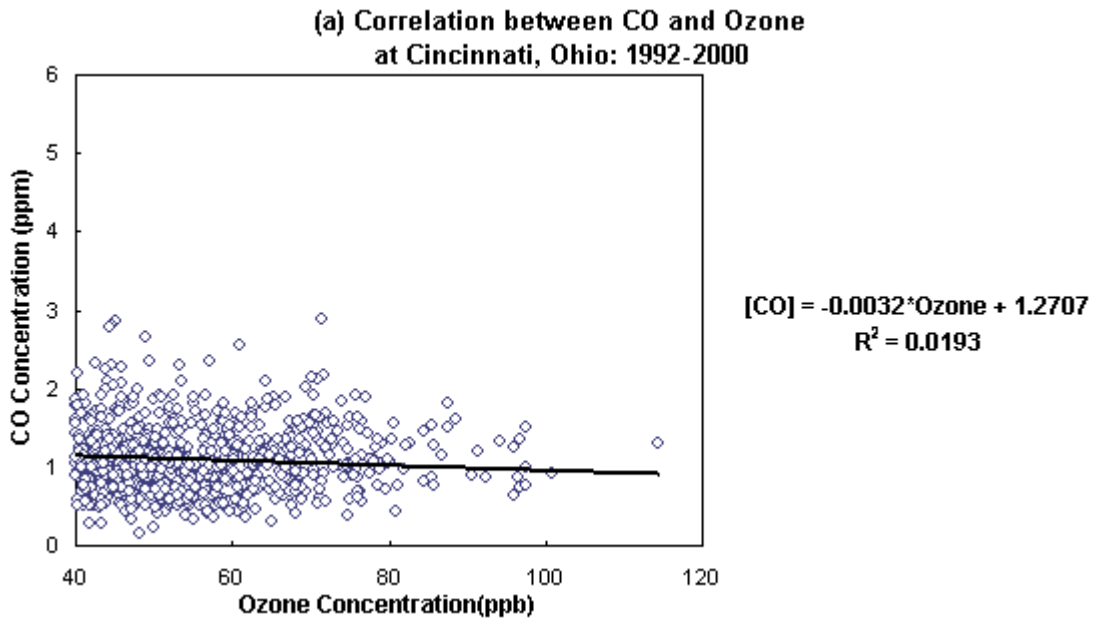


Figure D4-3. Hourly NO_2 distribution: (c) Steubenville



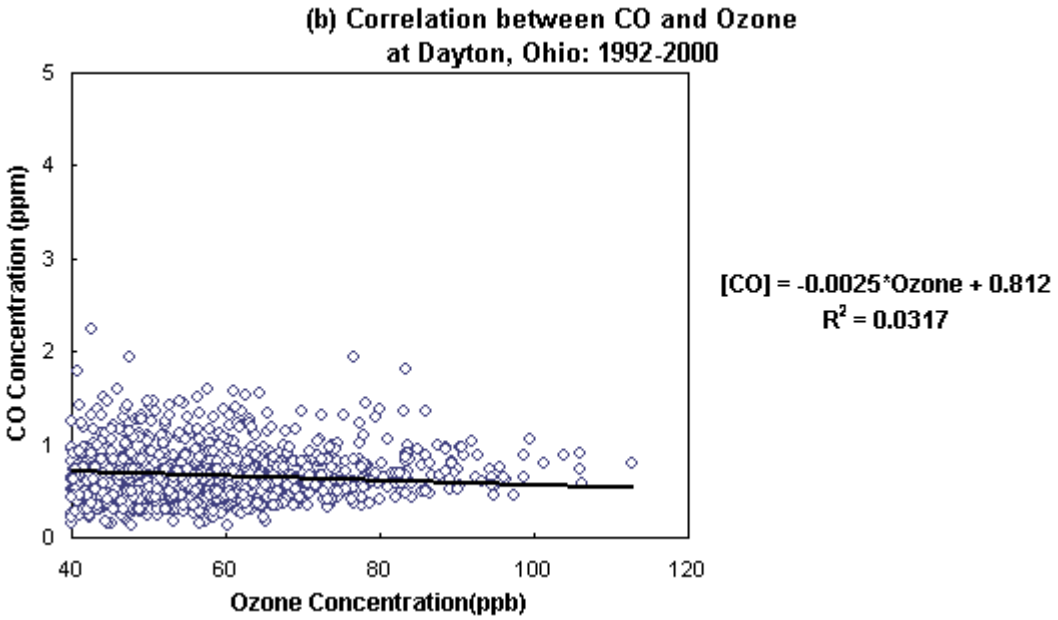
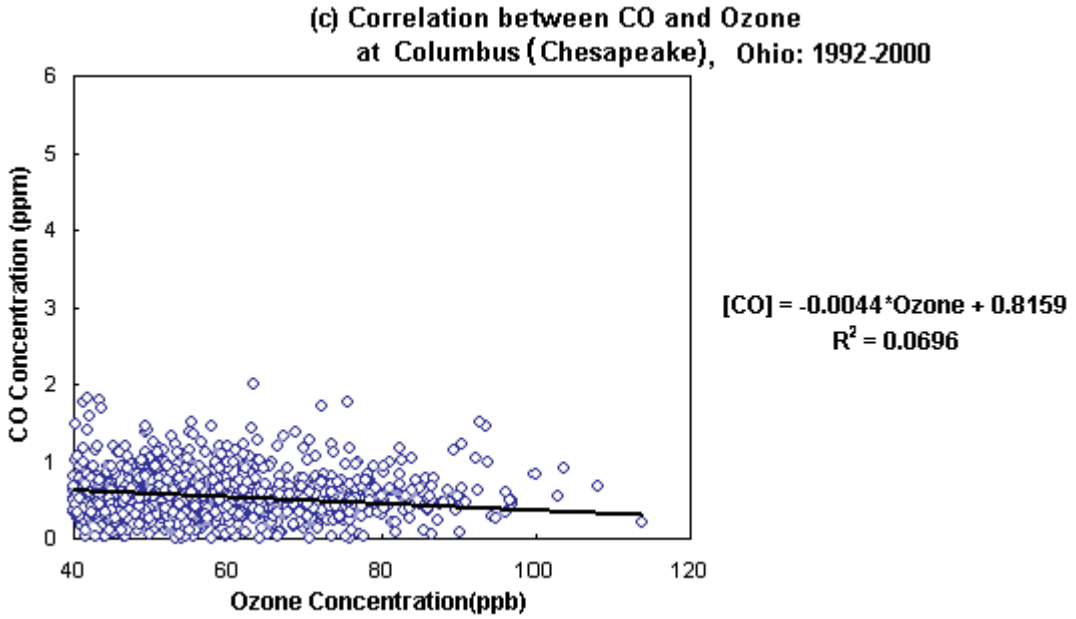


Figure D5-1. Correlation between CO and Ozone Concentration in 1992-2000: (a) Cincinnati and (b) Dayton.



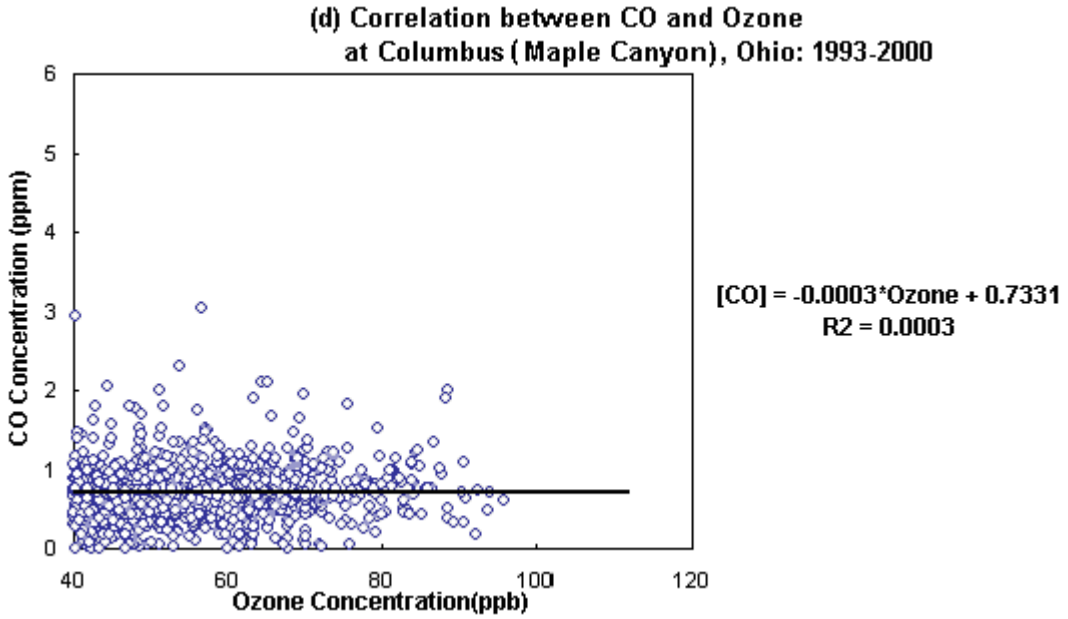
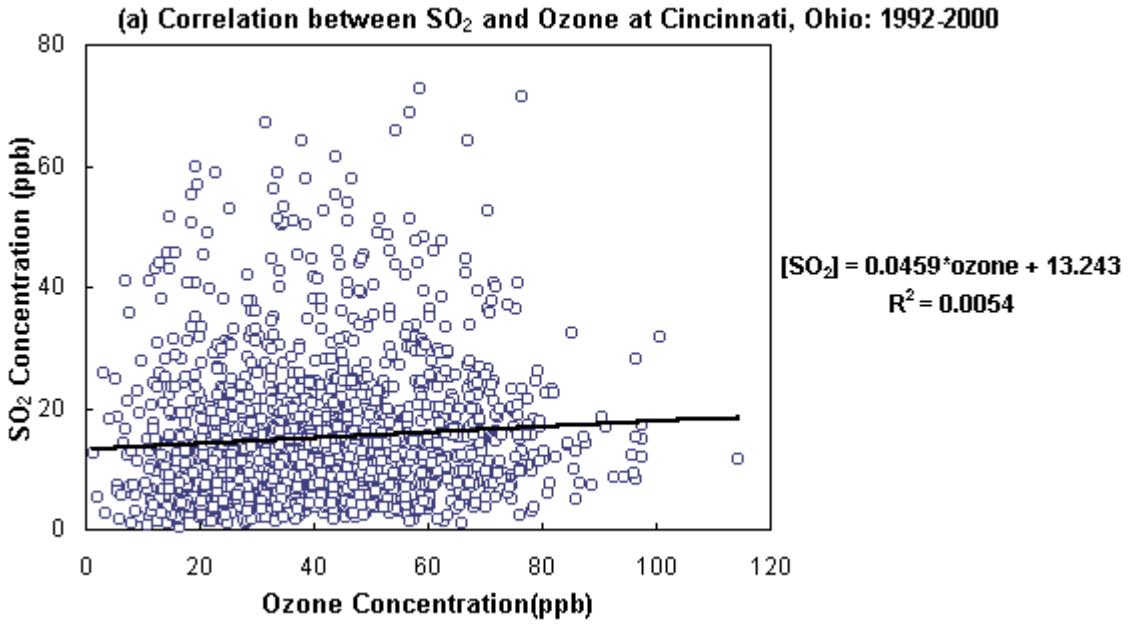


Figure D5-1. Correlation between CO and Ozone Concentration: (c) Columbus (Chesapeake), 1992-2000 and (d) Columbus (Maple Canyon), 1993-2000.



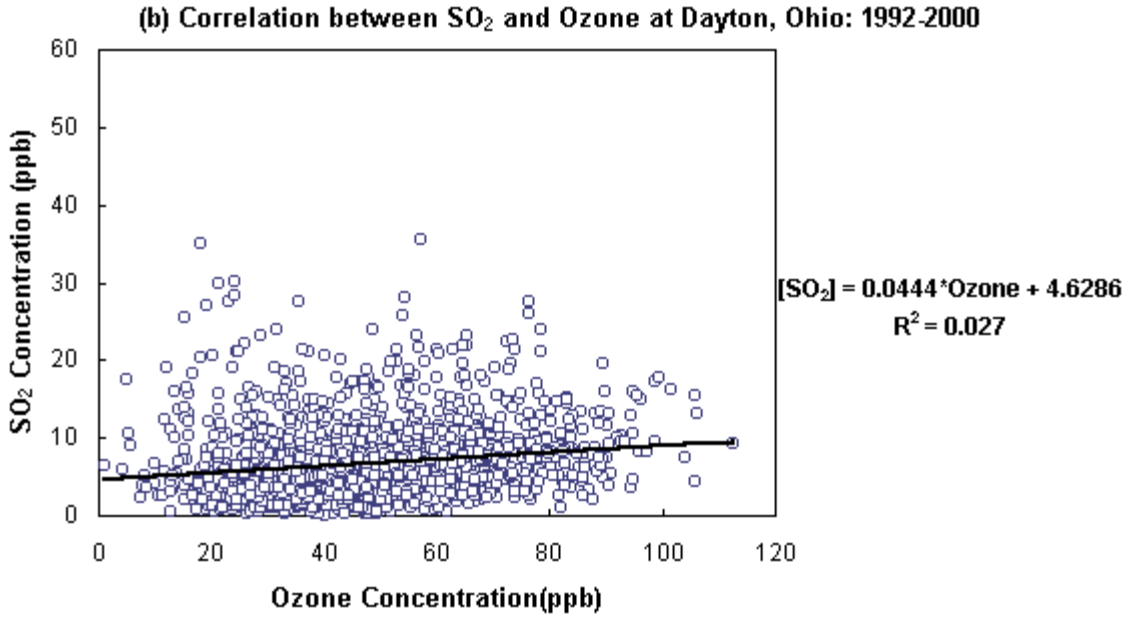


Figure D5-2. Correlation between SO_2 and Ozone Concentration in 1992-2000: (a) Cincinnati and (b) Dayton.

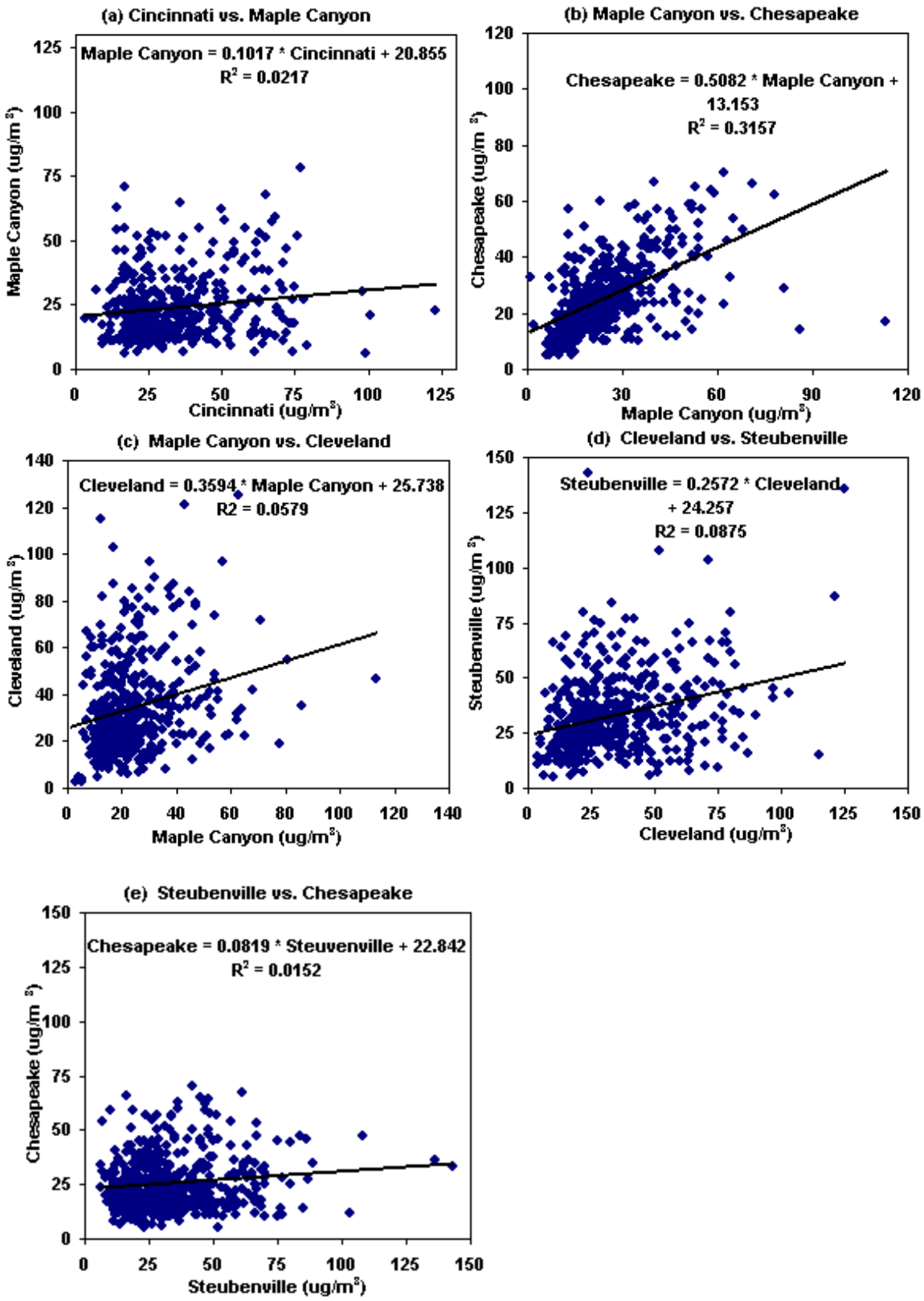


Figure D**6-1.** Spatial Coordination plots of PM_{10}, 1992-2000

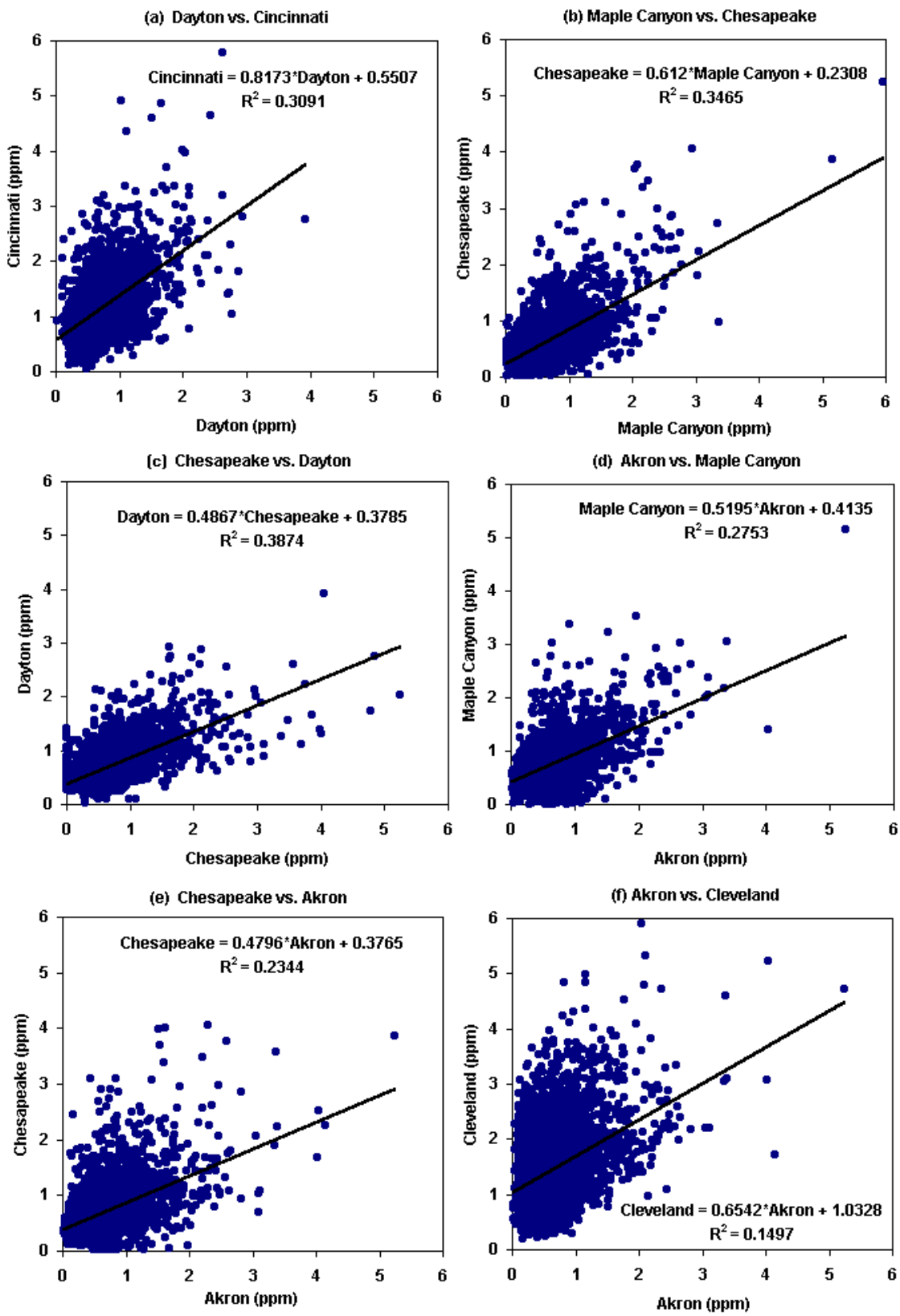


Figure D6-2. Spatial Coordination plots of CO, 1992-2000

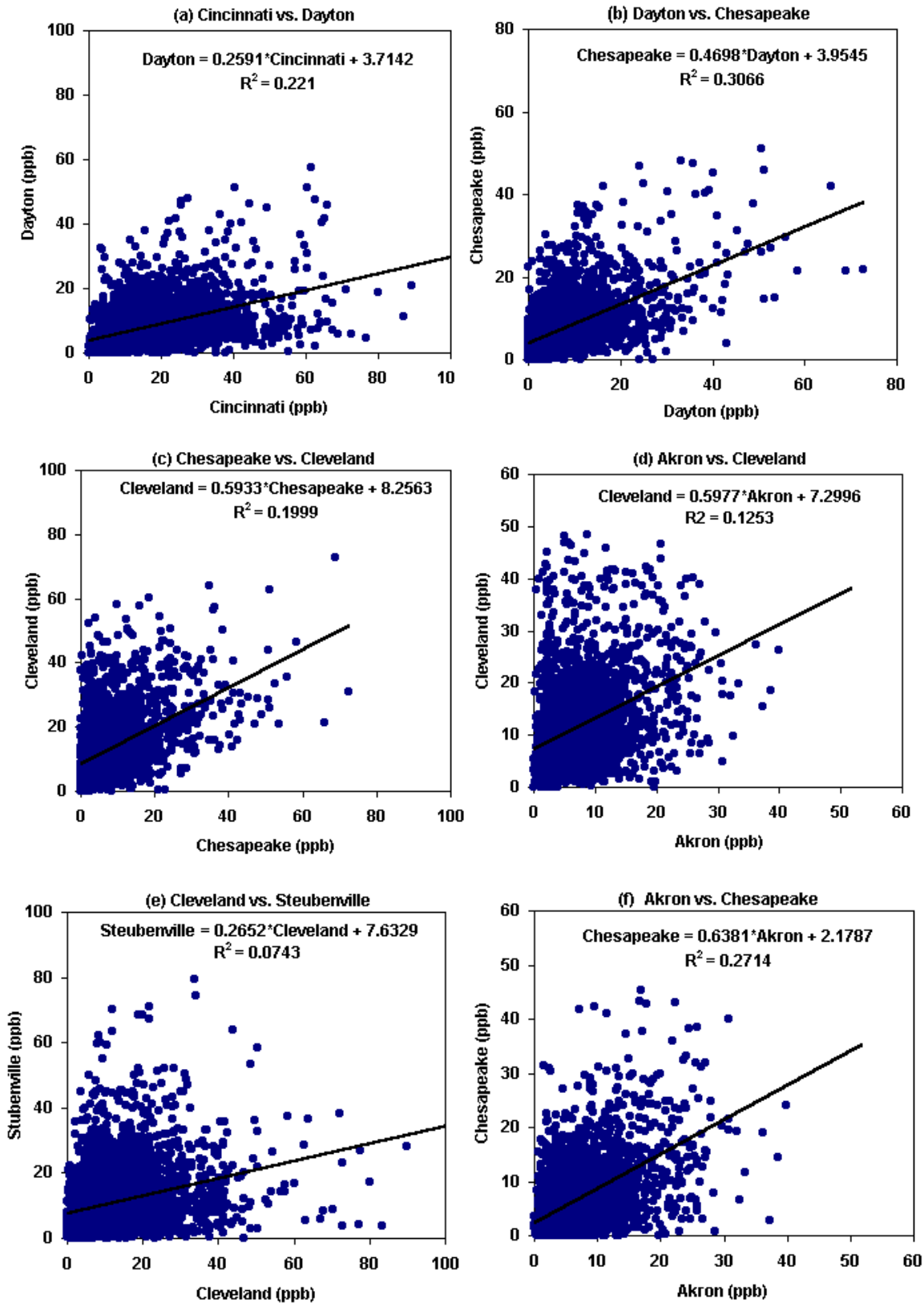


Figure D6-3. Spatial Coordination plots of SO_2 , 1992-2000

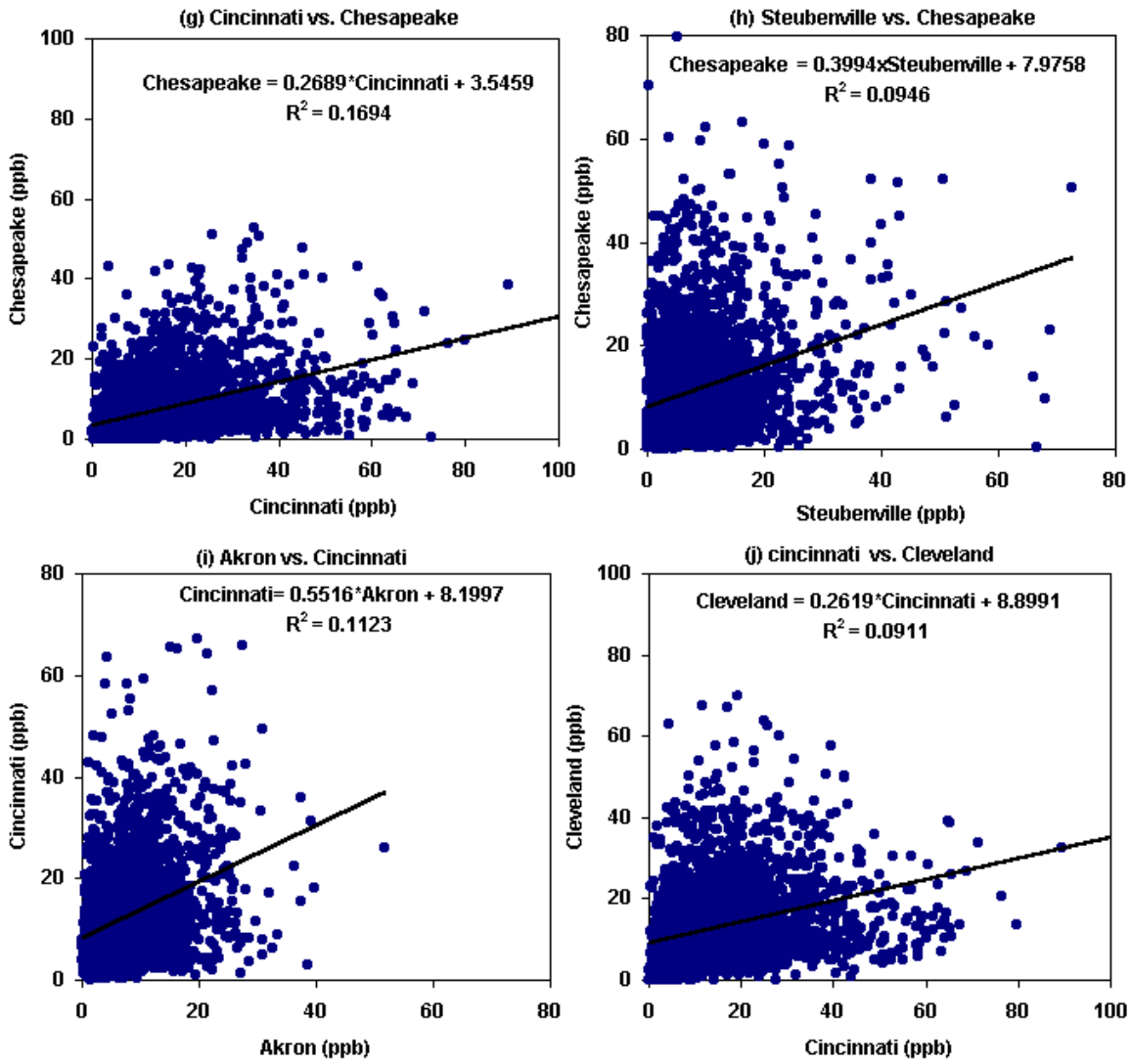


Figure D6-3. Spatial Coordination plots of SO_2, 1992-2000

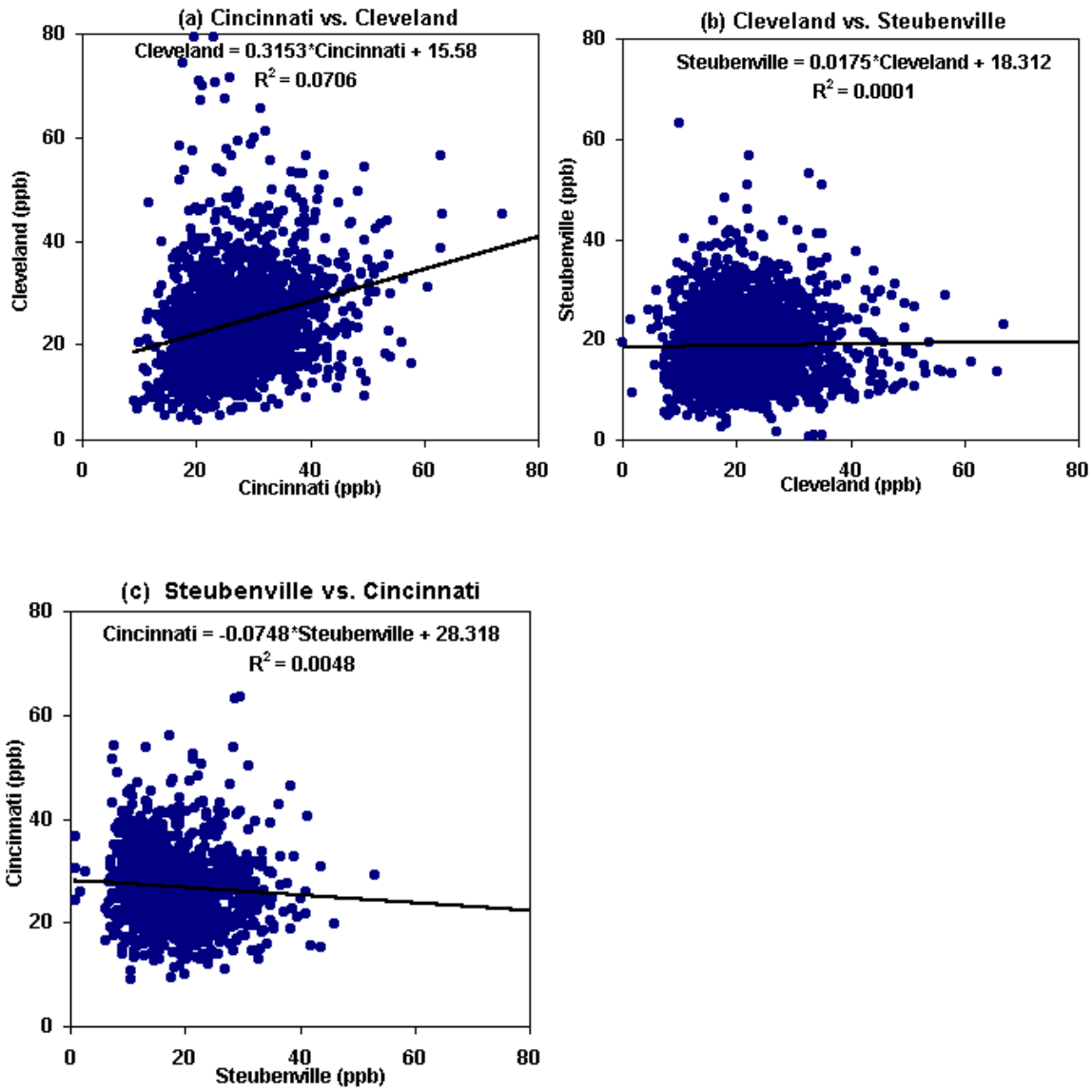


Figure D6-4. Spatial Coordination plots of NO_2, 1992-2000

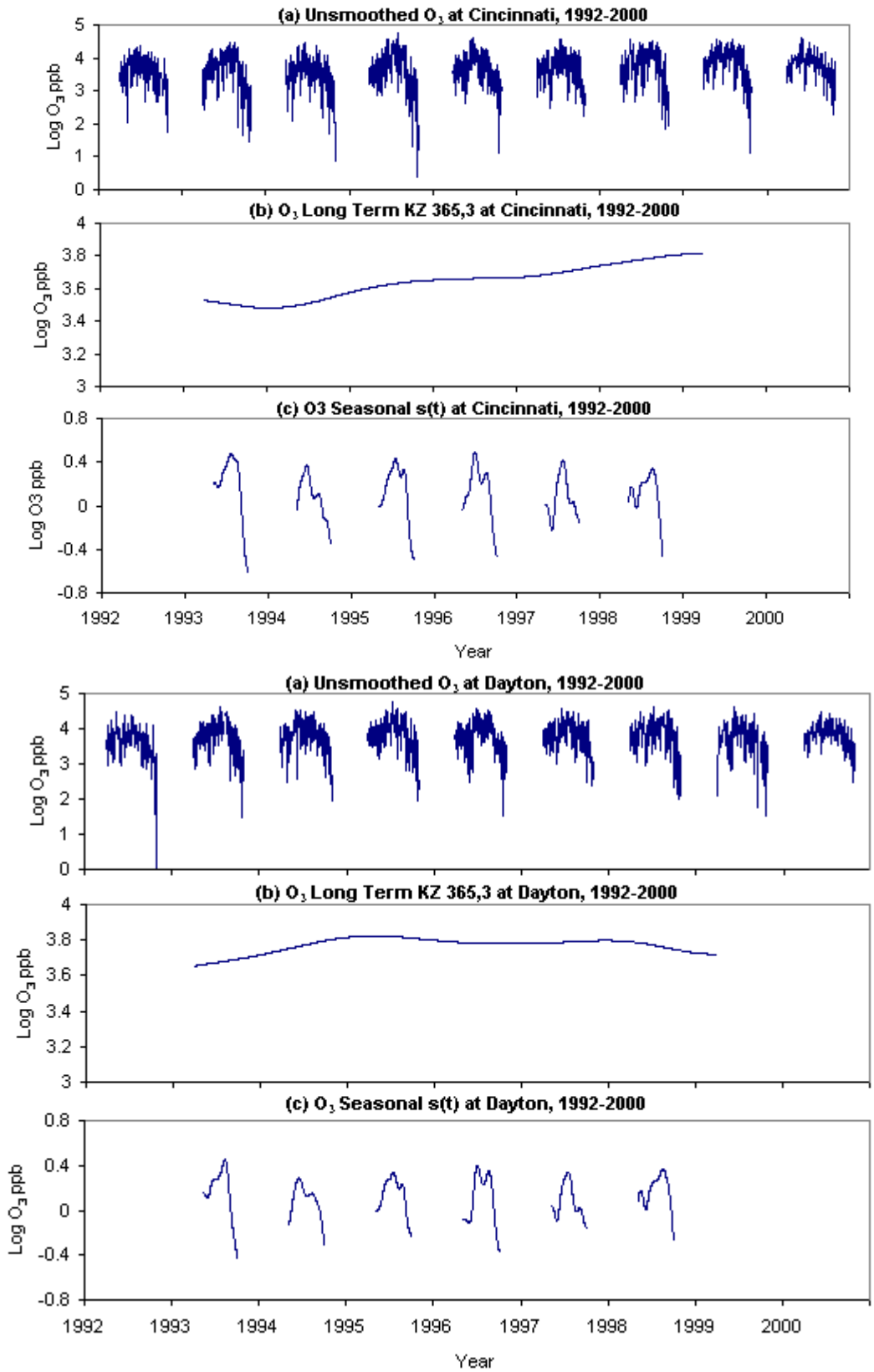


Figure D7. KZ Filter of ozone levels in (a) Cincinnati and (b) Dayton, 1992-2000

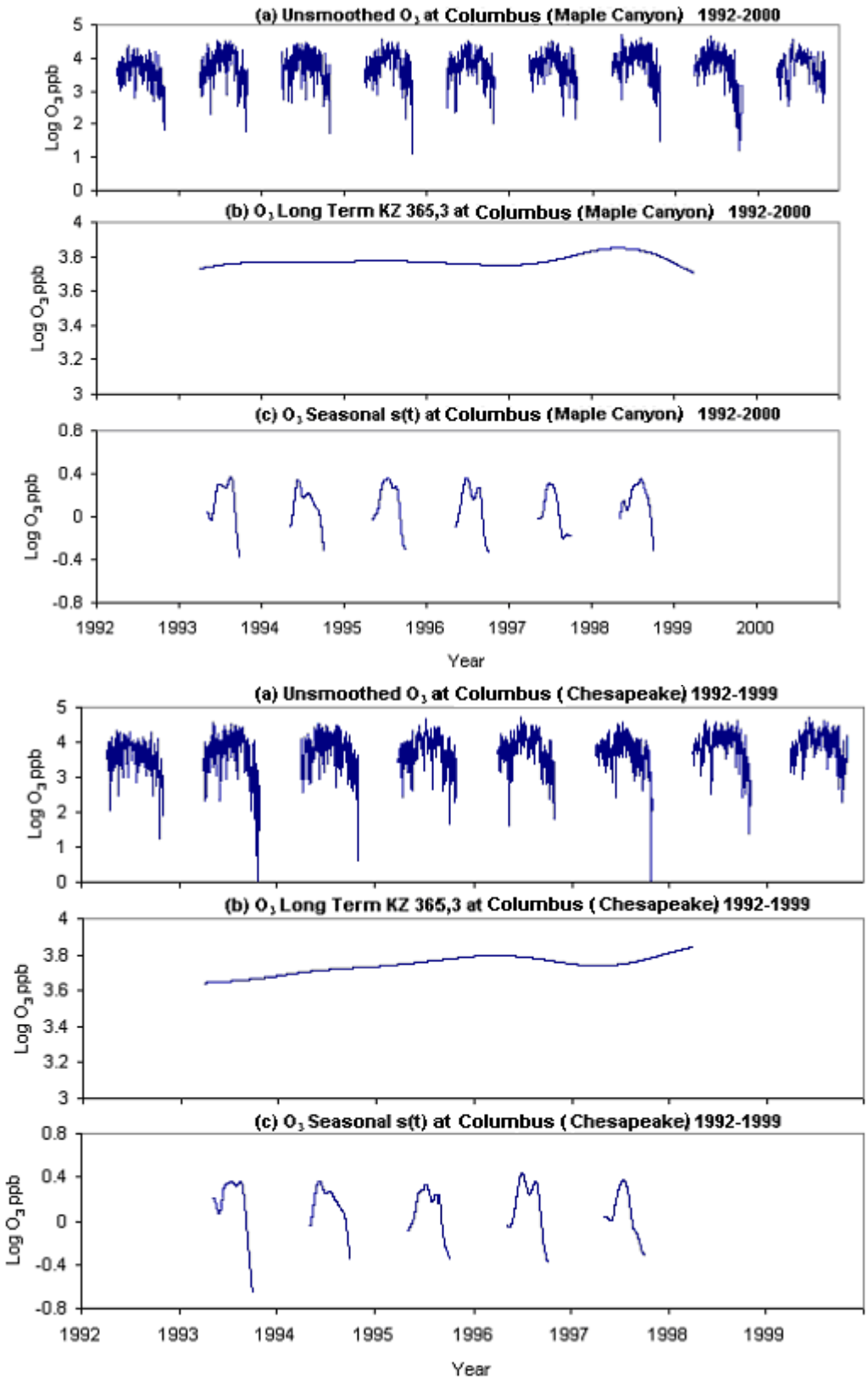


Figure D7. KZ Filter of ozone levels in (c) Columbus (Maple Canyon) and (d) Columbus (Chesapeake), 1992-2000

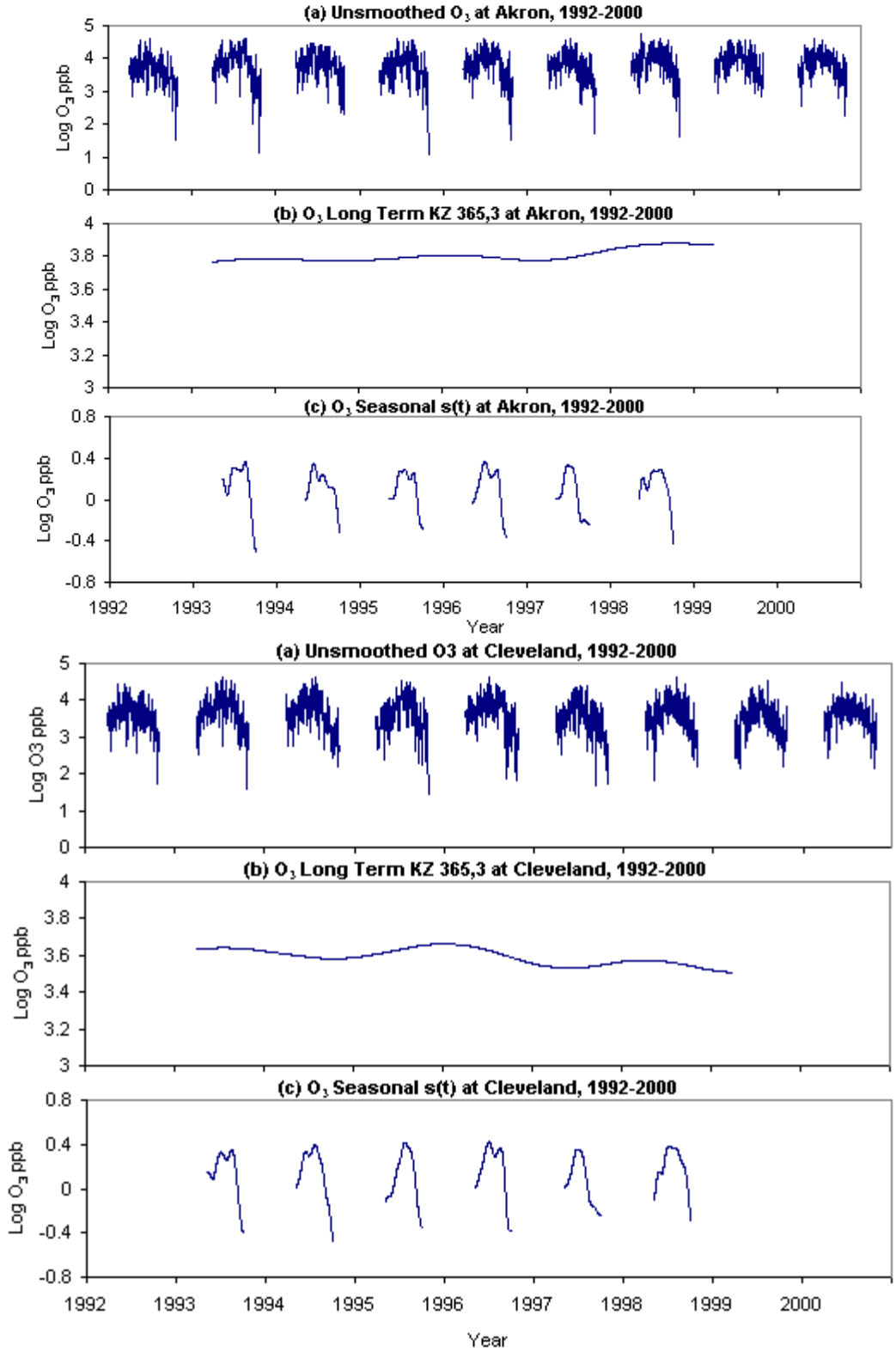


Figure D7. KZ Filter of ozone levels in (e) Akron and (f) Cleveland, 1992-2000

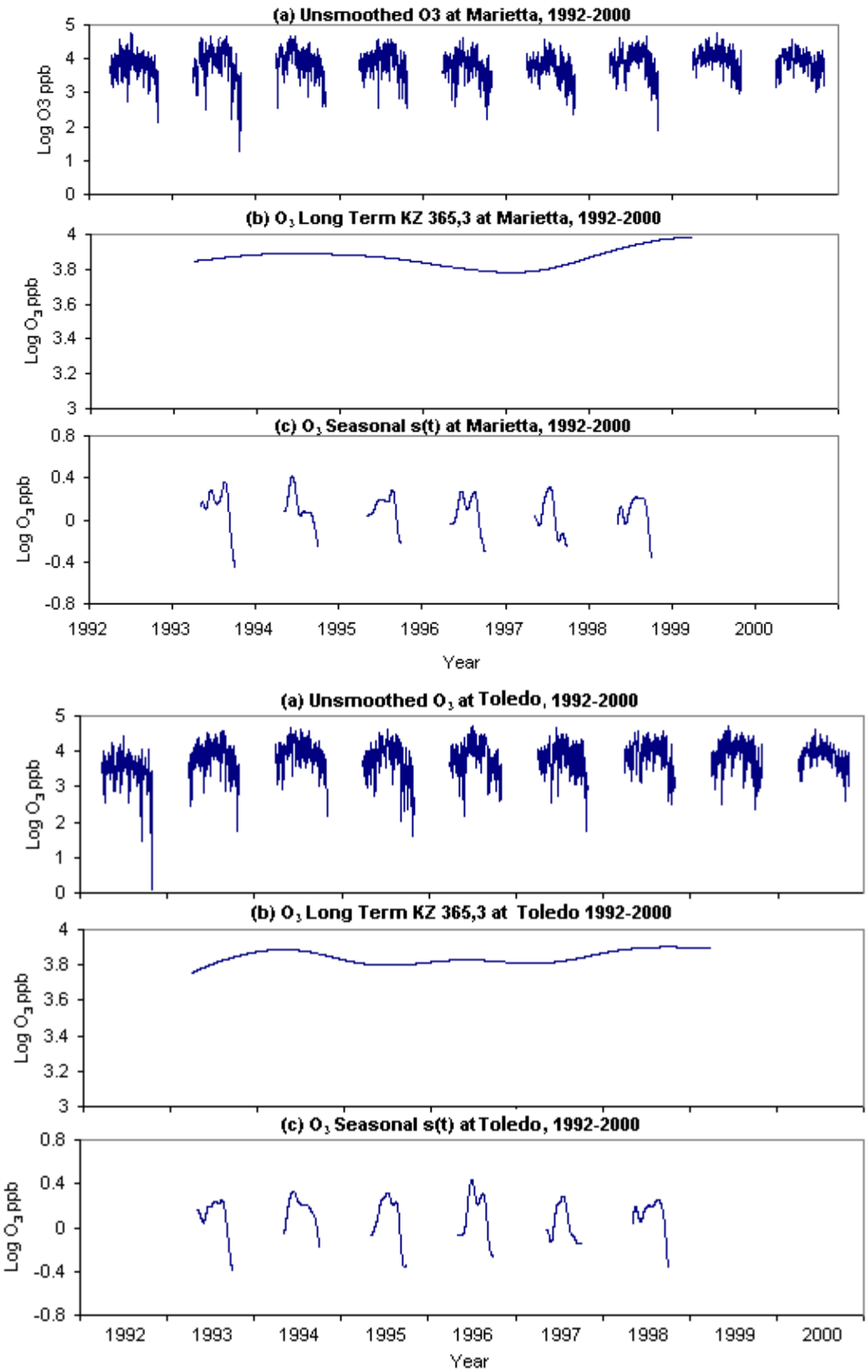


Figure D7. KZ Filter of ozone levels in (g) Marietta and (h) Toledo, 1992-2000

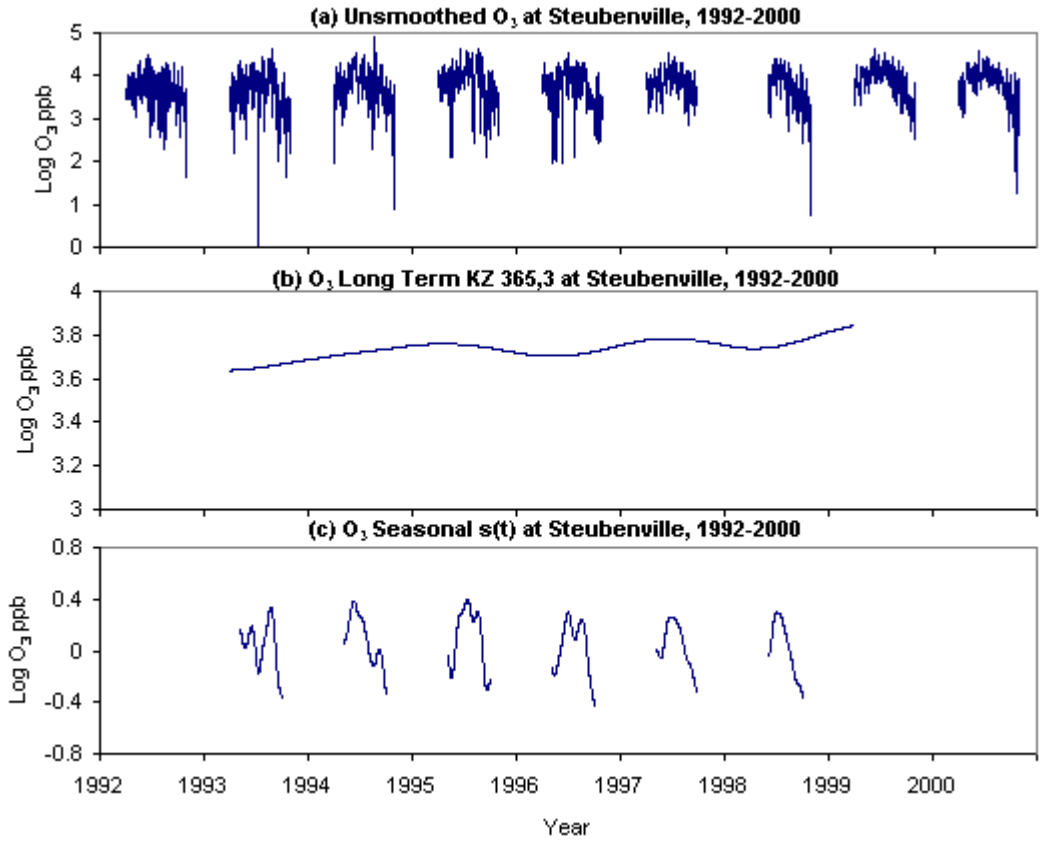


Figure D7. KZ Filter of ozone levels in (i) Steubenville, 1992-2000

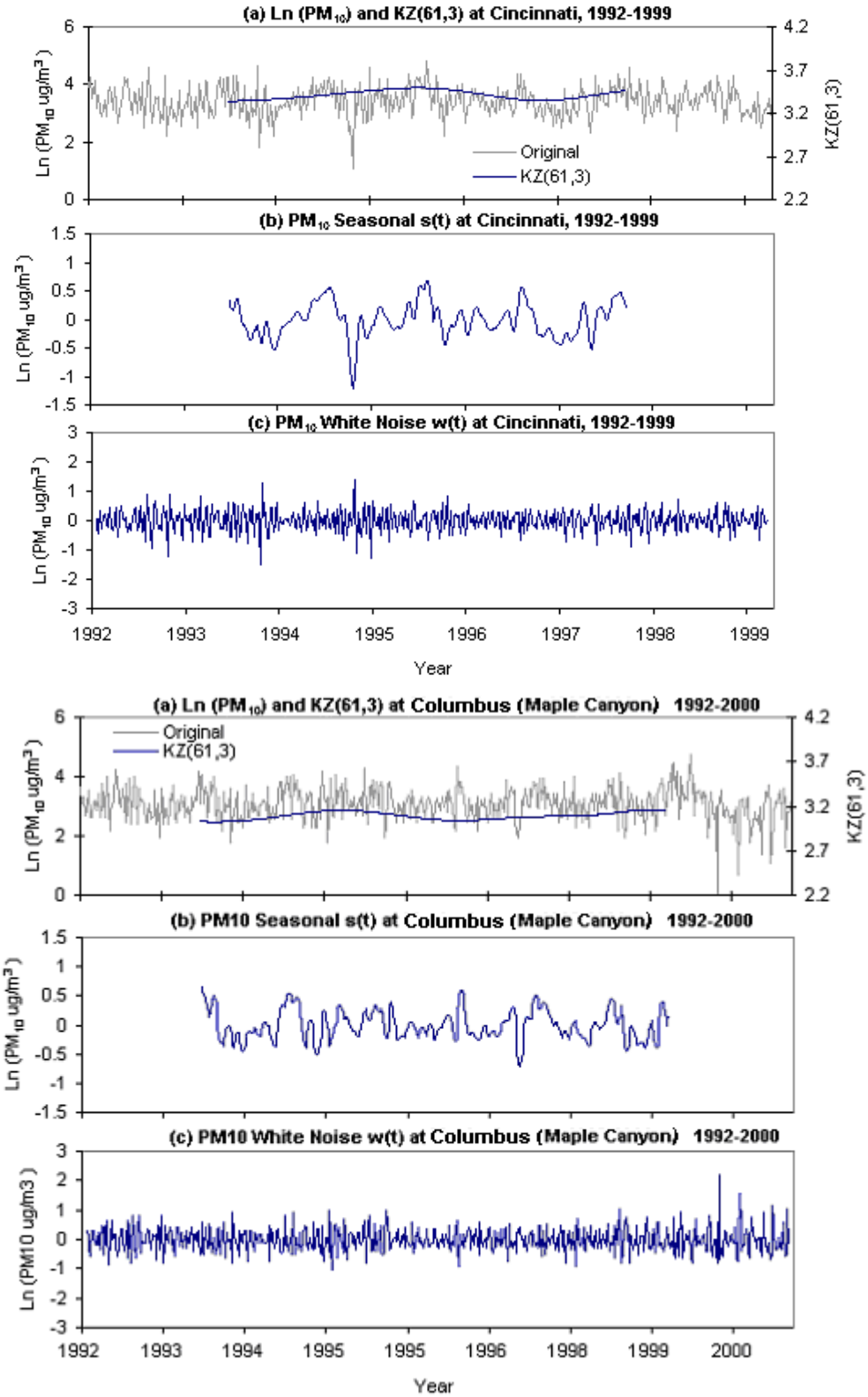


Figure D8. KZ Filter of PM_{10} levels in (a) Cincinnati, 1992-1999 and (b) Columbus (Maple Canyon), 1992-2000

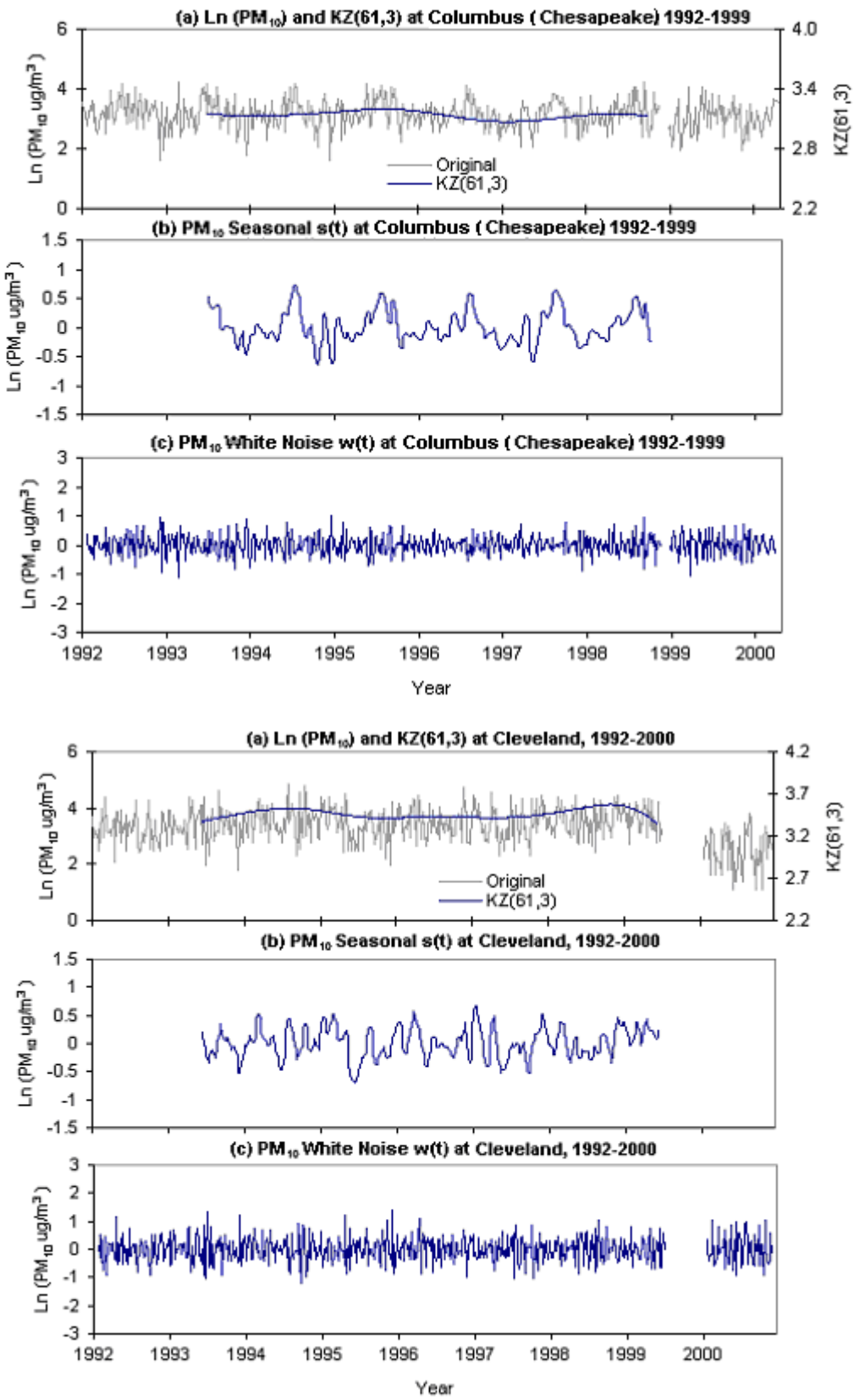


Figure D8. KZ Filter of PM_{10} levels in (c) Columbus (Chesapeake) and (d) Cleveland, 1992-2000

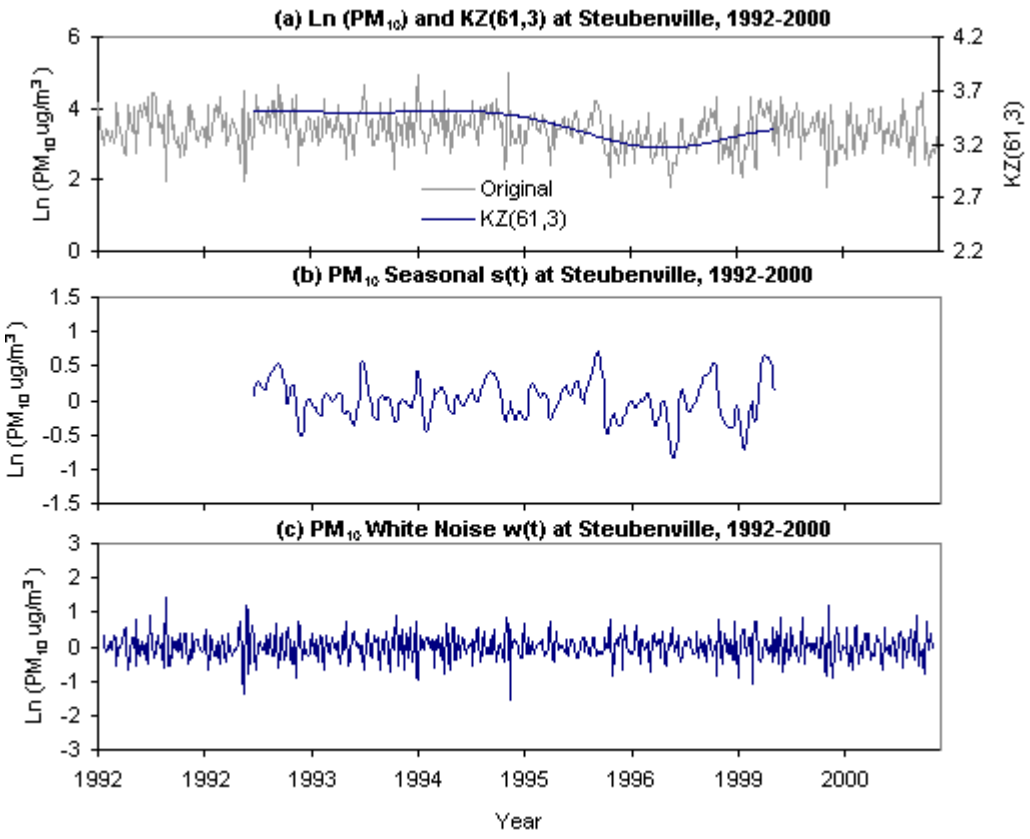


Figure D8. KZ Filter of PM_{10} levels in (e) Steubenville, 1992-2000

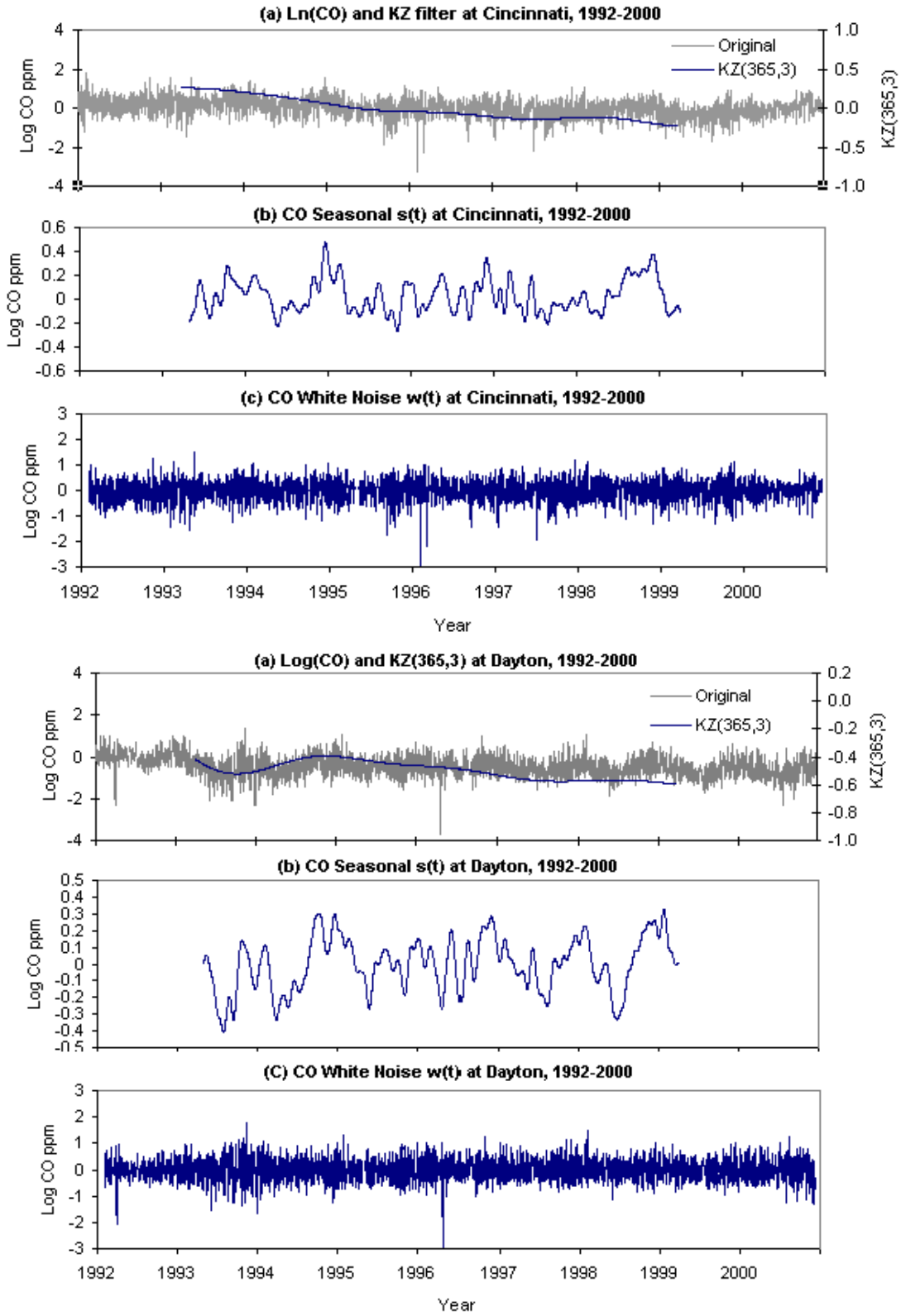


Figure D9. KZ Filter of CO levels in (a) Cincinnati and (b) Dayton, 1992-2000

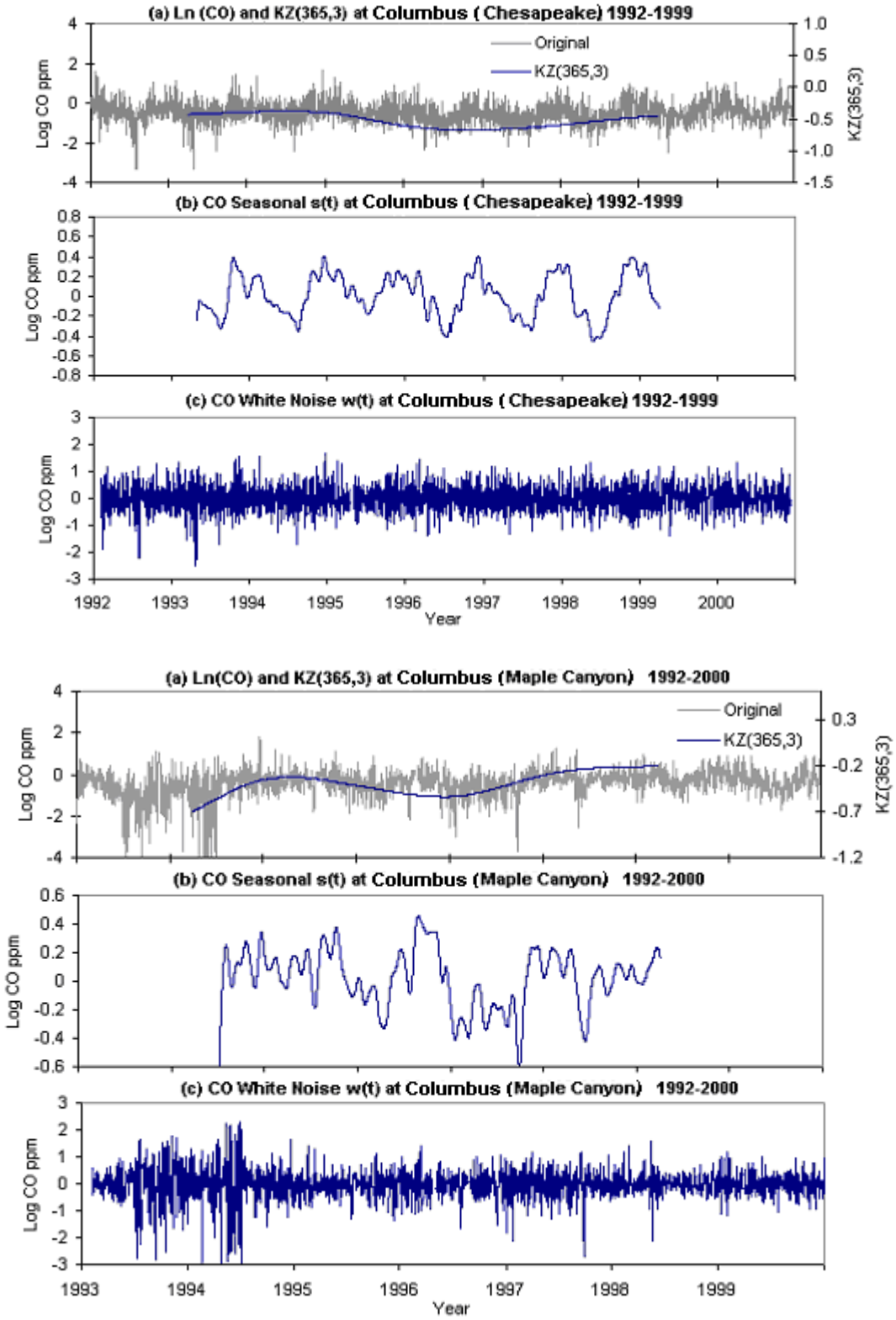


Figure D9. KZ Filter of CO levels in (c) Columbus (Chesapeake) and (d) Columbus (Maple Canyon), 1993-2000

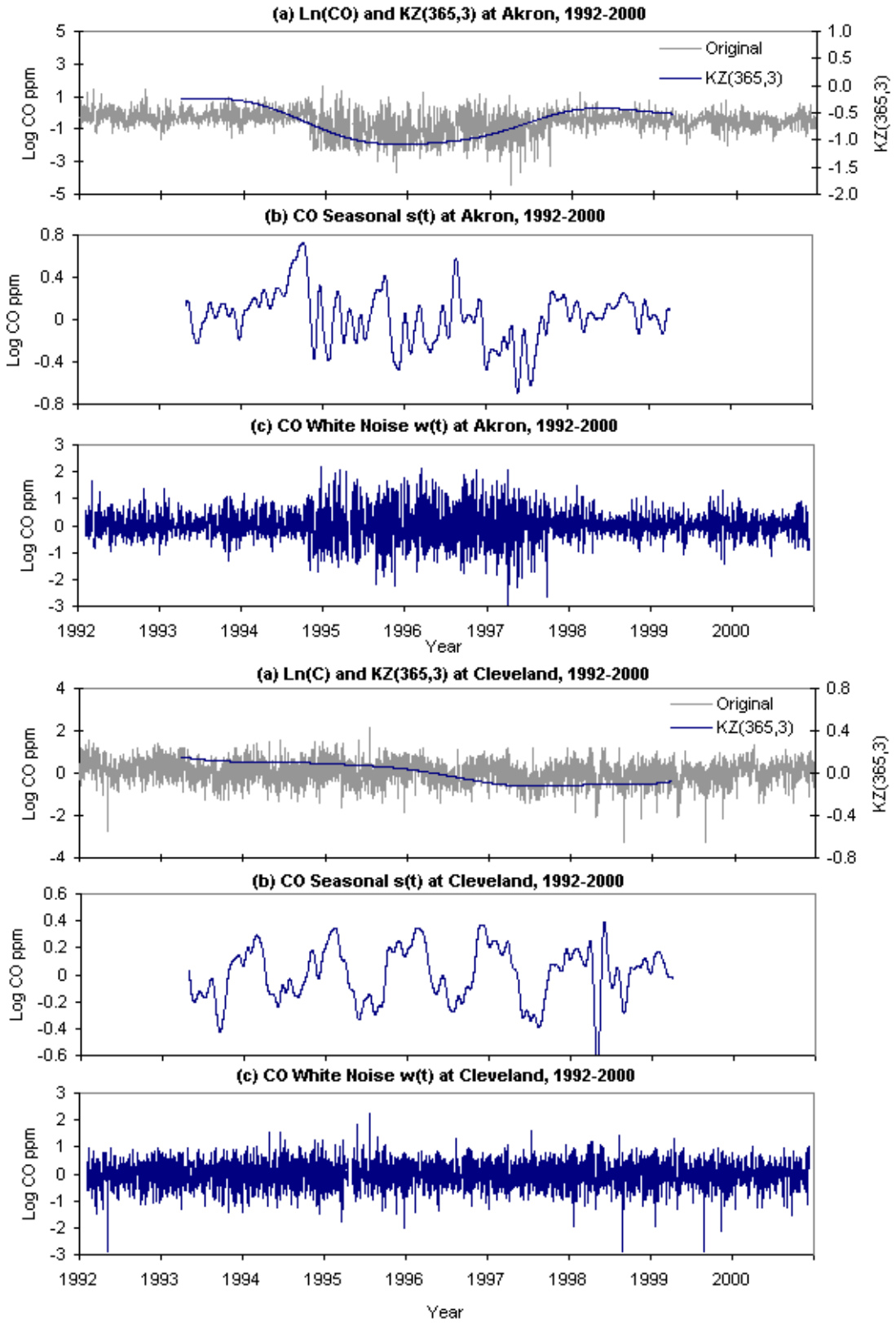


Figure D9. KZ Filter of CO levels in (e) Akron and (f) Cleveland, 1992-2000

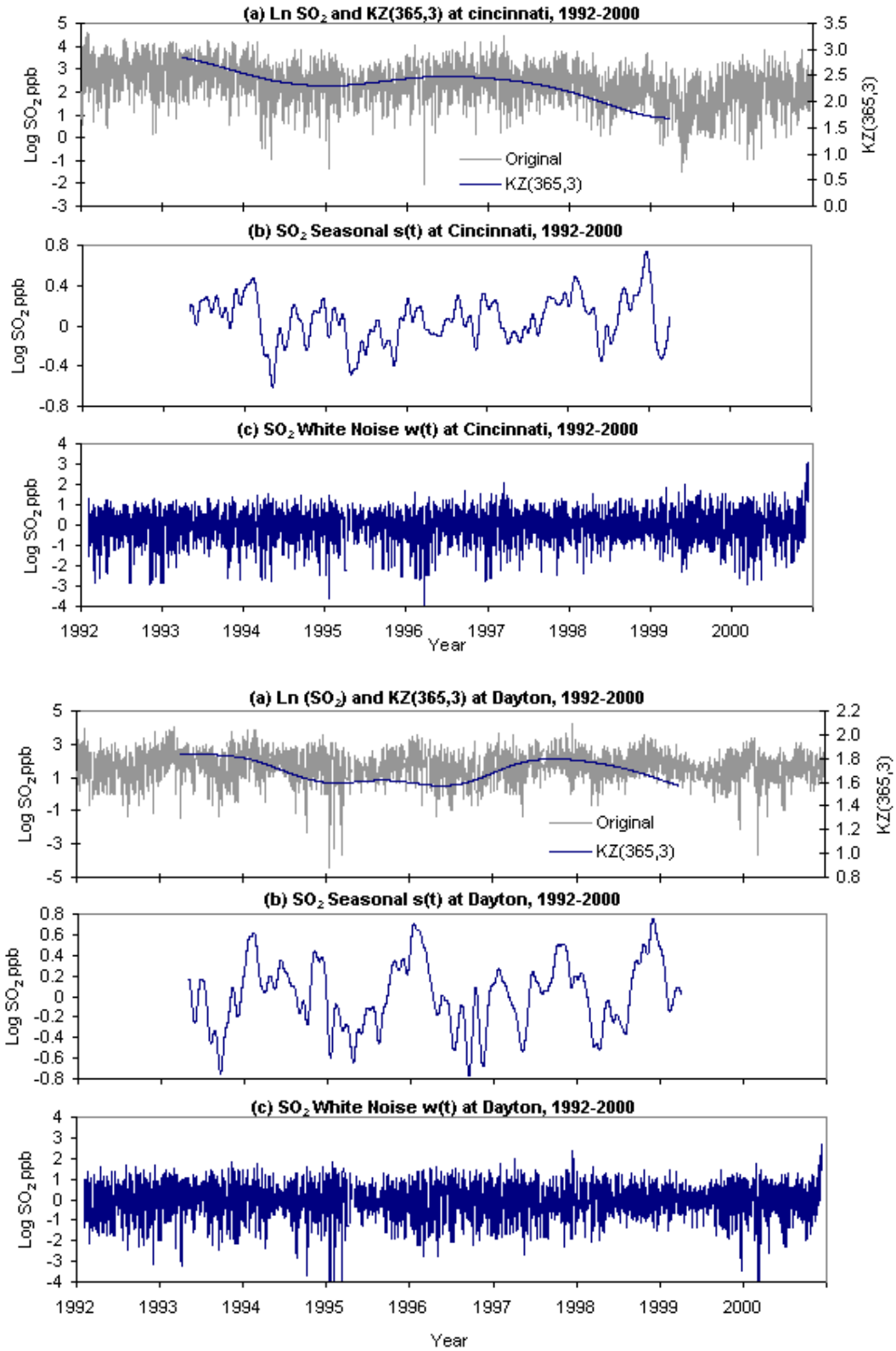


Figure D10. KZ Filter of SO_2 levels in (a) Cincinnati and (b) Dayton, 1992-2000

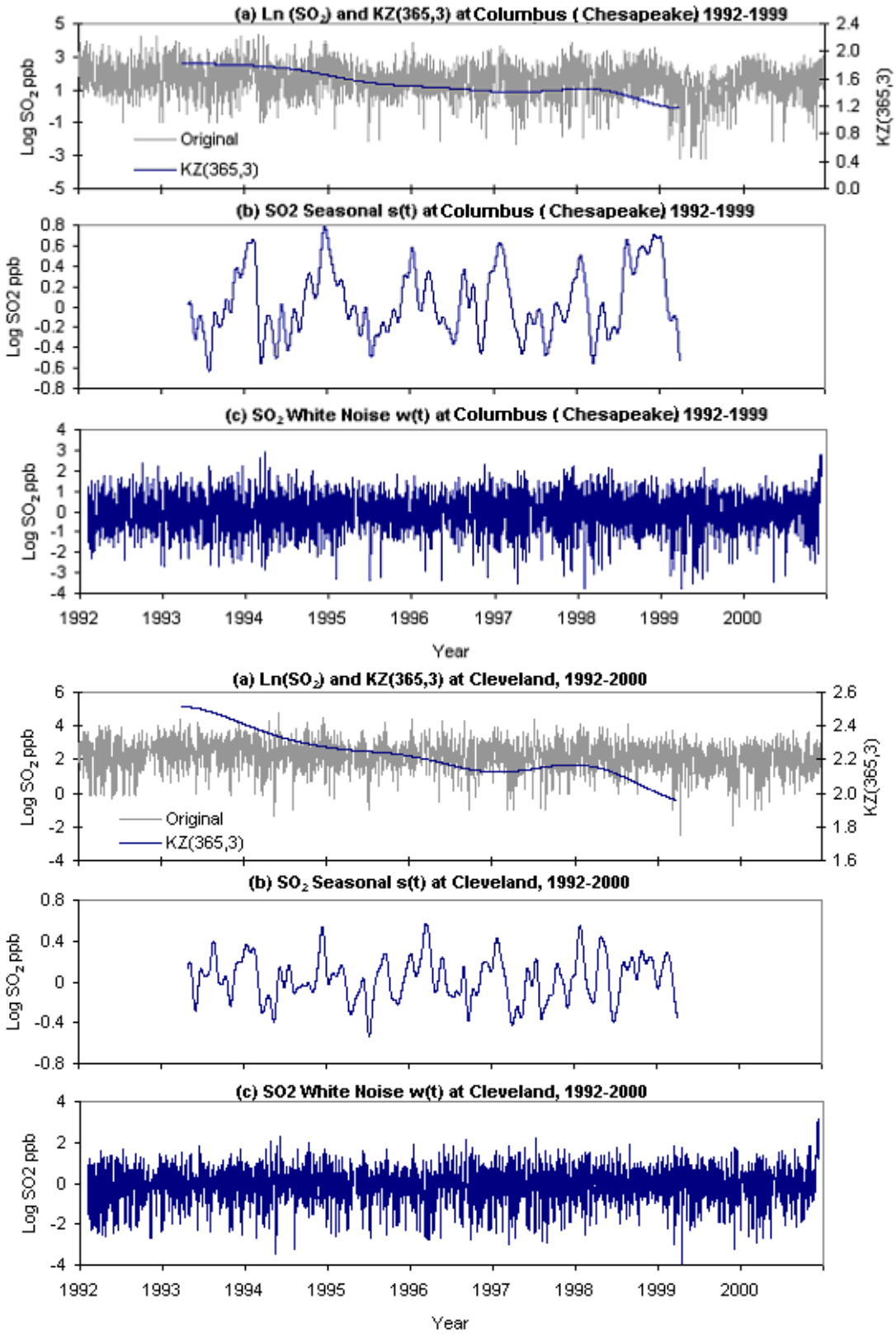


Figure D10. KZ Filter of SO_2 levels in (c) Columbus (Chesapeake) and (d) Cleveland, 1992-2000

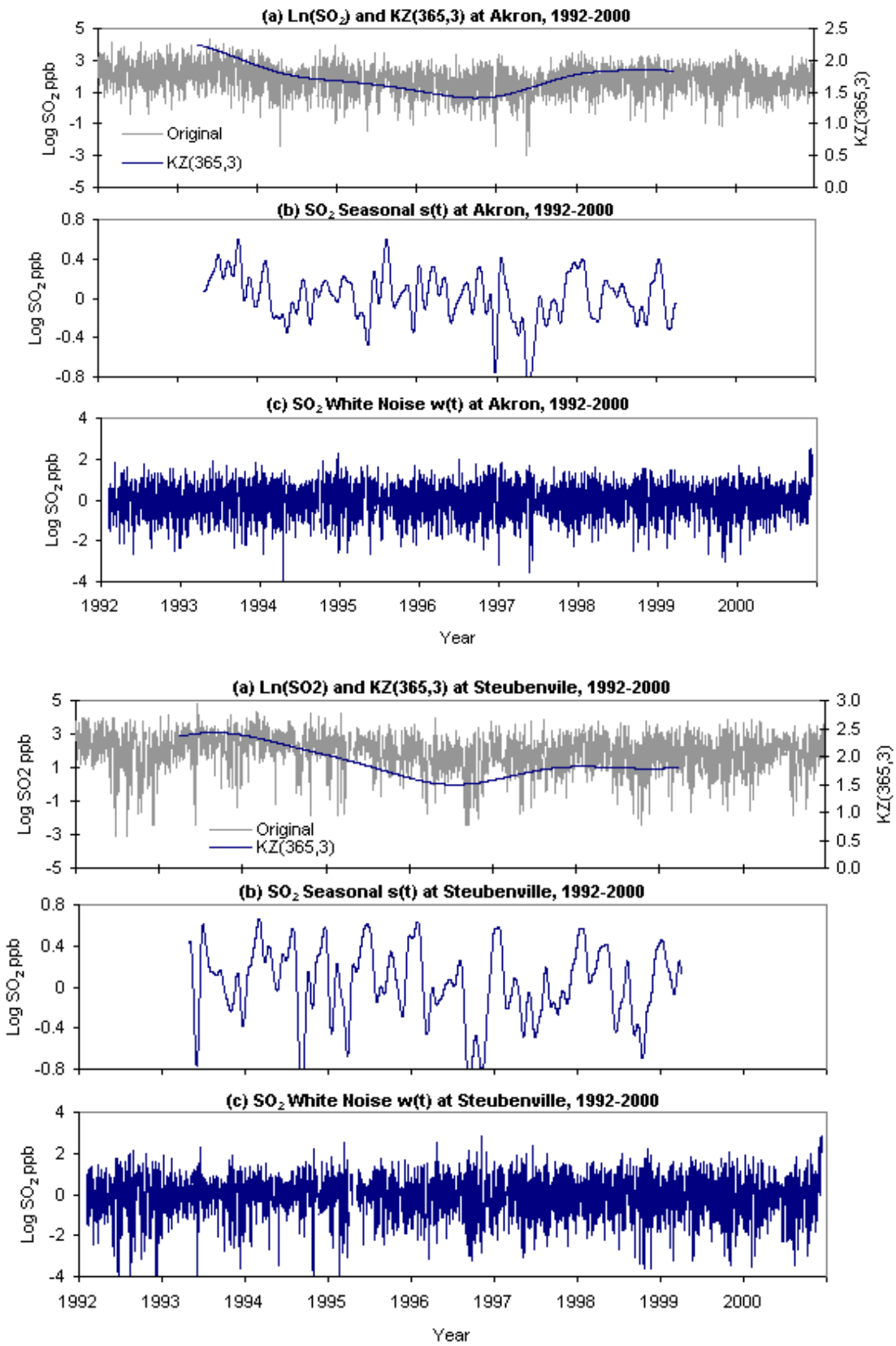


Figure D10. KZ Filter of SO_2 levels in (e) Akron and (f) Steubenville, 1992-2000

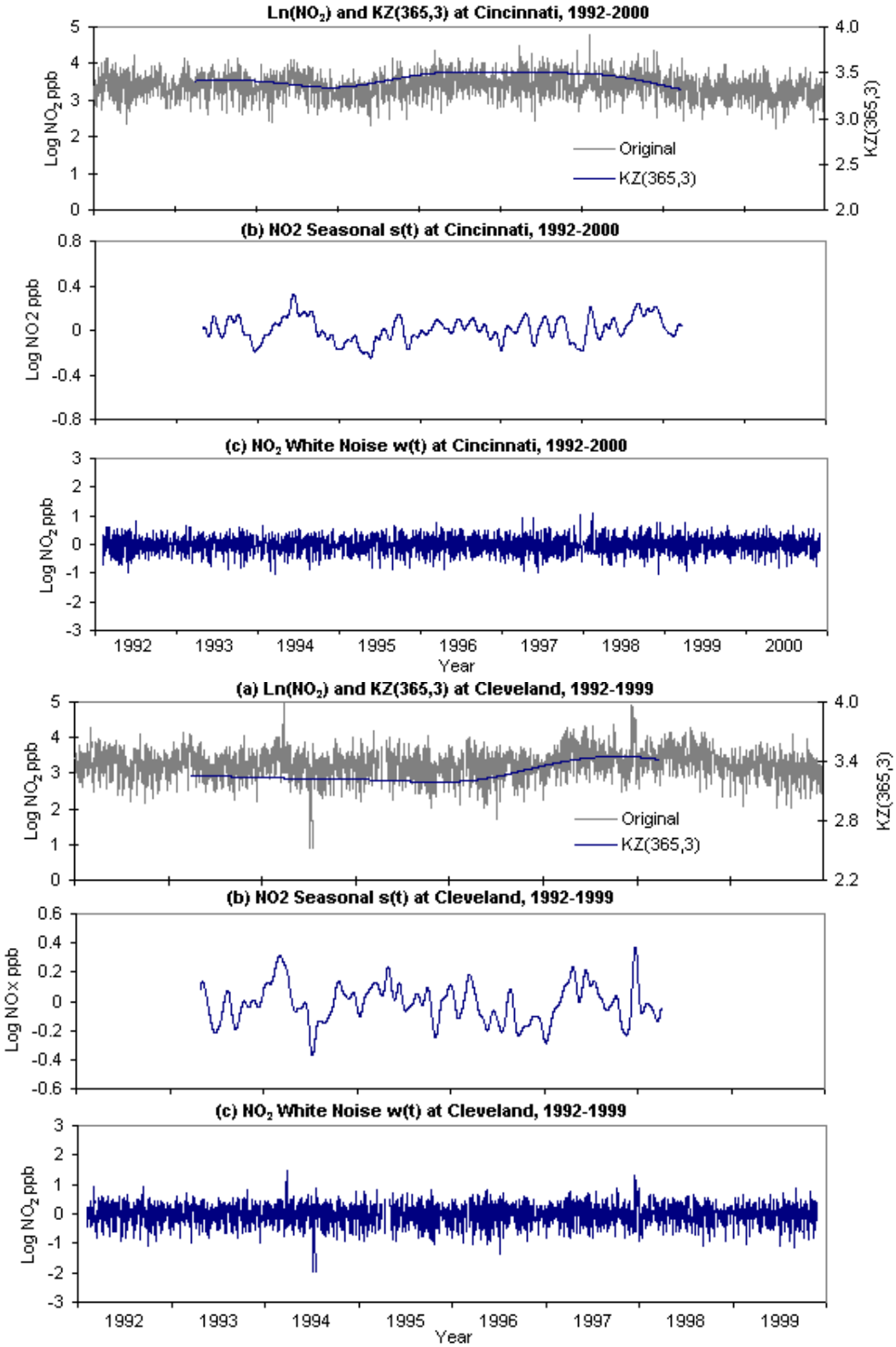


Figure D11. KZ Filter of NO_2 levels in (a) Cincinnati, 1992-2000 and (b) Cleveland, 1992-1999

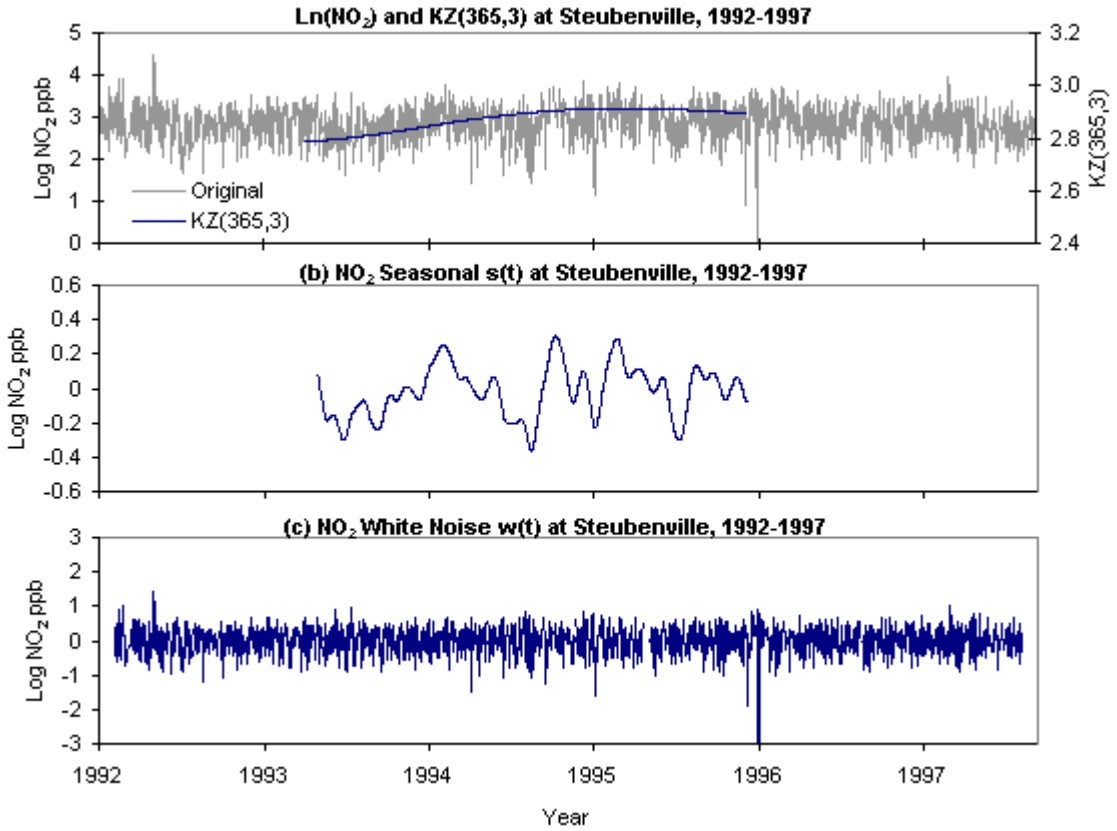


Figure D11. KZ Filter of NO_2 at (c) Steubenville, 1992-1997

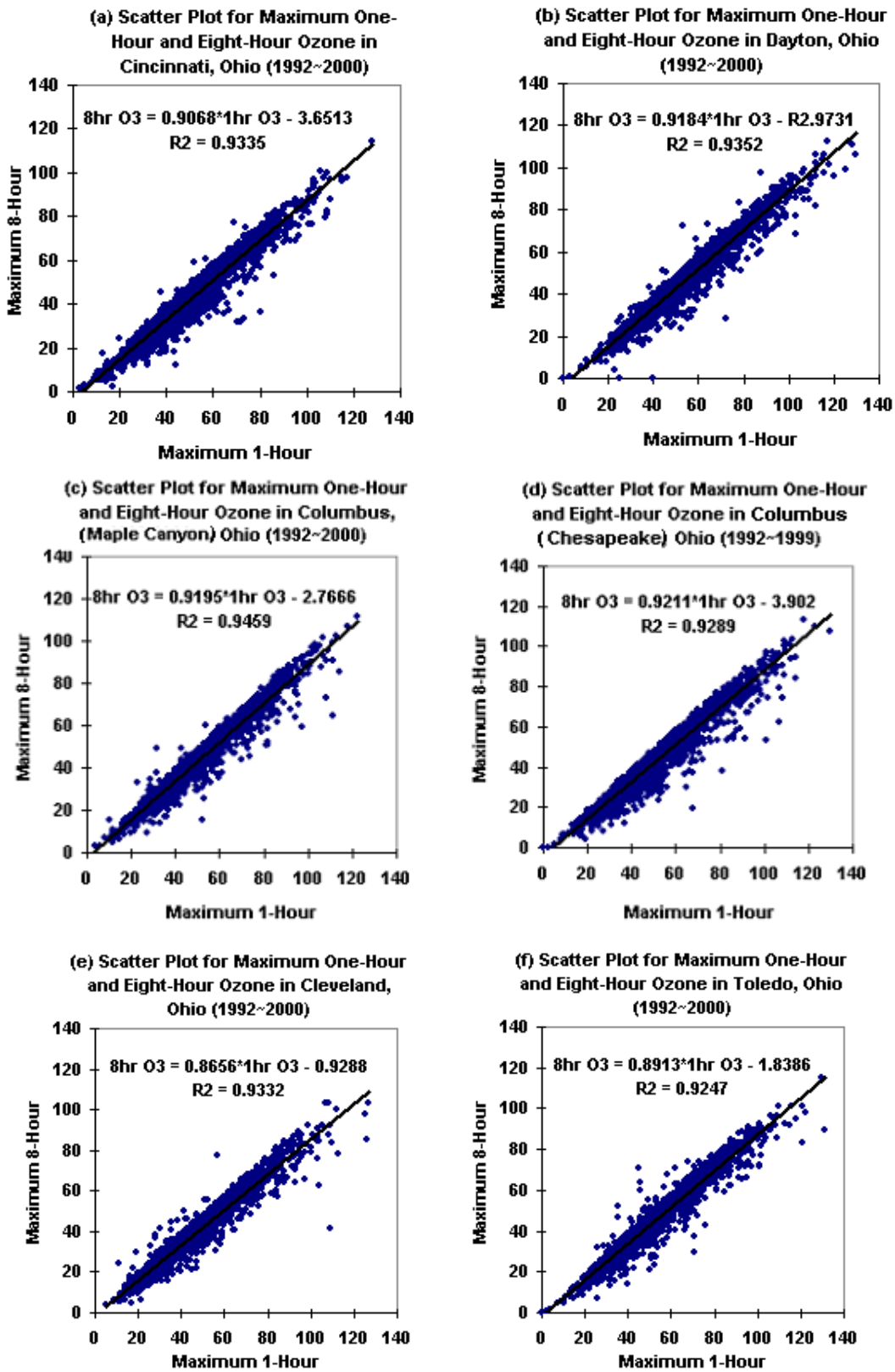


Figure D12. Co-relational plots of maximum eight-hour vs. one-hour ozone concentrations at the six monitoring site, 1992-2000

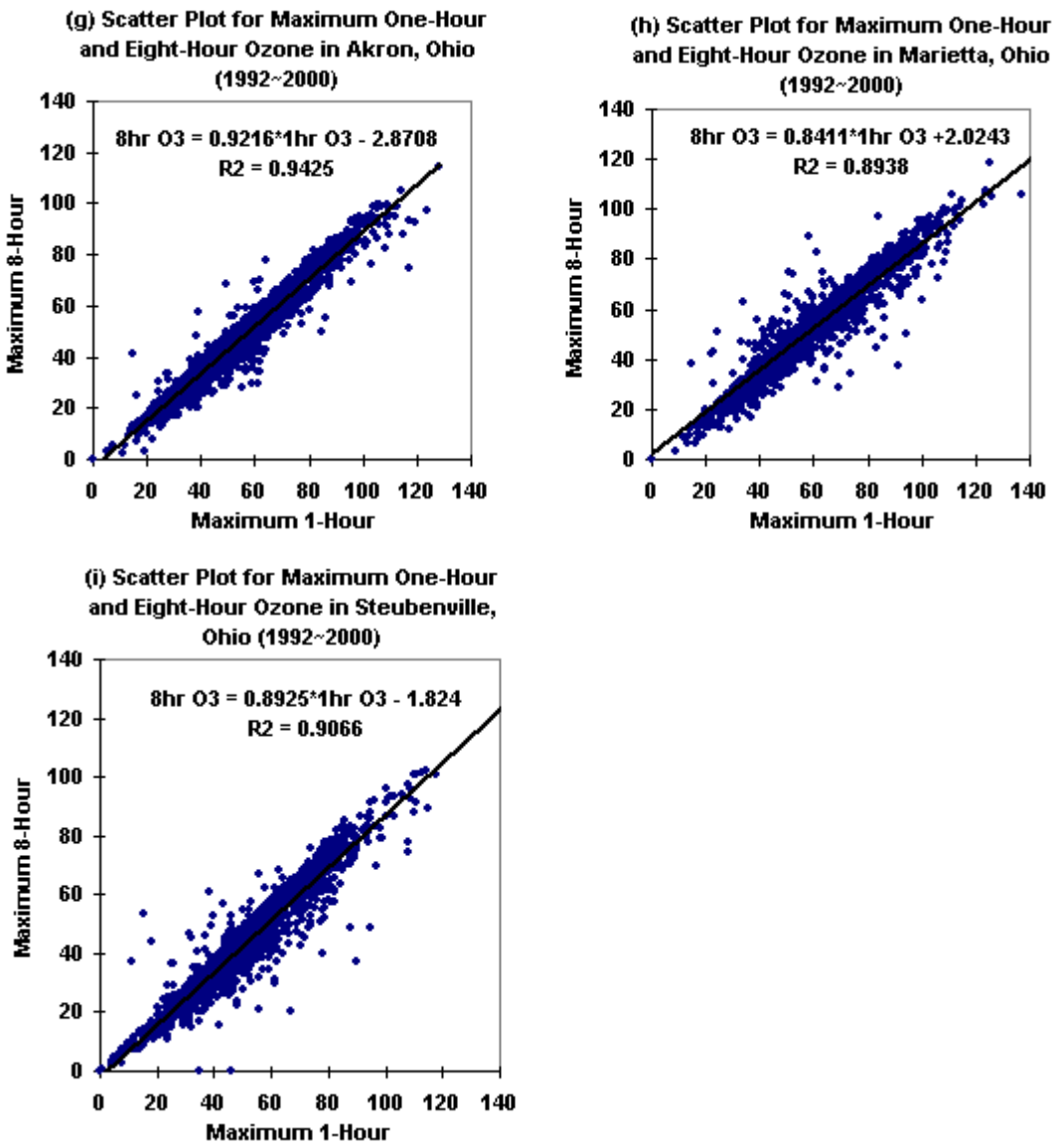


Figure D13. Co-relational plots of maximum eight-hour vs. one-hour ozone concentrations at the six monitoring site, 1992-2000

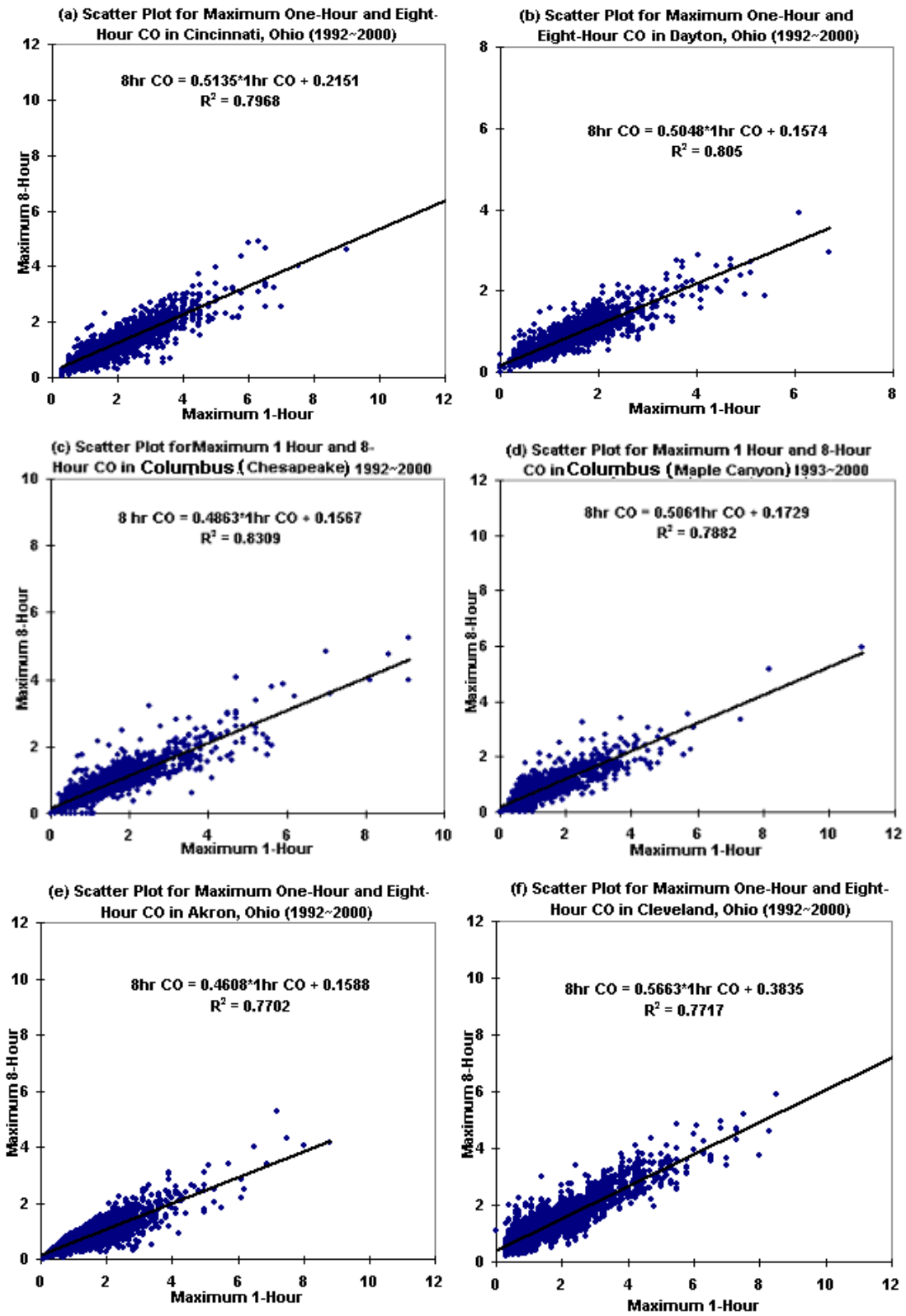


Figure D14. Correlation between 1 Hour and 8 Hour CO1992-2000: (a) Cincinnati, (b) Dayton, (c) Chesapeake, (d) Maple Canyon, (e) Akron and (f) Cleveland

Table D5. Regression equations for correlation analysis of one-hour vs. eight-hour

Monitoring Site	Regression Equation	R-value
Cincinnati	8hr O_3 = 0.9686 * 1hr O_3 – 3.6513	R^2 = 0.93
Dayton	8hr O_3 = 0.9184 * 1hr O_3 – 2.9731	R^2 = 0.94
Columbus (Maple Canyon)	8hr O_3 = 0.9195 * 1hr O_3 – 2.7666	R^2 = 0.95
Columbus (Chesapeake)	8hr O_3 = 0.9211 * 1hr O_3 - 3.902	R^2 = 0.93
Cleveland	8hr O_3 = 0.8651 * 1hr O_3 – 0.9288	R^2 = 0.93
Toledo	8hr O_3 = 0.8913 * 1hr O_3 – 1.8386	R^2 = 0.92
Akron	8hr O_3 = 0.9216 * 1hr O_3 –2.8708	R^2 = 0.94
Marietta	8hr O_3 = 0.8411 * 1hr O_3 + 2.0243	R^2 = 0.89
Steubenville	8hr O_3 = 0.8925 * 1hr O_3 – 1.824	R^2 = 0.91

Table D6. Climatological equivalency (S: Standard, E: Equivalency calculated with standard)

Monitoring Site	Basis	Maximum 1-hour Ozone (ppb)	Maximum 8-hour Ozone (ppb)
Cincinnati	1-hour	125 (S)	117.42 (E)
	8-hour	91.52 (E)	85 (S)
Dayton	1-hour	125 (S)	111.83 (E)
	8-hour	95.79 (E)	85 (S)
Columbus (Maple Canyon)	1-hour	125 (S)	111.61 (E)
	8-hour	95.45 (E)	85 (S)
Columbus (Chesapeake)	1-hour	125 (S)	111.24 (E)
	8-hour	96.52 (E)	85 (S)
Cleveland	1-hour	125 (S)	107.21 (E)
	8-hour	99.32 (E)	85 (S)
Toledo	1-hour	125 (S)	100.55 (E)
	8-hour	97.42(E)	85 (S)
Akron	1-hour	125 (S)	112.33 (E)
	8-hour	95.35(E)	85 (S)
Marietta	1-hour	125 (S)	107.16 (E)
	8-hour	98.65 (E)	85 (S)
Steubenville	1-hour	125 (S)	109.74 (E)
	8-hour	97.28 (E)	85 (S)

Table D7. Regression Equation for Correlation Analysis between 1hr CO and 8hr CO

Monitoring Site	Regression Equation	R-value
Cincinnati	8hr CO = 0.5135 * 1hr CO + 0.2151	$R^2 = 0.7968$
Dayton	8hr CO = 0.5048 * 1hr CO + 0.1574	$R^2 = 0.805$
Columbus (Chesapeake)	8hr CO = 0.4863 * 1hr CO + 0.1567	$R^2 = 0.8309$
Columbus (Maple Canyon)	8hr CO = 0.5061 * 1hr CO + 0.1729	$R^2 = 0.7882$
Akron	8hr CO = 0.4608 * 1hr CO + 0.1588	$R^2 = 0.7702$
Cleveland	8hr CO = 0.5663 * 1hr CO + 0.3835	$R^2 = 0.7717$

Table D8. Climatological equivalency (S: Standard, E: Equivalency calculated with standard)

Monitoring Site	Basis	Maximum 1-hour CO (ppm)	Maximum 8-hour CO (ppm)
Cincinnati	1-hour	35 (S)	18.19 (E)
	8-hour	17.11 (E)	9 (S)
Dayton	1-hour	35 (S)	17.83 (E)
	8-hour	17.52 (E)	9 (S)
Columbus (Chesapeake)	1-hour	35 (S)	17.18 (E)
	8-hour	18.19 (E)	9 (S)
Columbus (Maple Canyon)	1-hour	35 (S)	17.89 (E)
	8-hour	17.44 (E)	9 (S)
Akron	1-hour	35 (S)	16.29 (E)
	8-hour	19.19(E)	9 (S)
Cleveland	1-hour	35 (S)	20.2 (E)
	8-hour	15.22 (E)	9 (S)

Table D9. Regional analysis of ozone exceeding days for Cincinnati, Dayton, Toledo, Columbus (Maple Canyon), Cleveland, Akron, Marietta and Columbus (Chesapeake), 1992-2000 in ppb

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
5/9/92	56	50	52	41	39	32	43	39	31	27	62	40	41	32	41	29	38	33
5/10/92	67	57	57	54	69	63	68	62	49	41	70	63	84	71	63	59	64	58
5/11/92	78	71	72	70	64	62	72	64	103	**87**	96	**88**	80	77	84	77	72	66
5/12/92	75	52	74	58	78	71	82	76	83	80	88	63	88	81	93	**87**	70	59
5/13/92	52	46	49	44	45	37	47	38	59	38	53	47	53	43	62	54	67	60
6/16/93	71	62	83	75	69	63	82	73	43	34	94	79	77	67	103	**95**	76	72
6/17/93	69	63	100	**93**	101	**94**	86	82	92	**87**	85	78	104	**95**	124	108	31	30
6/18/93	87	70	77	68	89	71	92	76	73	63	76	65	90	80	93	82	27	25
6/19/93	81	72	105	**88**	91	78	103	**89**	85	74	88	79	84	80	93	77	33	30
6/20/93	41	33	42	38	67	61	66	55	69	59	32	27	72	60	91	81	59	54
6/21/93	44	41	50	45	45	37	46	39	55	48	52	45	47	39	44	36	45	26
6/22/93	84	67	62	59	73	57	58	43	66	52	80	64	77	65	75	70	77	73
6/23/93	68	61	83	75	62	56	80	75	51	42	80	73	70	62	86	57	74	66
6/24/93	68	60	103	**88**	94	**89**	91	75	103	**87**	89	80	98	**92**	92	82	49	40
6/25/93	30	27	57	46	81	73	58	53	65	57	42	37	76	66	91	**86**	69	64
7/22/93	68	61	72	60	60	36	70	57	39	35	74	63	65	50	40	36	84	73
7/23/93	80	75	65	56	96	70	73	60	50	39	77	71	96	69	40	38	82	62
7/24/93	95	77	105	**89**	95	**91**	81	70	66	55	121	**101**	102	**93**	110	**86**	76	69
7/25/93	97	**85**	95	82	97	**92**	91	77	105	**92**	103	84	106	**92**	124	**106**	55	52
7/26/93	75	63	62	56	70	62	60	53	72	59	76	43	73	60	*	*	94	83
8/13/93	53	43	63	58	83	66	71	61	85	57	*	*	78	68	87	81	43	37
8/14/93	87	72	77	71	108	**91**	84	78	70	60	94	80	108	**92**	90	**85**	86	82
8/15/93	110	**88**	101	**95**	98	**89**	93	82	109	**92**	95	**88**	105	**100**	100	**95**	84	71
8/16/93	72	45	66	57	72	65	65	61	65	59	*	*	65	60	106	84	72	64
8/17/93	44	37	60	56	73	68	62	56	71	65	*	*	74	70	59	48	74	62
8/18/93	75	69	84	74	57	53	62	41	59	47	*	*	62	51	78	70	70	64
8/19/93	89	76	**125**	**99**	85	78	86	81	84	70	**131**	**89**	79	72	91	80	54	46
8/20/93	48	44	60	58	69	60	65	53	70	57	54	47	82	68	60	57	84	64

Table D1. Continued.

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
6/3/94	38	34	72	67	60	53	58	53	34	30	78	69	58	48	68	64	83	82
6/4/94	54	49	87	83	94	83	92	**85**	62	50	84	79	101	**86**	100	**94**	78	74
6/5/94	48	45	116	**106**	85	83	100	**94**	84	67	101	**92**	88	**86**	111	**106**	66	63
6/6/94	63	45	66	57	81	74	76	71	77	61	55	44	71	68	77	70	50	40
6/7/94	62	41	80	71	87	79	80	63	70	64	32	13	91	84	104	78	71	57
6/8/94	45	31	37	27	61	38	35	19	42	30	30	23	61	35	68	48	73	68
6/9/94	60	45	63	58	75	65	67	58	54	44	62	51	64	59	78	70	97	83
6/10/94	76	68	97	**89**	82	69	98	**92**	60	51	95	**87**	70	64	101	**95**	69	64
6/11/94	45	43	90	84	89	84	90	**86**	103	85	82	78	89	**85**	91	80	80	71
6/12/94	36	29	82	73	67	62	79	77	61	56	65	57	66	61	108	**93**	73	64
6/13/94	55	48	83	76	72	69	66	61	69	59	66	60	75	67	80	72	82	69
6/14/94	51	46	85	76	76	70	66	38	57	45	66	60	78	72	79	70	90	80
6/15/94	68	57	76	71	78	72	62	45	58	46	73	67	78	64	109	83	98	83
6/16/94	61	37	78	69	81	51	101	53	80	69	68	57	88	72	102	**89**	109	**93**
6/17/94	87	71	96	84	72	68	85	77	69	63	92	79	92	**85**	112	**93**	82	73
6/18/94	109	83	89	76	87	65	86	79	92	84	98	77	86	74	90	78	80	73
6/19/94	89	78	94	**90**	82	68	80	74	69	56	88	81	110	**88**	110	**90**	71	55
6/20/94	82	69	98	78	85	72	102	75	93	72	92	77	95	78	**126**	**105**	68	62
6/21/94	62	52	97	80	68	63	85	74	83	78	75	68	87	77	87	79	72	59
6/22/94	98	**87**	103	**95**	81	70	89	83	40	35	113	**93**	78	62	85	66	43	38
6/23/94	66	57	67	53	89	83	58	42	46	30	72	56	78	69	100	83	30	29
7/11/94	62	52	76	67	55	48	55	51	58	51	87	69	65	52	49	45	88	81
7/12/94	66	59	118	**101**	76	73	87	83	**125**	**98**	103	**87**	81	79	73	67	45	32
7/13/94	21	14	45	34	94	**88**	*	*	93	64	37	26	96	84	41	34	60	49
7/14/94	33	24	61	57	62	51	62	55	66	52	50	44	56	47	29	25	56	54
7/15/94	24	16	65	59	52	16	61	47	68	61	43	34	67	62	54	43	77	68

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
6/16/95	75	64	76	52	69	65	95	80	34	30	97	84	89	75	86	77	114	**102**
6/17/95	84	75	87	83	100	**94**	91	81	46	43	115	**92**	109	**99**	95	85	100	**91**
6/18/95	103	**97**	90	**86**	104	**96**	87	83	50	48	97	**90**	96	**93**	94	91	72	62
6/19/95	103	**94**	87	83	98	**93**	95	87	65	53	96	**87**	100	**92**	109	98	78	40
6/20/95	59	41	87	70	90	80	76	58	86	67	59	49	92	78	110	99	87	71
6/21/95	86	53	82	57	92	81	94	70	70	59	95	66	83	70	25	13	62	52
6/22/95	78	57	89	74	83	76	76	68	67	62	90	75	119	**92**	76	63	53	50
6/23/95	55	50	71	52	77	70	71	62	91	77	73	61	72	66	52	38	60	47
6/24/95	54	44	62	52	62	47	51	46	50	42	73	54	63	48	67	58	78	62
6/25/95	89	76	93	**85**	61	49	65	56	60	51	66	58	67	51	71	62	62	50
6/26/95	56	45	67	51	73	59	70	61	58	44	68	50	59	36	100	64	53	45
7/11/95	93	69	78	72	90	80	90	72	65	59	91	79	97	80	86	49	108	**98**
7/12/95	101	**91**	115	**104**	87	84	130	**108**	78	66	**130**	**115**	96	**89**	83	80	109	**96**
7/13/95	86	76	101	**93**	91	**88**	95	**85**	103	**91**	91	78	90	**86**	*	*	100	**87**
7/14/95	86	79	93	**90**	93	83	101	**97**	88	76	87	67	89	82	108	79	79	74
7/15/95	101	76	103	69	98	84	107	80	91	82	101	72	101	84	91	38	60	47
7/29/95	74	66	67	63	63	62	64	59	77	67	79	71	68	66	64	60	86	82
7/30/95	87	80	94	78	100	**87**	86	77	64	57	99	**88**	87	80	78	73	102	**93**
7/31/95	**128**	**115**	109	85	92	85	76	72	79	65	109	**97**	87	84	112	**99**	111	**91**
8/1/95	58	42	95	75	91	**89**	97	81	96	**87**	71	55	95	**89**	111	**94**	70	65
8/2/95	78	62	80	67	87	78	74	71	65	56	96	82	77	73	95	81	17	15
8/18/95	65	36	60	45	78	63	53	45	62	50	54	43	85	50	93	69	118	**101**
8/19/95	74	50	74	61	89	81	93	79	101	**87**	70	60	105	**87**	69	61	83	72
8/20/95	71	64	70	63	83	72	83	76	88	75	78	71	117	**94**	85	76	44	42
8/21/95	82	64	76	65	76	63	108	74	89	66	65	59	78	70	88	83	80	59
8/22/95	57	52	49	38	46	39	46	36	40	28	59	52	41	39	56	52	88	82
8/23/95	81	68	78	69	68	56	81	67	47	39	79	73	70	63	74	62	68	57
8/24/95	109	81	79	61	67	55	101	83	40	28	93	81	58	52	83	44	108	78
8/25/95	83	68	62	53	68	54	54	50	41	39	86	72	59	47	84	70	101	**93**
8/26/95	83	71	81	71	101	**88**	98	81	83	69	88	76	124	**98**	110	**90**	90	37
8/27/95	65	58	94	84	90	84	90	85	74	67	70	57	88	71	96	84	15	14

Table D9. Continued.

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
6/15/96	83	77	84	81	90	79	92	84	67	59	70	64	93	84	85	71	82	79
6/16/96	106	**93**	93	**90**	89	84	94	**89**	84	73	88	84	92	**87**	105	**93**	69	63
6/17/96	80	64	85	78	84	76	97	73	71	54	84	68	82	67	79	72	71	59
6/18/96	60	41	62	54	70	57	68	55	51	47	65	50	60	46	67	62	70	64
6/19/96	71	63	69	56	78	70	79	71	77	67	62	55	71	67	61	44	72	63
6/20/96	58	56	67	55	65	62	63	60	71	64	56	53	74	66	79	62	68	65
6/21/96	102	77	84	77	79	70	83	75	65	59	69	54	81	77	67	62	56	49
6/22/96	70	66	79	70	68	63	76	71	72	63	79	72	71	67	76	70	66	46
6/23/96	115	**96**	98	**87**	66	62	76	74	40	26	92	78	70	64	65	63	41	35
6/24/96	51	38	66	63	59	43	68	50	83	69	71	56	60	48	76	58	47	40
6/25/96	60	51	55	51	44	39	55	38	51	39	56	51	50	42	54	50	57	44
6/26/96	78	67	68	62	58	48	68	62	38	34	74	65	62	52	61	55	78	75
6/27/96	103	**96**	98	**86**	95	75	101	91	85	64	106	**97**	79	72	78	74	86	80
6/28/96	107	**98**	112	**106**	92	**86**	100	91	110	84	96	**91**	113	**99**	113	**100**	85	69
6/29/96	106	**101**	101	**95**	94	**91**	118	114	92	82	107	**96**	96	**93**	99	**92**	71	64
6/30/96	72	67	86	79	81	70	89	81	88	85	78	74	84	76	83	79	80	71
7/1/96	75	65	97	**90**	74	69	77	75	49	43	98	**86**	84	71	75	67	40	32
7/2/96	82	74	91	**86**	85	78	91	73	87	82	91	82	98	**91**	79	67	51	45
7/3/96	52	44	52	48	43	32	55	51	40	35	49	42	43	38	43	35	69	59
7/4/96	73	66	65	60	51	44	56	52	59	54	62	56	57	51	27	25	100	**92**
7/5/96	84	72	87	84	72	68	89	84	76	68	88	78	76	73	50	45	94	**86**
7/6/96	90	85	117	**113**	89	**85**	101	97	94	**88**	108	**92**	98	**91**	67	61	63	59
7/7/96	81	69	107	**99**	98	**89**	104	95	108	**103**	90	74	103	**96**	46	43	47	47
7/8/96	77	61	77	70	70	63	80	71	72	48	76	65	66	62	33	31	53	47
8/3/96	72	67	88	84	74	69	76	68	85	78	82	75	79	74	75	70	77	61
8/4/96	85	76	87	75	72	68	92	86	91	**85**	88	83	86	75	84	76	78	72
8/5/96	74	65	106	**89**	90	81	85	79	94	82	91	75	94	82	85	75	87	75
8/6/96	97	71	*	*	84	80	96	88	100	81	90	80	94	**89**	97	82	82	58
8/7/96	76	69	107	**89**	88	79	89	70	86	81	84	80	87	80	97	87	41	35
8/8/96	40	20	67	60	71	52	65	46	62	57	56	43	63	49	76	51	42	34

Table D9. Continued.

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
8/24/96	54	46	51	47	59	51	59	51	51	46	59	50	57	52	38	33	74	49
8/25/96	72	66	69	64	77	67	73	61	68	66	76	68	76	72	62	58	78	62
8/26/96	85	69	99	**90**	91	80	92	79	72	65	106	**90**	80	74	88	75	71	61
8/27/96	33	19	93	79	80	75	107	62	85	71	65	47	98	**87**	94	85	74	69
8/28/96	74	63	77	70	82	69	82	75	61	55	86	74	85	76	79	70	70	57
8/29/96	75	68	75	71	68	63	71	68	50	43	85	59	68	60	74	65	71	67
6/21/97	62	56	79	69	74	69	75	66	70	65	72	62	83	74	70	64	87	83
6/22/97	64	60	63	59	69	59	64	61	50	46	57	55	78	67	57	52	53	42
6/23/97	87	74	77	74	77	70	97	82	66	54	118	**95**	79	76	106	**97**	62	55
6/24/97	87	72	**130**	**106**	87	**86**	100	**91**	82	76	96	84	99	**95**	110	**90**	75	67
6/25/97	77	71	82	73	85	76	81	38	65	56	76	73	76	69	76	70	75	70
6/26/97	57	52	66	57	75	54	59	54	64	56	58	47	88	69	52	44	51	44
7/10/97	58	54	52	46	50	47	54	51	34	29	66	59	52	45	58	44	81	77
7/11/97	96	**86**	85	78	93	82	92	**85**	59	51	94	84	109	**91**	86	77	80	69
7/12/97	115	**98**	95	**89**	98	**90**	101	**97**	87	76	100	**88**	112	**99**	79	75	64	60
7/13/97	110	**97**	88	84	89	**86**	91	**89**	86	81	78	76	97	**94**	80	77	71	57
7/14/97	58	48	71	49	83	78	93	81	70	62	68	46	84	78	97	90	78	61
7/15/97	63	53	68	59	62	53	61	59	67	55	64	55	68	59	68	64	54	48
7/16/97	75	65	70	64	74	63	67	62	69	60	68	63	76	65	66	62	68	55
7/17/97	75	70	87	80	61	51	74	65	60	52	74	70	72	65	80	71	80	73
7/18/97	83	77	96	**90**	81	74	79	75	87	79	101	**90**	85	80	89	82	48	41
7/19/97	93	75	54	50	54	49	58	50	38	34	68	61	55	50	77	68	43	39
7/20/97	117	**98**	85	74	69	60	84	76	60	54	84	75	90	76	77	74	42	32
7/21/97	93	80	93	71	75	66	93	76	46	36	101	73	73	60	90	**85**	68	57

Table D9. Continued.

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
5/13/98	76	72	96	77	55	49	68	59	40	29	92	73	59	47	80	68	*	*
5/14/98	88	74	95	**86**	101	**90**	105	**94**	85	73	87	78	110	**98**	80	73	*	*
5/15/98	97	76	102	**91**	122	**112**	104	**93**	73	69	105	**89**	**128**	**114**	115	**103**	*	*
5/16/98	73	68	70	67	77	67	75	69	63	53	64	61	82	77	62	59	*	*
5/17/98	82	76	80	74	75	72	77	74	58	53	69	67	79	78	78	74	*	*
5/18/98	75	62	82	77	79	73	73	52	57	52	83	70	84	80	85	77	*	*
5/19/98	115	**97**	101	**95**	102	**97**	109	**103**	72	68	109	**85**	114	**105**	103	**92**	*	*
5/20/98	60	54	69	61	74	70	77	72	55	51	57	33	98	**88**	79	63	*	*
5/21/98	70	63	65	60	57	51	57	55	35	32	70	61	64	58	61	58	*	*
6/22/98	65	52	71	63	82	78	82	70	65	57	67	57	86	82	53	52	74	66
6/23/98	56	48	66	61	57	49	56	50	67	60	58	53	55	46	47	38	51	45
6/24/98	87	75	93	79	98	85	82	74	98	83	93	83	104	**89**	89	74	85	75
6/25/98	100	**86**	94	78	100	**89**	105	**96**	86	76	86	80	96	**87**	97	81	89	83
6/26/98	63	58	75	70	77	59	81	70	81	73	68	63	84	79	85	79	86	70
6/27/98	57	51	53	49	65	59	64	61	47	36	55	49	67	55	66	56	53	43
6/28/98	62	56	55	49	68	58	76	64	80	65	51	46	68	58	61	50	68	57
7/11/98	64	62	55	53	62	53	59	56	37	36	65	60	61	53	61	52	63	50
7/12/98	87	81	77	73	67	61	82	76	61	56	79	77	83	75	70	65	79	69
7/13/98	85	77	97	**93**	97	**92**	100	**91**	88	69	116	**101**	105	**98**	103	**90**	72	55
7/14/98	25	18	52	43	88	85	61	52	84	82	49	40	92	85	83	72	93	82
7/15/98	39	27	56	41	71	63	66	59	59	53	43	31	70	55	61	53	41	32
8/2/98	81	72	75	72	84	77	80	76	61	56	79	73	74	70	71	66	66	59
8/3/98	72	65	73	67	107	**93**	84	75	75	65	74	69	98	**91**	95	**87**	62	58
8/4/98	65	54	70	44	102	**90**	82	62	74	65	*	*	96	**89**	93	**87**	66	60
8/5/98	74	66	63	39	106	**88**	71	53	76	52	47	29	60	55	89	**85**	62	57
8/6/98	81	68	112	82	107	**102**	98	**89**	84	79	88	69	99	**94**	104	**93**	50	41
8/7/98	101	**89**	92	83	113	**103**	107	**96**	112	**100**	102	77	107	**99**	88	83	55	47
8/8/98	74	66	106	**89**	82	74	103	**93**	88	79	93	66	85	75	49	47	41	36
8/9/98	45	41	59	51	77	66	61	54	49	38	53	44	69	58	78	56	39	32

Table D9. Continued.

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max
9/11/98	65	56	77	68	74	67	85	76	60	55	82	71	76	71	78	71	48	43
9/12/98	85	76	93	84	92	84	109	**100**	76	66	95	**85**	87	82	97	**90**	64	55
9/13/98	101	**88**	102	**96**	98	**89**	113	**104**	96	84	102	**91**	102	**94**	**125**	**106**	58	48
9/14/98	74	61	96	74	114	**85**	108	**91**	87	79	79	65	101	83	100	81	50	35
9/15/98	51	41	58	53	78	67	61	56	50	38	57	51	60	53	84	80	38	36
5/28/99	89	78	85	80	80	75	79	75	43	38	42	40	84	81	87	81	88	81
5/29/99	103	**95**	106	**98**	109	**95**	99	**93**	40	38	43	40	79	75	93	**90**	77	75
5/30/99	83	80	100	**96**	103	**98**	**101**	**96**	63	58	53	49	98	**90**	99	**96**	92	82
5/31/99	55	47	64	51	59	52	63	58	37	33	26	23	77	70	72	67	83	79
6/1/99	46	38	44	34	39	34	49	44	32	28	20	18	38	33	41	44	50	55
6/8/99	86	79	79	74	71	68	74	72	79	74	40	27	93	83	79	72	79	74
6/9/99	85	68	107	**85**	111	**99**	112	**94**	60	48	69	54	112	**95**	89	83	74	56
6/10/99	103	**93**	**127**	**113**	118	**107**	123	**110**	77	70	122	**98**	102	**95**	123	**102**	111	**101**
6/11/99	93	**86**	**128**	**111**	102	**94**	98	**92**	94	74	110	**101**	103	**92**	97	**86**	113	**102**
6/12/99	95	69	96	73	111	**91**	114	**95**	96	78	85	72	101	**93**	75	65	94	87
6/13/99	89	82	91	77	104	**95**	98	**92**	72	68	73	60	86	80	83	70	63	68
6/14/99	56	54	58	55	54	47	54	51	50	40	52	50	61	49	46	53	53	46
6/20/99	87	83	84	81	89	83	89	84	67	62	81	77	78	73	83	73	79	77
6/21/99	84	79	94	**89**	92	**86**	86	82	59	49	77	73	63	58	82	73	73	67
6/22/99	102	**88**	84	78	86	78	88	79	61	55	90	80	85	76	60	65	79	73
6/23/99	83	69	110	**96**	97	**91**	104	**97**	72	64	93	**88**	93	**86**	82	78	77	64
6/24/99	44	33	42	38	56	52	57	52	49	43	57	48	68	65	74	69	72	64
7/13/99	63	54	75	69	81	73	78	72	64	58	54	32	81	71	69	61	75	55
7/14/99	91	72	91	81	96	**87**	88	82	91	80	*	*	98	85	76	60	62	56
7/15/99	95	**88**	95	83	86	76	89	83	68	66	*	*	88	84	107	**98**	85	83
7/16/99	78	72	97	**89**	76	72	82	79	72	65	83	80	102	**95**	**125**	**118**	96	92
7/17/99	82	66	72	67	80	74	89	80	64	59	75	68	80	79	84	**97**	86	81

Table D9. Continued.

Date	Cincinnati		Dayton		Columbus (Maple Canyon)		Columbus (Chesapeake)		Cleveland		Toledo		Akron		Marietta		Steubenville	
	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	1hr Max	8hr Max	8hr Max	1hr Max
8/14/99	26	20	25	20	24	18	31	25	30	21	45	40	44	26	23	43	45	43
8/15/99	55	51	51	45	50	45	57	52	31	27	42	40	54	47	33	29	37	33
8/16/99	75	67	83	75	78	69	88	76	99	**92**	68	62	78	67	85	78	65	55
8/17/99	93	80	96	84	98	**85**	110	**98**	97	66	66	61	105	**94**	103	**97**	86	85
8/18/99	64	51	48	39	50	44	59	54	37	33	37	33	43	38	58	**89**	43	57
8/19/99	46	42	54	41	50	37	53	39	29	25	35	25	40	36	61	50	38	31
6/1/00	109	**100**	86	83	88	83			66	56	87	78	82	74	80	74	70	67
6/2/00	69	77	78	**84**	79	78			67	58	68	74	76	71	81	76	76	70
6/3/00	64	57	53	50	54	49			35	33	49	46	38	48	41	52	39	49
6/8/00	90	84	87	84	81	76			78	72	89	84	88	84	74	72	73	71
6/9/00	107	**98**	112	**102**	105	**97**			94	**89**	91	**88**	106	**100**	103	**94**	100	**96**
6/10/00	85	80	88	**97**	84	80			92	85	85	81	103	**96**	113	**98**	103	**93**
6/11/00	86	75	64	73	69	58			57	77	46	60	64	78	68	69	79	78
6/12/00	92	**86**	71	58	111	65			11	25	30	26	27	34	45	56	45	47
6/13/00	90	77	50	46	64	63			53	35	62	51	66	61	68	58	76	70
6/14/00	51	51	61	52	94	64			75	61	76	56	85	73	73	63	79	62
7/8/00	92	76	74	70	72	69			52	47	59	55	59	53	76	68	60	52
7/9/00	103	**86**	84	75	88	82			67	63	70	64	86	82	87	82	95	**86**
7/10/00	74	75	69	70	94	76			42	39	48	52	61	66	64	69	74	76
7/11/00	48	42	53	51	66	62			37	31	49	47	54	50	54	50	66	57
7/12/00	65	59	68	60	76	72			39	38	68	61	61	54	71	64	76	68
7/13/00	77	67	70	69	77	74			61	55	97	84	110	**95**	78	73	86	80

Table D10. High Concentration and High Frequency in Correlation With Wind Direction.

	Cincinnati	Dayton	Columbus (Maple Canyon)	Columbus (Chesapeake)	Akron	Cleveland	Marietta	Toledo	Steubenville
PM_{10}	*E/SW	-	S/SW	E/SW		S/SW	-	-	S/SW
CO	E/SW	SW/SW	SE/SW	E/SW	N/SW	NW/SW	-	-	-
SO_2	SW/SW	S/SW	-	W/SW	W/SW	NE/SW	-	-	S/SW
NO_2	S/SW	-	-	-	-	SE/SW	-	-	NW/SW

* E/SW means East High Directional Concentration / Southwest High Directional Frequency of Wind.

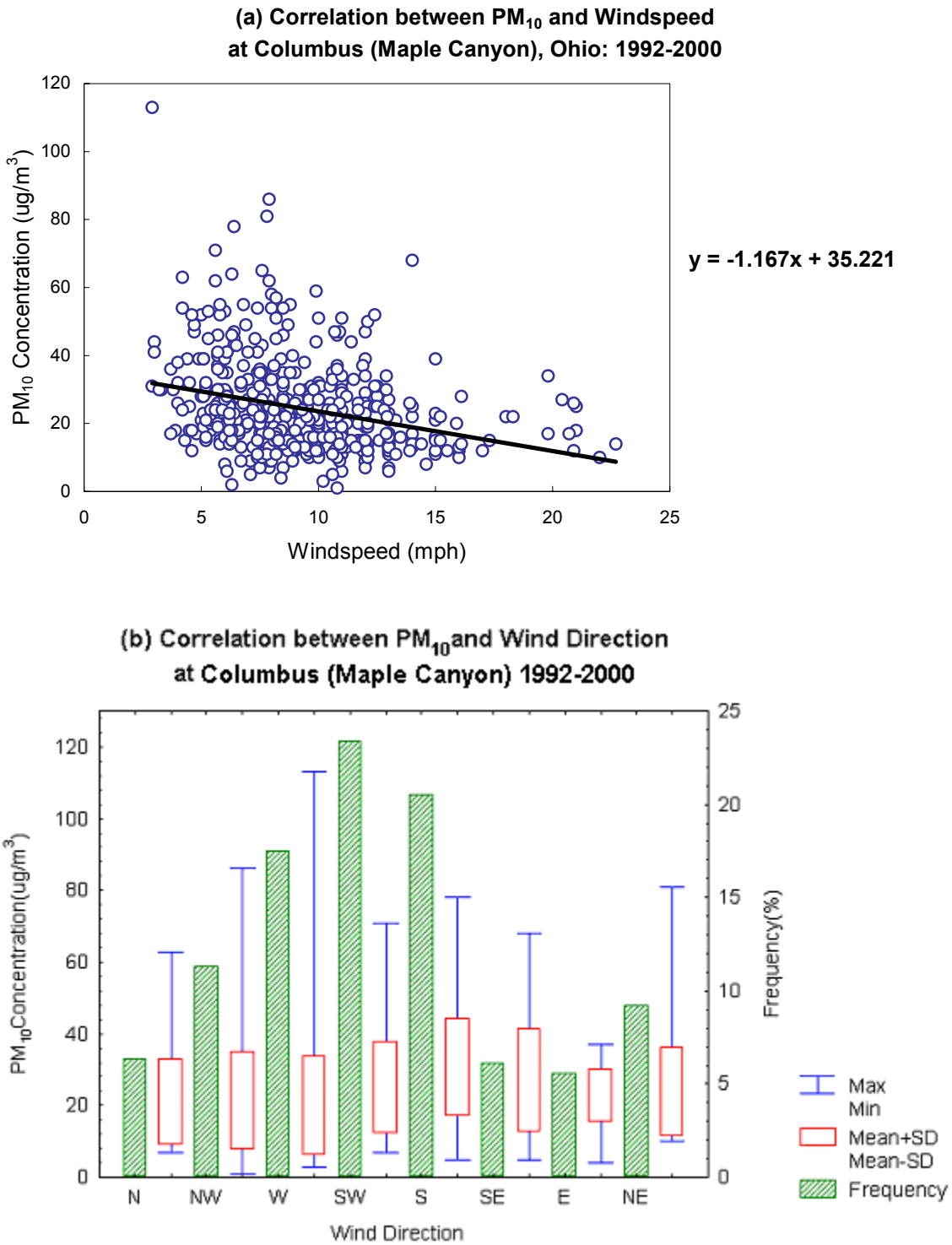


Figure D15. Correlations between PM_{10} and weather components at Columbus (Maple Canyon), Ohio in 1992-2000: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction

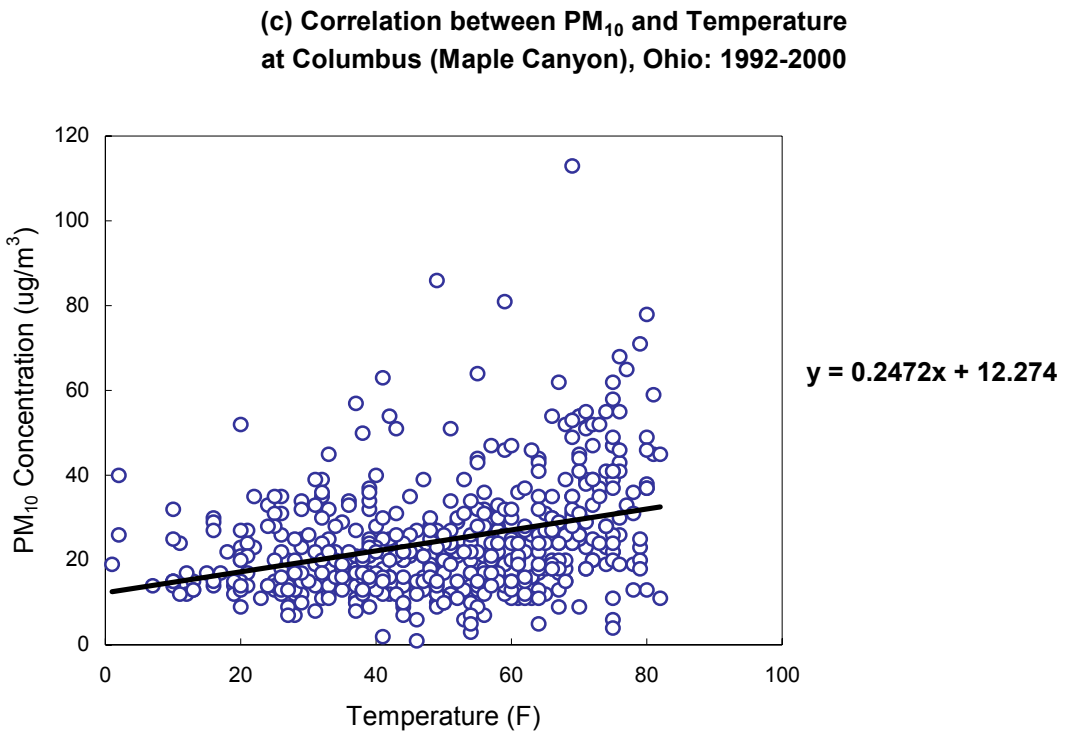
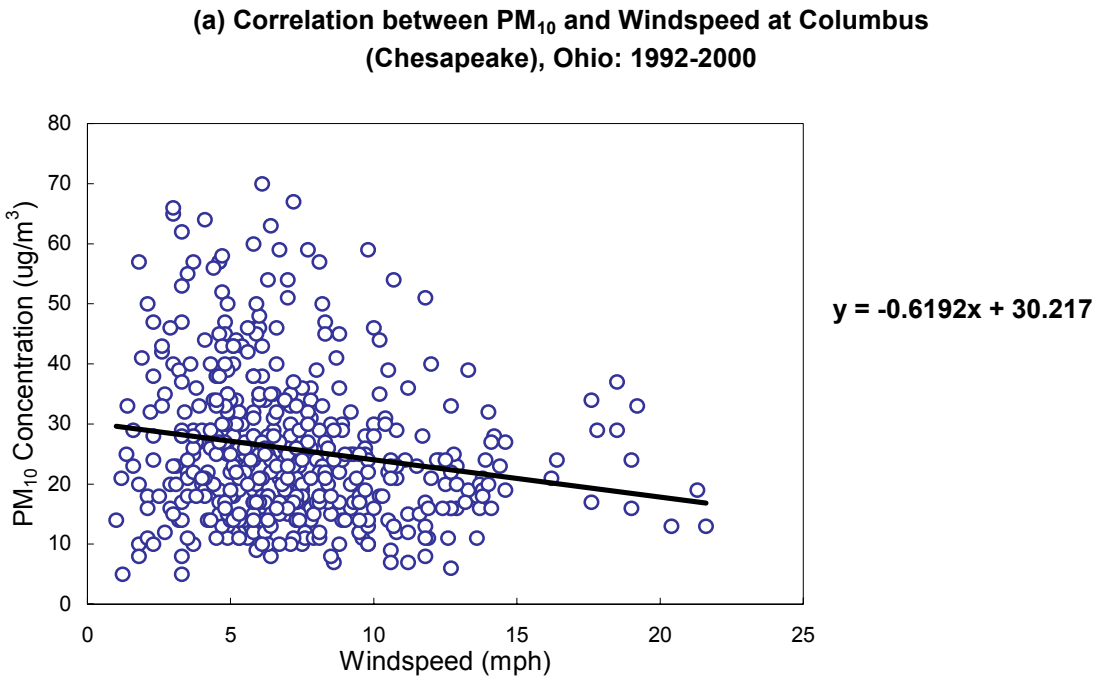


Figure D15. Correlations between PM_{10} and weather components at Columbus (Maple Canyon), Ohio in 1992-1999: (c) PM_{10} vs. temperature



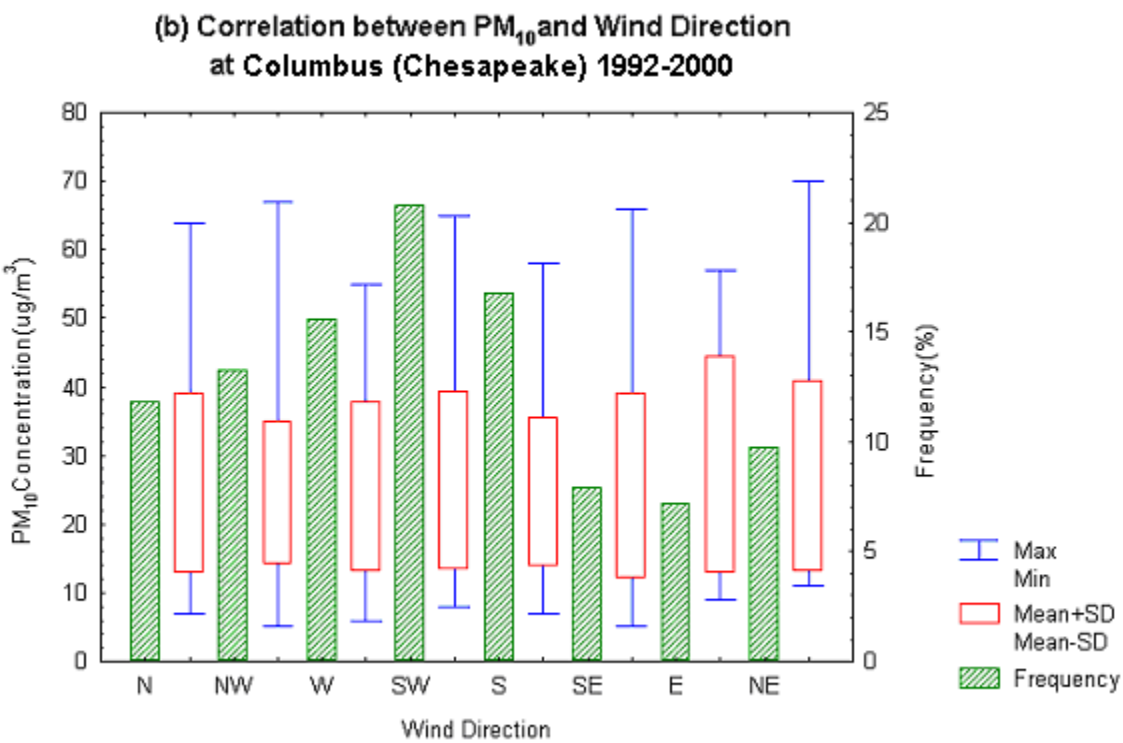


Figure D16. Correlations between PM_{10} and weather components at Columbus (Chesapeake), Ohio in 1992-1999: (a) PM_{10} vs. wind speed and: (b) PM_{10} and wind direction.

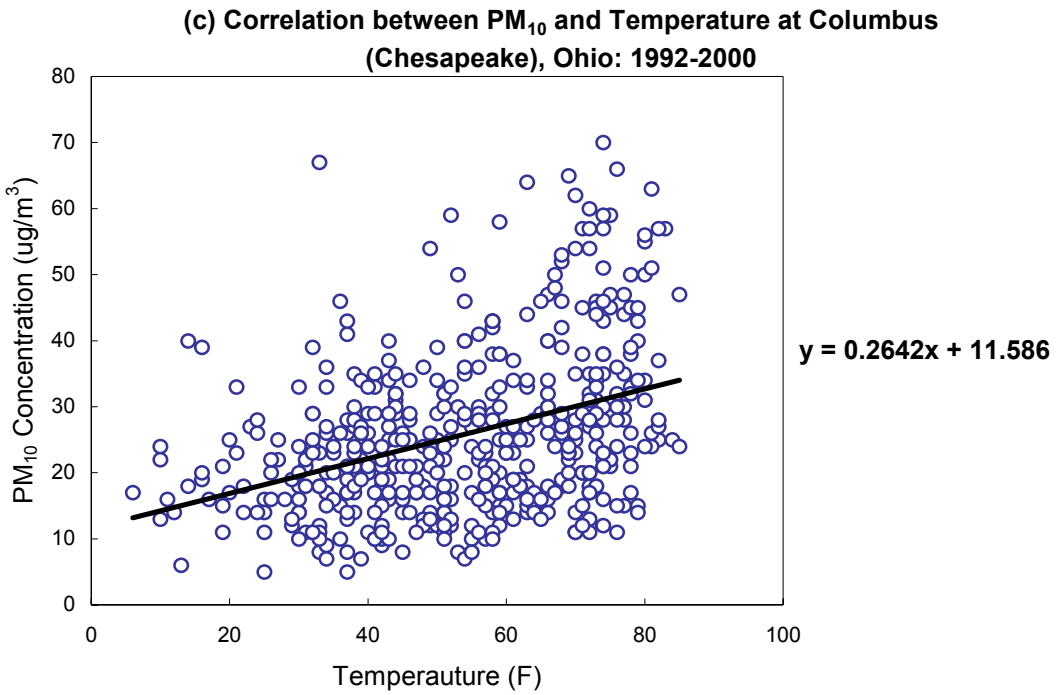
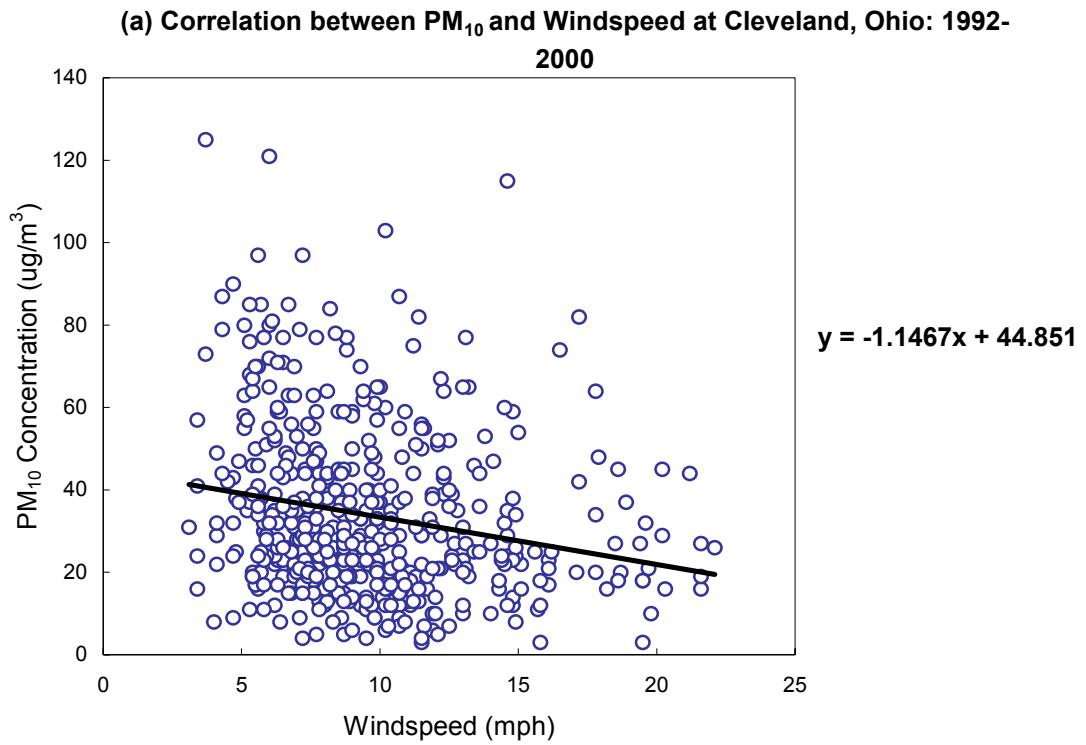


Figure D16. Correlations between PM_{10} and weather components at Columbus (Chesapeake), Ohio in 1992-2000 and (c) PM_{10} vs. temperature



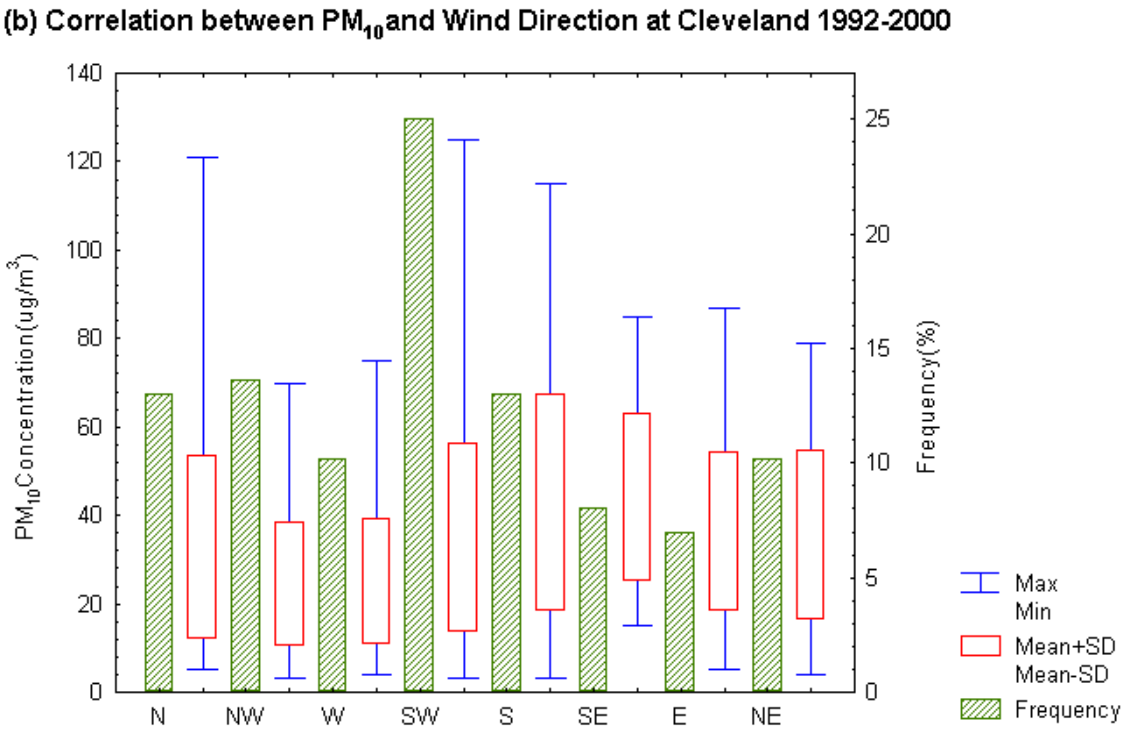


Figure D17. Correlations between PM_{10} and weather components at Cleveland, Ohio in 1992-2000: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction

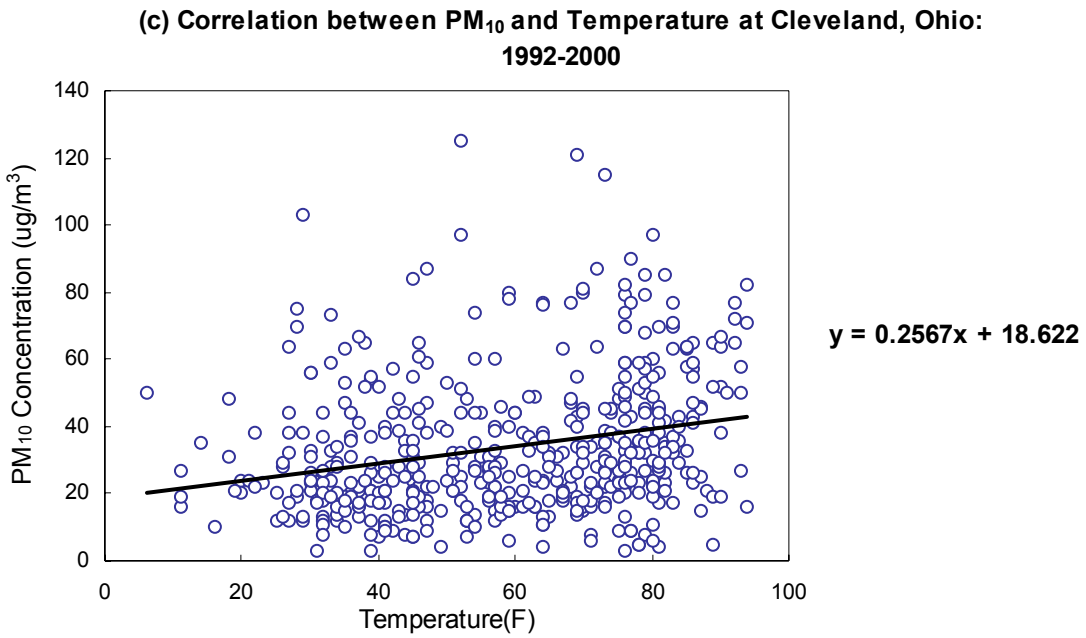


Figure D17. Correlations between PM_{10} and weather components at Cleveland, Ohio in 1992-2000: (c) PM_{10} vs. temperature.

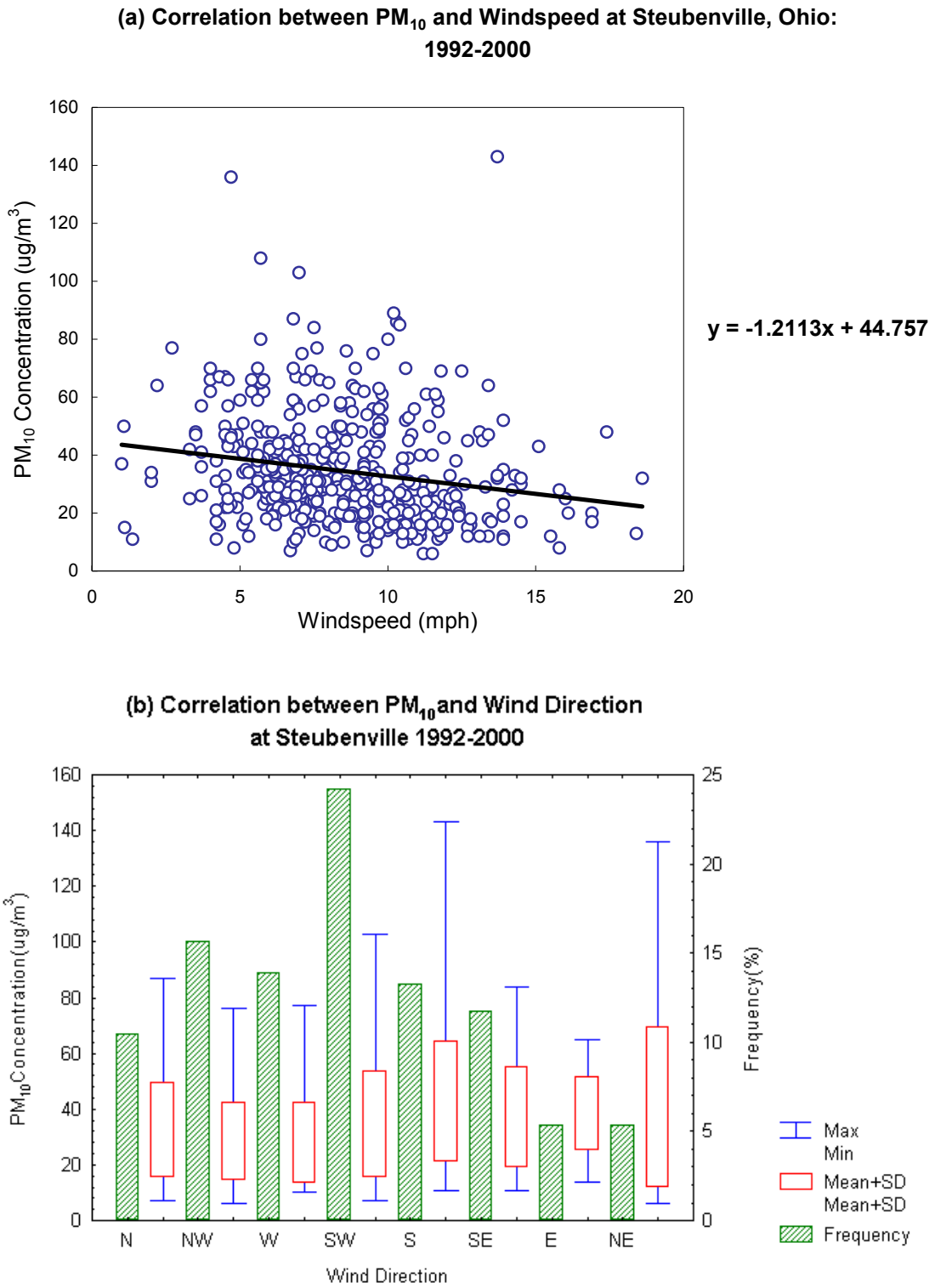


Figure D18. Correlations between PM_{10} and weather components at Steubenville, Ohio in 1992-2000: (a) PM_{10} vs. wind speed and (b) PM_{10} vs. wind direction

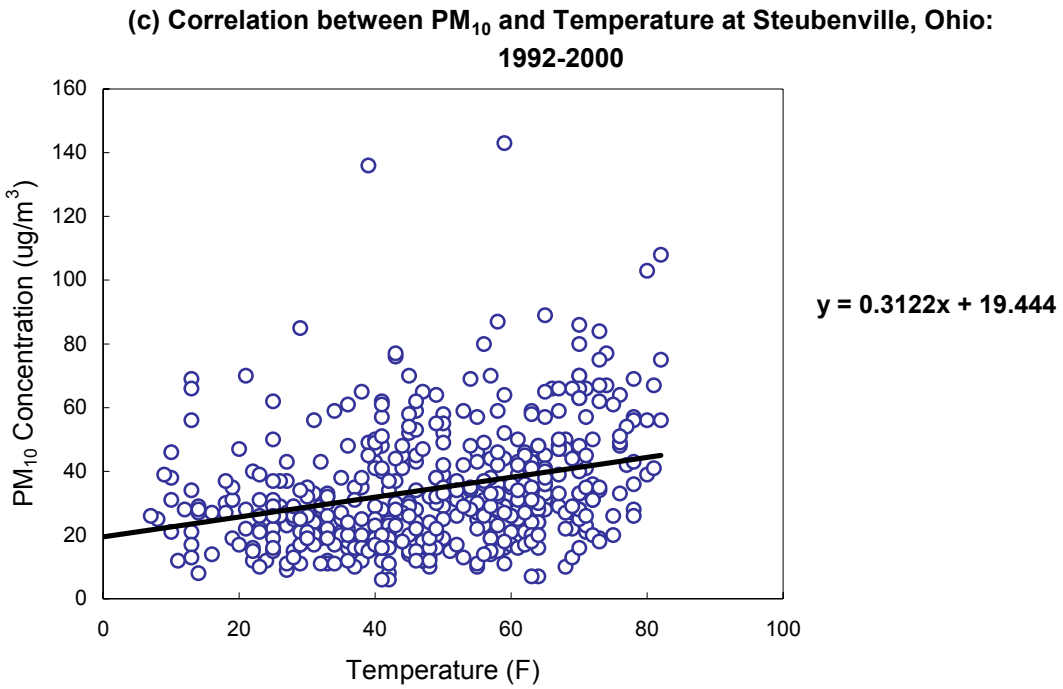


Figure D18. Correlations between PM_{10} and weather components at Steubenville, Ohio in 1992-2000: and (c) PM_{10} vs temperature

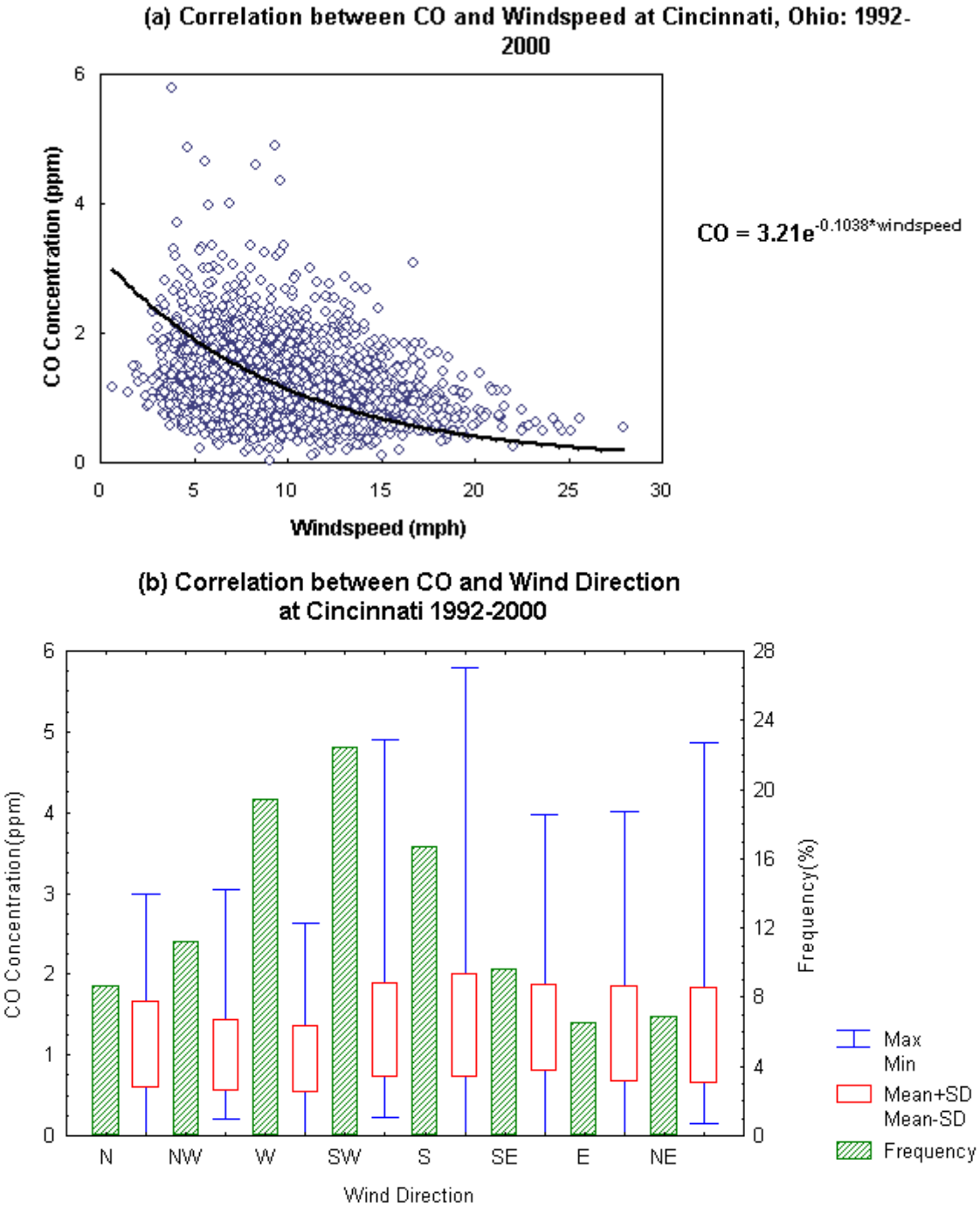


Figure D19. Correlations between CO and weather components at Cincinnati, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

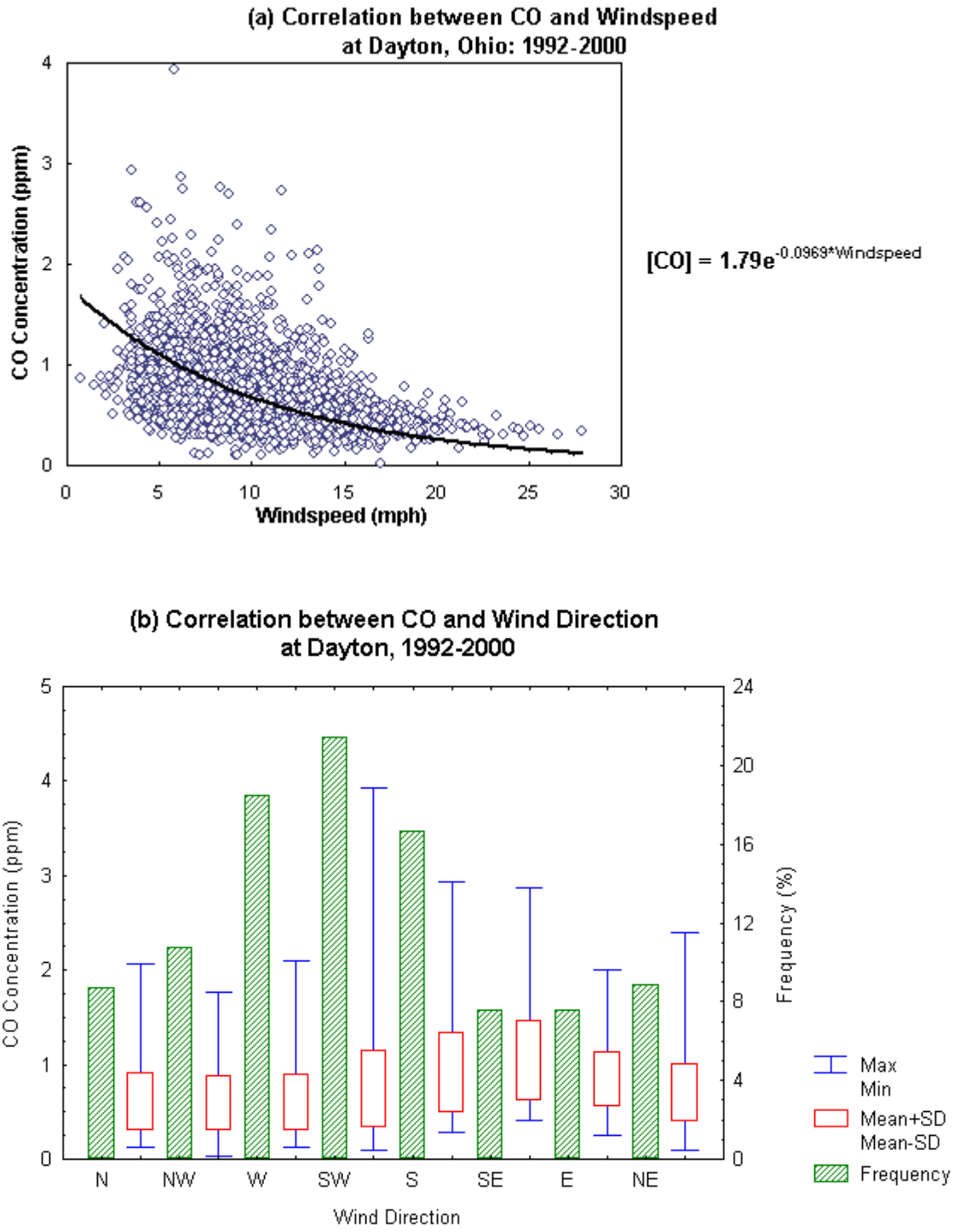


Figure D20. Correlations between CO and weather components at Dayton, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

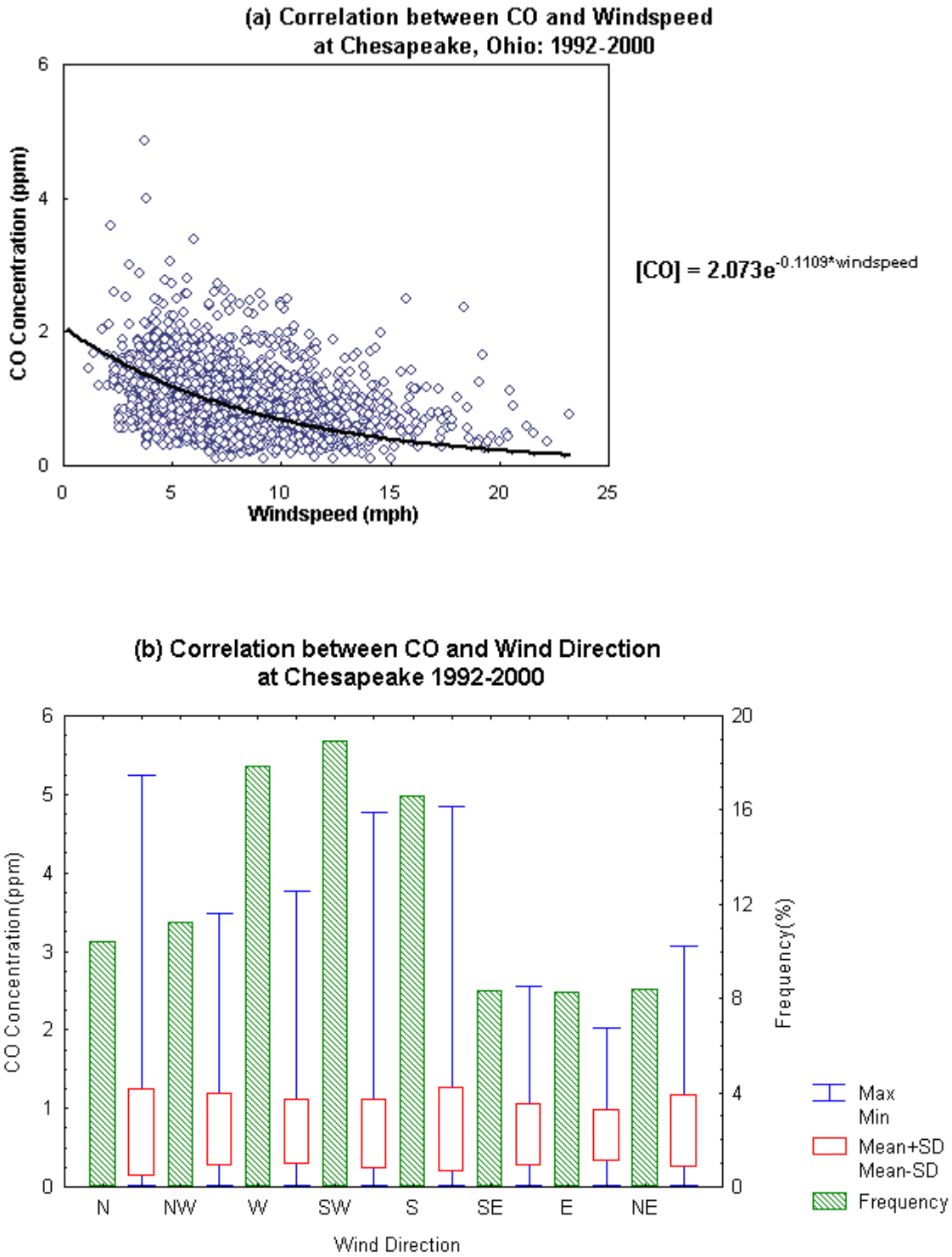


Figure D21. Correlations between CO and weather components at Chesapeake, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

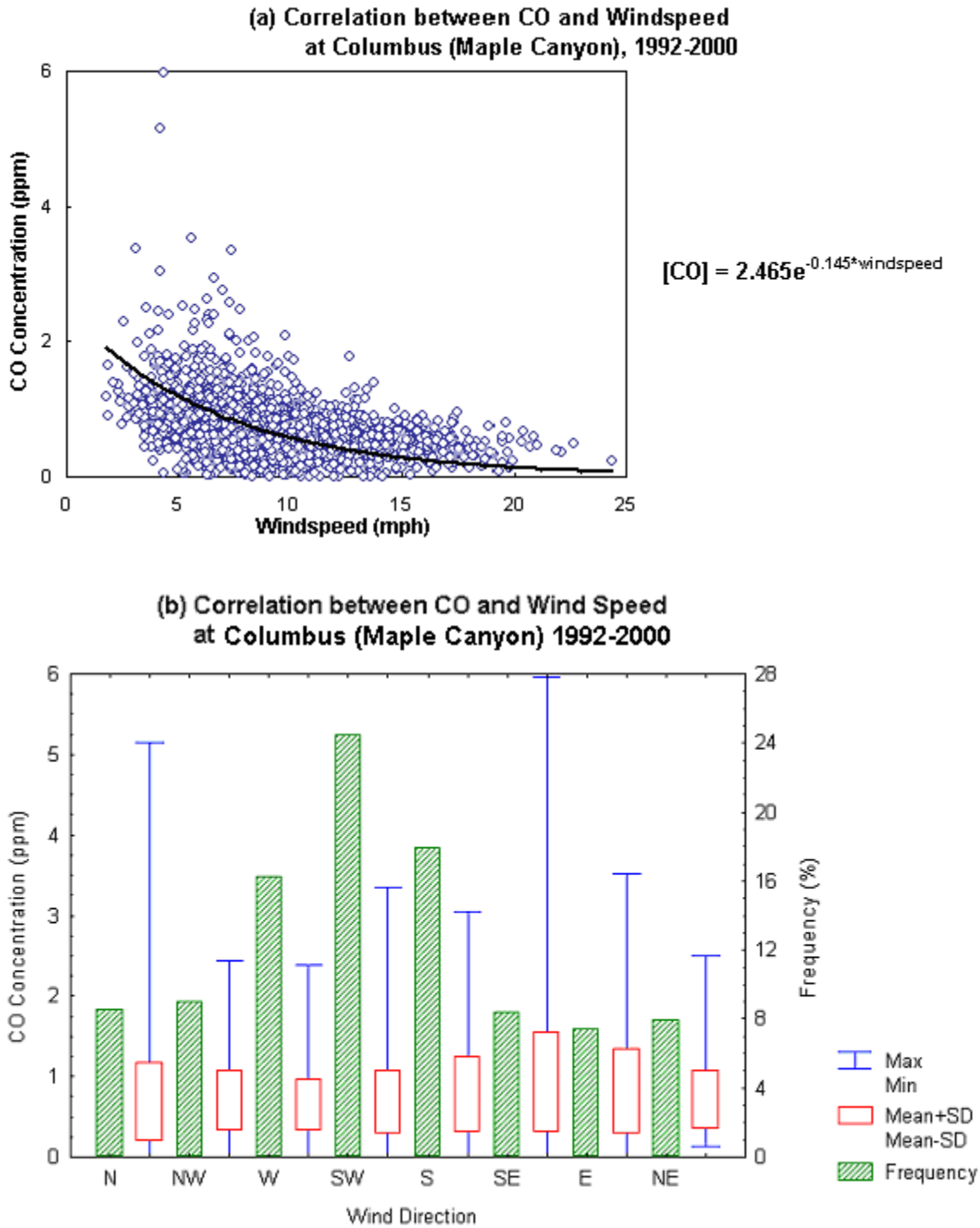


Figure D22. Correlations between CO and weather components at Columbus (Maple Canyon), Ohio in 1993-2000 (a) CO vs. wind speed and (b) CO vs. wind direction

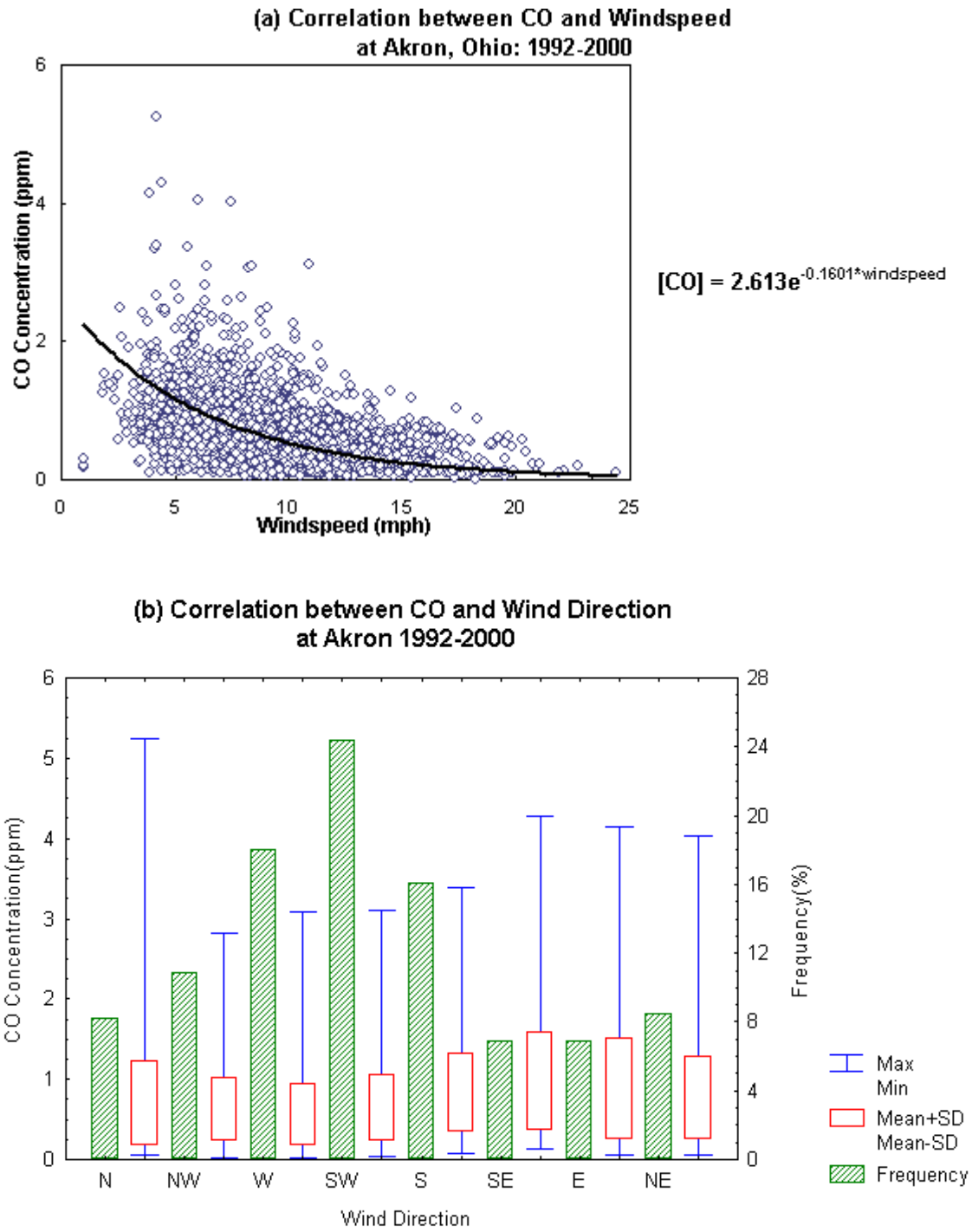


Figure D23. Correlations between CO and weather components at Akron, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction

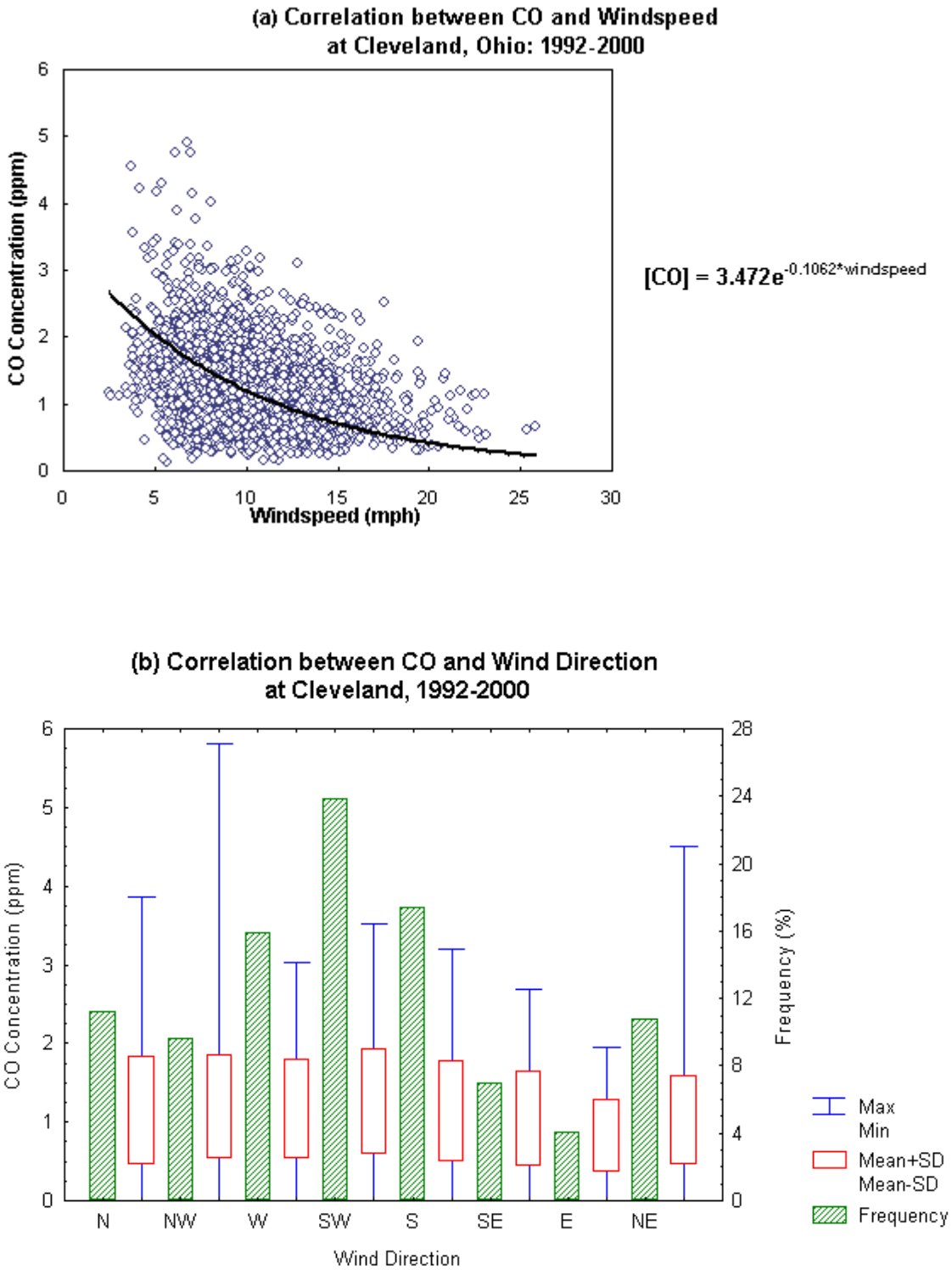
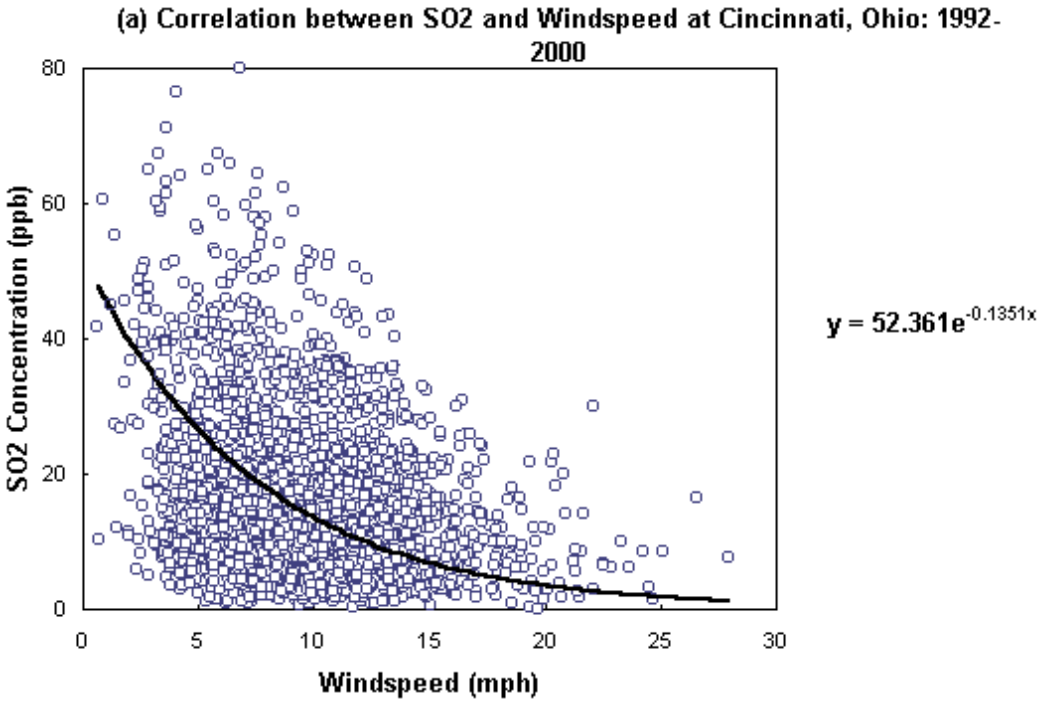


Figure D24. Correlations between CO and weather components at Cleveland, Ohio in 1992-2000: (a) CO vs. wind speed and (b) CO vs. wind direction



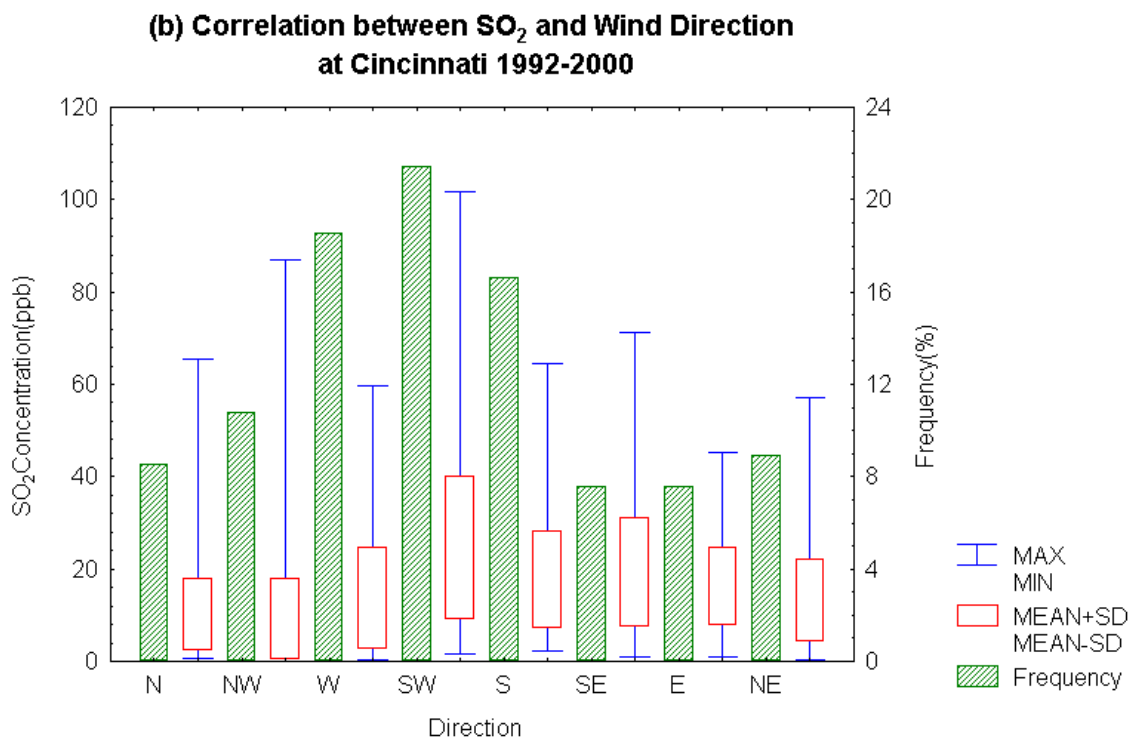


Figure D25. Correlations between SO_2 and weather components at Cincinnati, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

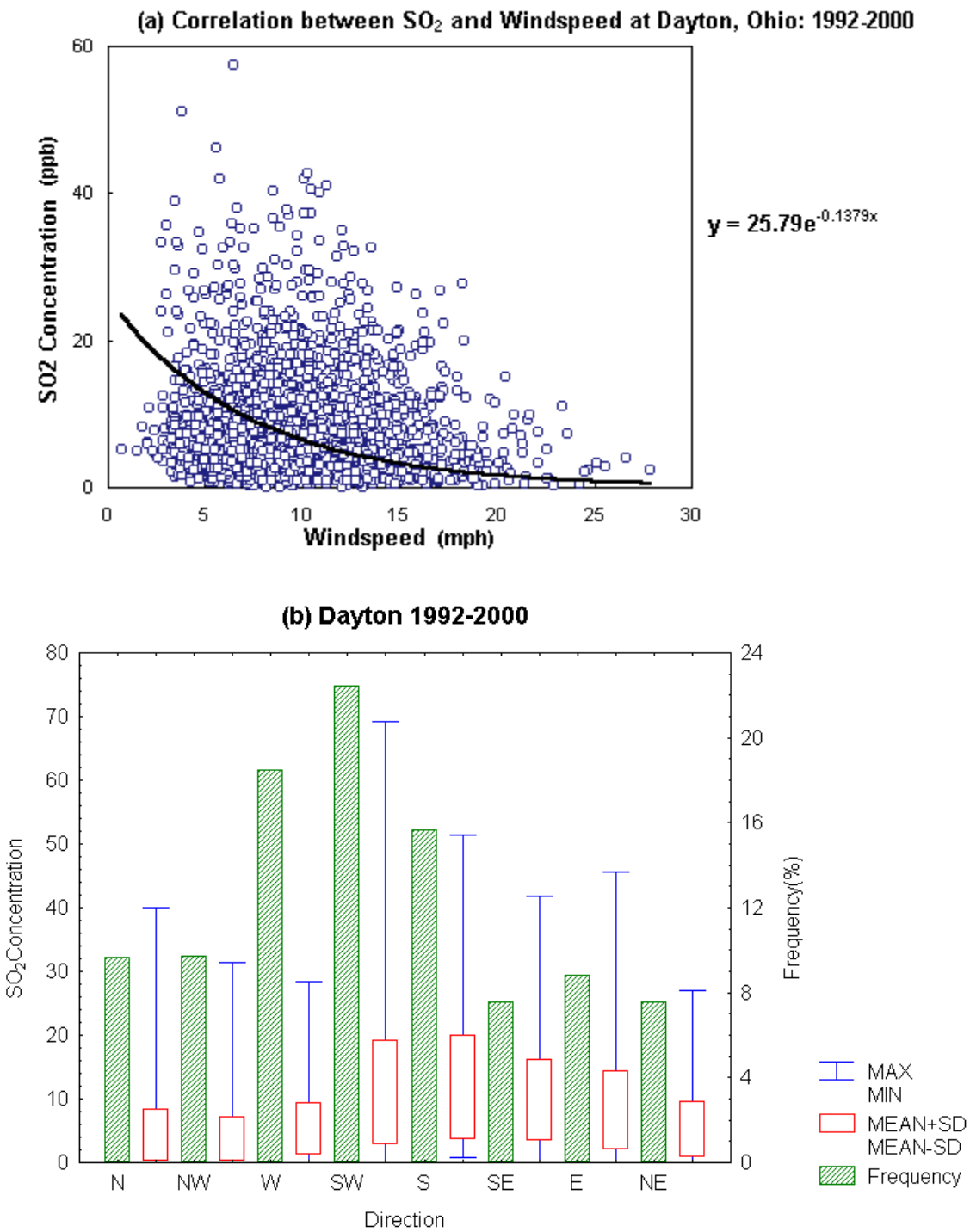
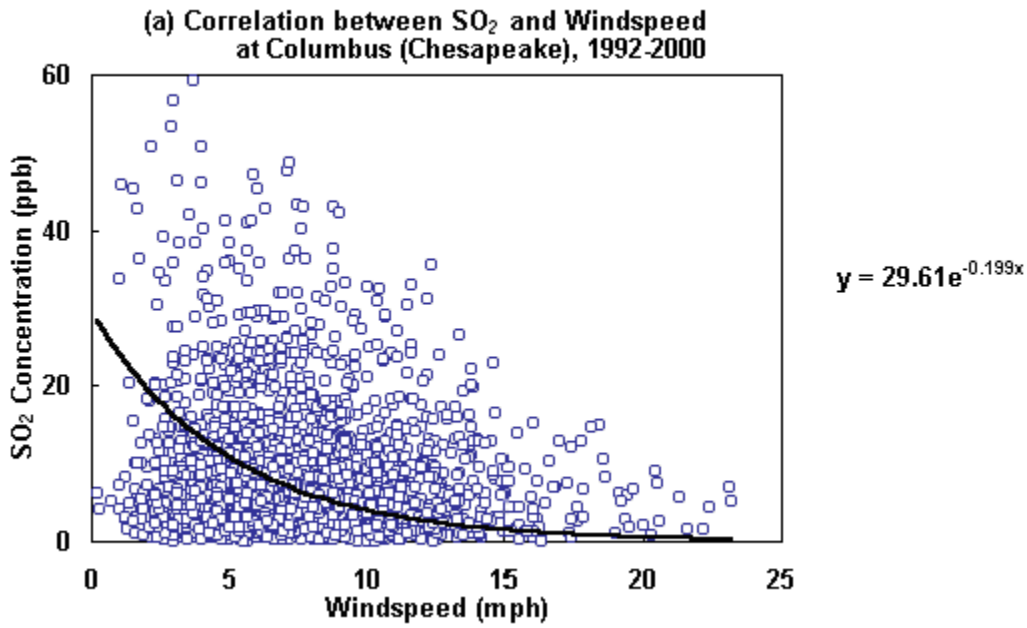


Figure D26. Correlations between SO_2 and weather components at Dayton, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction



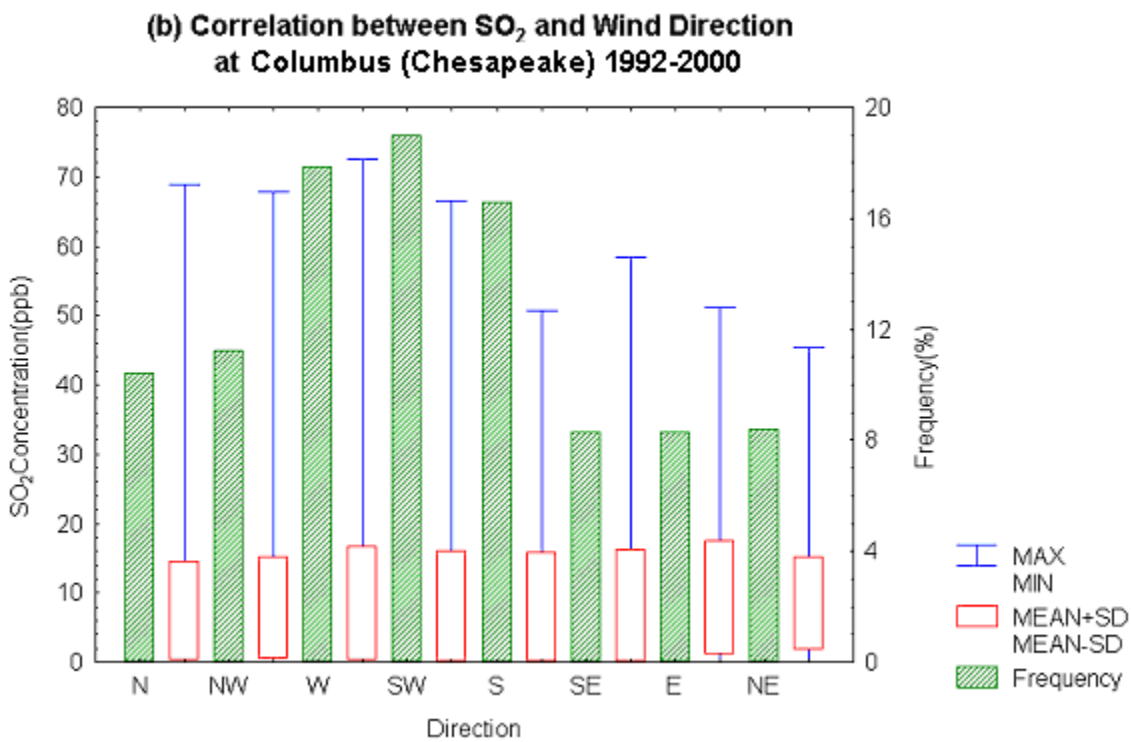
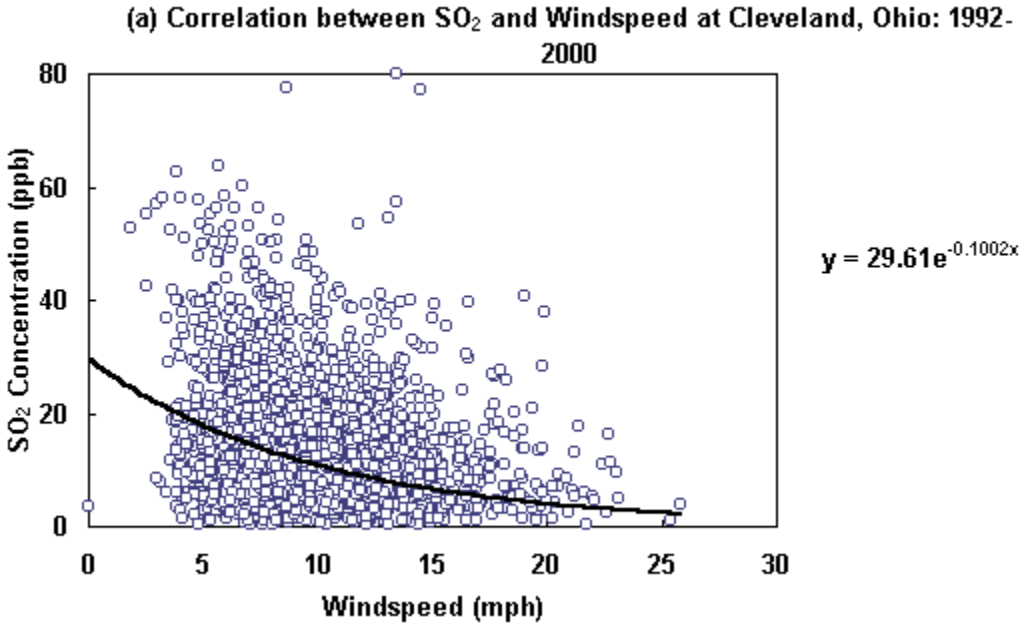


Figure D27. Correlations between SO_2 and weather components at Columbus (Chesapeake), Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction



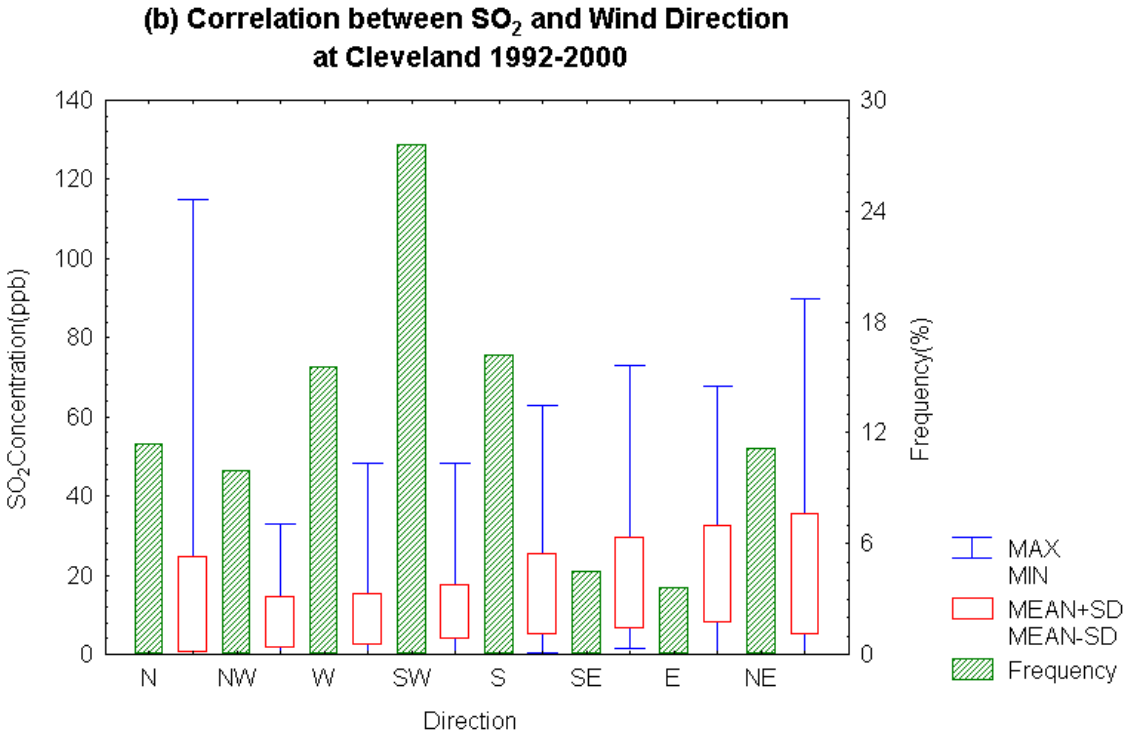


Figure D28. Correlations between SO_2 and weather components at Cleveland, Ohio in 1992-2000 (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction

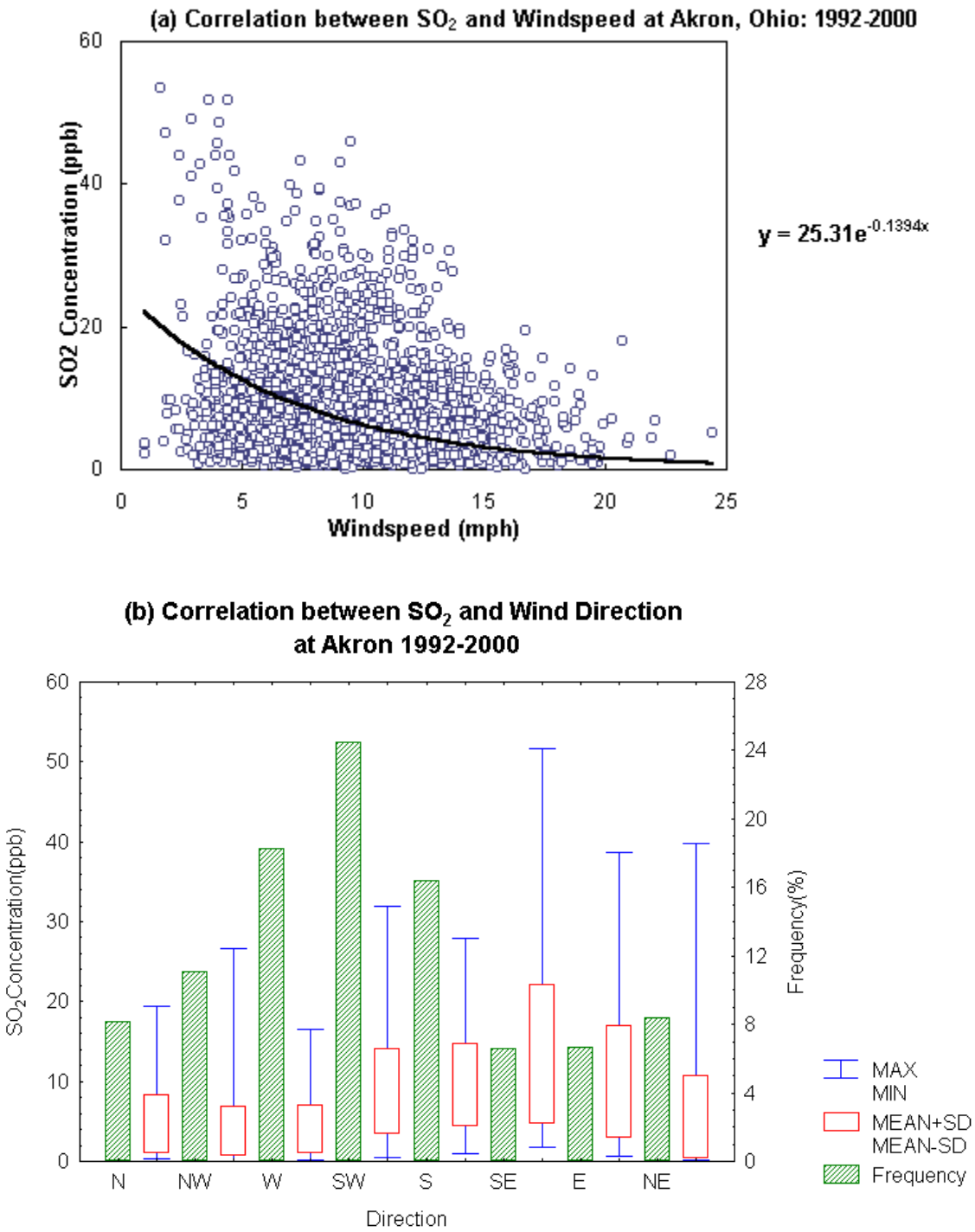
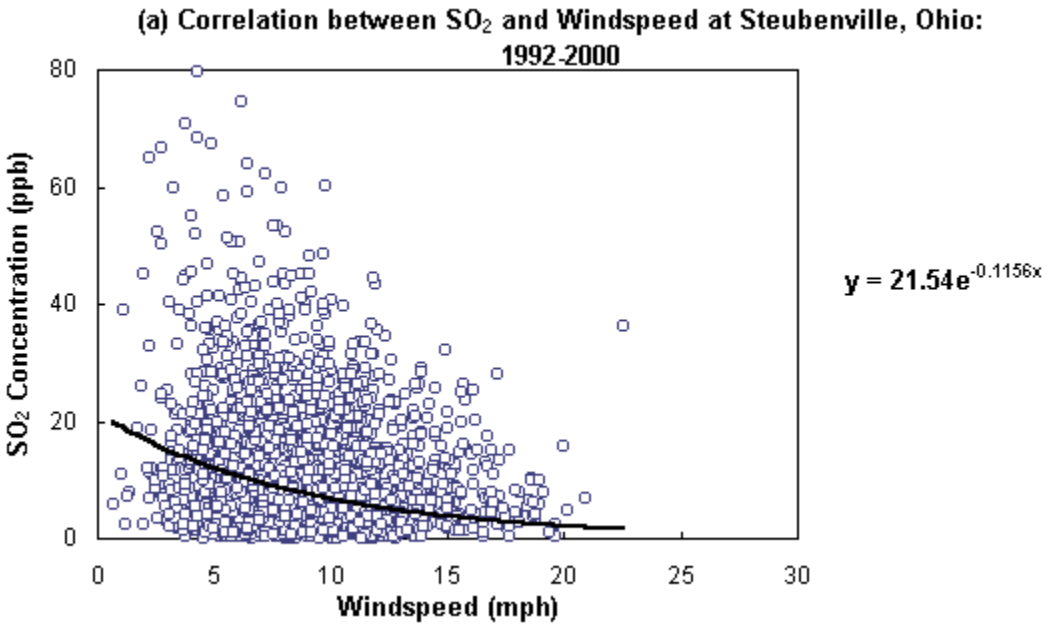


Figure D29. Correlations between SO_2 and weather components at Akron, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction



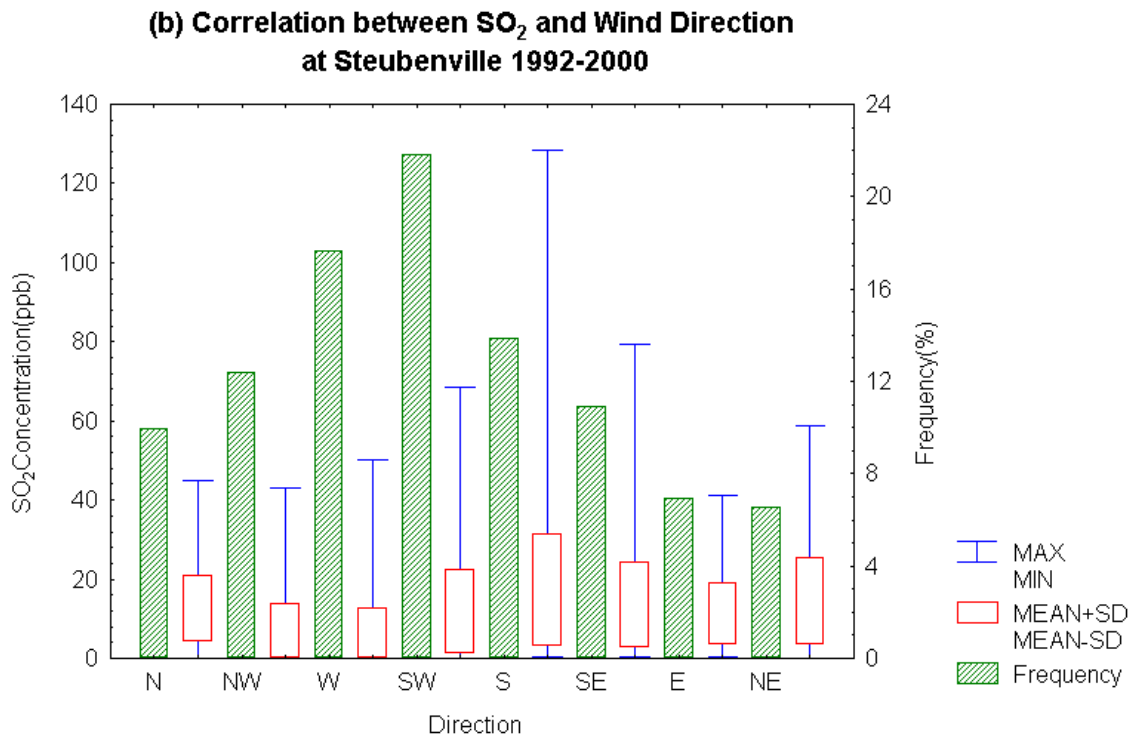
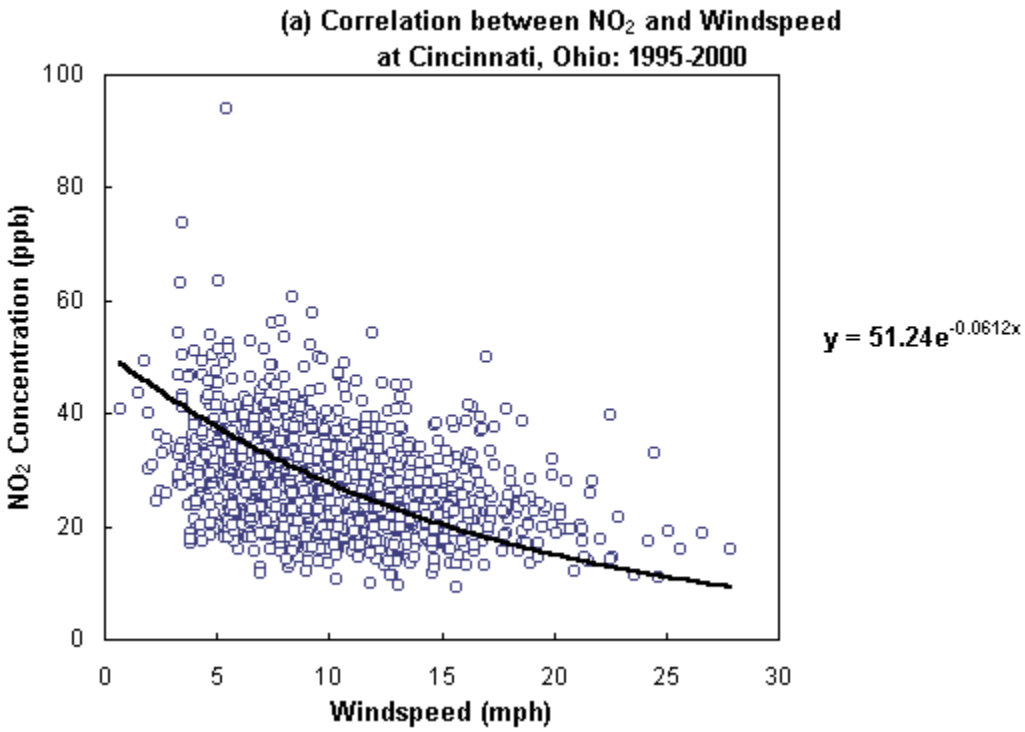


Figure D30. Correlations between SO_2 and weather components at Steubenville, Ohio in 1992-2000: (a) SO_2 vs. wind speed and (b) SO_2 vs. wind direction



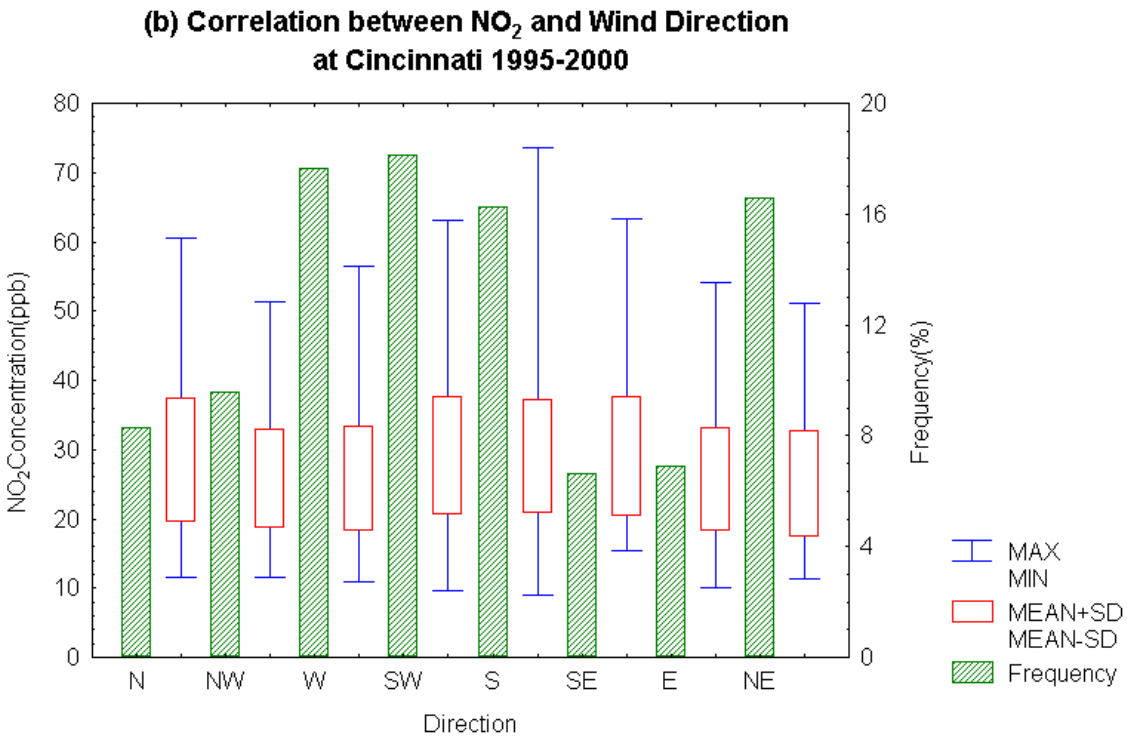


Figure D31. Correlations between NO_2 and weather components at Cincinnati, Ohio in 1995-2000: (a) NO_2 vs. wind speed and (b) NO_2 vs. wind direction

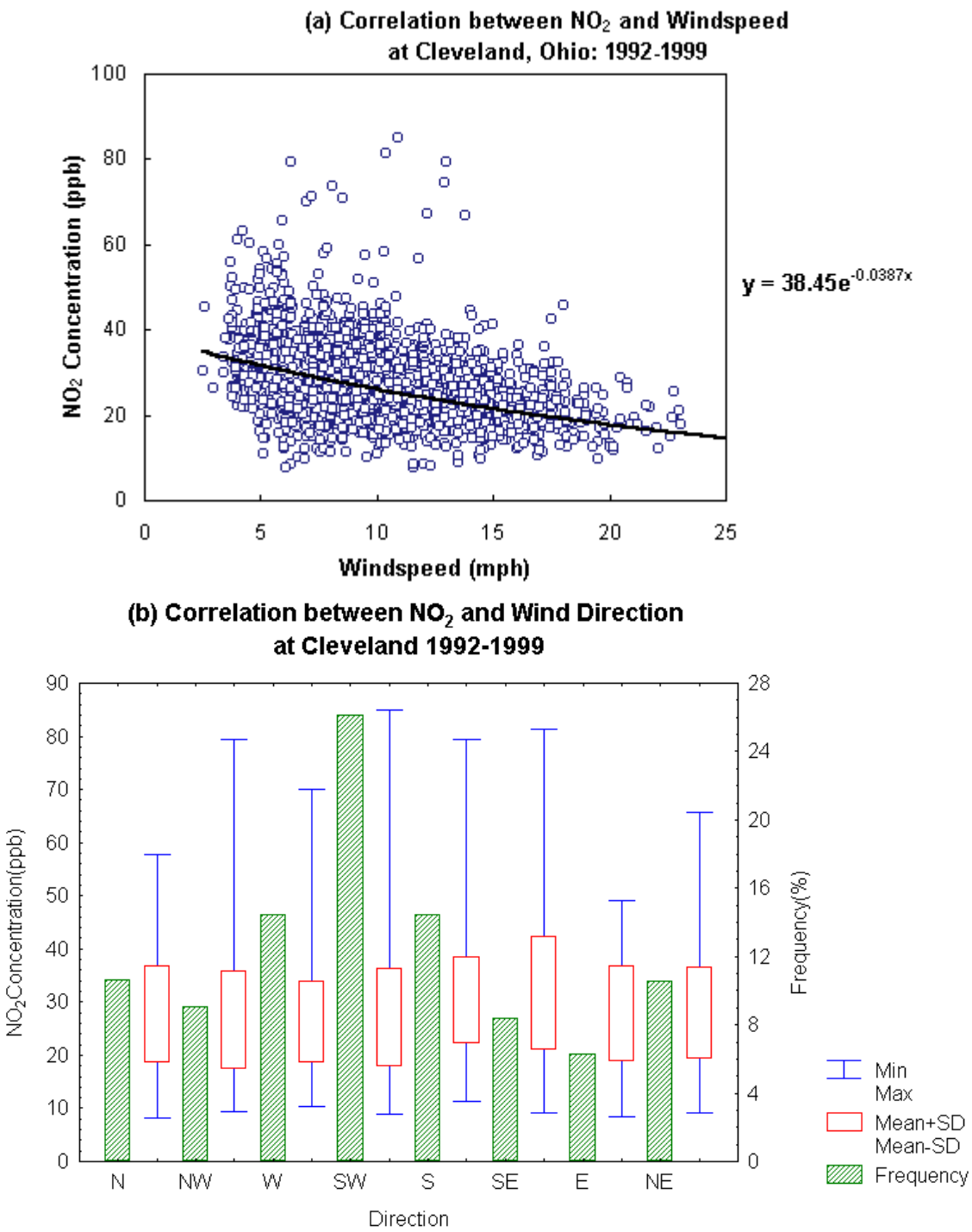
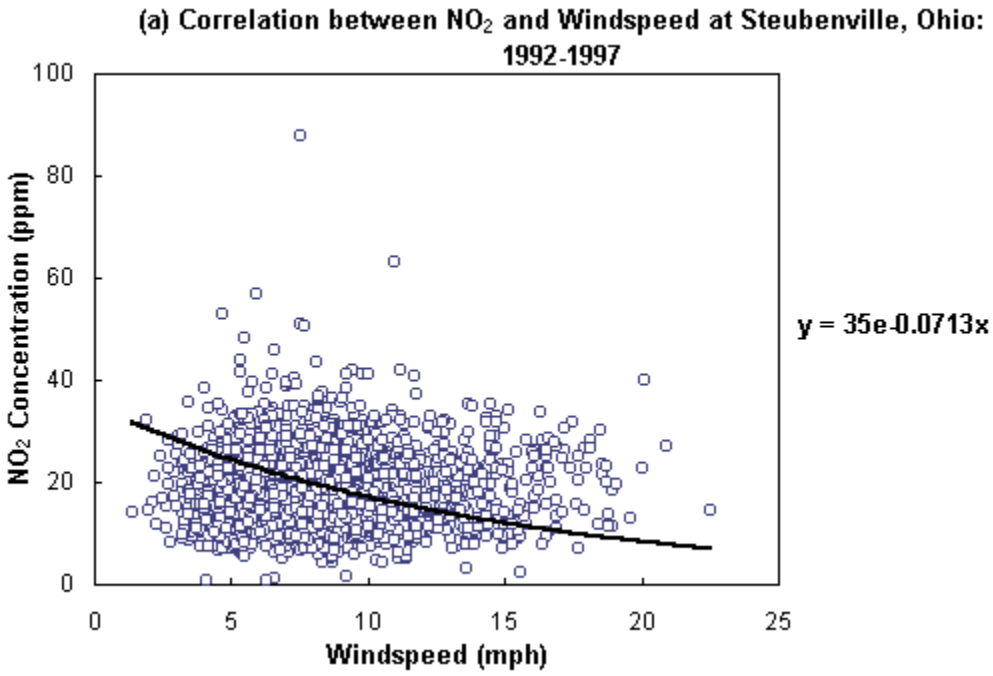


Figure D32. Correlations between NO_2 and weather components at Dayton, Ohio in 1992-1999: (a) NO_2 vs. wind speed and (b) NO_2 vs. wind direction



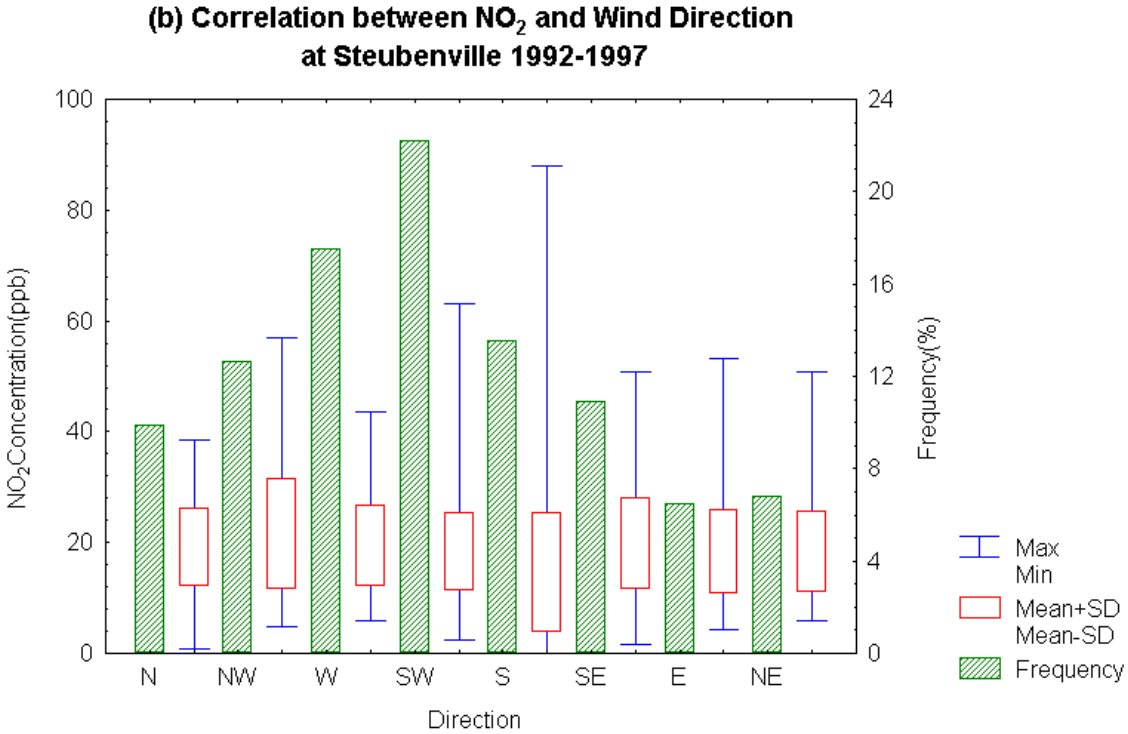


Figure D33. Correlations between NO_2 and weather components at Steubenville, Ohio in 1992-1997: (a) NO_2 vs. wind speed and (b) NO_2 vs. wind direction

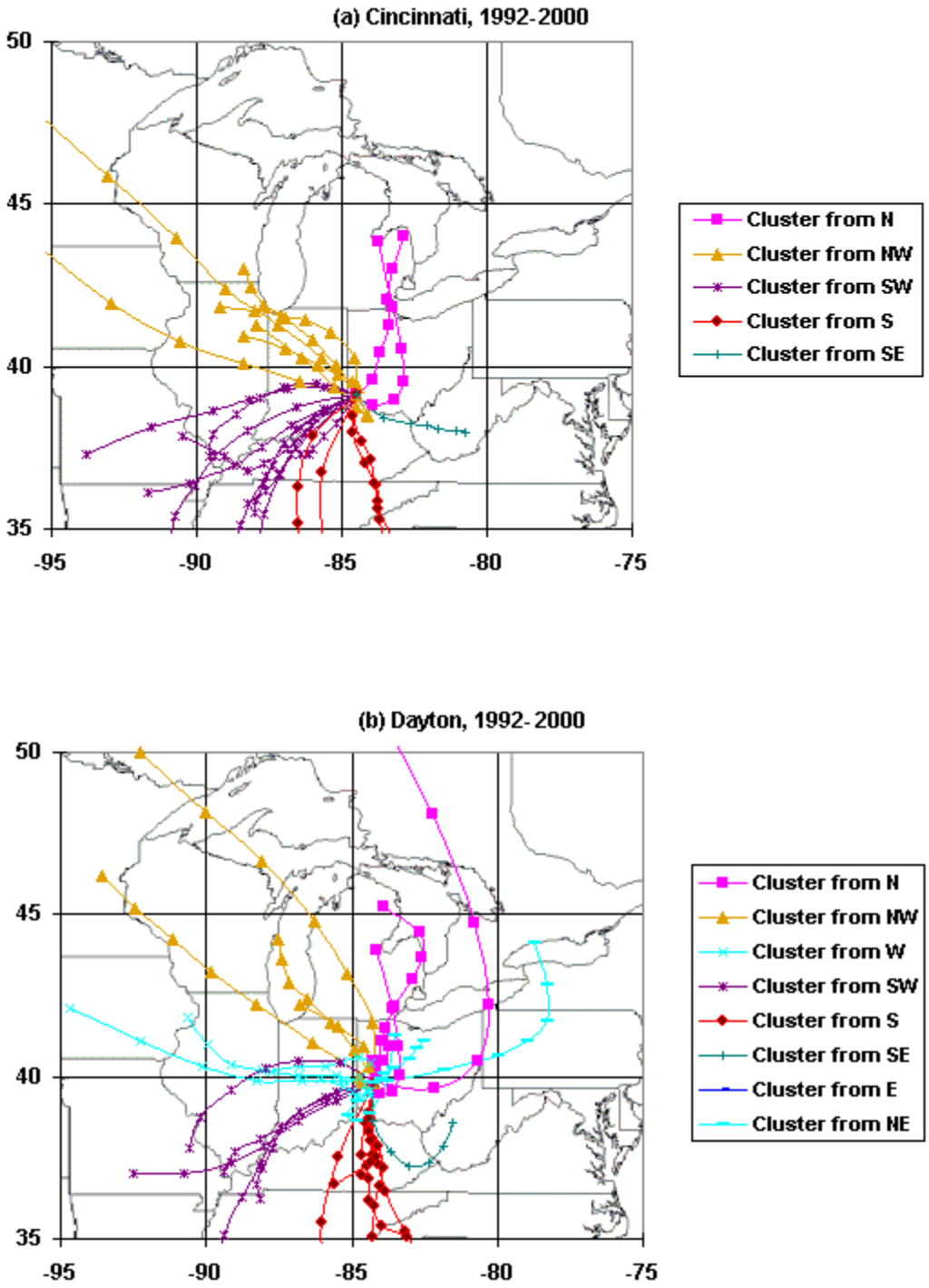
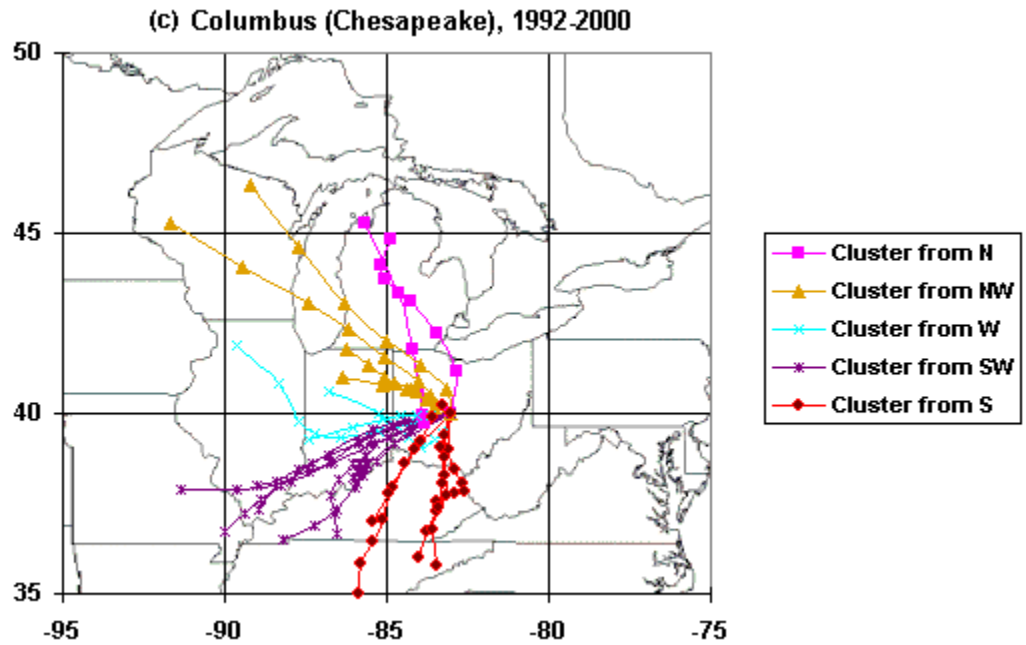


Figure D34. Back trajectories for high CO days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati and (b) Dayton



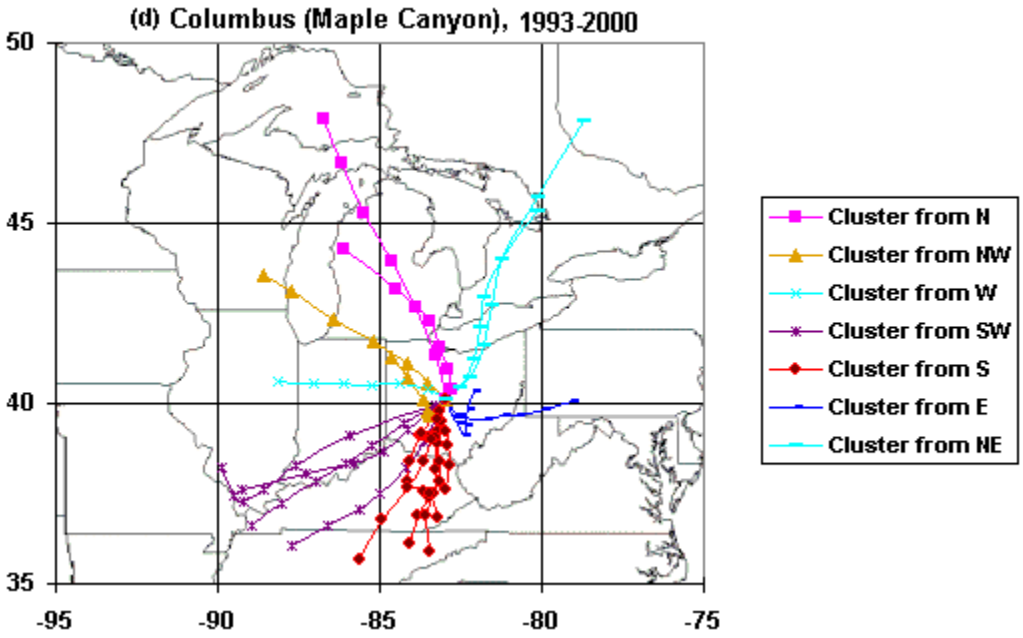


Figure D34. Back trajectories for high CO days at the monitoring sites selected in Ohio: (c) Columbus (Chesapeake), 1992-2000 and (d) Columbus (Maple Canyon), 1993-2000

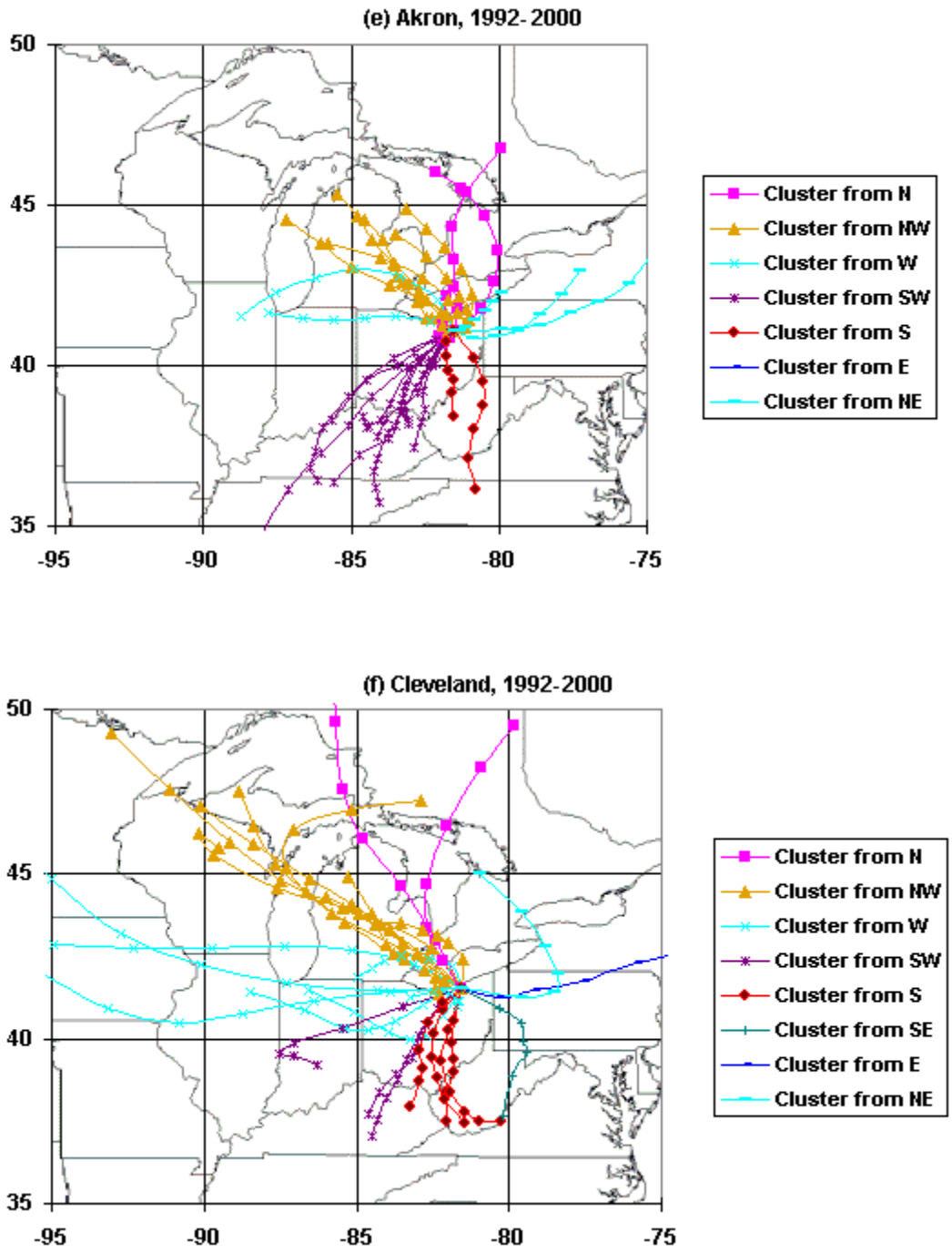


Figure D34. Back trajectories for high CO days at the monitoring sites selected in Ohio, 1992-2000: (e) Akron and (f) Cleveland

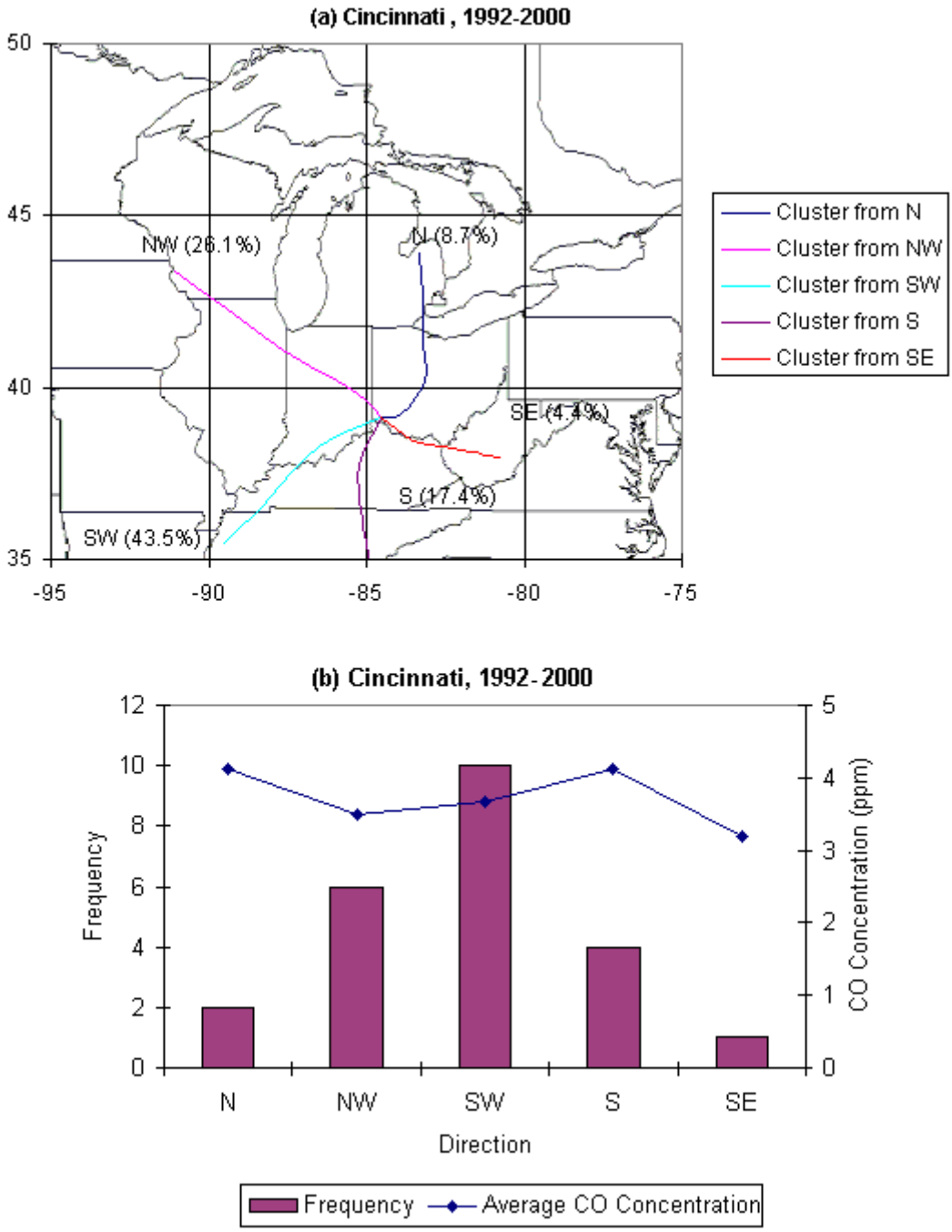


Figure D35. (a) Cluster plot at Cincinnati, 1992-2000 (b) Frequencies and average CO concentrations by cluster at Cincinnati, 1992-2000

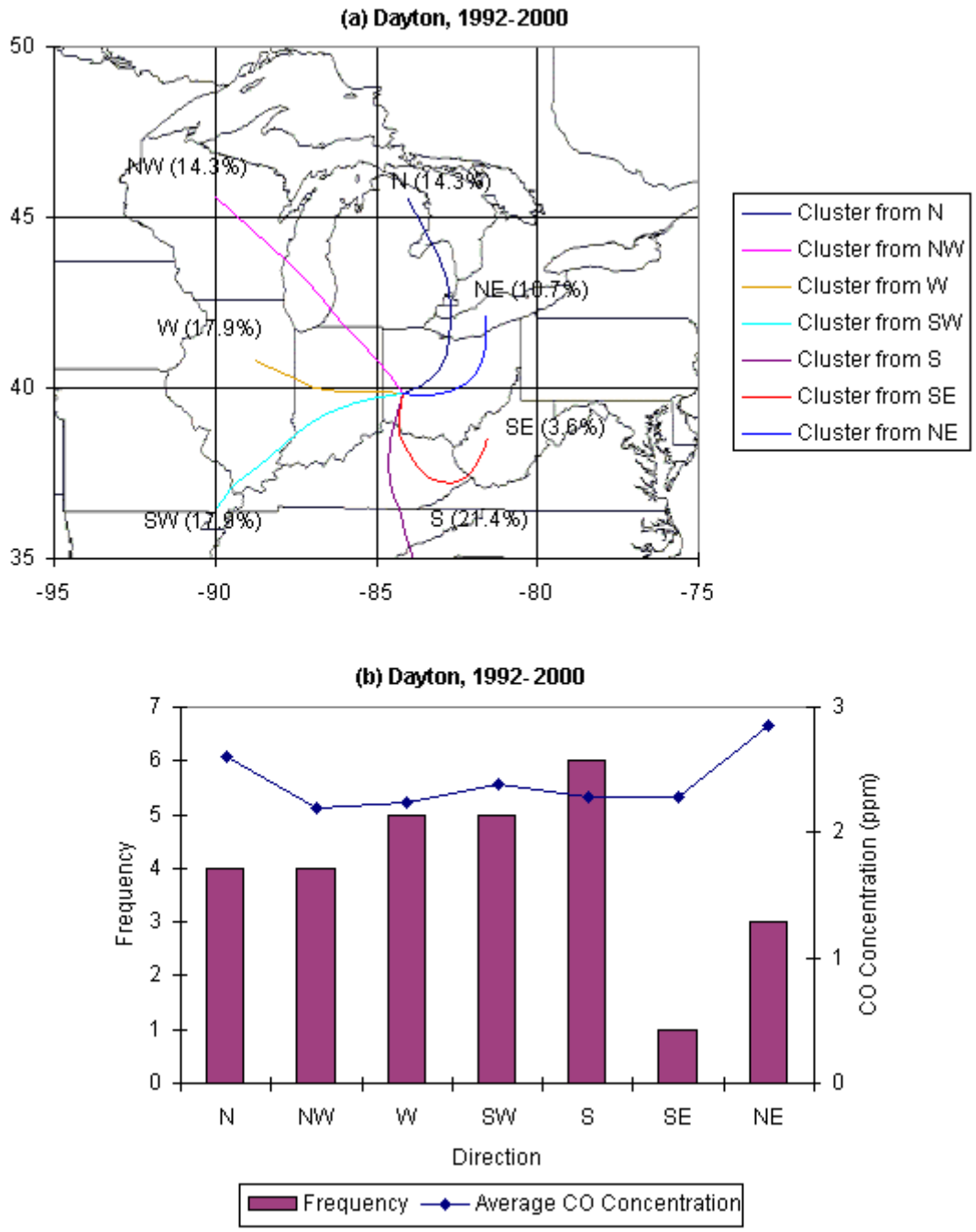


Figure D36. (a) Cluster plot at Dayton, 1992-2000 (b) Frequencies and average CO concentrations by cluster at Dayton, 1992-2000

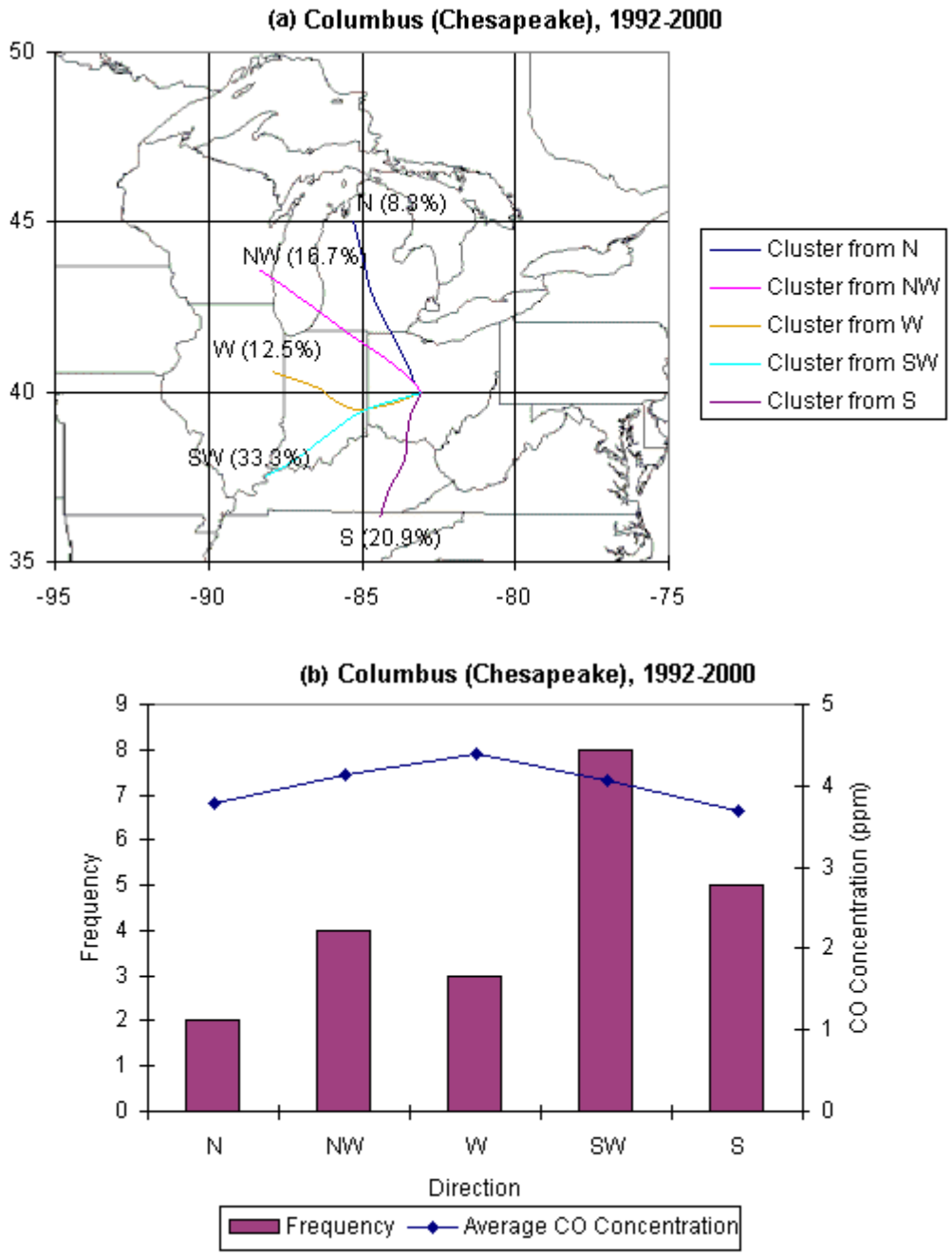


Figure D37. (a) Cluster plot at Columbus (Chesapeake), 1992-2000 (b) Frequencies and average CO concentrations by cluster at Columbus (Chesapeake), 1992-2000

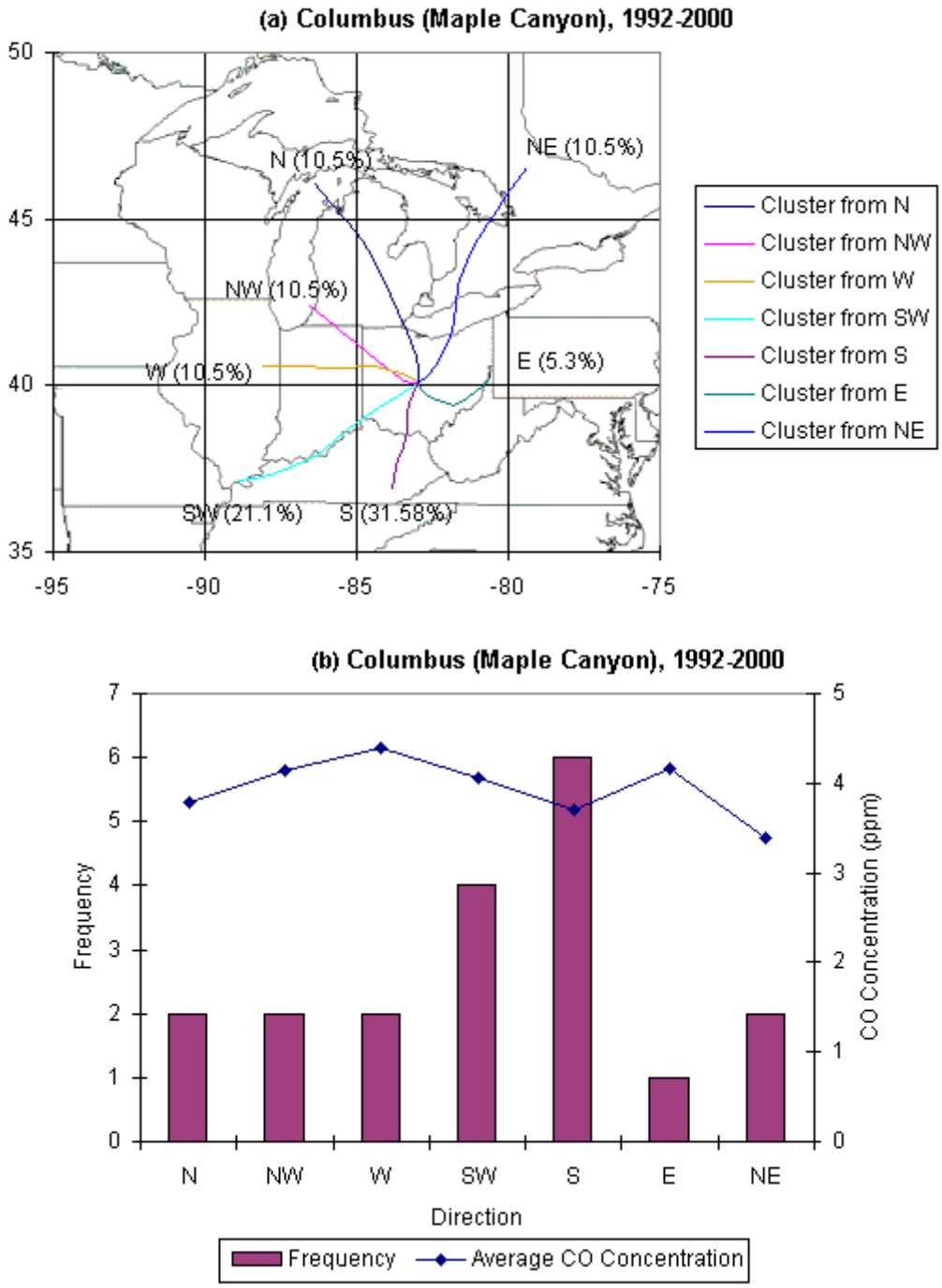


Figure D38. (a) Cluster plot at Columbus (Maple Canyon), 1993-2000 (b) Frequencies and average CO concentrations by cluster at Columbus (Maple Canyon), 1993-2000

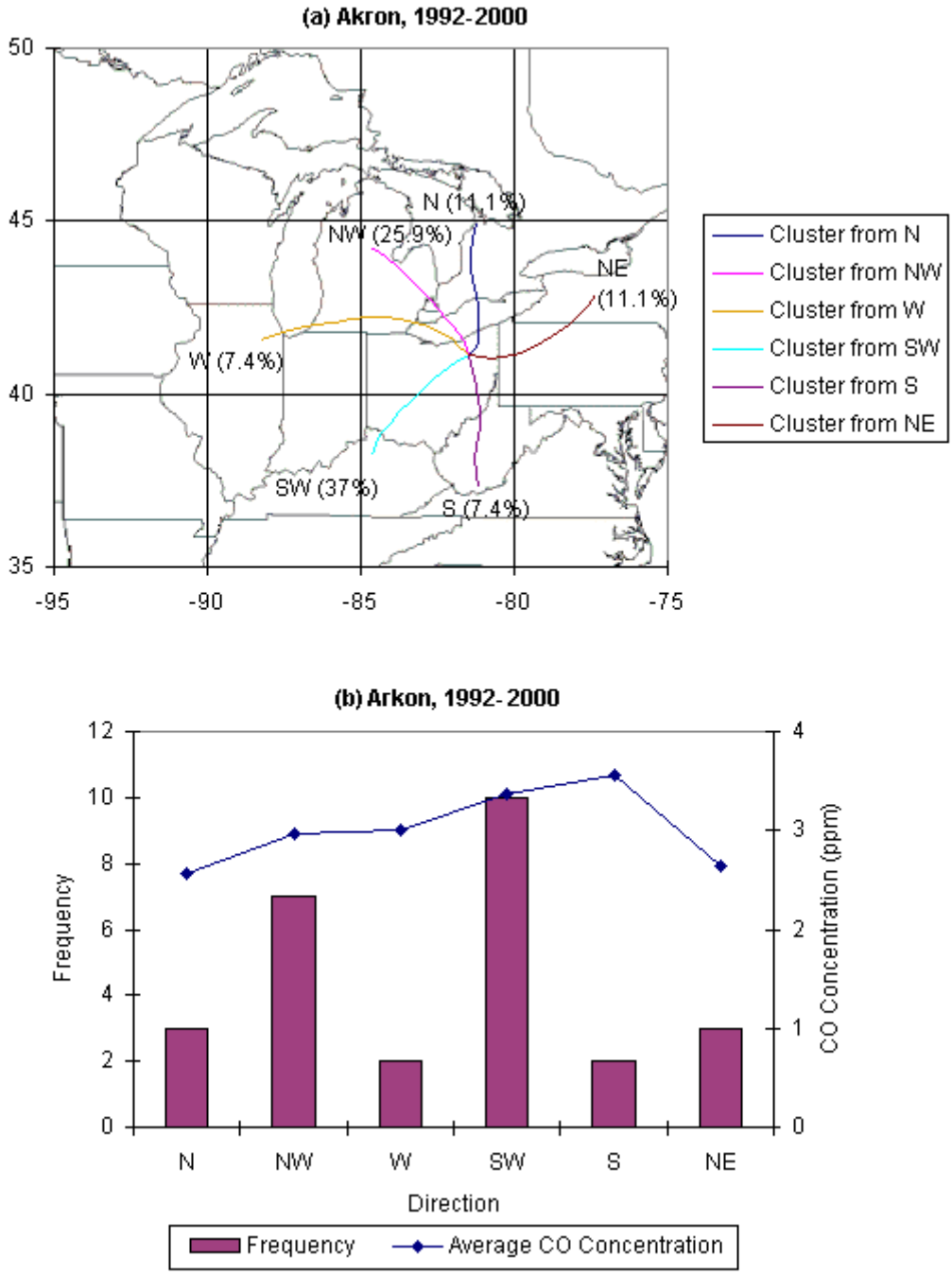


Figure D39. (a) Cluster plot at Akron 1992-2000 (b) Frequencies and average CO concentrations by cluster at Akron, 1992-2000

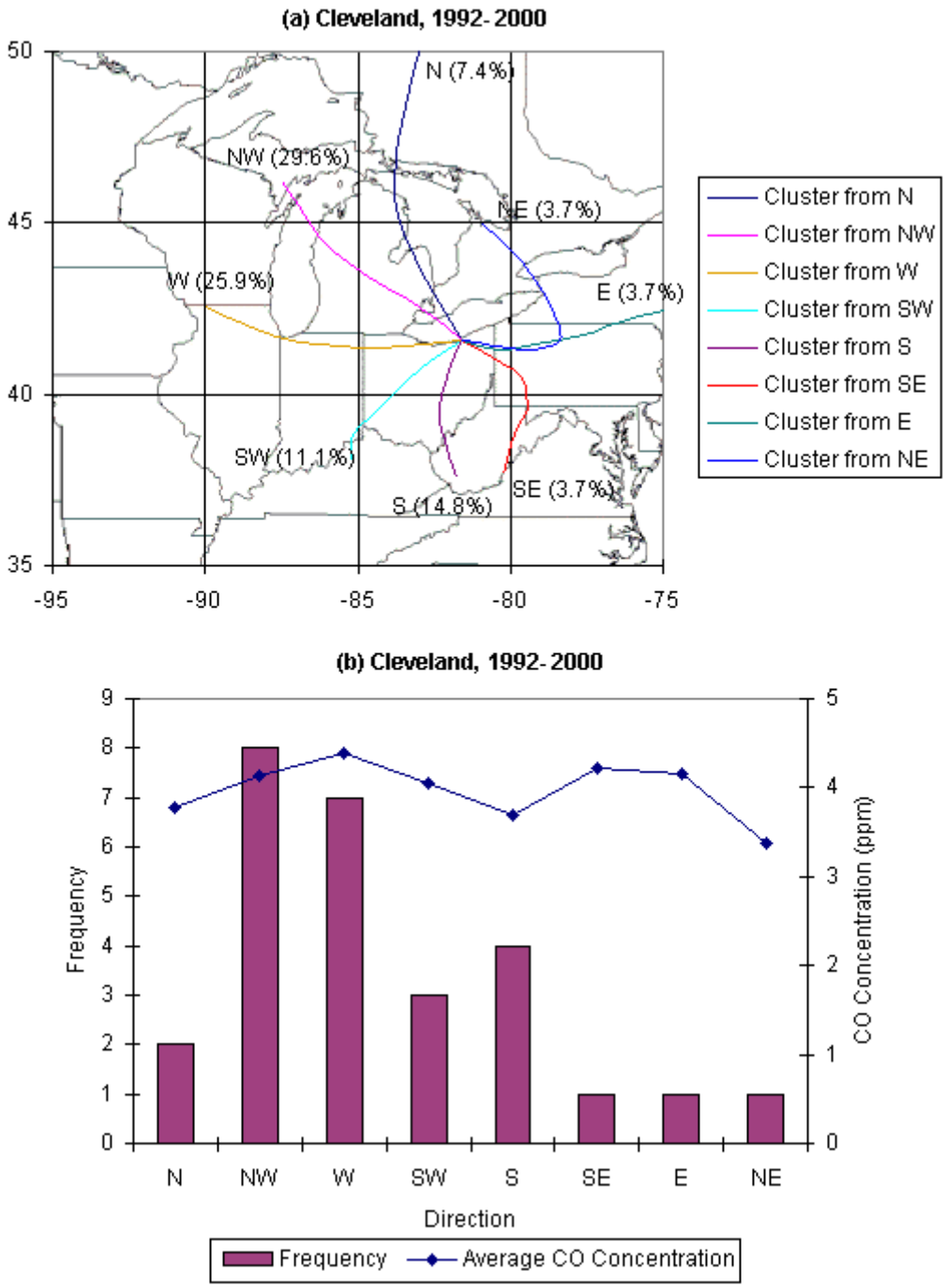


Figure D40. (a) Cluster plot at Cleveland, 1992-2000 (b) Frequencies and average CO concentrations by cluster at Cleveland, 1992-2000

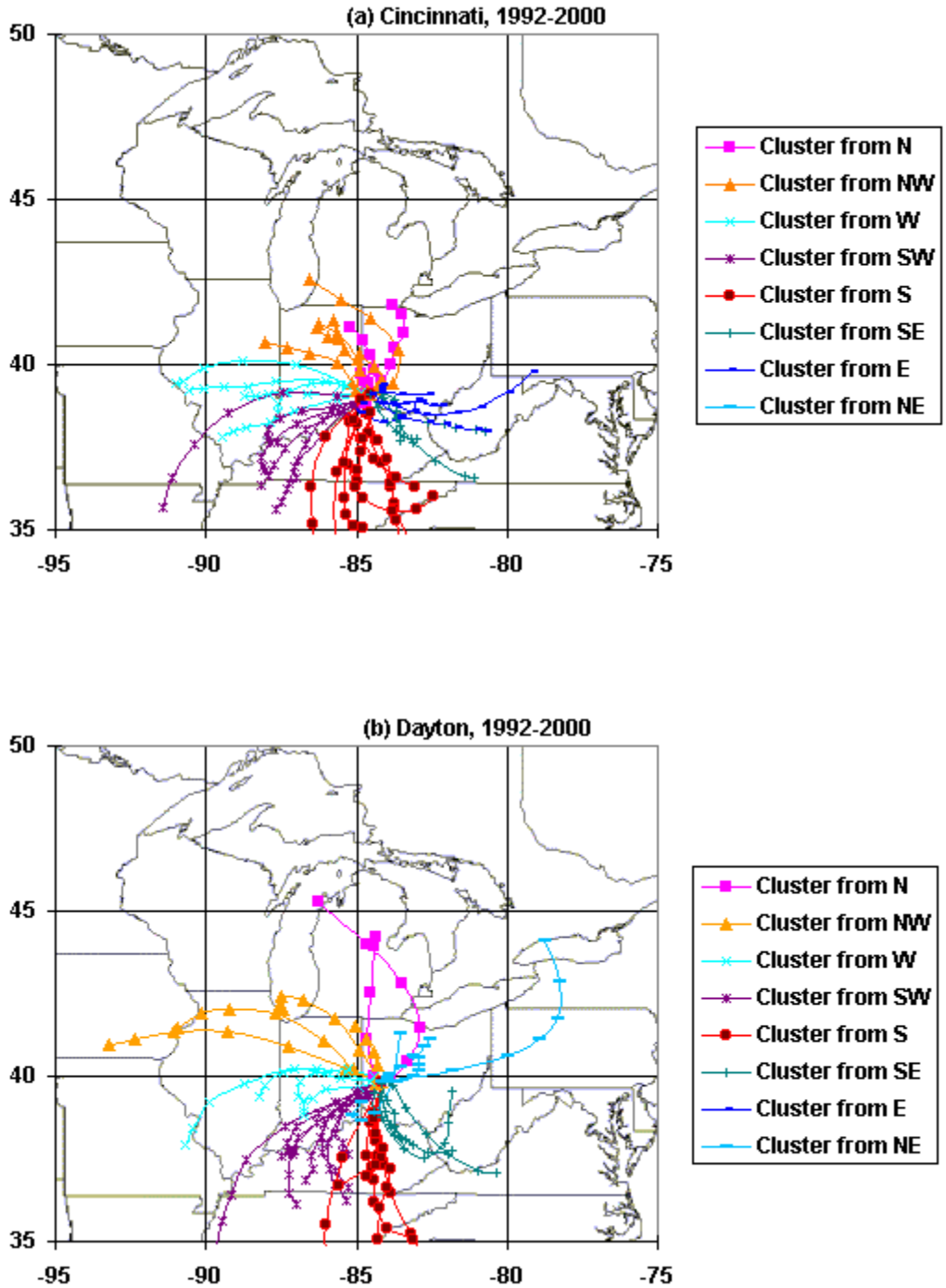
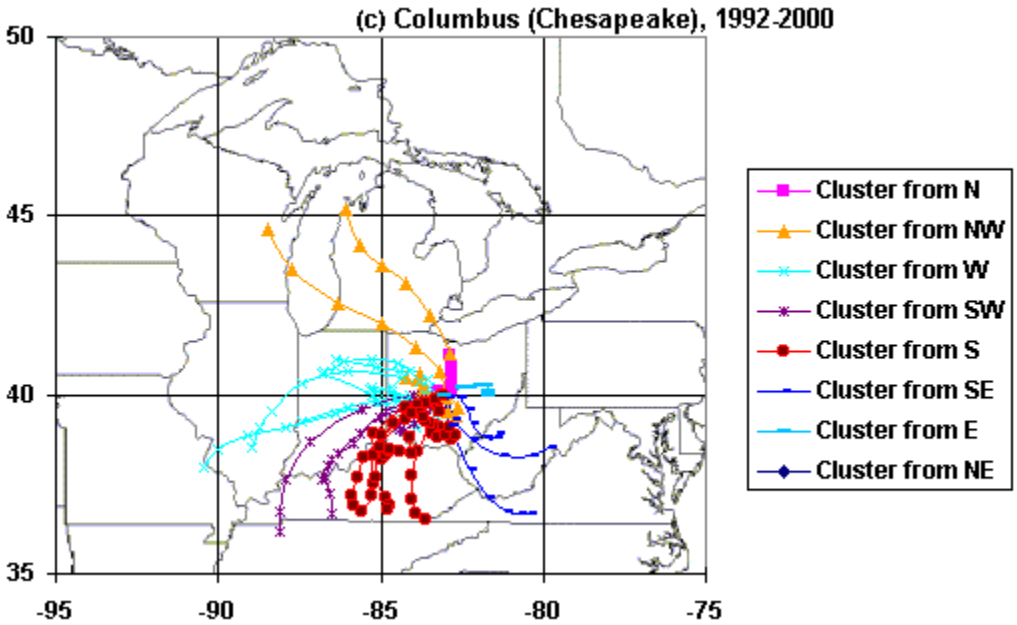


Figure D41. Back trajectories for high SO_2 days at the monitoring sites selected in Ohio, 1992-2000: (a) Cincinnati and (b) Dayton



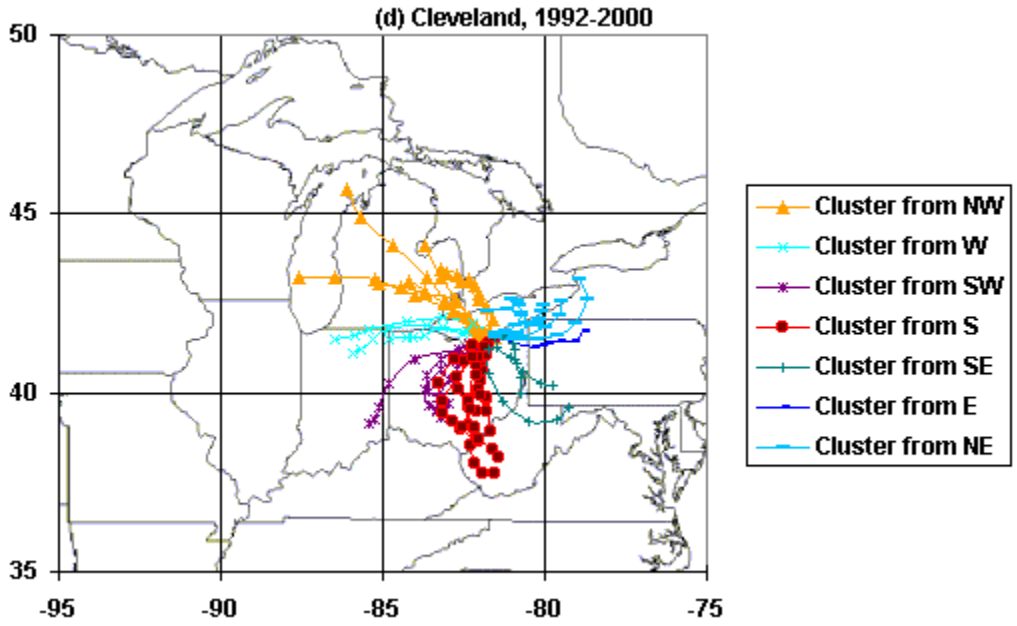
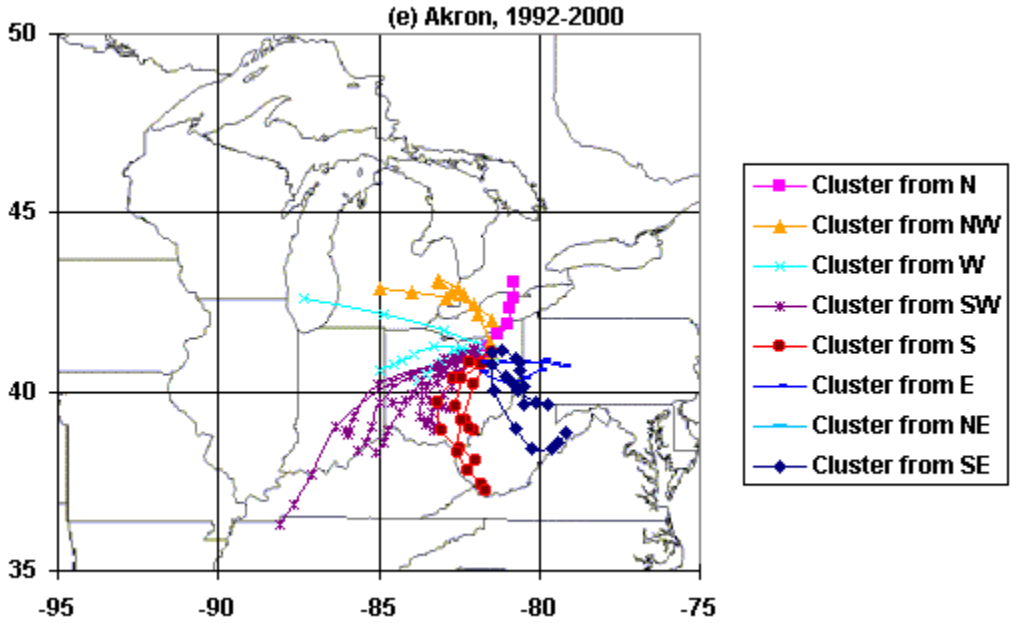


Figure D41 Back trajectories for high SO_2 days at the monitoring sites selected in Ohio, 1992-2000: (c) Columbus (Chesapeake) and (d) Cleveland.



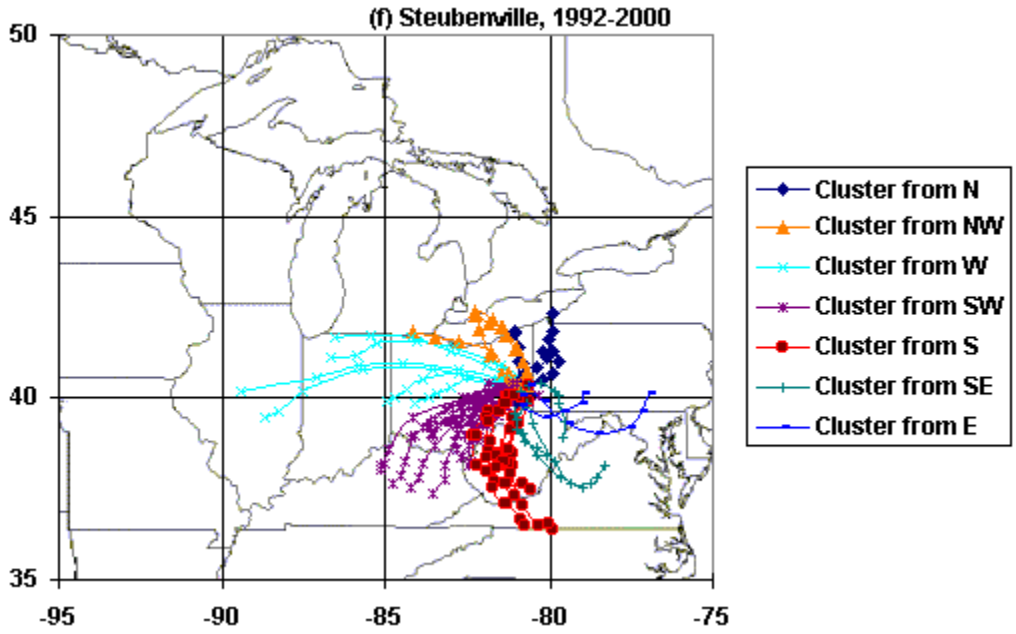


Figure D41. Back trajectories for high SO_2 days at the monitoring sites selected in Ohio, 1992-2000: (e) Akron and (f) Steubenville

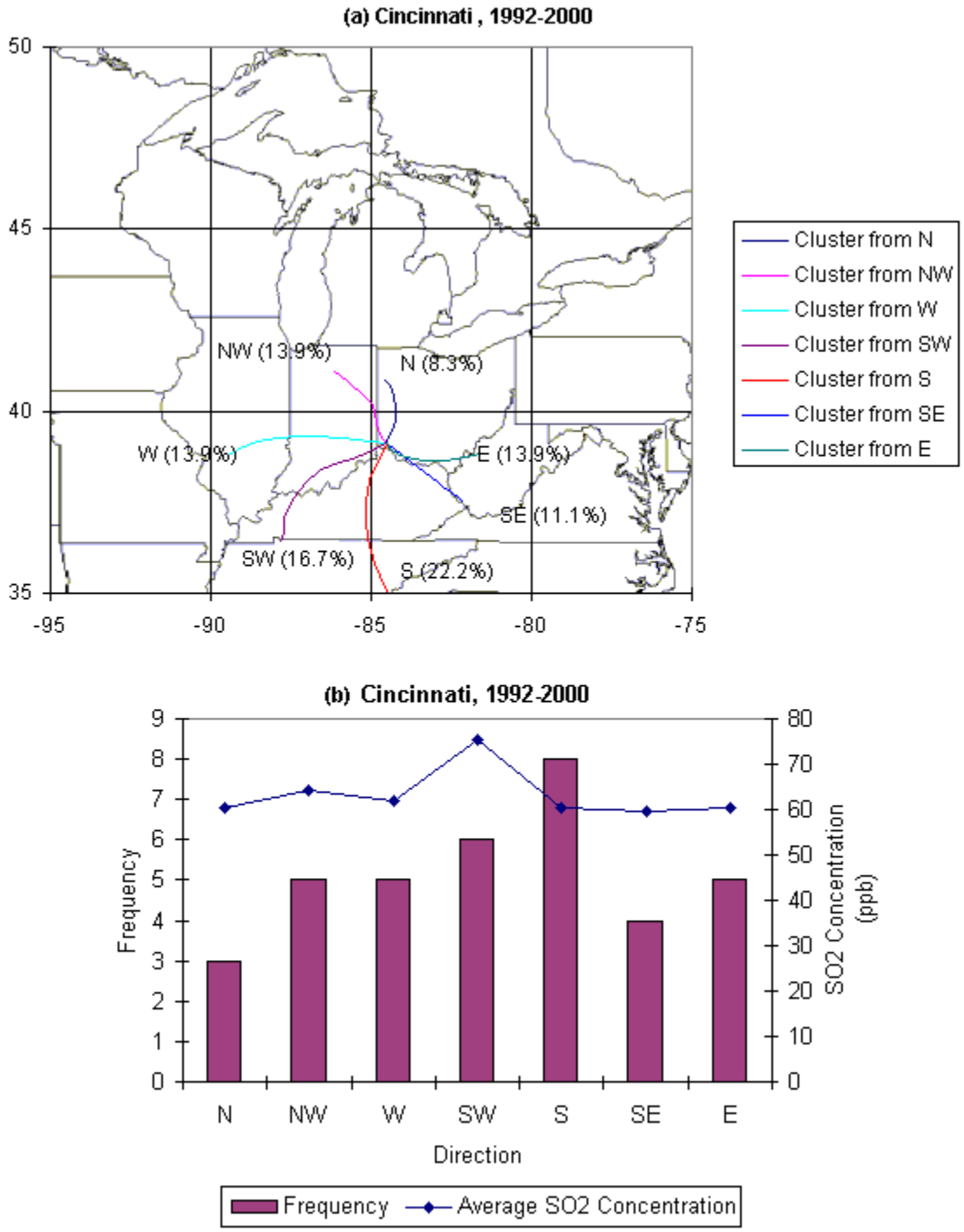


Figure D42. (a) Cluster plot at Cincinnati, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Cincinnati, 1992-2000

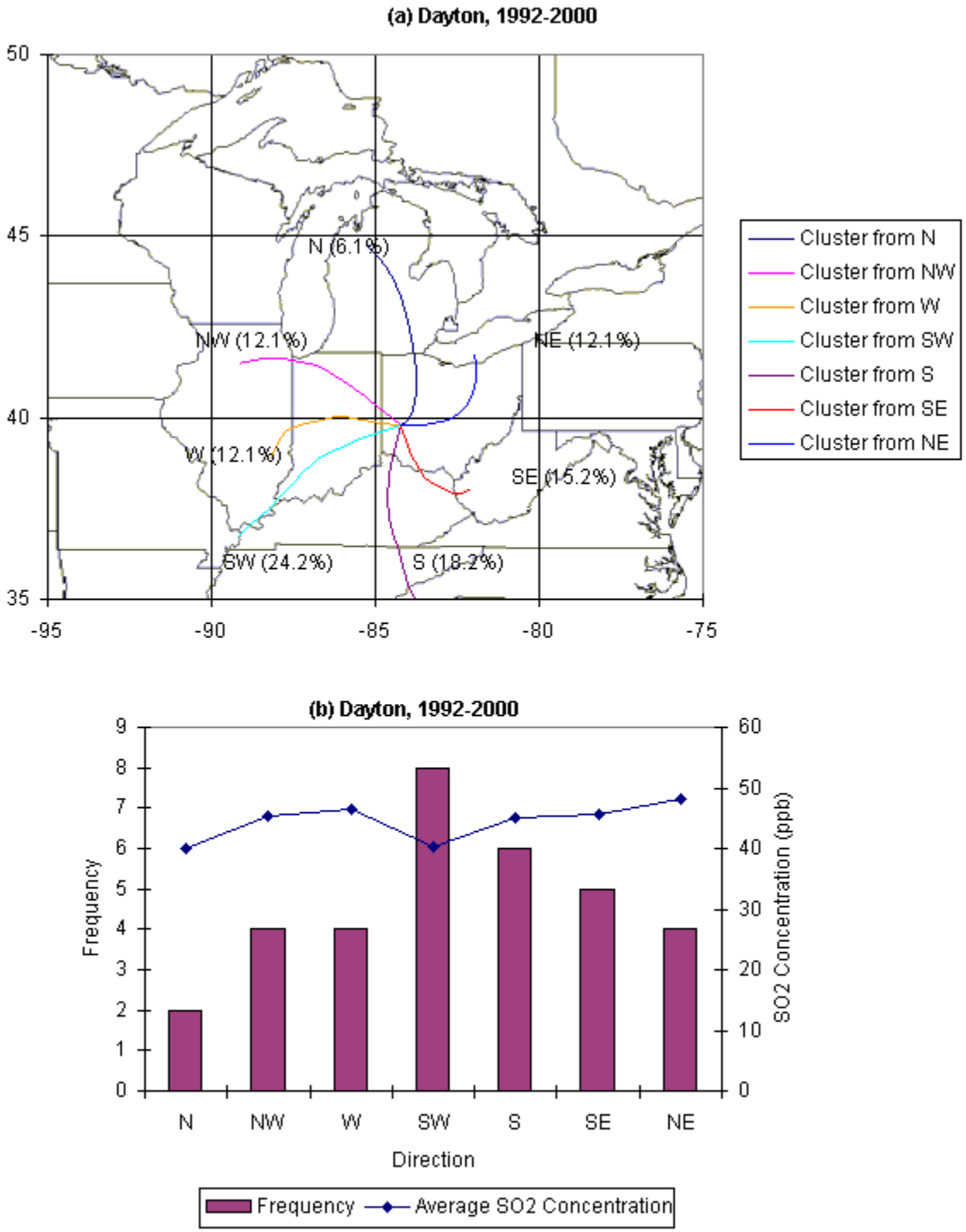


Figure D43. (a) Cluster plot at Dayton, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Dayton, 1992-2000

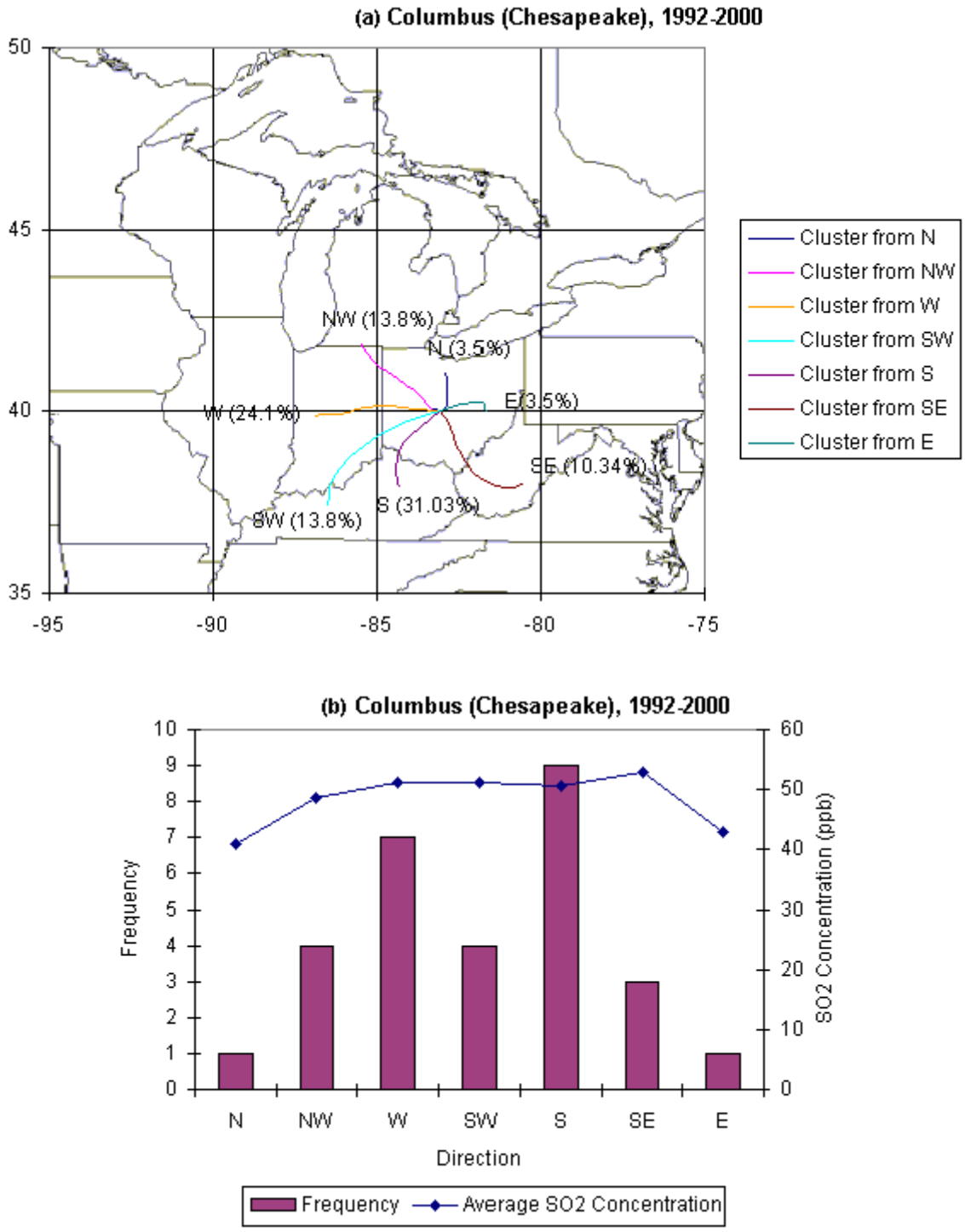


Figure D44. (a) Cluster plot at Columbus (Chesapeake), 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Columbus (Chesapeake), 1992-2000

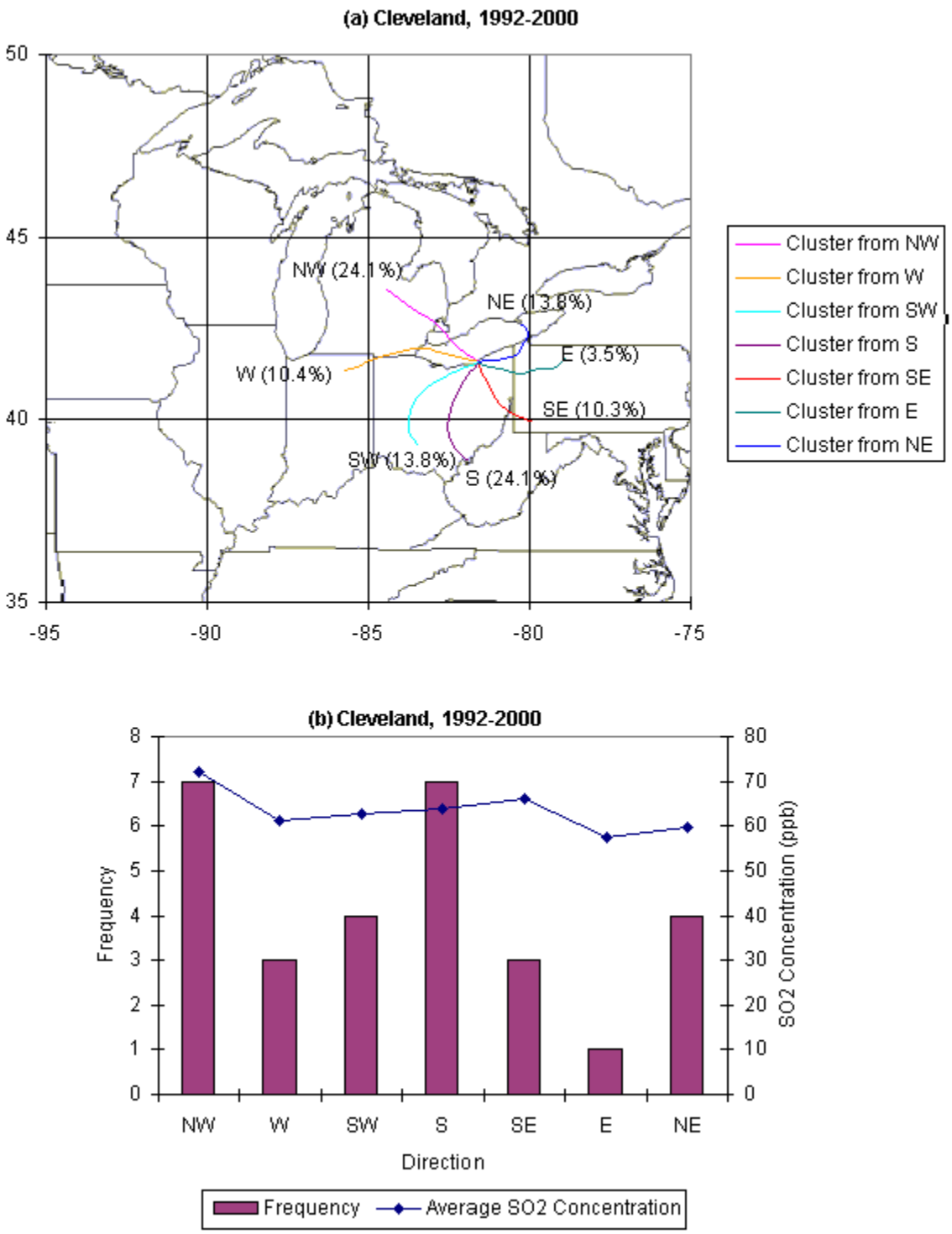


Figure D45. (a) Cluster plot at Cleveland, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Cleveland, 1992-2000

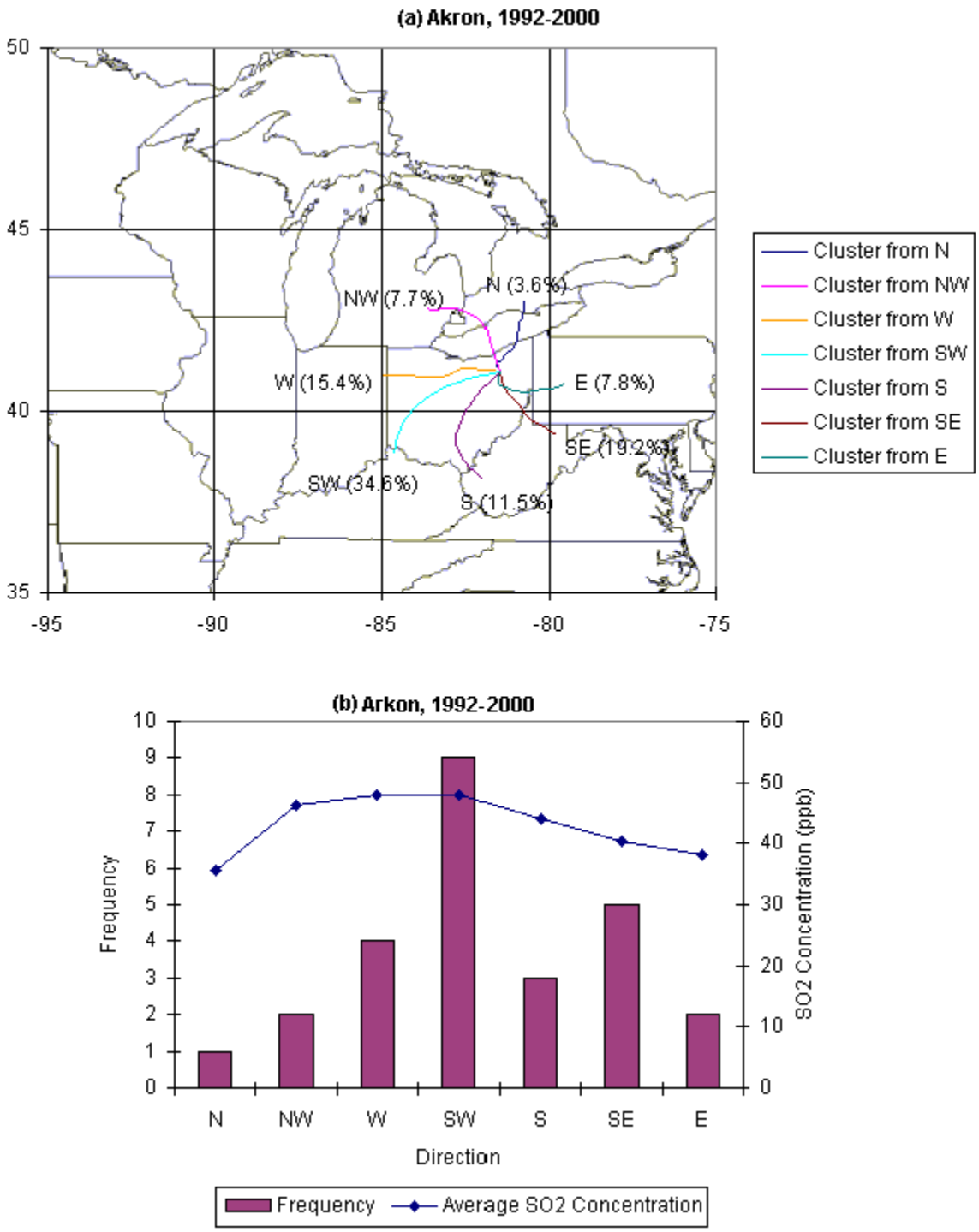


Figure D46. (a) Cluster plot at Akron 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Akron, 1992-2000

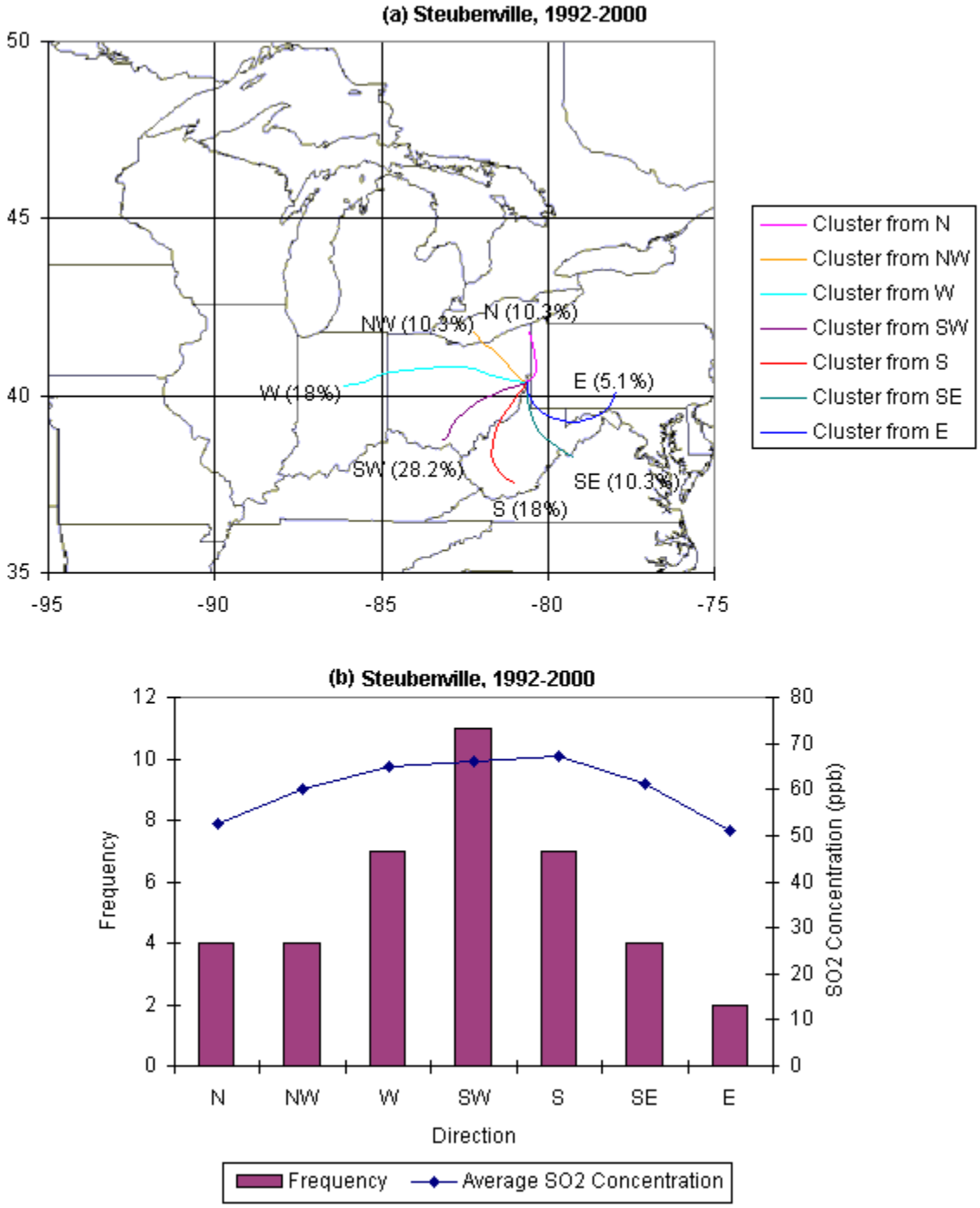


Figure D47. (a) Cluster plot at Steubenville, 1992-2000 (b) Frequencies and average SO_2 concentrations by cluster at Steubenville, 1992-2000

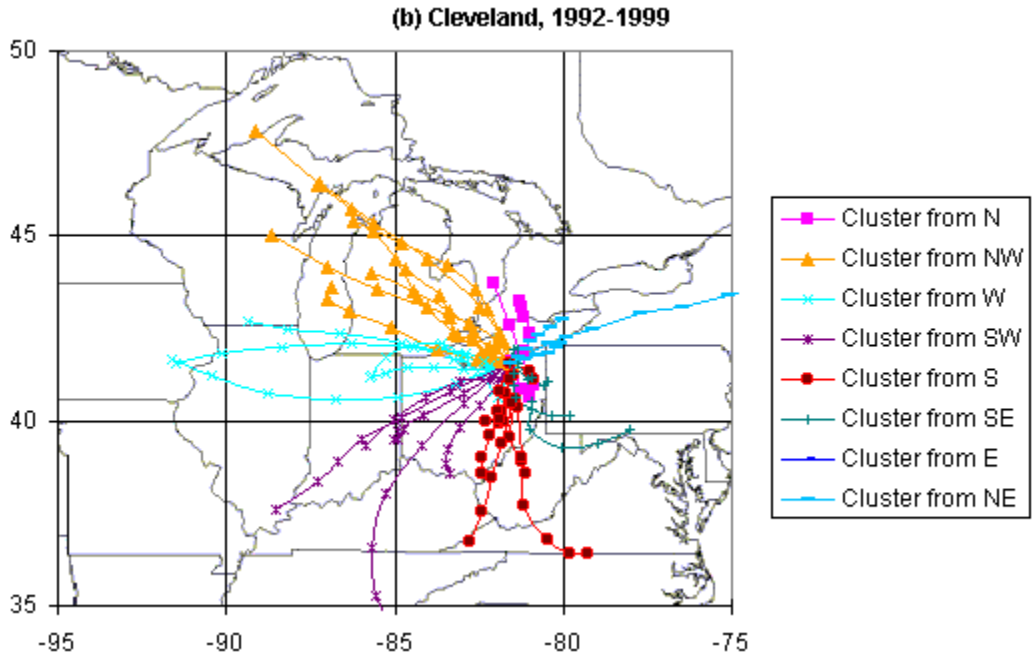


Figure D48. Back trajectories for high NO_2 days at the monitoring sites selected in Ohio: Cleveland, 1992-1999

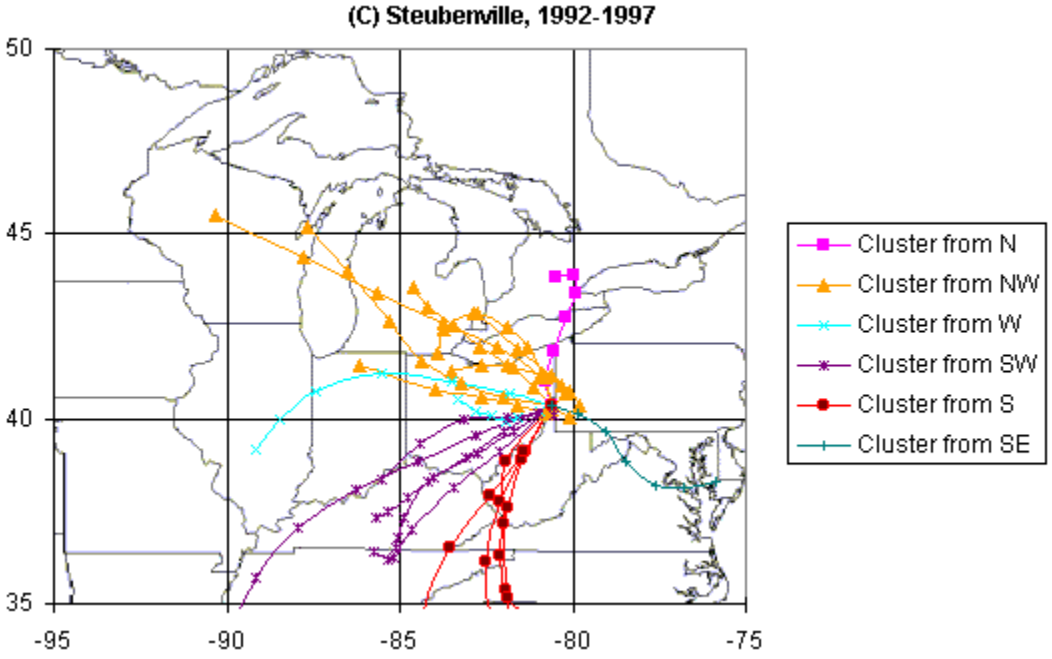


Figure D49. Back trajectories for high NO_2 days at the monitoring sites selected in Ohio: Steubenville, 1992-1997

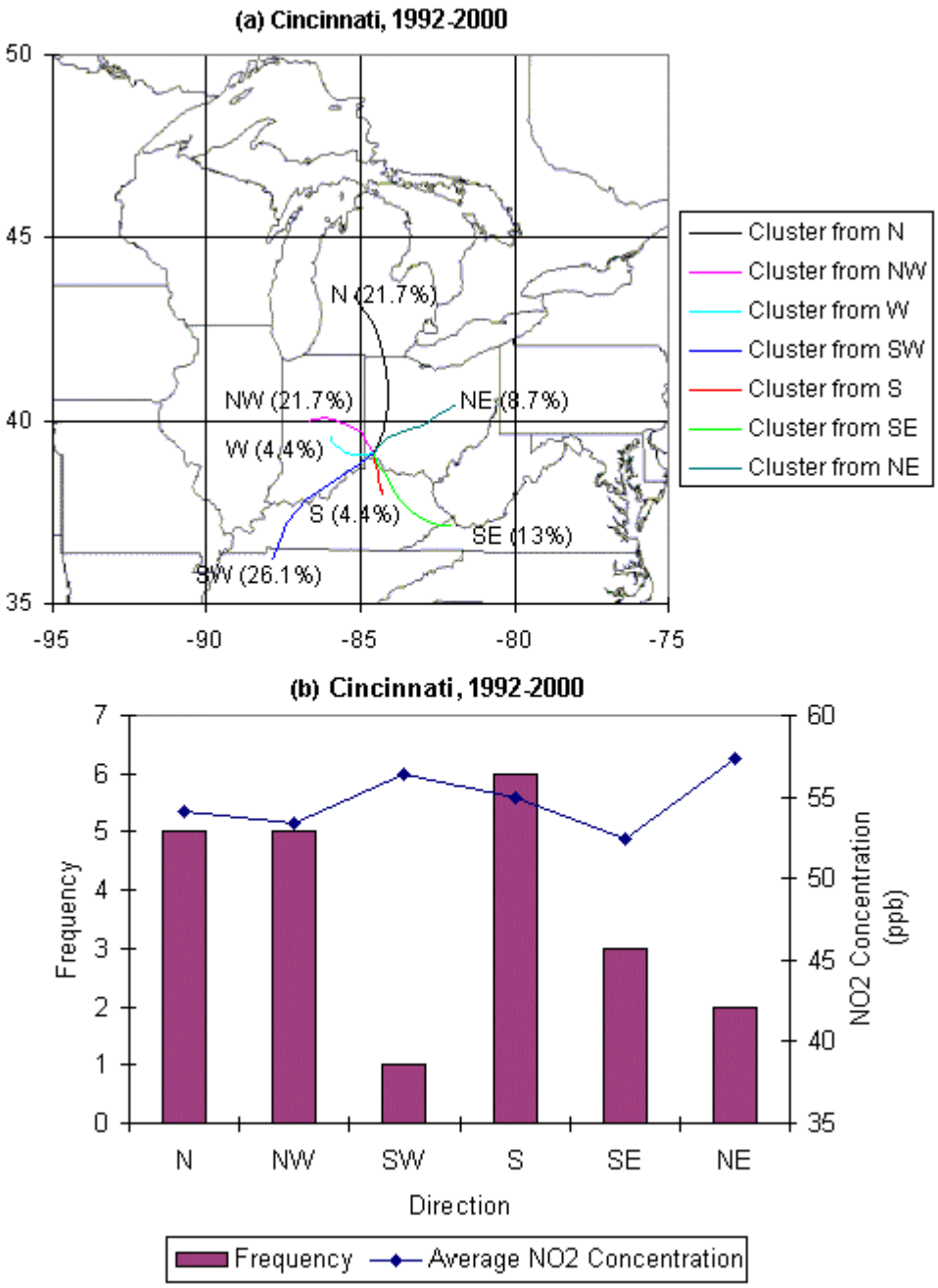
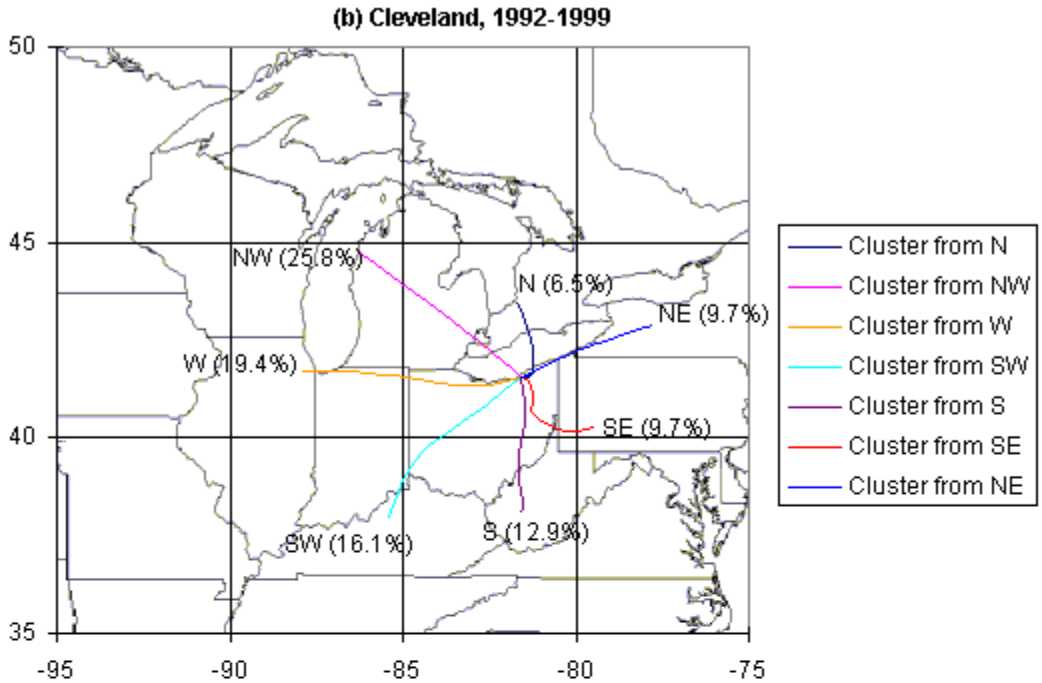


Figure D50. (a) Cluster plot at Cincinnati, 1995-2000 (b) Frequencies and average NO_2 concentrations by cluster at Cincinnati, 1995-2000



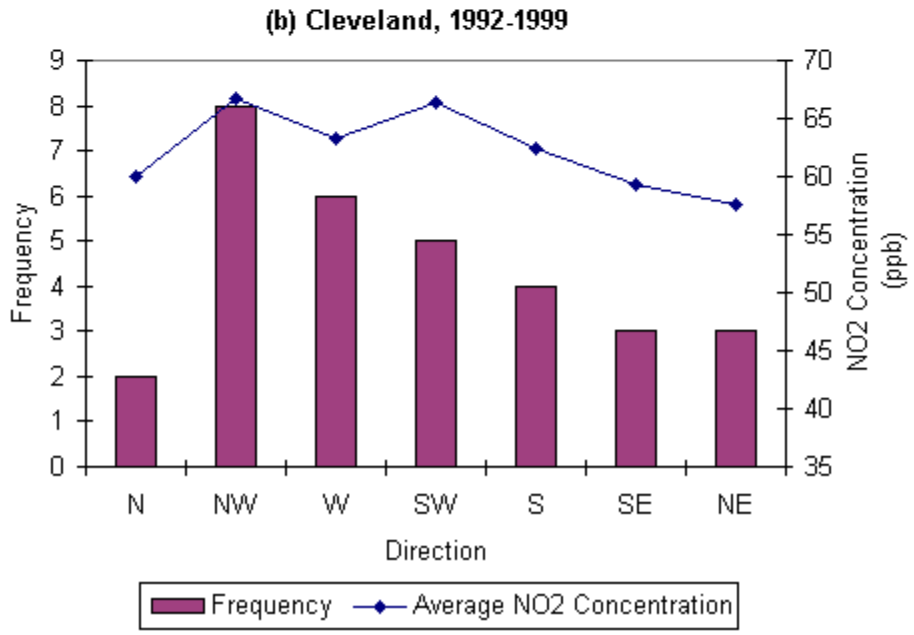


Figure D51. (a) Cluster plot at Cleveland, 1995-2000 (b) Frequencies and average NO_2 concentrations by cluster at Clevland, 1995-2000

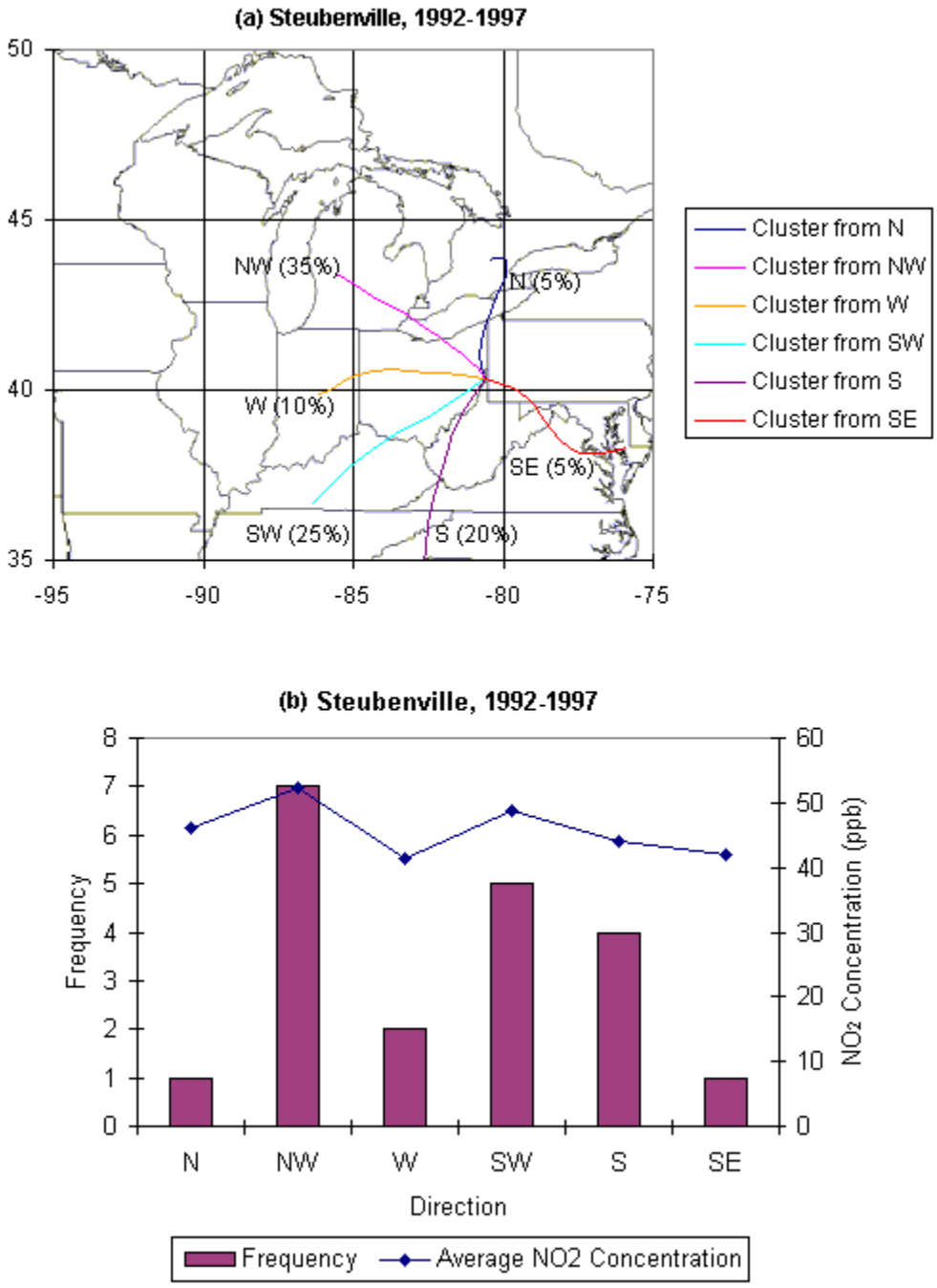


Figure D52. (a) Cluster plot at Steubenville, 1992-1997 (b) Frequencies and average NO_2 concentrations by cluster at Steubenville, 1992-1997

Appendix E
Retrospective Tables

Table E1a
Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Akron Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2462	9.1	3.3	0.0	6.8	8.7	11.0	24.4
Average relative humidity	2367	73.2	10.7	36.0	67.0	73.5	80.5	100.0
Precipitation	2303	0.1	0.3	0.0	0.0	0.0	0.1	3.7
Barometric pressure	2453	28.7	0.2	28.0	28.6	28.7	28.8	29.4
Maximum daily temperature	2460	58.9	19.9	-5.0	43.0	61.0	76.0	95.0
Average daily temperature	2465	50.1	18.3	-15.0	36.0	51.0	66.0	83.0

Table E1b
Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Cincinnati Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2464	9.7	3.7	0.7	6.9	9.1	11.9	27.9
Average relative humidity	2373	72.1	10.6	38.0	65.5	72.0	79.0	100.0
Precipitation	2407	0.1	0.3	0.0	0.0	0.0	0.1	3.5
Barometric pressure	2462	29.0	0.2	28.3	28.9	29.0	29.1	29.6
Maximum daily temperature	2463	61.5	20.1	-4.0	45.0	64.0	79.0	99.0
Average daily temperature	2465	52.5	18.7	-15.0	38.0	54.0	69.0	86.0

Table E1c
Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Cleveland Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2343	9.7	3.6	0.0	7.0	9.2	11.7	25.8
Average relative humidity	2253	73.0	10.2	36.0	66.5	73.0	80.0	100.0
Precipitation	2343	0.1	0.3	0.0	0.0	0.0	0.1	4.6
Barometric pressure	2308	29.2	0.2	28.5	29.1	29.2	29.3	29.9
Maximum daily temperature	2309	58.0	19.6	-3.0	42.0	59.0	75.0	98.0
Average daily temperature	2343	49.9	18.0	-12.0	36.0	50.0	65.0	86.0

Table E1d

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Columbus Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2464	7.3	3.3	0.2	4.9	6.7	9.0	23.2
Average relative humidity	2374	71.1	10.1	36.5	65.0	71.0	78.0	98.0
Precipitation	2433	0.1	0.3	0.0	0.0	0.0	0.1	5.1
Barometric pressure	2462	29.1	0.2	28.5	29.0	29.2	29.3	29.8
Maximum daily temperature	2464	62.7	19.7	-1.0	47.0	65.0	80.0	98.0
Average daily temperature	2464	53.4	18.2	-12.0	39.0	55.0	69.0	86.0

Table E1e

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Dayton Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2464	9.7	3.7	0.7	6.9	9.1	11.9	27.9
Average relative humidity	2373	72.1	10.6	38.0	65.5	72.0	79.0	100.0
Precipitation	2407	0.1	0.3	0.0	0.0	0.0	0.1	3.5
Barometric pressure	2462	29.0	0.2	28.3	28.9	29.0	29.1	29.6
Maximum daily temperature	2463	61.5	20.1	-4.0	45.0	64.0	79.0	99.0
Average daily temperature	2465	52.5	18.7	-15.0	38.0	54.0	69.0	86.0

Table E1f

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Steubenville Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2465	8.6	3.1	0.7	6.3	8.2	10.5	22.5
Average relative humidity	2375	73.2	10.5	35.0	66.5	73.0	80.0	100.0
Precipitation	2352	0.1	0.3	0.0	0.0	0.0	0.1	3.5
Barometric pressure	2464	28.8	0.2	28.0	28.7	28.8	28.9	29.4
Maximum daily temperature	2463	58.7	19.9	-6.00	42.0	61.0	76.0	98.0
Average daily temperature	2465	49.4	18.0	-14.0	35.0	50.0	65.0	84.0

Table E1g

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Toledo Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2465	9.1	3.7	1.0	6.4	8.7	11.3	25.9
Average relative humidity	2374	72.7	10.3	38.0	66.0	72.5	79.5	100.0
Precipitation	2379	0.1	0.2	0.0	0.0	0.0	0.0	3.1
Barometric pressure	2459	29.3	0.2	28.7	29.2	29.3	29.4	30.0
Maximum daily temperature	2463	59.7	20.8	-3.0	42.0	62.0	78.0	104.0
Average daily temperature	2465	50.5	18.9	-10.0	35.0	51.0	67.0	89.0

Table E1h

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Meteorological Variables at the Youngstown Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
Average wind speed	2465	8.6	3.1	0.7	6.3	8.2	10.5	22.5
Average relative humidity	2375	73.2	10.5	35.0	66.5	73.0	80.0	100.0
Precipitation	2352	0.1	0.3	0.0	0.0	0.0	0.1	3.5
Barometric pressure	2464	28.8	0.2	28.0	28.7	28.8	28.9	29.4
Maximum daily temperature	2463	58.7	19.9	-6.0	42.0	61.0	76.0	98.0
Average daily temperature	2465	49.4	18.0	-14.0	35.0	50.0	65.0	84.0

Table E2a

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Akron Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)								
NO_2 (Max 8 Hr Ave)								
CO (Max 1 Hr Ave)	2449	1.2	0.9	0.0	0.6	0.9	1.5	11.0
CO (Max 8 Hr Ave)	2449	0.7	0.5	0.0	0.4	0.6	0.9	5.3
SO_2 (Max 1 Hr Ave)	2403	41.1	35.4	1.0	15.0	29.0	57.0	255.0
SO_2 (Max 8 Hr Ave)	2403	20.0	17.5	0.6	7.9	14.6	27.0	129.1
Ozone (Max 1 Hr Ave)	1462	56.0	19.9	5.0	42.0	55.0	69.0	128.0
Ozone (Max 8 Hr Ave)	1462	48.6	19.0	2.5	35.0	47.3	61.1	114.4
PM10 (24 Hr Ave)	2195	5.6	11.6	0.0	0.0	0.0	0.0	82.0

Table E2b

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Cincinnati Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)	2339	44.2	14.6	13.0	33.0	42.0	53.0	151.0
NO_2 (Max 8 Hr Ave)	2339	32.8	10.3	10.0	25.8	31.4	38.1	119.5
CO (Max 1 Hr Ave)	2429	1.9	1.0	0.0	1.3	1.8	2.3	13.5
CO (Max 8 Hr Ave)	2429	1.2	0.6	0.0	0.8	1.1	1.5	5.8
SO_2 (Max 1 Hr Ave)	2255	28.4	21.4	1.0	13.0	22.0	38.0	153.0
SO_2 (Max 8 Hr Ave)	2255	17.0	12.7	0.1	7.8	14.0	22.3	101.6
Ozone (Max 1 Hr Ave)	1457	50.8	19.5	3.0	37.0	48.0	63.0	128.0
Ozone (Max 8 Hr Ave)	1457	42.1	18.2	1.5	28.8	40.6	54.4	114.5
PM10 (24 Hr Ave)	391	34.9	18.3	3.0	21.0	30.0	45.0	123.0

Table E2c

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Cleveland Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)	2417	38.9	16.0	0.0	28.0	36.0	46.0	253.0
NO_2 (Max 8 Hr Ave)	2417	28.8	11.7	0.0	21.3	27.1	34.3	143.5
CO (Max 1 Hr Ave)	2450	2.7	2.1	0.3	1.5	2.3	3.3	37.5
CO (Max 8 Hr Ave)	2450	1.7	1.0	0.1	1.1	1.6	2.2	19.8
SO_2 (Max 1 Hr Ave)	2414	28.2	28.0	0.0	11.0	20.0	35.0	325.0
SO_2 (Max 8 Hr Ave)	2414	13.8	11.1	0.0	6.3	10.8	17.9	114.8
Ozone (Max 1 Hr Ave)	1453	48.9	19.3	5.0	35.0	46.0	60.0	127.0
Ozone (Max 8 Hr Ave)	1453	41.1	17.3	4.0	28.4	38.6	52.3	103.5
PM10 (24 Hr Ave)	2256	37.9	20.5	3.0	22.0	33.0	50.0	141.0

Table E2d

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Columbus Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)								
NO_2 (Max 8 Hr Ave)								
CO (Max 1 Hr Ave)	2439	1.1	0.9	0.0	0.6	0.9	1.3	9.1
CO (Max 8 Hr Ave)	2439	0.7	0.5	0.0	0.4	0.6	0.8	5.2
SO_2 (Max 1 Hr Ave)	2427	13.8	14.4	0.0	4.0	9.0	18.0	129.0
SO_2 (Max 8 Hr Ave)	2427	8.0	8.4	0.0	2.6	5.4	10.3	72.6
Ozone (Max 1 Hr Ave)	1459	55.4	20.2	2.0	41.0	54.0	68.0	130.0
Ozone (Max 8 Hr Ave)	1459	47.0	19.3	0.3	33.3	46.6	59.1	113.6
PM10 (24 Hr Ave)	390	26.2	12.6	5.0	17.0	24.0	32.0	70.0

Table E2e

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Dayton Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)								
NO_2 (Max 8 Hr Ave)								
CO (Max 1 Hr Ave)	2444	3.2	5.1	0.1	0.8	1.1	2.1	49.9
CO (Max 8 Hr Ave)	2444	2.0	3.1	0.0	0.5	0.8	1.3	28.6
SO_2 (Max 1 Hr Ave)	2451	12.0	11.1	0.0	5.0	9.0	16.0	180.0
SO_2 (Max 8 Hr Ave)	2451	7.8	6.9	0.0	3.3	5.8	10.3	69.1
Ozone (Max 1 Hr Ave)	1455	56.7	19.8	3.0	42.0	56.0	69.0	130.0
Ozone (Max 8 Hr Ave)	1455	49.0	18.7	1.1	35.4	48.1	61.5	112.6
PM10 (24 Hr Ave)								

Table E2f

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Steubenville Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)	2082	34.2	12.8	1.0	26.0	33.0	41.0	148.0
NO_2 (Max 8 Hr Ave)	2082	24.0	9.1	0.6	17.5	23.3	29.1	93.9
CO (Max 1 Hr Ave)	2380	1.8	1.8	0.1	0.8	1.2	2.2	26.1
CO (Max 8 Hr Ave)	2380	1.0	0.9	0.0	0.5	0.7	1.2	11.3
SO_2 (Max 1 Hr Ave)	2364	49.8	51.7	0.0	16.0	33.0	63.0	416.0
SO_2 (Max 8 Hr Ave)	2364	25.3	23.8	0.0	10.0	18.4	32.5	229.8
Ozone (Max 1 Hr Ave)	2219	44.0	20.4	1.0	29.0	41.0	57.0	153.0
Ozone (Max 8 Hr Ave)	2215	37.2	18.7	0.4	23.5	34.4	49.0	136.1
PM10 (24 Hr Ave)	2055	35.6	18.3	4.0	22.0	32.0	45.0	143.0

Table E2g

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Toledo Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)								
NO_2 (Max 8 Hr Ave)								
CO (Max 1 Hr Ave)	2442	13.3	10.3	1.0	6.0	11.0	18.0	140.0
CO (Max 8 Hr Ave)	2442	8.5	5.9	0.1	4.3	7.4	11.3	45.1
SO_2 (Max 1 Hr Ave)	2285	14.9	17.1	0.0	5.0	9.0	19.0	262.0
SO_2 (Max 8 Hr Ave)	2285	7.7	8.2	0.0	2.5	5.1	9.8	100.5
Ozone (Max 1 Hr Ave)	1415	55.3	19.4	2.0	42.0	54.0	67.0	131.0
Ozone (Max 8 Hr Ave)	1415	46.8	17.9	1.0	33.9	46.1	58.3	115.0

Table E2h

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for the Air Quality Variables at the Youngstown Monitor

	N	M	SD	Min	25th	Mdn	75th	Max
NO_2 (Max 1 Hr Ave)								
NO_2 (Max 8 Hr Ave)								
CO (Max 1 Hr Ave)								
CO (Max 8 Hr Ave)								
SO_2 (Max 1 Hr Ave)	2462	25.4	21.4	0.0	10.0	19.0	33.3	208.0
SO_2 (Max 8 Hr Ave)	2462	13.9	11.2	0.0	5.9	10.9	18.6	102.3
Ozone (Max 1 Hr Ave)	1467	52.7	20.7	0.0	38.0	51.0	67.0	132.0
Ozone (Max 8 Hr Ave)	1467	44.9	19.6	0.0	31.0	43.4	58.3	113.4
PM10 (24 Hr Ave)	620	28.0	14.2	5.0	18.3	25.0	33.8	132.0

Table E3a

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Akron Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.4	0.7	0.0	0.0	0.0	1.0	4.0
Total - Respiratory Illness	2465	16.8	7.1	3.0	12.0	16.0	21.0	53.0
Children - Asthma	2465	0.2	0.5	0.0	0.0	0.0	0.0	4.0
Elderly - COPD	2465	1.8	1.4	0.0	1.0	2.0	3.0	8.0
Total – Respiratory deaths	2465	2.7	1.7	0.0	1.0	3.0	4.0	11.0

Table E3b

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Cincinnati Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.6	0.8	0.0	0.0	0.0	1.0	4.0
Total - Respiratory Illness	2465	21.1	9.4	3.0	15.0	20.0	26.0	94.0
Children - Asthma	2465	0.4	0.7	0.0	0.0	0.0	1.0	7.0
Elderly - COPD	2465	1.6	1.4	0.0	1.0	1.0	2.0	10.0
Total – Respiratory deaths	2465	3.6	2.2	0.0	2.0	3.0	5.0	15.0

Table E3c

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Cleveland Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.7	0.8	0.0	0.0	0.0	1.0	5.0
Total - Respiratory Illness	2465	26.9	10.9	3.0	19.0	25.0	33.0	95.0
Children - Asthma	2465	0.4	0.7	0.0	0.0	0.0	1.0	4.0
Elderly - COPD	2465	3.6	2.4	0.0	2.0	3.0	5.0	18.0
Total – Respiratory deaths	2465	4.5	2.4	0.0	3.0	4.0	6.0	15.0

Table E3d

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Columbus Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.4	0.7	0.0	0.0	0.0	1.0	5.0
Total - Respiratory Illness	2465	14.4	6.4	2.0	10.0	13.0	18.0	53.0
Children - Asthma	2465	0.3	0.6	0.0	0.0	0.0	0.0	5.0
Elderly - COPD	2465	1.5	1.3	0.0	1.0	1.0	2.0	10.0
Total – Respiratory deaths	2465	2.4	1.6	0.0	1.0	2.0	3.0	9.0

Table E3e

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Dayton Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.4	0.6	0.0	0.0	0.0	1.0	4.0
Total - Respiratory Illness	2465	11.7	5.5	0.0	8.0	11.0	15.0	39.0
Children - Asthma	2465	0.6	0.8	0.0	0.0	0.0	1.0	6.0
Elderly - COPD	2465	0.9	1.0	0.0	0.0	1.0	1.0	8.0
Total – Respiratory deaths	2465	2.1	1.5	0.0	1.0	2.0	3.0	9.0

Table E3f

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Steubenville Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.1	0.3	0.0	0.0	0.0	0.0	3.0
Total - Respiratory Illness	2465	3.1	2.1	0.0	2.0	3.0	4.0	14.0
Children - Asthma	2465	0.1	0.2	0.0	0.0	0.0	0.0	2.0
Elderly - COPD	2465	0.4	0.7	0.0	0.0	0.0	1.0	5.0
Total – Respiratory deaths	2465	0.5	0.7	0.0	0.0	0.0	1.0	6.0

Table E3g

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Toledo Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.3	0.6	0.0	0.0	0.0	1.0	4.0
Total - Respiratory Illness	2465	10.1	5.1	0.0	7.0	9.0	13.0	42.0
Children - Asthma	2465	0.2	0.5	0.0	0.0	0.0	0.0	4.0
Elderly - COPD	2465	1.2	1.2	0.0	0.0	1.0	2.0	9.0
Total – Respiratory deaths	2465	1.8	1.4	0.0	1.0	2.0	3.0	8.0

Table E3h

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum, and Quartiles) for Daily Cases of Respiratory Illness within 20 Miles of the Youngstown Monitor by Diagnosis Type and Age

	N	M	SD	Min	25th	Mdn	75th	Max
Total - Non-Respiratory Illness	2465	0.2	0.5	0.0	0.0	0.0	0.0	3.0
Total - Respiratory Illness	2465	8.6	4.5	0.0	5.0	8.0	11.0	30.0
Children - Asthma	2465	0.1	0.3	0.0	0.0	0.0	0.0	3.0
Elderly - COPD	2465	0.8	1.0	0.0	0.0	1.0	1.0	6.0
Total – Respiratory deaths	2465	1.7	1.4	0.0	1.0	1.0	3.0	8.0

Table E4a
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Akron Monitor

	1	2	3	4	5	6
1. Average wind speed		.080	.188	-.361	-.319	-.314
		(.000)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.361	-.319	-.233	-.135
			(.000)	(.000)	(.000)	(.000)
3. Precipitation				-.313	.077	.108
				(.000)	(.000)	(.000)
4. Barometric Pressure					-.086	-.124
					(.000)	(.000)
5. Maximum Daily Temperature						.985
						(.000)
6. Average Daily Temperature						

Table E4b
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Cincinnati Monitor

	1	2	3	4	5	6
1. Average wind speed		.092	.177	-.377	-.274	-.274
		(.000)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.357	-.293	-.229	-.130
			(.000)	(.000)	(.000)	(.000)
3. Precipitation				-.292	.073	.105
				(.000)	(.000)	(.000)
4. Barometric Pressure					-.174	-.209
					(.000)	(.000)
5. Maximum Daily Temperature						.986
						(.000)
6. Average Daily Temperature						

Table E4c
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Cleveland Monitor

	1	2	3	4	5	6
1. Average wind speed		-.033	.192	-.343	-.227	-.224
		(.118)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.345	-.273	-.149	-.061
			(.000)	(.000)	(.000)	(.004)
3. Precipitation				-.306	.080	.104
				(.000)	(.000)	(.000)
4. Barometric Pressure					-.177	-.208
					(.000)	(.000)
5. Maximum Daily Temperature						.983
						(.000)
6. Average Daily Temperature						

Table E4d
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Columbus Monitor

	1	2	3	4	5	6
1. Average wind speed		.002	.124	-.352	-.308	-.288
		(.920)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.345	-.268	-.131	-.035
			(.000)	(.000)	(.000)	(.087)
3. Precipitation				-.278	.092	.129
				(.000)	(.000)	(.000)
4. Barometric Pressure					-.203	-.244
					(.000)	(.000)
5. Maximum Daily Temperature						.983
						(.000)
6. Average Daily Temperature						

Table E4e
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Dayton Monitor

	1	2	3	4	5	6
1. Average wind speed		.092	.177	-.377	-.274	-.274
		(.000)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.357	-.293	-.229	-.130
			(.000)	(.000)	(.000)	(.000)
3. Precipitation				-.292	.073	.105
				(.000)	(.000)	(.000)
4. Barometric Pressure					-.174	-.209
					(.000)	(.000)
5. Maximum Daily Temperature						.986
						(.000)
6. Average Daily Temperature						

Table E4f
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Steubenville Monitor

	1	2	3	4	5	6
1. Average wind speed		.015	.183	-.376	-.281	-.257
		(.454)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.342	-.295	-.188	-.076
			(.000)	(.000)	(.000)	(.000)
3. Precipitation				-.302	.068	.104
				(.000)	(.001)	(.000)
4. Barometric Pressure					-.067	-.118
					(.001)	(.000)
5. Maximum Daily Temperature						.982
						(.000)
6. Average Daily Temperature						

Table E4g
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Toledo Monitor

	1	2	3	4	5	6
1. Average wind speed		-.048	.131	-.346	-.304	-.289
		(.018)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.360	-.204	-.197	-.100
			(.000)	(.000)	(.000)	(.000)
3. Precipitation				-.279	.033	.068
				(.000)	(.113)	(.001)
4. Barometric Pressure					-.205	-.246
					(.000)	(.000)
5. Maximum Daily Temperature						.984
						(.000)
6. Average Daily Temperature						

Table E4h
Correlation Matrix (and Significance Levels) for the Meteorological Variables at the Youngstown Monitor

	1	2	3	4	5	6
1. Average wind speed		.015	.183	-.376	-.281	-.257
		(.454)	(.000)	(.000)	(.000)	(.000)
2. Average relative humidity			.342	-.295	-.188	-.076
			(.000)	(.000)	(.000)	(.000)
3. Precipitation				-.302	.068	.104
				(.000)	(.001)	(.000)
4. Barometric Pressure					-.067	-.118
					(.001)	(.000)
5. Maximum Daily Temperature						.982
						(.000)
6. Average Daily Temperature						

Table E5a
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Akron Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)									
2. NO_2 (Max 8 Hr Ave)									
3. CO (Max 1 Hr Ave)				.894	.061	.083	.067	.046	.195
				(.000)	(.003)	(.000)	(.010)	(.082)	(.000)
4. CO (Max 8 Hr Ave)					.105	.130	.089	.056	.268
					(.000)	(.000)	(.001)	(.033)	(.000)
5. SO_2 (Max 1 Hr Ave)						.890	.191	.180	.228
						(.000)	(.000)	(.000)	(.000)
6. SO_2 (Max 8 Hr Ave)							.194	.187	.214
							(.000)	(.000)	(.000)
7. Ozone (Max 1 Hr Ave)								.975	-.011
								(.000)	(.701)
8. Ozone (Max 8 Hr Ave)									-.022
									(.421)
9. PM10 (24 Hr Ave)									

Table E5b
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Cincinnati Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)		.865	.250	.231	.209	.199	.428	.403	.436
		(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
2. NO_2 (Max 8 Hr Ave)			.360	.369	.328	.339	.282	.229	.450
			(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
3. CO (Max 1 Hr Ave)				.917	.297	.349	-.014	-.073	.294
				(.000)	(.000)	(.000)	(.605)	(.006)	(.000)
4. CO (Max 8 Hr Ave)					.319	.372	-.033	-.099	.305
					(.000)	(.000)	(.204)	(.000)	(.000)
5. SO_2 (Max 1 Hr Ave)						.919	.160	.116	.253
						(.000)	(.000)	(.000)	(.000)
6. SO_2 (Max 8 Hr Ave)							.165	.115	.273
							(.000)	(.000)	(.000)
7. Ozone (Max 1 Hr Ave)								.965	.440
								(.000)	(.000)
8. Ozone (Max 8 Hr Ave)									.371
									(.000)
9. PM10 (24 Hr Ave)									

Table E5c
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Cleveland Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)		.873	.161	.194	.170	.181	.265	.252	.428
		(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
2. NO_2 (Max 8 Hr Ave)			.201	.257	.199	.258	.149	.133	.479
			(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
3. CO (Max 1 Hr Ave)				.877	.023	.088	.097	.095	.247
				(.000)	(.262)	(.000)	(.000)	(.000)	(.000)
4. CO (Max 8 Hr Ave)					.009	.107	.156	.140	.352
					(.669)	(.000)	(.000)	(.000)	(.000)
5. SO_2 (Max 1 Hr Ave)						.863	.043	.036	.199
						(.000)	(.102)	(.174)	(.000)
6. SO_2 (Max 8 Hr Ave)							.068	.055	.320
							(.010)	(.040)	(.000)
7. Ozone (Max 1 Hr Ave)								.968	.485
								(.000)	(.000)
8. Ozone (Max 8 Hr Ave)									.461
									(.000)
9. PM10 (24 Hr Ave)									

Table E5d
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Columbus Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)									
2. NO_2 (Max 8 Hr Ave)									
3. CO (Max 1 Hr Ave)				.934	.358	.381	-.102	-.131	.220
				(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
4. CO (Max 8 Hr Ave)					.373	.404	-.154	-.182	.194
					(.000)	(.000)	(.000)	(.000)	(.000)
5. SO_2 (Max 1 Hr Ave)						.921	.051	.005	.257
						(.000)	(.052)	(.863)	(.000)
6. SO_2 (Max 8 Hr Ave)							.058	.008	.314
							(.027)	(.755)	(.000)
7. Ozone (Max 1 Hr Ave)								.961	.589
								(.000)	(.000)
8. Ozone (Max 8 Hr Ave)									.494
									(.000)
9. PM10 (24 Hr Ave)									

Table E5e
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Dayton Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)									
2. NO_2 (Max 8 Hr Ave)									
3. CO (Max 1 Hr Ave)				.967 (.000)	.142 (.000)	.139 (.000)	.104 (.000)	.108 (.000)	
4. CO (Max 8 Hr Ave)					.148 (.000)	.150 (.000)	.082 (.002)	.081 (.002)	
5. SO_2 (Max 1 Hr Ave)						.928 (.000)	.225 (.000)	.186 (.000)	
6. SO_2 (Max 8 Hr Ave)							.240 (.000)	.194 (.000)	
7. Ozone (Max 1 Hr Ave)								.970 (.000)	
8. Ozone (Max 8 Hr Ave)									
9. PM10 (24 Hr Ave)									

Table E5f

Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Steubenville Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)		.855	.447	.455	.376	.390	.206	.192	.424
		(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)	(.000)
2. NO_2 (Max 8 Hr Ave)			.459	.515	.406	.485	.008	-.010	.423
			(.000)	(.000)	(.000)	(.000)	(.719)	(.654)	(.000)
3. CO (Max 1 Hr Ave)				.923	.305	.341	-.010	-.033	.344
				(.000)	(.000)	(.000)	(.624)	(.118)	(.000)
4. CO (Max 8 Hr Ave)					.316	.366	-.057	-.080	.380
					(.000)	(.000)	(.008)	(.000)	(.000)
5. SO_2 (Max 1 Hr Ave)						.910	.008	-.019	.323
						(.000)	(.704)	(.371)	(.000)
6. SO_2 (Max 8 Hr Ave)							-.059	-.087	.364
							(.005)	(.000)	(.000)
7. Ozone (Max 1 Hr Ave)								.972	.208
								(.000)	(.000)
8. Ozone (Max 8 Hr Ave)									.189
									(.000)
9. PM10 (24 Hr Ave)									

Table E5g
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Toledo Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)									
2. NO_2 (Max 8 Hr Ave)									
3. CO (Max 1 Hr Ave)				.905 (.000)	.198 (.000)	.225 (.000)	-.131 (.000)	-.156 (.000)	
4. CO (Max 8 Hr Ave)					.230 (.000)	.267 (.000)	-.129 (.000)	-.162 (.000)	
5. SO_2 (Max 1 Hr Ave)						.909 (.000)	-.026 (.351)	-.043 (.116)	
6. SO_2 (Max 8 Hr Ave)							-.032 (.250)	-.051 (.066)	
7. Ozone (Max 1 Hr Ave)								.966 (.000)	
8. Ozone (Max 8 Hr Ave)									
9. PM10 (24 Hr Ave)									

Table E5h
Correlation Matrix (and Significance Levels) for the Air Quality Variables at the Youngstown Monitor

	1	2	3	4	5	6	7	8	9
1. NO_2 (Max 1 Hr Ave)									
2. NO_2 (Max 8 Hr Ave)									
3. CO (Max 1 Hr Ave)									
4. CO (Max 8 Hr Ave)									
5. SO_2 (Max 1 Hr Ave)						.902 (.000)	-.021 (.415)	-.047 (.071)	.169 (.000)
6. SO_2 (Max 8 Hr Ave)							-.068 (.009)	-.103 (.000)	.185 (.000)
7. Ozone (Max 1 Hr Ave)								.973 (.000)	.606 (.000)
8. Ozone (Max 8 Hr Ave)									.571 (.000)
9. PM10 (24 Hr Ave)									

Table E6a

Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Akron Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)						
NO_2 (Max 8 Hr Ave)						
CO (Max 1 Hr Ave)	-.407 (.000)	-.236 (.000)	-.121 (.000)	.247 (.000)	.150 (.000)	.098 (.000)
CO (Max 8 Hr Ave)	-.369 (.000)	-.170 (.000)	-.075 (.000)	.222 (.000)	.123 (.000)	.077 (.000)
SO_2 (Max 1 Hr Ave)	.152 (.000)	-.128 (.000)	-.002 (.909)	-.100 (.000)	.142 (.000)	.119 (.000)
SO_2 (Max 8 Hr Ave)	.158 (.000)	-.127 (.000)	-.029 (.164)	-.074 (.000)	.088 (.000)	.061 (.003)
Ozone (Max 1 Hr Ave)	-.270 (.000)	-.338 (.000)	-.134 (.000)	.089 (.001)	0.721 (.000)	.647 (.000)
Ozone (Max 8 Hr Ave)	-.245 (.000)	-.376 (.000)	-.181 (.000)	.096 (.000)	.684 (.000)	.610 (.000)
PM10 (24 Hr Ave)	.028 (.183)	-.016 (.456)	.015 (.499)	.063 (.003)	.064 (.003)	.063 (.003)

Table E6b
Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Cincinnati Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)	-.407 (.000)	-.427 (.000)	-.151 (.000)	.134 (.000)	.402 (.000)	.347 (.000)
NO_2 (Max 8 Hr Ave)	-.369 (.000)	-.345 (.000)	-.136 (.000)	.154 (.000)	.249 (.000)	.200 (.000)
CO (Max 1 Hr Ave)	-.251 (.000)	-.048 (.020)	-.032 (.121)	.180 (.000)	-.025 (.221)	-.050 (.013)
CO (Max 8 Hr Ave)	-.254 (.000)	-.012 (.558)	-.020 (.329)	.159 (.000)	-.011 (.603)	-.031 (.130)
SO_2 (Max 1 Hr Ave)	-.116 (.000)	-.132 (.000)	-.085 (.000)	.096 (.000)	.084 (.000)	.051 (.015)
SO_2 (Max 8 Hr Ave)	-.102 (.000)	-.112 (.000)	-.110 (.000)	.113 (.000)	.025 (.244)	-.008 (.708)
Ozone (Max 1 Hr Ave)	-.260 (.000)	-.243 (.000)	-.116 (.000)	.083 (.002)	.671 (.000)	.615 (.000)
Ozone (Max 8 Hr Ave)	-.233 (.000)	-.287 (.000)	-.144 (.000)	.085 (.001)	.627 (.000)	.568 (.000)
PM10 (24 Hr Ave)	-.392 (.000)	-.148 (.004)	-.095 (.063)	.181 (.000)	.393 (.000)	.372 (.000)

Table E6c
Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Cleveland Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)	-.400 (.000)	-.219 (.000)	-.174 (.000)	.119 (.000)	.182 (.000)	.140 (.000)
NO_2 (Max 8 Hr Ave)	-.378 (.000)	-.150 (.000)	-.152 (.000)	.145 (.000)	.014 (.498)	-.029 (.160)
CO (Max 1 Hr Ave)	-.182 (.000)	-.086 (.000)	-.062 (.003)	.074 (.000)	.004 (.845)	-.034 (.105)
CO (Max 8 Hr Ave)	-.203 (.000)	-.081 (.000)	-.061 (.003)	.072 (.001)	.025 (.227)	-.021 (.301)
SO_2 (Max 1 Hr Ave)	-.227 (.000)	-.116 (.000)	-.124 (.000)	.232 (.000)	.041 (.051)	.011 (.588)
SO_2 (Max 8 Hr Ave)	-.177 (.000)	-.095 (.000)	-.123 (.000)	.224 (.000)	-.028 (.188)	-.065 (.002)
Ozone (Max 1 Hr Ave)	-.118 (.000)	-.188 (.000)	-.087 (.001)	-.025 (.377)	.694 (.000)	.646 (.000)
Ozone (Max 8 Hr Ave)	-.091 (.001)	-.234 (.000)	-.116 (.000)	-.011 (.691)	.672 (.000)	.622 (.000)
PM10 (24 Hr Ave)	-.253 (.000)	-.195 (.000)	-.107 (.000)	.113 (.000)	.394 (.000)	.331 (.000)

Table E6d

Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Columbus Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)						
NO_2 (Max 8 Hr Ave)						
CO (Max 1 Hr Ave)	.025 (.225)	.047 (.023)	-.039 (.055)	.007 (.734)	-.189 (.000)	-.200 (.000)
CO (Max 8 Hr Ave)	.029 (.147)	.063 (.002)	-.037 (.067)	.023 (.255)	-.235 (.000)	-.246 (.000)
SO_2 (Max 1 Hr Ave)	.002 (.913)	.076 (.000)	-.027 (.186)	.035 (.082)	-.140 (.000)	-.143 (.000)
SO_2 (Max 8 Hr Ave)	.009 (.674)	.103 (.000)	-.037 (.069)	.041 (.046)	-.176 (.000)	-.176 (.000)
Ozone (Max 1 Hr Ave)	-.137 (.000)	-.041 (.120)	.011 (.672)	-.033 (.202)	.482 (.000)	.506 (.000)
Ozone (Max 8 Hr Ave)	-.116 (.000)	-.063 (.017)	.012 (.639)	-.042 (.110)	.465 (.000)	.487 (.000)
PM10 (24 Hr Ave)	-.224 (.000)	.052 (.317)	.058 (.257)	-.050 (.325)	.376 (.000)	.404 (.000)

Table E6e

Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Dayton Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)						
NO_2 (Max 8 Hr Ave)						
CO (Max 1 Hr Ave)	-.096 (.000)	-.094 (.000)	-.061 (.003)	.152 (.000)	-.054 (.008)	-.083 (.000)
CO (Max 8 Hr Ave)	-.076 (.000)	-.063 (.002)	-.049 (.017)	.147 (.000)	-.071 (.000)	-.097 (.000)
SO_2 (Max 1 Hr Ave)	-.021 (.302)	-.206 (.000)	-.102 (.000)	.133 (.000)	-.058 (.004)	-.106 (.000)
SO_2 (Max 8 Hr Ave)	-.009 (.671)	-.159 (.000)	-.103 (.000)	.115 (.000)	-.067 (.001)	-.108 (.000)
Ozone (Max 1 Hr Ave)	-.225 (.000)	-.314 (.000)	-.140 (.000)	.056 (.031)	.699 (.000)	.623 (.000)
Ozone (Max 8 Hr Ave)	-.194 (.000)	-.362 (.000)	-.171 (.000)	.061 (.021)	.664 (.000)	.585 (.000)
PM10 (24 Hr Ave)						

Table E6f
Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Steubenville Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)	-.355 (.000)	-.391 (.000)	-.115 (.000)	.218 (.000)	.255 (.000)	.175 (.000)
NO_2 (Max 8 Hr Ave)	-.309 (.000)	-.306 (.000)	-.085 (.000)	.228 (.000)	.040 (.066)	-.031 (.159)
CO (Max 1 Hr Ave)	-.168 (.000)	-.199 (.000)	-.042 (.046)	.136 (.000)	.125 (.000)	.076 (.000)
CO (Max 8 Hr Ave)	-.162 (.000)	-.196 (.000)	-.039 (.062)	.154 (.000)	.082 (.000)	.035 (.090)
SO_2 (Max 1 Hr Ave)	-.159 (.000)	-.193 (.000)	-.043 (.043)	.145 (.000)	.120 (.000)	.073 (.000)
SO_2 (Max 8 Hr Ave)	-.147 (.000)	-.198 (.000)	-.050 (.018)	.173 (.000)	.057 (.006)	.006 (.784)
Ozone (Max 1 Hr Ave)	-.228 (.000)	-.208 (.000)	-.030 (.167)	-.014 (.511)	.605 (.000)	.578 (.000)
Ozone (Max 8 Hr Ave)	-.205 (.000)	-.204 (.000)	-.035 (.113)	-.037 (.084)	.577 (.000)	.553 (.000)
PM10 (24 Hr Ave)	-.234 (.000)	-.230 (.000)	-.042 (.066)	.157 (.000)	.340 (.000)	.296 (.000)

Table E6g
Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Toledo Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)						
NO_2 (Max 8 Hr Ave)						
CO (Max 1 Hr Ave)	-.268 (.000)	.014 (.497)	-.029 (.165)	.264 (.000)	-.064 (.002)	-.107 (.000)
CO (Max 8 Hr Ave)	-.262 (.000)	.082 (.000)	.003 (.875)	.236 (.000)	-.086 (.000)	-.115 (.000)
SO_2 (Max 1 Hr Ave)	-.068 (.001)	-.116 (.000)	-.097 (.000)	.138 (.000)	.043 (.042)	.016 (.456)
SO_2 (Max 8 Hr Ave)	-.079 (.000)	-.096 (.000)	-.097 (.000)	.158 (.000)	.007 (.725)	-.021 (.319)
Ozone (Max 1 Hr Ave)	-.258 (.000)	-.191 (.000)	-.048 (.075)	.061 (.021)	.648 (.000)	.593 (.000)
Ozone (Max 8 Hr Ave)	-.232 (.000)	-.237 (.000)	-.082 (.002)	.064 (.017)	.615 (.000)	.556 (.000)
PM10 (24 Hr Ave)						

Table E6h
Correlation Matrix (and Significance Levels) for the Air Quality Variables with the Meteorological Variables at the Youngstown Monitor

	Average wind speed	Average relative humidity	Precipitation	Barometric Pressure	Maximum Daily Temperature	Average Daily Temperature
NO_2 (Max 1 Hr Ave)						
NO_2 (Max 8 Hr Ave)						
CO (Max 1 Hr Ave)						
CO (Max 8 Hr Ave)						
SO_2 (Max 1 Hr Ave)	-.088 (.000)	-.117 (.000)	-.142 (.000)	.133 (.000)	-.174 (.000)	-.215 (.000)
SO_2 (Max 8 Hr Ave)	-.050 (.013)	-.094 (.000)	-.146 (.000)	.157 (.000)	-.240 (.000)	-.279 (.000)
Ozone (Max 1 Hr Ave)	-.199 (.000)	-.276 (.000)	-.092 (.001)	.042 (.107)	.713 (.000)	.639 (.000)
Ozone (Max 8 Hr Ave)	-.165 (.000)	-.304 (.000)	-.126 (.000)	.042 (.108)	.681 (.000)	.611 (.000)
PM10 (24 Hr Ave)	-.328 (.000)	-.206 (.000)	-.158 (.000)	.178 (.000)	.350 (.000)	.309 (.000)

Table E7a
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Akron Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.016	-.010	.019	.007
		(.414)	(.627)	(.340)	(.728)
2. Total - Respiratory Illness			.134	.396	.333
			(.000)	(.000)	(.000)
3. Children – Asthma				.014	.055
				(.500)	(.007)
4. Elderly – COPD					.108
					(.000)
5. Total – Respiratory deaths					

Table E7b
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cincinnati Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.040	.001	-.007	.053
		(.046)	(.979)	(.721)	(.009)
2. Total - Respiratory Illness			.122	.366	.402
			(.000)	(.000)	(.000)
3. Children – Asthma				.022	.004
				(.265)	(.852)
4. Elderly – COPD					.195
					(.000)
5. Total – Respiratory deaths					

Table E7c
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cleveland Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.091	.062	.090	.053
		(.000)	(.002)	(.000)	(.009)
2. Total - Respiratory Illness			.184	.557	.417
			(.000)	(.000)	(.000)
3. Children – Asthma				.104	.067
				(.000)	(.001)
4. Elderly – COPD					.274
					(.000)
5. Total – Respiratory deaths					

Table E7d
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Columbus Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.007	-.018	.036	.012
		(.731)	(.370)	(.073)	(.536)
2. Total - Respiratory Illness			.132	.373	.320
			(.000)	(.000)	(.000)
3. Children – Asthma				.056	.035
				(.006)	(.082)
4. Elderly – COPD					.135
					(.000)
5. Total – Respiratory deaths					

Table E7e

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Dayton Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.001	.005	-.001	.040
		(.957)	(.821)	(.965)	(.048)
2. Total - Respiratory Illness			.317	.336	.290
			(.000)	(.000)	(.000)
3. Children – Asthma				.071	.030
				(.000)	(.140)
4. Elderly – COPD					.094
					(.000)
5. Total – Respiratory deaths					

Table E7f

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Steubenville Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.029	.029	-.013	.022
		(.152)	(.155)	(.506)	(.270)
2. Total - Respiratory Illness			.128	.369	.176
			(.000)	(.000)	(.000)
3. Children – Asthma				-.006	.009
				(.749)	(.659)
4. Elderly – COPD					.066
					(.001)
5. Total – Respiratory deaths					

Table E7g
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Toledo Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.027	-.011	.013	.069
		(.182)	(.596)	(.522)	(.001)
2. Total - Respiratory Illness			.169	.434	.263
			(.000)	(.000)	(.000)
3. Children – Asthma				.023	.023
				(.264)	(.243)
4. Elderly – COPD					.125
					(.000)
5. Total – Respiratory deaths					

Table E7h
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Youngstown Monitor by Diagnosis Type and Age

	1	2	3	4	5
1. Total - Non-Respiratory Illness		.040	.022	.018	.055
		(0.49)	(.279)	(.362)	(.006)
2. Total - Respiratory Illness			.106	.345	.237
			(.000)	(.000)	(.000)
3. Children – Asthma				-.031	-.005
				(.128)	(.803)
4. Elderly – COPD					.070
					(.000)
5. Total – Respiratory deaths					

Table E8a
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Akron Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.017 (.408)	.016 (.423)	.017 (.416)	.027 (.193)	-.020 (.434)	-.013 (.620)	.029 (.178)
Total - Respiratory Illness			.002 (.907)	.018 (.385)	.000 (.991)	.039 (.057)	-.168 (.000)	-.177 (.000)	.042 (.049)
Children – Asthma			.034 (.096)	.027 (.174)	.066 (.001)	.060 (.003)	-.083 (.001)	-.095 (.000)	.131 (.000)
Elderly – COPD			.022 (.281)	.041 (.044)	.036 (.081)	.037 (.073)	.016 (.551)	.009 (.740)	.052 (.014)
Total – Respiratory deaths			.026 (.197)	.035 (.080)	.032 (.118)	.043 (.036)	-.062 (.018)	-.061 (.019)	.113 (.000)

Table E8b
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cincinnati Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.017 (.412)	.032 (.122)	-.006 (.764)	.013 (.529)	-.054 (.010)	-.053 (.012)	.004 (.878)	-.004 (.871)	-.031 (.538)
Total - Respiratory Illness	-.147 (.000)	-.018 (.395)	.138 (.000)	.130 (.000)	-.013 (.548)	.036 (.091)	-.232 (.000)	-.227 (.000)	-.138 (.006)
Children – Asthma	-.054 (.008)	-.018 (.372)	.033 (.100)	.042 (.040)	.013 (.551)	.013 (.553)	-.112 (.000)	-.123 (.000)	-.077 (.126)
Elderly – COPD	-.084 (.000)	-.034 (.098)	.161 (.000)	.172 (.000)	.079 (.000)	.086 (.000)	-.124 (.000)	-.137 (.000)	-.065 (.200)
Total – Respiratory deaths	-.052 (.012)	.018 (.395)	.117 (.000)	.103 (.000)	.057 (.006)	.075 (.000)	-.072 (.006)	-.070 (.007)	-.082 (.107)

Table E8c
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cleveland Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.006 (.779)	.030 (.141)	.044 (.031)	.058 (.004)	.035 (.087)	.056 (.006)	.003 (.914)	-.005 (.863)	.011 (.596)
Total - Respiratory Illness	-.082 (.000)	.015 (.459)	.144 (.000)	.191 (.000)	.047 (.021)	.124 (.000)	-.169 (.000)	-.185 (.000)	-.078 (.000)
Children – Asthma	-.052 (.011)	-.016 (.437)	.046 (.023)	.064 (.001)	.022 (.274)	.041 (.045)	-.150 (.000)	-.147 (.000)	-.053 (.012)
Elderly – COPD	-.051 (.012)	-.041 (.043)	.125 (.000)	.158 (.000)	.068 (.001)	.076 (.000)	.016 (.544)	-.003 (.900)	-.056 (.008)
Total – Respiratory deaths	-.053 (.009)	-.005 (.792)	.104 (.000)	.145 (.000)	.069 (.001)	.087 (.000)	-.039 (.133)	-.054 (.041)	-.036 (0.91)

Table E8d
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Columbus Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			-.002 (.907)	-.013 (.531)	.007 (.716)	-.002 (.914)	-.004 (.869)	.004 (.875)	-.080 (.114)
Total - Respiratory Illness			.181 (.000)	.204 (.000)	.148 (.000)	.172 (.000)	-.193 (.000)	-.210 (.000)	-.189 (.000)
Children – Asthma			.081 (.000)	.084 (.000)	.010 (.627)	.019 (.341)	-.119 (.000)	-.129 (.000)	-.034 (.508)
Elderly – COPD			.068 (.001)	.075 (.000)	.089 (.000)	.084 (.000)	-.004 (.874)	-.020 (.452)	.035 (.489)
Total – Respiratory deaths			.082 (.000)	.082 (.000)	.068 (.001)	.079 (.000)	-.020 (.456)	-.034 (.193)	-.109 (.032)

Table E8e
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Dayton Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.036 (.075)	.024 (.236)	.026 (.191)	.025 (.221)	.010 (.706)	-.008 (.749)	
Total - Respiratory Illness			.085 (.000)	.093 (.000)	.113 (.000)	.134 (.000)	-.183 (.000)	-.109 (.000)	
Children – Asthma			.026 (.192)	.024 (.243)	.014 (.487)	.015 (.444)	-.161 (.000)	-.175 (.000)	
Elderly – COPD			.083 (.000)	.095 (.000)	.070 (.000)	.075 (.000)	-.063 (.016)	-.056 (.032)	
Total – Respiratory deaths			-.073 (.000)	-.068 (.001)	.048 (.017)	.066 (.001)	-.042 (.111)	-.044 (.092)	

Table E8f
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Steubenville Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.047 (.031)	.045 (.040)	.071 (.000)	.068 (.001)	.018 (.383)	.027 (.185)	-.021 (.312)	-.022 (.308)	.013 (.551)
Total - Respiratory Illness	.088 (.000)	.158 (.000)	.107 (.000)	.133 (.000)	.030 (.148)	.069 (.001)	-.168 (.000)	-.161 (.000)	.005 (.808)
Children – Asthma	-.042 (.057)	-.031 (.152)	.002 (.906)	.001 (.956)	-.002 (.913)	.012 (.545)	-.042 (.048)	-.045 (.033)	-.028 (.205)
Elderly – COPD	.018 (.418)	.017 (.434)	.005 (.790)	.007 (.722)	-.010 (.634)	-.015 (.454)	.009 (.686)	.005 (.812)	-.022 (.329)
Total – Respiratory deaths	.006 (.772)	.008 (.699)	.026 (.208)	.019 (.349)	.004 (.846)	.003 (.871)	-.090 (.000)	-.084 (.000)	-.011 (.612)

Table E8g
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Toledo Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.027 (.174)	.024 (.245)	-.039 (.065)	-.021 (.319)	-.021 (.425)	-.015 (.571)	
Total - Respiratory Illness			.206 (.000)	.224 (.000)	.072 (.001)	.094 (.000)	-.183 (.000)	-.184 (.000)	
Children – Asthma			.001 (.957)	.005 (.817)	-.009 (.669)	-.008 (.702)	-.079 (.003)	-.085 (.001)	
Elderly – COPD			.120 (.000)	.133 (.000)	.052 (.014)	.070 (.001)	-.011 (.691)	-.018 (.510)	
Total – Respiratory deaths			.057 (.005)	.080 (.000)	.011 (.586)	.036 (.085)	-.062 (.020)	-.060 (.024)	

Table E8h
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Youngstown Monitor by Diagnosis Type and Age with the Air Quality Variables

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness					-.022 (.274)	-.025 (.214)	.004 (.887)	-.005 (.855)	.011 (.784)
Total - Respiratory Illness					.154 (.000)	.198 (.000)	-.182 (.000)	-.190 (.000)	-.009 (.827)
Children – Asthma					.023 (.260)	.051 (.011)	-.106 (.000)	-.113 (.000)	-.041 (.302)
Elderly – COPD					.030 (.140)	.035 (.084)	-.020 (.442)	-.031 (.228)	-.006 (.887)
Total – Respiratory deaths					.033 (.102)	.033 (.103)	-.005 (.837)	-.004 (.869)	-.008 (.840)

Table E9a

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Akron Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.041 (.250)	.044 (.214)	.037 (.297)	.056 (.112)	*	*	.000 (.995)
Total - Respiratory Illness			.008 (.822)	-.007 (.832)	-.056 (.108)	-.017 (.629)	*	*	-.006 (.863)
Children – Asthma			.023 (.518)	.029 (.405)	.062 (.078)	.057 (.103)	*	*	.182 (.000)
Elderly – COPD			-.009 (.801)	-.001 (.969)	-.023 (.515)	-.022 (.528)	*	*	-.015 (.683)
Total – Respiratory deaths			-.036 (.309)	-.027 (.442)	-.025 (.480)	-.005 (.891)	*	*	.037 (.315)

* Ozone was not measured during the winter months.

Table E9b

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cincinnati Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.028 (.429)	.027 (.449)	.014 (.696)	.028 (.428)	-.038 (.286)	-.048 (.182)	*	*	.022 (.808)
Total - Respiratory Illness	.008 (.816)	.040 (.265)	.025 (.474)	.011 (.753)	-.084 (.018)	-.050 (.163)	*	*	-.078 (.388)
Children – Asthma	.034 (.348)	.037 (.308)	-.008 (.826)	-.002 (.945)	.017 (.625)	.019 (.591)	*	*	.078 (.383)
Elderly – COPD	-.077 (.032)	-.057 (.112)	.127 (.000)	.129 (.000)	.022 (.532)	.030 (.408)	*	*	-.148 (.099)
Total – Respiratory deaths	.017 (.642)	.063 (.078)	.085 (.016)	.075 (.035)	.015 (.675)	.034 (.341)	*	*	-.027 (.764)

* Ozone was not measured during the winter months.

Table E9c

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cleveland Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.029 (.409)	.029 (.418)	.035 (.321)	.036 (.304)	.068 (.055)	.089 (.011)	*	*	-.002 (.952)
Total - Respiratory Illness	.018 (.605)	.029 (.414)	.129 (.000)	.170 (.000)	.109 (.002)	.060 (.090)	*	*	.009 (.813)
Children – Asthma	-.013 (.703)	.000 (.995)	.042 (.226)	.053 (.132)	.062 (.079)	.059 (.095)	*	*	-.043 (.236)
Elderly – COPD	-.014 (.683)	.001 (.973)	.100 (.004)	.138 (.000)	.068 (.054)	.026 (.465))	*	*	-.073 (.044)
Total – Respiratory deaths	-.026 (.456)	-.003 (.943)	.079 (.024)	.128 (.000)	.079 (.025)	.060 (.088)	*	*	-.013 (.723)

* Ozone was not measured during the winter months.

Table E9d

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Columbus Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			-.001 (.969)	-.019 (.592)	.008 (.825)	-.017 (.633)	*	*	-.095 (.293)
Total - Respiratory Illness			.015 (.663)	.025 (.479)	-.024 (.505)	-.007 (.834)	*	*	.107 (.233)
Children – Asthma			.102 (.004)	.118 (.001)	.025 (.484)	.030 (.393)	*	*	.035 (.696)
Elderly – COPD			.035 (.316)	.039 (.271)	.043 (.224)	.048 (.174)	*	*	.064 (.475)
Total – Respiratory deaths			.020 (.576)	.007 (.846)	-.004 (.909)	.007 (.853)	*	*	-.034 (.704)

* Ozone was not measured during the winter months.

Table E9e

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Dayton Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.079 (.023)	.060 (.085)	-.022 (.539)	-.019 (.596)	*	*	
Total - Respiratory Illness			-.003 (.934)	.002 (.944)	-.045 (.201)	-.024 (.503)	*	*	
Children – Asthma			-.034 (.334)	-.037 (.285)	-.052 (.139)	-.050 (.152)	*	*	
Elderly – COPD			.060 (.088)	.062 (.079)	.059 (.095)	.068 (.053)	*	*	
Total – Respiratory deaths			-.097 (.005)	-.087 (.013)	-.010 (.766)	.016 (.648)	*	*	

* Ozone was not measured during the winter months.

Table E9f

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Steubenville Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.003 (.934)	.012 (.760)	.066 (.064)	.060 (.090)	.007 (.844)	.030 (.402)	-.096 (.011)	-.118 (.002)	-.015 (.701)
Total - Respiratory Illness	.122 (.001)	.111 (.004)	.104 (.003)	.106 (.003)	-.004 (.921)	.008 (.825)	.004 (.912)	.004 (.908)	.093 (.015)
Children – Asthma	-.020 (.603)	-.021 (.589)	-.010 (.781)	-.012 (.734)	.054 (.130)	.052 (.144)	.025 (.502)	.027 (.469)	-.046 (.228)
Elderly – COPD	.000 (.990)	-.019 (.618)	-.001 (.967)	-.010 (.786)	-.030 (.399)	-.040 (.267)	.033 (.381)	.013 (.724)	-.052 (.172)
Total – Respiratory deaths	-.053 (.166)	-.081 (.035)	-.017 (.630)	-.019 (.592)	-.036 (.314)	-.054 (.133)	-.087 (.021)	-.076 (.044)	-.036 (.342)

Table E9g

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Toledo Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.036 (.307)	.035 (.324)	-.007 (.848)	.014 (.708)	*	*	
Total - Respiratory Illness			.193 (.000)	.204 (.000)	.076 (.034)	.067 (.065)	*	*	
Children – Asthma			-.017 (.622)	.000 (.990)	.007 (.840)	.017 (.632)	*	*	
Elderly – COPD			.119 (.001)	.115 (.001)	.021 (.566)	.005 (.889)	*	*	
Total – Respiratory deaths			.045 (.197)	.080 (.022)	.057 (.112)	.084 (.020)	*	*	

* Ozone was not measured during the winter months.

Table E9h

Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Youngstown Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Coldest Months (December, January, February, March)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness					-.035 (.313)	-.071 (.042)	*	*	.041 (.545)
Total - Respiratory Illness					.017 (.626)	.034 (.338)	*	*	.107 (.111)
Children – Asthma					.039 (.269)	.057 (.104)	*	*	-.027 (.686)
Elderly – COPD					-.026 (.463)	-.021 (.545)	*	*	-.025 (.711)
Total – Respiratory deaths					-.028 (.416)	-.029 (.401)	*	*	-.002 (.972)

* Ozone was not measured during the winter months.

Table E10a
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Akron Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.007 (.846)	.042 (.220)	-.060 (.107)	-.063 (.089)	-.002 (.964)	-.005 (.877)	-.173 (.042)
Total - Respiratory Illness			.093 (.006)	.136 (.000)	-.038 (.308)	-.025 (.505)	-.119 (.001)	-.111 (.001)	.000 (.996)
Children – Asthma			.076 (.028)	.077 (.024)	.004 (.912)	.013 (.732)	-.059 (.085)	-.074 (.031)	-.062 (.469)
Elderly – COPD			.186 (.000)	.199 (.000)	.033 (.375)	.037 (.319)	-.116 (.001)	-.131 (.000)	.059 (.487)
Total – Respiratory deaths			.077 (.025)	.060 (.078)	.036 (.338)	.038 (.302)	-.051 (.138)	-.038 (.263)	-.024 (.779)

Table E10b
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cincinnati Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.029 (.409)	.051 (.148)	.007 (.846)	.042 (.220)	-.060 (.107)	-.063 (.089)	-.002 (.964)	-.005 (.877)	-.173 (.042)
Total - Respiratory Illness	.028 (.430)	.106 (.003)	.093 (.006)	.136 (.000)	-.038 (.308)	-.025 (.505)	-.119 (.001)	-.111 (.001)	.000 (.996)
Children – Asthma	-.021 (.547)	.039 (.270)	.076 (.028)	.077 (.024)	.004 (.912)	.013 (.732)	-.059 (.085)	-.074 (.031)	-.062 (.469)
Elderly – COPD	.006 (.856)	.018 (.608)	.186 (.000)	.199 (.000)	.033 (.375)	.037 (.319)	-.116 (.001)	-.131 (.000)	.059 (.487)
Total – Respiratory deaths	-.017 (.628)	.010 (.780)	.077 (.025)	.060 (.078)	.036 (.338)	.038 (.302)	-.051 (.138)	-.038 (.263)	-.024 (.779)

Table E10c
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Cleveland Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	-.030 (.377)	-.020 (.569)	.091 (.008)	.121 (.000)	.007 (.835)	.017 (.626)	.018 (.601)	-.002 (.963)	.067 (.060)
Total - Respiratory Illness	-.100 (.004)	-.107 (.002)	.117 (.001)	.187 (.000)	.055 (.113)	.107 (.002)	-.030 (.391)	-.056 (1.04)	.068 (.058)
Children – Asthma	-.033 (.332)	-.014 (.678)	.008 (.814)	.028 (.419)	.009 (.804)	.007 (.833)	-.134 (.000)	-.123 (.000)	-.022 (.532)
Elderly – COPD	-.086 (.012)	-.136 (.000)	.123 (.000)	.154 (.000)	.078 (.024)	.101 (.003)	.086 (.012)	.060 (.079)	.027 (.449)
Total – Respiratory deaths	-.064 (.063)	-.052 (.129)	.087 (.011)	.137 (.000)	.047 (.171)	.047 (.179)	-.028 (.424)	-.039 (.253)	.005 (.897)

Table E10d
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Columbus Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.047 (.173)	.025 (.461)	.002 (.959)	.004 (.909)	.019 (.573)	.031 (.363)	-.073 (.393)
Total - Respiratory Illness			.125 (.000)	.116 (.001)	.118 (.001)	.132 (.000)	-.100 (.004)	-.141 (.000)	.053 (.533)
Children – Asthma			.073 (.033)	.058 (.094)	-.021 (.546)	-.007 (.832)	-.166 (.000)	-.174 (.000)	-.098 (.255)
Elderly – COPD			.057 (.098)	.039 (.260)	.025 (.467)	.019 (.581)	.020 (.568)	-.005 (.895)	.102 (.235)
Total – Respiratory deaths			.052 (.128)	.034 (.325)	.053 (.129)	.058 (.093)	.014 (.685)	.000 (.994)	-.039 (.652)

Table E10e
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Dayton Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			-.006 (.872)	-.020 (.554)	.071 (.039)	.059 (.087)	.028 (.411)	.012 (.731)	
Total - Respiratory Illness			.017 (.629)	.018 (.601)	.033 (.338)	.038 (.275)	-.129 (.000)	-.135 (.000)	
Children – Asthma			.030 (.392)	.041 (.240)	-.003 (.928)	-.003 (.920)	-.159 (.000)	-.174 (.000)	
Elderly – COPD			.132 (.000)	.138 (.000)	-.010 (.769)	-.011 (.745)	-.065 (.060)	-.054 (.119)	
Total – Respiratory deaths			-.047 (.177)	-.047 (.169)	-.002 (.963)	-.007 (.833)	-.020 (.565)	-.017 (.613)	

Table E10f
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Steubenville Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness	.097 (.008)	.099 (.007)	.117 (.001)	.124 (.000)	.021 (.545)	.034 (.322)	-.001 (.967)	.007 (.833)	.037 (.320)
Total - Respiratory Illness	.044 (.240)	.055 (.140)	.081 (.018)	.113 (.001)	-.007 (.828)	.023 (.503)	.043 (.213)	.037 (.281)	.009 (.820)
Children – Asthma	-.012 (.752)	-.006 (.861)	.099 (.004)	.091 (.008)	.008 (.808)	.031 (.370)	-.032 (.350)	-.042 (.226)	.033 (.379)
Elderly – COPD	-.056 (.133)	-.072 (.050)	-.071 (.037)	-.071 (.039)	-.068 (.050)	-.087 (.011)	.054 (.117)	.054 (.119)	-.028 (.452)
Total – Respiratory deaths	.000 (.989)	.010 (.782)	.063 (.065)	.047 (.174)	.035 (.306)	.041 (.232)	-.064 (.062)	-.067 (.051)	-.003 (.933)

Table E10g
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Toledo Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness			.062 (.071)	.051 (.137)	-.048 (.177)	-.032 (.368)	-.029 (.411)	-.019 (.582)	
Total - Respiratory Illness			.139 (.000)	.143 (.000)	.117 (.001)	.123 (.000)	-.122 (.001)	-.129 (.000)	
Children – Asthma			.004 (.913)	.000 (.992)	-.018 (.606)	-.014 (.687)	-.092 (.009)	-.100 (.004)	
Elderly – COPD			.084 (.015)	.113 (.001)	.054 (.128)	.068 (.052)	-.018 (.617)	-.030 (.390)	
Total – Respiratory deaths			.079 (.021)	.106 (.002)	-.023 (.508)	.000 (.994)	-.025 (.483)	-.023 (.521)	

Table E10h
Correlation Matrix (and Significance Levels) for Daily Cases of Respiratory Illness within 20 Miles of the Youngstown Monitor by Diagnosis Type and Age with the Air Quality Variables during the Four Hottest Months (June, July, August, September)

	NO_2 (1 Hr)	NO_2 (8 Hr)	CO (1 Hr)	CO (8 Hr)	SO_2 (1 Hr)	SO_2 (8 Hr)	Ozone (1 Hr)	Ozone (8 Hr)	PM10 (24 Hr)
Total - Non-Respiratory Illness					.007 (.836)	.032 (.356)	.000 (.991)	-.013 (.702)	-.036 (.614)
Total - Respiratory Illness					.062 (.069)	.065 (.059)	-.081 (.018)	-.097 (.005)	-.008 (.904)
Children – Asthma					.082 (.016)	.104 (.002)	-.092 (.007)	-.097 (.005)	-.037 (.602)
Elderly – COPD					.027 (.432)	.028 (.412)	-.013 (.708)	-.017 (.612)	-.010 (.890)
Total – Respiratory deaths					.016 (.631)	.000 (.993)	-.001 (.971)	-.003 (.921)	-.025 (.721)

Table E11a
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Akron Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0								.003 (.080)	
	1									
	2									
	3									
2. Total - Respiratory Illness	0									
	1									
	2			-.013 (.065)	-.036 (.025)					
	3									
3. Children – Asthma	0							.002 (.041)		
	1				-.254 (.005)					
	2									.009 (.093)
	3									
4. Elderly – COPD	0									
	1									
	2									
	3									
5. Total – Respiratory deaths	0									
	1					-.003 (.051)				
	2				-.057 (.083)					
	3									

Table E11b
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Cincinnati Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0									
	1									
	2									
	3				-.118 (.062)					
2. Total - Respiratory Illness	0			.013 (.056)	.031 (.014)					
	1									
	2					-.001 (.019)	-.001 (.050)			
	3									
3. Children – Asthma	0	-.006 (.048)				.012 (.008)	.010 (.045)			
	1	-.005 (.055)		-.079 (.039)	-.172 (.013)		-.008 (.037)			
	2					-.011 (.001)	-.013 (.001)			
	3									
4. Elderly – COPD	0				.069 (.076)					
	1									
	2				-.066 (.082)					
	3									
5. Total – Respiratory deaths	0									-.004 (.096)
	1									
	2									
	3			-.026 (.062)						

Table E11c
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Cleveland Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0		.006 (.034)			.006 (.079)				
	1									
	2									
	3									
2. Total - Respiratory Illness	0									
	1	.001 (.005)	.002 (.000)							.001 (.036)
	2			-.004 (.081)	-.008 (.099)	-.001 (.080)	-.001 (.095)			
	3									
3. Children – Asthma	0									
	1					.007 (.061)	.008 (.056)			
	2									
	3					-.009 (.001)				
4. Elderly – COPD	0									-.001 (.071)
	1									
	2									
	3							-.001 (.025)		
5. Total – Respiratory deaths	0									
	1									
	2									
	3				.016 (.099)				-.002 (.078)	

Table E11d

Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Columbus Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0									-.016 (.060)
	1									
	2									
	3							-.008 (.061)		
2. Total - Respiratory Illness	0									
	1									
	2					-.001 (.026)	-.001 (.049)			
	3									
3. Children – Asthma	0					-.008 (.033)	-.008 (.078)	-.006 (.025)	-.010 (.024)	
	1									-.017 (.064)
	2									-.014 (.100)
	3									
4. Elderly – COPD	0									
	1					-.003 (.057)				
	2									
	3				.095 (.023)			.003 (.020)	.005 (.009)	
5. Total – Respiratory deaths	0									
	1								.003 (.078)	
	2									
	3									

Table E11e
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Dayton Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0					.008 (.050)				
	1									
	2									
	3									
2. Total - Respiratory Illness	0				-.009 (.057)					
	1									
	2				-.009 (.044)					
	3			-.004 (.070)	-.008 (.061)					
3. Children – Asthma	0							-.005 (.067)	-.008 (.048)	
	1									
	2									
	3									
4. Elderly – COPD	0									
	1					.005 (.070)	.005 (.049)			
	2							-.005 (.024)	-.007 (.055)	
	3									
5. Total – Respiratory deaths	0									
	1									
	2									
	3									

Table E11f
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Steubenville Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0	.012 (.000)	.022 (.000)	.091 (.000)	.209 (.000)					
	1									.009 (.002)
	2		.011 (.046)			.013 (.004)	.011 (.021)			.006 (.022)
	3									
2. Total - Respiratory Illness	0	.004 (.008)	.005 (.012)		.027 (.098)					
	1					.003 (.035)	.033 (.042)			
	2									
	3									
3. Children – Asthma	0				-.190 (.004)					
	1									
	2	.018 (.000)	.023 (.000)	.069 (.000)	.129 (.001)			.004 (.000)	.006 (.001)	.006 (.049)
	3			.062 (.002)	.132 (.001)					
4. Elderly – COPD	0									
	1									
	2									
	3			-.047 (.034)	-.092 (.033)					
5. Total – Respiratory deaths	0			-.030 (.095)						
	1									
	2									
	3			.030 (.063)	.064 (.051)					

Table E11g
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Toledo Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0									
	1									
	2						-.006 (.095)			
	3			.008 (.030)	.020 (.005)	-.006 (.059)				
2. Total - Respiratory Illness	0			.002 (.064)		.002 (.096)	.002 (.063)			
	1									
	2									
	3									
3. Children – Asthma	0									
	1						-.008 (.062)			
	2									
	3			-.010 (.039)	-.016 (.085)					
4. Elderly – COPD	0									
	1					-.004 (.082)	-.004 (.025)			
	2									
	3							.003 (.025)	.005 (.066)	
5. Total – Respiratory deaths	0									
	1									
	2									
	3			-.004 (.040)						

Table E11h
Relationship between Air Pollutants and Daily Cases of Respiratory Illness within 20 Miles of the Youngstown Monitor by Diagnosis Type and Age

	Lag	NO_2		CO		O_3		SO_2		PM10
		1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	1 Hr	8 Hr	
1. Total - Non-Respiratory Illness	0							-.004 (.052)	-.007 (.090)	
	1					.008 (.020)	.078 (.040)			
	2							-.006 (.005)	-.010 (.010)	
	3									
2. Total - Respiratory Illness	0					-.003 (.004)	-.003 (.010)		.002 (.028)	.003 (.046)
	1							.001 (.077)		
	2									
	3									
3. Children – Asthma	0					-.012 (.035)	-.015 (.010)			
	1									
	2									
	3									
4. Elderly – COPD	0									
	1									
	2									
	3									
5. Total – Respiratory deaths	0									
	1									
	2									
	3									